THE HYDRO-GEOLOGY OF THE CHUKA-SOUTH AREA

(KENYA)

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2wlz

CONTENTS

	page:
LIST OF FIGURES	
1. INTRODUCTION	1
2. THE GEOLOGY AND GEOMORPHOLOGY OF THE CHUKA-SOUTH AREA	11
2.1 Geology of the mapping units	11
2.1.1 The Basement System	12
2.1.1.1 Banded gabroic-ultramafic complex (M)	12
2.1.1.2 Granites and granitoid gneisses (G)	13
2.1.1.3 Banded migmatitic gneisses complex (X)	16
2.1.1.4 Quartzites and muscovite schists (Q)	21
2.1.2 The Volcanic rocks	22
2.1.2.1 Lava flows (V)	22
2.1.2.2 Complex of lahars and lava flows (L)	23
2.1.3 The Colluvial and Fluviatile deposits	28
2.1.3.1 Fluviatile deposits (F)	28
2.1.3.2 Colluvial deposits (C)	29
2.2 Structures	31
2.3 Geomorphology	35
3. THE HYDROGEOLOGY OF THE CHUKA-SOUTH AREA	45
3.1 The Basement System	45
3.2 The Volcanics	52
3.3 The Colluvial and Fluviatile deposits	58
4. WATERSUPPLY AND POSSIBILITIES OF IMPROVEMENTS	61
4.1 Watersupply	61
4.1.1 Surface water	61
4.1.2 Near surface water	64
4.1.3 Groundwater	64
4.1.4 Rainwater	65
4.2 Posibilities of improvements	65
4.2.1 Surface water	65
4.2.2 Near surface water	66
4.2.3 Groundwater	69
5. A CASE STUDY IN KONYU WADI	70
5.1 Introduction	70
5.2 Physiography and hydrology	72
5.3 Climate and vegetation	74
5.4 Regional geology	75
5.5 Hydrogeology	76
5.6 The geoelectrical measurements and their interpretations	79
5.7 The watersupply and possible improvements	93
SUMMARY	97
REFERENCES AND LITERATURE USED	103

APPENDICES

1 Survey methods
2 Chemical properties of surface-, near surface- and groundwater
3 Hydrogeological map of the Chuka-South area and legend
4 The Geomorphological map of the Chuka-South area
5 Aerial photographs index map
6 Augerings in Konyu wadi

LIST OF FIGURES.

		Page:
Fig. 1.	-THE LOCATION OF THE CHUKA-SOUTH AREA IN KENYA.	2
Fig. 2.	-SIMPLIFIED TOPOGRAPHICAL MAP OF THE CHUKA-SOUTH AREA.	3
Fig. 3.	-INTERPRETATION OF THE SATELLITE IMAGE.	4
Fig. 4.	-THE AVERAGE ANNUAL RAINFALL (IN MM) OF THE CHUKA-SOUTH AREA.	8
Fig. 5.	-THE ANNUAL POTENTIAL EVAPORATION (IN MM) OF THE CHUKA-SOUTH AREA.	9
Fig. 6.	-CROSS SECTION THROUGH A PART OF UNIT LIa, THE SLOPING LAHAR AND LAVA COMPLEX.	25
Fig. 7.	-DETAIL OF FIG. 6. , A PHONOLITE FLOW ENCLOSED BY LAHARS.	26
Fig. 8.	-GEOLOGICAL CROSS-SECTIONS THROUGH THE AREA.	30
Fig. 9.	-GENERAL DRAINAGE PATTERN OF THE EASTERN SLOPES OF MOUNT KENYA.	38
Fig. 10.	-DETAILS OF THE DRAINAGE PATTERNS AND SCHEMATIC CROSS SECTIONS THROUGH A NUMBER OF LANDSCAPES OF THE VOLCANIC AREA.	39
Fig. 11.	-DEVELOPMENT OF A VOLCANIC RIDGE (VR) IN THE BASEMENT SYSTEM AREA BY A PROCESS OF RELIEF INVERSION.	40
Fig. 12.	-DETAILS OF THE DRAINAGE PATTERNS AND SCHEMATIC CROSS SECTIONS THROUGH A NUMBER OF LANDSCAPES OF THE BASEMENT SYSTEM AREA.	43 + 44
Fig. 13.	-WATERTRANSPORT IN AND AROUND A WADI IN THE BASEMENT SYSTEM AREA.	50
Fig. 14.	-GENERAL WATERTRANSPORT IN THE BASEMENT SYSTEM AREA	51
Fig. 15.	-WATER TRANSPORT IN THE SLOPING LAHAR AREA.	55
Fig. 16.	-WATER TRANSPORT IN THE PLATEAU LAHARS.	56
Fig. 17.	-SIX BOREHOLES IN THE VOLCANIC AREA.	57
Fig. 18.	-WATERTRANSSPORT IN THE BOUNDARY ZONE OF THE VOLCANIC AND BASEMENT SYSTEM AREAS.	60
Fig. 19.	-TYPES OF WATER SUPPLY IN THE AREA.	62
Fig. 20.	-WATERINLET IN PERENNIAL RIVER IN MOUNT KENYA FOREST.	63
Fig. 21.	-SUBSURFACE DAM IN WADI.	67
Fig. 22.	-CONSTRUCTION PLAN OF A SUBSURFACE DAM IN INDIA.	68
Fig. 23.	-LOCATION OF THE CASE STUDY AREA IN KONYU WADI.	71
Fig. 24.	-SUBDIVISION OF THE KONYU BASIN.	73
Fig. 25.	-THE SEEPAGE ZONE ALONG THE TERRACES OF KONYU WADI.	77
Fig. 26.	-MAP OF THE WATERTABLE DEPTH IN KONYU WADI.	78
Fig. 27.	-SITUATION SKETCH OF THE CASE STUDY AREA WITH LOCATIONS OF THE GEOELECTRICAL ARRAYS	83
Fig. 28.	-SCHLUMBERGER SOUNDING S4 AND WENNER SOUNDINGS-CROSSECTION W4 AND THEIR INTERPRETATION.	84
Fig. 29.	-SCHLUMBERGER SOUNDING S1 AND WENNER SOUNDINGS-CROSSECTION W1 AND THEIR INTERPRETAION.	85
Fig. 30.	-SCHLUMBERGER SOUNDING S2 AND WENNER SOUNDINGS-CROSSECTION W2 AND THEIR INTERPRETATION.	86

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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 0o15'S and 0o30'S and by the longitudes 37o30'E and 38o00'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 hydro-geological survey was carried out during six weeks between December 1985 and February 1986 as a part of a MSc thesis-research and was a part of The Training Project In Pedology of the Agricultural University of Wageningen (The Netherlands).
The hydrogeological survey is based on the geological survey done in 1985 by the authors of this report (for report on the geology of the Chuka-South area see no.30 in list of references and literature used). The hydrology and hydro-geology of each unit of the geological map was studied. This resulted in a hydrogeological map (appendix 3), which is derived from the geological map. 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.
The geology, structures and geomorphology of the units of this hydrogeological map are described in chapter 2. The hydrogeological features of the mapunits are described in chapter 3. Also a general investigation on the water-supply of the survey area was made. The results of this investigation can be found in chapter 4.
Next to this general exploration a more detailed survey on the groundwater in a large dry riverbed was carried out with the help of geoelectrical survey methods. The results of this survey are described in chapter 5.
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.

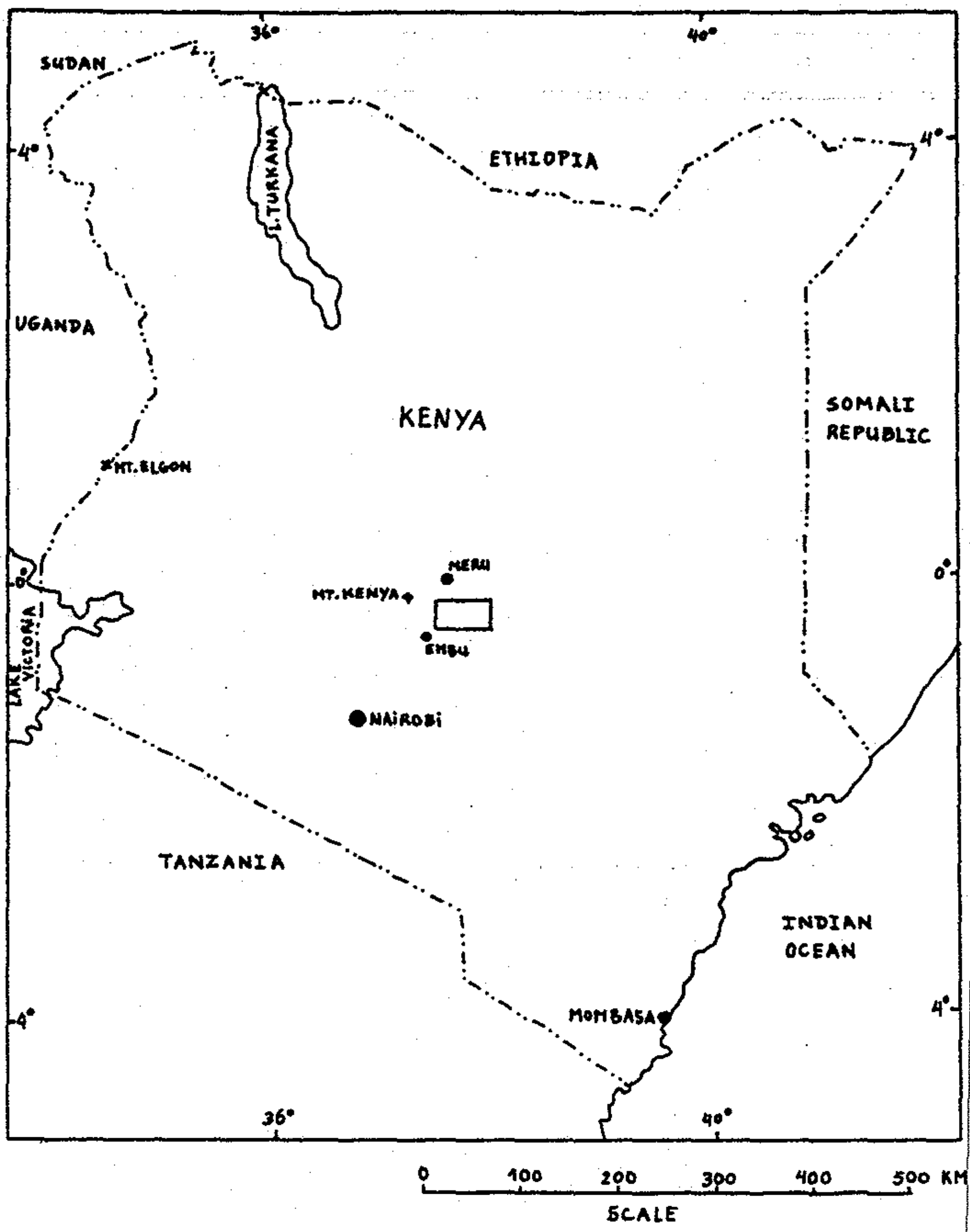


FIG. 1. -THE LOCATION OF THE CHUKA-SOUTH AREA IN KENYA.

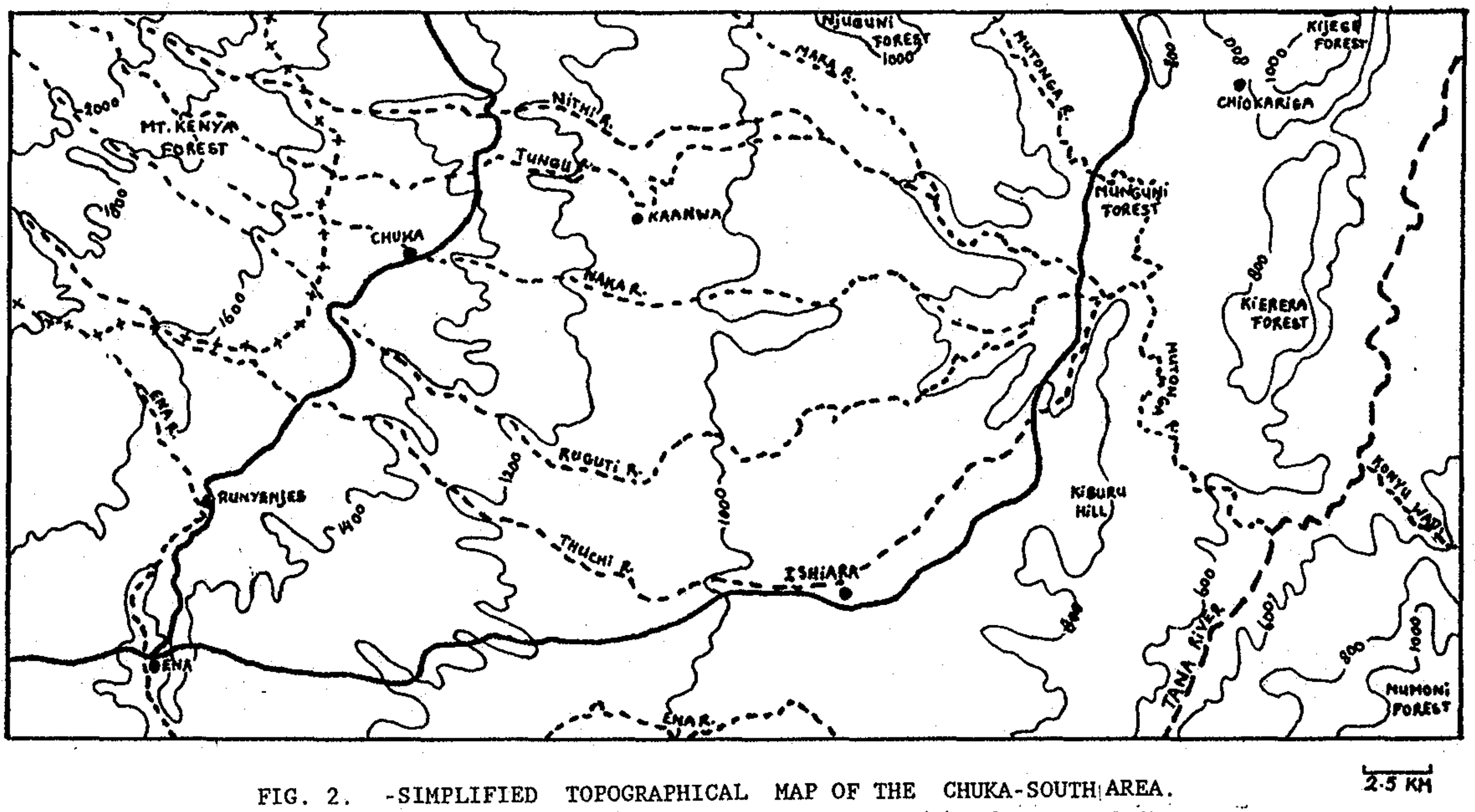


FIG. 2. -SIMPLIFIED TOPOGRAPHICAL MAP OF THE CHUKA-SOUTH AREA.
(This map is derived from the topographical map of Kenya, scale 1:250,000, mapsheet Chuka)

ROAD
RIVER
CONTOUR-LINE (M)
VILLAGE
MT. KENYA FOREST BOUNDARY

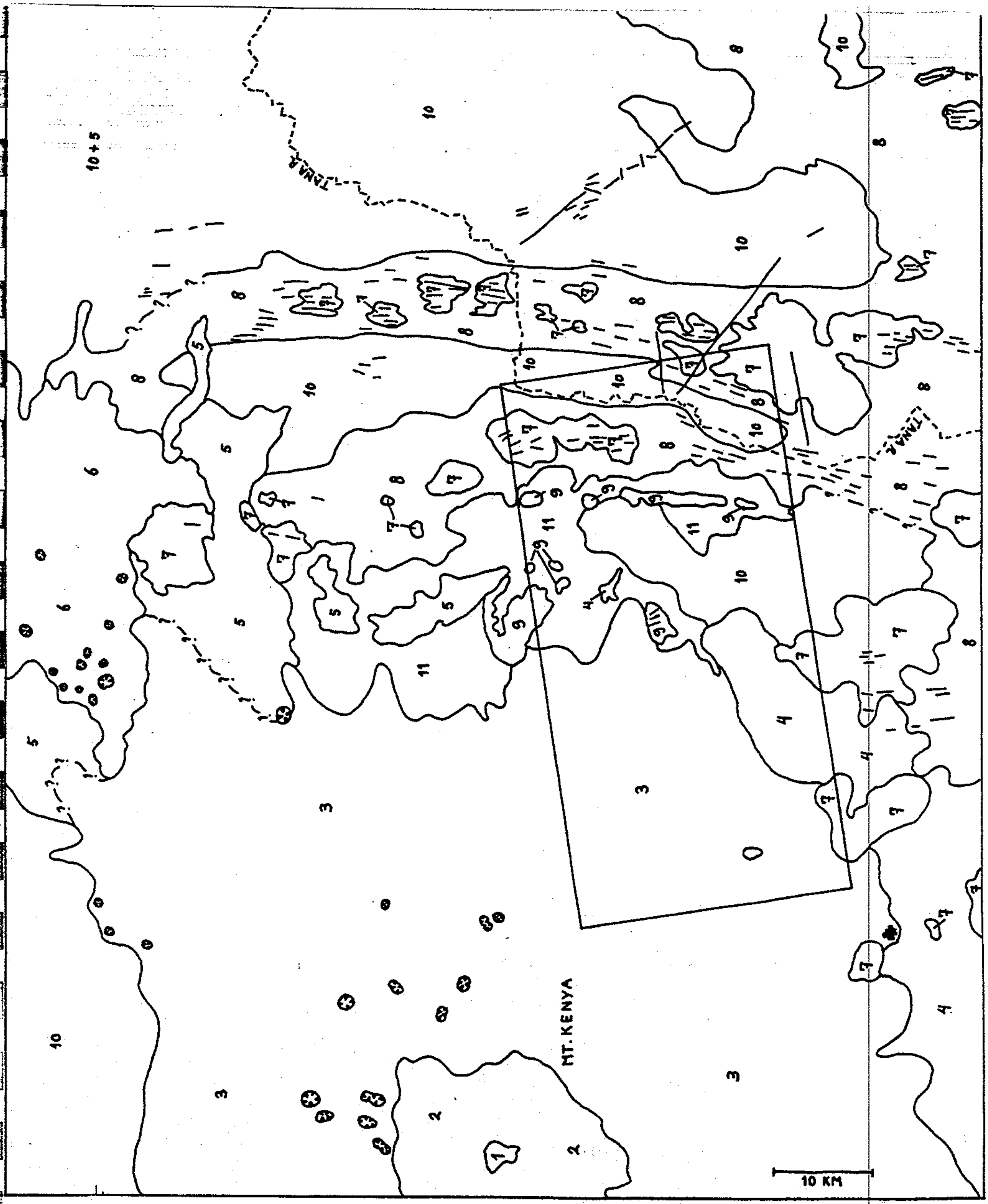


FIG. 3. -INTERPRETATION OF THE SATELLITE IMAGE.
The rectangle in the southern half of the interpretation is the Chuka-South area. For the legend see next page.

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.

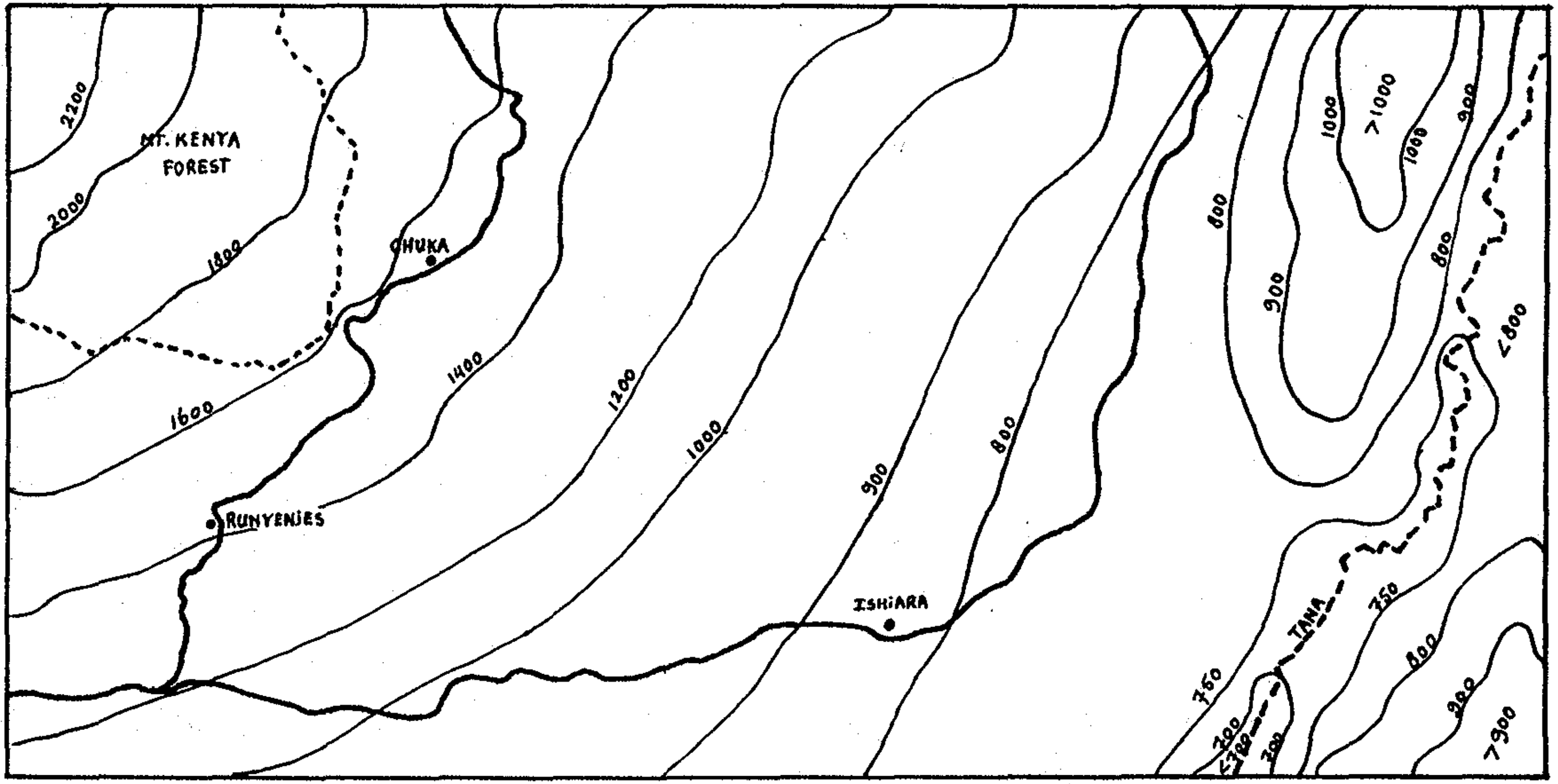


FIG. 4. -THE AVERAGE ANNUAL RAINFALL (IN MM) OF THE CHUKA-
SOUTH AREA.

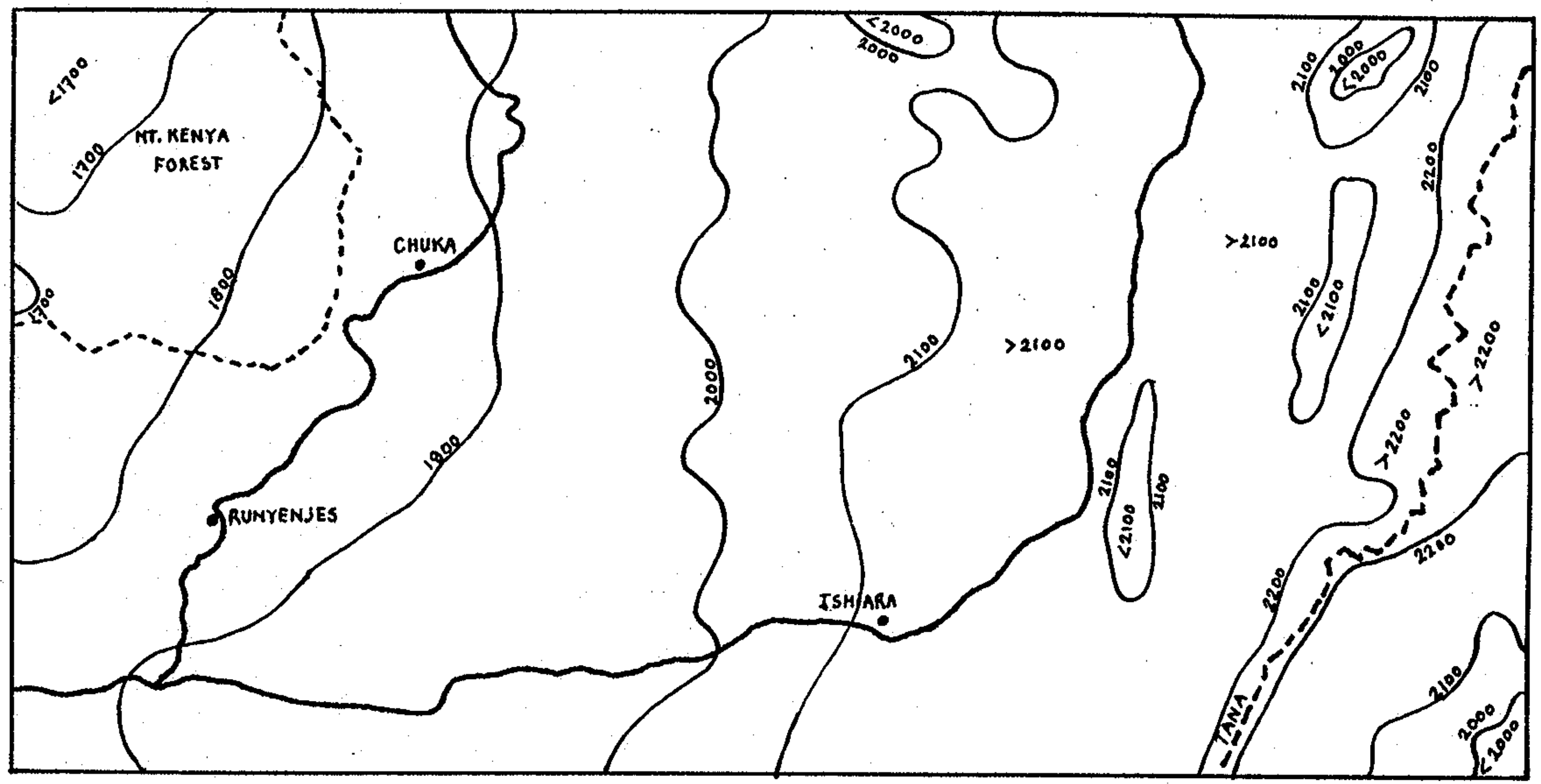


FIG. 5. -THE ANNUAL POTENTIAL EVAPORATION (IN MM) OF THE CHUKA-SOUTH AREA.

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 chapter of this report.

2. THE GEOLOGY AND GEOMORPHOLOGY OF THE CHUKA-SOUTH AREA.

The hydrogeology of the area is not only determined by the types of rock and their characteristics but also by their structures. Structures like major flexures, the general strikes and dips and major faults determine the general groundwaterflows in an hard-rock area and to a less exent also in volcanic areas. The minor structures as a result of subsidiary deformation and joints and cleavage are very important to the permeability and groundwaterflows in the various types of rocks.
The lithology and the structures of the rocks have determined the landforms and the drainage patterns of the area. These landforms and drainage patterns can deliver important information about the build up of the area. The landforms also have an important influence on the hydrology. The groundwaterflows are, to a great extent, determined by the topography of the water bearing area. This is why also the geomorphology of the area will be described in this chapter.
In this chapter first the petrography of the units of the hydrogeological map will be described. The second sub-chapter will deal with the geological structures and the last sub-chapter will describe the geomorphology and drainage of the area. For the geomorphological map of the survey area see Appendix 4.

2.1. The geology of the hydrogeological 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 sections in which the geological map units are described. A third section is added, describing the predominantly Quaternary colluvial and fluviatile deposits. These deposits only cover a relatively small part of the area.

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 studies could not be included in this report yet.

2.1.1. 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) (11+25).
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 (25).
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 (25).
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 (25).

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

2.1.1.1. Precambrian banded gabbroic-ultramafic complex (M)

Field-occurence: These units form large and small hills in the area. The slopes of the hills are usually gentle. These hills are hornblende-gabbro intrusions. The hornblende-gabbros are accompanied by other ultra-basics as a talc-tremolite rock, peridotite, and at one spot chromite. The intrusives are surrounded and partly dissected by granulites.
The hornblende gabbros and granulites often form ridges. The talc- tremolite rock is only found in the lower parts in between the ridges.
Some small hills consists almost only of hornblende gabbro and hardly any granulite. The most common hill type shows in the centre several hornblende gabbro bands and along the edges predominantly granulites.

Petrology: 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 is about 5 mm

and the grains rather angular. Plagioclase does occur as traces in these rocks.

Granulites
The granulites 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 units the granulites usually become darker and the rusty spots disappear. This darker type of granulite seems to contain much more hypersthene and less feldspars.

Talc-tremolite rock
This rock type possibly also contains 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 the brown colours of conversions of spots of iron ore inside the rock to pinkish brown.

Peridotite
Locally this rock type is abundant in some units. The weathered surface is brown to black and coarse. The rock itself is medium-fine grained. The fresh cleavage surface is irregular. The olivine crystals are shiny, glassy, brownish-greenish coloured . The olivine crystals form the bulk of this rock. The diameter of the crystals is about 3 mm.

<u>2.1.1.2. Granites and granitoid gneisses (G)</u>

G1:<u>Granites and granodiorites</u>

Field-occurence

These units form the high mountain ranges as the Kijege-Kierera Forest area and Mumoni Forest. But also the lower hill complex South-west of Ishiara and the Basement System islands in the lahar area. These unit often form the highest parts of the Basement System area. The hills exhibit steep slopes with many rock outcrops and tors. The hills form inselbergs which 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.
The highest parts in the centre of the units consist of granites or granodiorites, surrounded by migmatites. The augengneisses and gneisssose granites and migmatites are usually found at the less higher parts. The granite intrusions are accompanied by many thin pegmatite veins which are too thin to have any importance for the hydrogeology.In the granodiorite 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).

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.

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 zones 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.

Augengneisses
The granitoid gneisses 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.

G2:<u>Predominantly gneissose granites</u>

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 G1 macroscopically in composition and texture. Only in this type of rock more micas with a preferred orientation occur.

G3:<u>predominantly granitoid gneisses</u>

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.

2.1.1.3.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, X4do 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.

X2:<u>Sequence of various banded gneisses with granitoid bands</u>

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 (350/50oW)) 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.

X3:<u>Banded gneisses complex rich in hornblende gabbro veins and granulite bands</u>

Field-occurence
This unit is situated in an undulating area around and in between the M-units. In this unit the gabbro bands, and other vein intrusions form low ridges or small hills. Many intermittent rivers dissect the area.

Hornblende gneisses are the most common rock types. There are many small (mostly concordant) hornblende gabbro veins with accompanying granulites and dolerite and pegmatite vein intrusions. The average strike of the hornblende gneisses is about 20.
The tors and ridges are granitoid rocks or vein intrusives.

Petrography
This unit is composed of rocks which have been described in other unit descriptions. For description of these rocks see previous or following pages.
Hornblende gneisses see X2
Gabbros see M
Dolerite see X5
Granulites see X1

X4: Hornblende plagioclase gneisses with migmatitic and granulitic bands

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(330/45o-100oW). There are many discordant and concordant granulitic and pegmatite bands and vein intrusives. The granulites form ridges in the area near the M units.
Loccally the gneisses are more migmatised, and sometimes migmatites occur.

Petrography

Hornblende-plagioclase gneisses
These gneisses have been described for unit X2. The macroscopic characteristics of this type of rock do not differ in these two units. For description of this rock type see X2.
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.

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.

X5: Hornblende-, biotite-, and hornblende-biotite gneisses and migmatites with dolerite veins

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 10o) contains hornblende gneisses, biotite gneisses, biotite-hornblende gneisses and migmatites. The migmatites and granitoid gneisses form the tors. Close to unit G1 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 X2.

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.

2.1.1.4. 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 (33/40oW).
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).

2.1.2. 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 of a 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 (2+16+21).

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) (3). 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) (3+8). While the Nyambeni volcanoes produced mainly basalts, Mt. Kenya produced phonolite flows, and later more trachytic lavas from parasitic vents and fissures (3+8).
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 (5+8).

2.1.2.1. Lava flows (V)

Field-occurence	These inverted basalt and phonolite flows form narrow elongated ridges in the Basement System area. On their slopes usually there is a colluvial deposit (C). The phonolites and basalts show columnar jointing The phonolites have their phenocrysts parallel to the flow direction. Below the lava cap sometimes fluviatile deposits are found. These fluviatile deposits are indicated by ooooo on the map.The flows have many rock outcrops on top.
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 but are found up to 2 mm. There are

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.

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.

2.1.2.2 Complex of lahars and lava flows (L)

L1a:Sloping complex of lahars and lava flows

Field-occurence	In this area in the deep valleys with steep slopes rock outcrops occur. 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.6. and 7.). 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:Plateau like complex of lahars and lava flows

Field-occurence	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, are not very common (see Fig. 7.). 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 of lava 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 G1.
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 a few mm 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 V

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.

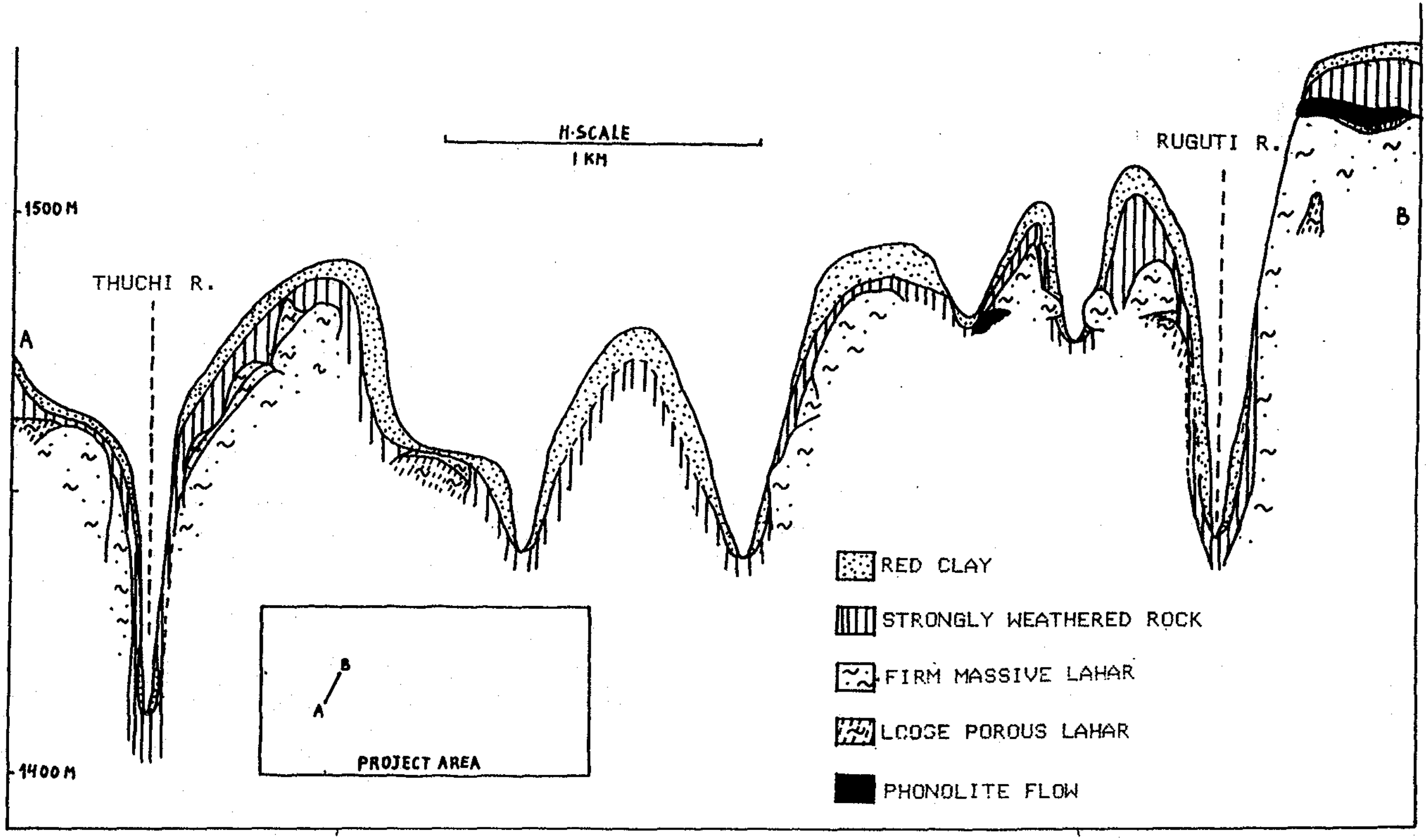


FIG. 6. -CROSS SECTION THROUGH A PART OF UNIT LIa, THE SLOPING LAHAR AND LAVA COMPLEX.

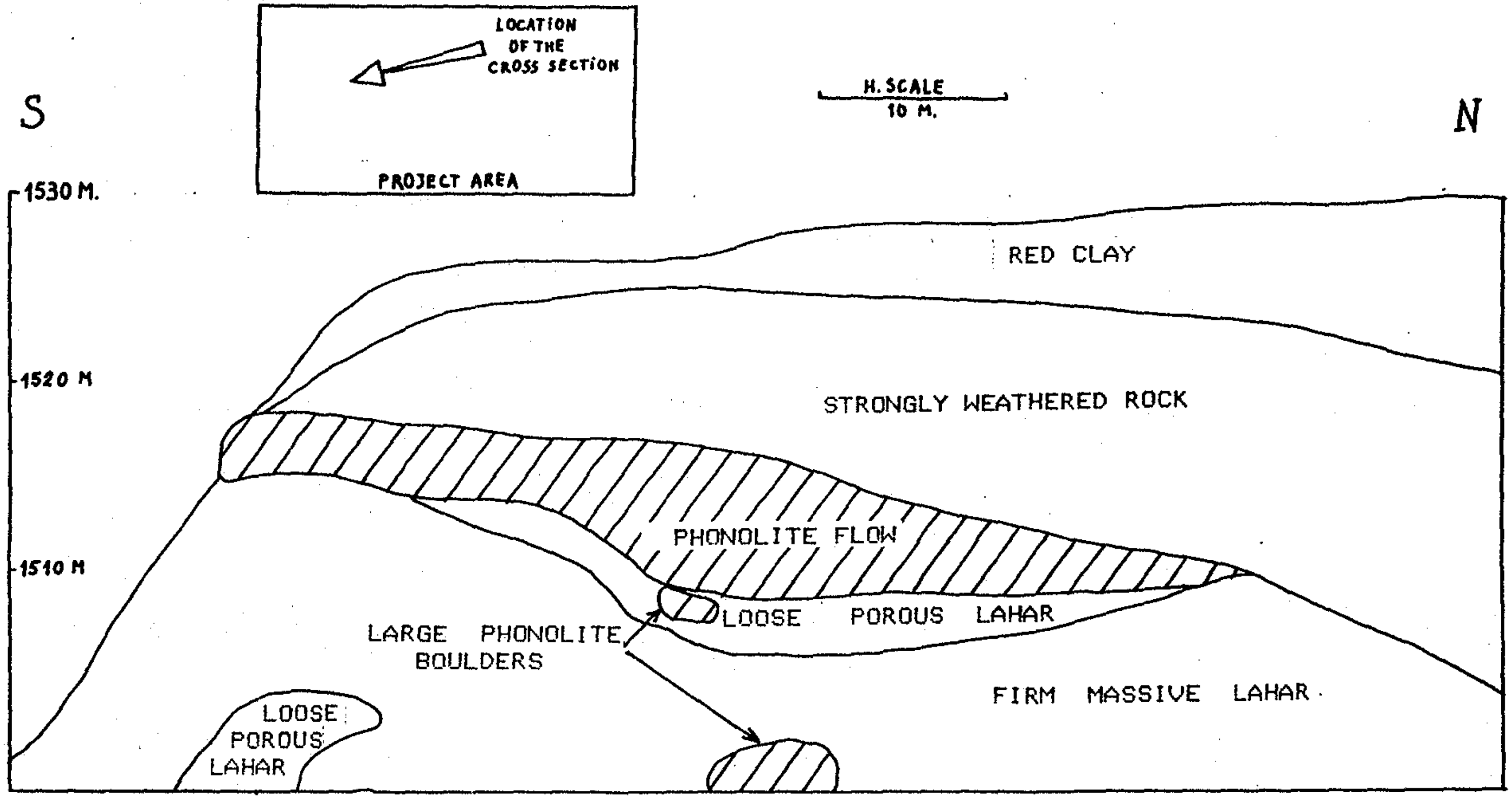


FIG. 7. -DETAIL OF FIG. 6. , A PHONOLITE FLOW ENCLOSED BY LAHARS.

L2: Lahar complex which is overlying a granitoid complex

Field-occurence	This unit forms the higher parts of the lahar complex area. The unit can be recognised 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

2.1.3. Colluvial and fluviatile deposits.

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

The buried fluviatile deposits

These fluviatile deposits are indicated by ●●●●● and ooooo on the hydrogeological map (see Appendix 3).
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 unburied fluviatile 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 two groups of deposits:
- The terrace deposits, predominantly conglomerates (F1)
- The present river bed, predominantly sand and gravel. (F2)

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.

2.1.3.1. The fluviatile deposits (F)

F1: The terrace 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.

F2:<u>The river bed deposits</u>

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. Clay is not deposited in the area since the velocity of the water is still too high.

2.1.3.2. Colluvium (C)

C:<u>Colluvial deposits</u>

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 bordering to C.
Petrography	Colluvium Many boulders, stones and gravel of various sources.

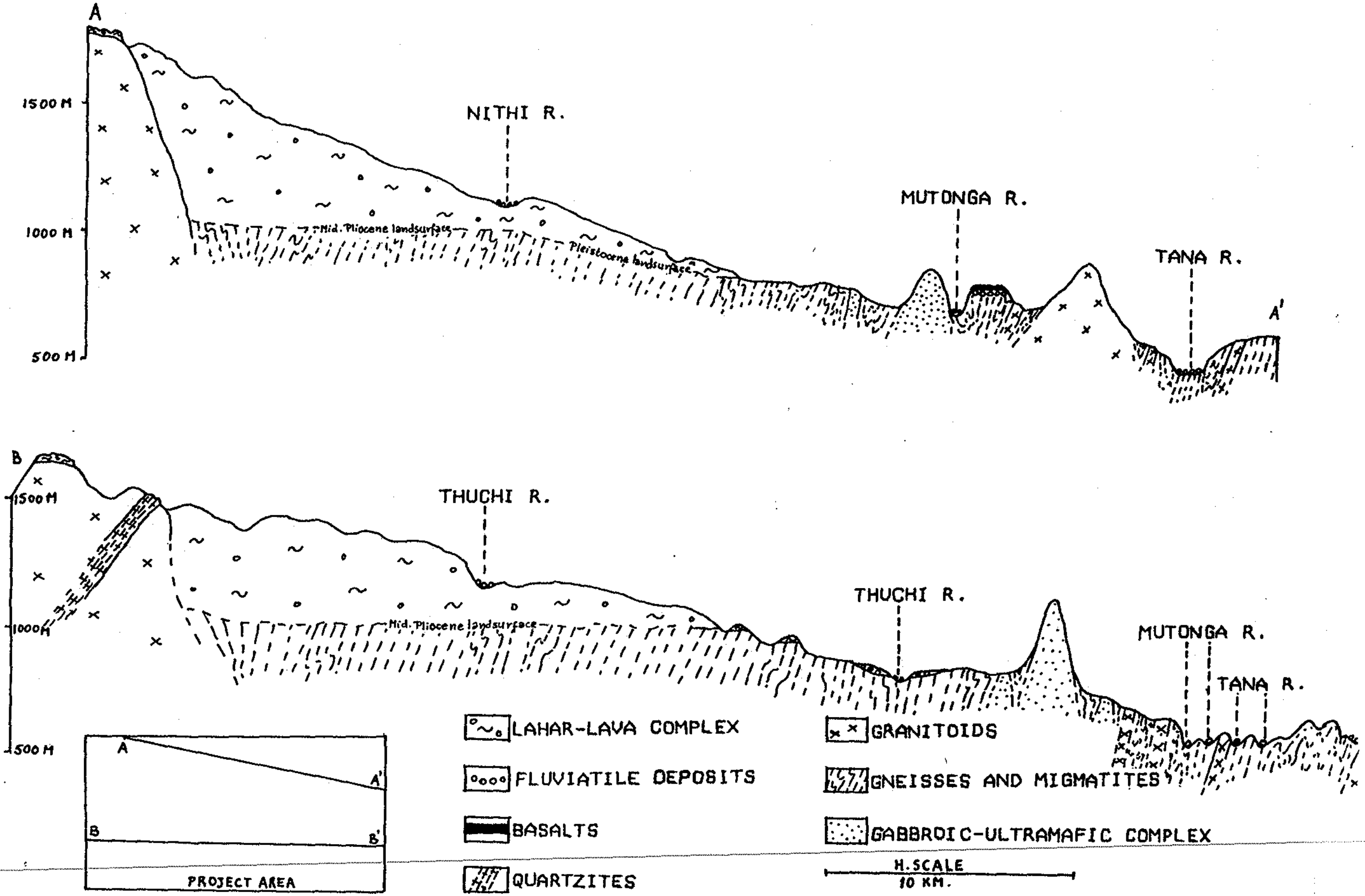


FIG. 8. -GEOLOGICAL CROSS-SECTIONS THROUGH THE AREA.

1w1z2w1z

2.2. Structures.

Major structures.

A dominant aspect of the Basement System is its broad stratiform disposition. Most strikes vary roughly between North to South and North-east to South-west. The general dip varies from 30o to 90o. Since no distinctive marker horizons or any recognizable repetition of strata are found, it is not possible to determine whether this implies simple tilting or close steep-angle folding. In adjacent Basement System areas marker horizons, strikes and dips suggest major foldings.
The hook-like shape of the most southern M-unit and to some extent the repetition of this shape in the adjoining rocks, illustrated by their stikes, indicates a large flexure. Also other parts of M-units in the area and North of it suggest flexures (28). It is not known if these ultra-basic intrusions are partially discordant or of post-flexing date or whether they were involved in the flexing themselves.
Between the M-unit in the centre of the area and Thuchi river a stong disconformity is present. This disconformity is not indicated on the hydrogeological map since it is not known if it has any influence on the hydrogeology.
The structure of the Mt. Kenya volcanics reflect the large volcanic pile with radial outward dips, centered on the syenite plug, which forms the present peak (see Fig. 3). The dips of the lahars in the Chuka-South area vary from about 2o to 4o in West-south-westwardly to Southwardly direction.

Major faults.

No major faults can be recognised in the Chuka-South area. A number of smaller faults can be recognised in the Gl- and M-units. These faults all have a North-west to South-east direction and are steeply dipping. Also numerous lineaments can be marked on the hydrogeological map. A number of these lineaments will be faults, but it is not certain whether displacement has taken place along these lineaments. Other lineaments will be major joints or strongly jointed zones.
Also the tendency of streams to cut across strata at right angles over certain distances, especially between Kijege Forest and Mumoni Forest, may indicate transverse faulting or strongly developed jointing.
A fissure or fault is suggested by the only clear lineament in the volcanic area. On this lineament in the eastern part of the volcanic area two depressions are located.
West and North-west of the Chuka-South area ten basaltic craters occur nearly on a straight line. These craters seam to be located on a large fracture or fissure trending East-north-east. This fracture or fissure runs only a few kilometres West of the north-western corner of the Chuka-South area.

Minor structures.

The minor structures are formed by generally intense subsidiary deformation. Deformation in all stages of intensity as extremely tight folding, boudinage structures, ptygmatic veining and other typical features are especilally well developed in the migmatitic gneisses and migmatites.

Joints and Cleavage.

On the whole jointing is well developed as well in the Basement System rocks as in the volcanics.
The jointing of the Basement System rocks can be regarded as late tectonic features resulting from declining temperature and regional pressure. The jointing of the volcanic rocks can be regarded as a result of declining temperature and in the lahars also as a result of the loss of water and solidification of the volcanics.
The jointing in the Basement System rocks is usually normal to the strike and foliation. Cleavage is usually parallel to the foliation. As far as could be observed, in the Chuka-South area cleavage plays only an important role in the strongly deformed migmatites. In the following text no distinction will be made between jointing and cleavage sensu stricto.
At some spots closely spaced jointing has imparted flaggy and slabby aspects to the gneisses.
Many joints in the Basement System rocks are filled with quartz veins or with secondary lime in the weathered rock.
Because the jointing almost completely determines the permeability of the rocks in the survey area this feature will be discussed more elaborate and per unit in the text below.
The granulite and migmatite areas of unit X1 show little and tight jointing. Locally the granulites show a more dense pattern of jointing. Here the granulites do not form hills but lower tors or cover the surface with large granulite boulders. In these cases the granulites are included in the migmatitic gneisses units like X3 and X4.
In unit X2 successions of para- and ortho-gneisses occur. In these gneisses also bands of granitoids occur. This unit shows a stream fabric in which many rivers cut across the strata at right angles, locally forming a rectangular drainage pattern. Since no displacement along the straight courses of the streams cutting the strata could be proved, these lineaments should be considered as zones with a strongly developed jointing. Also between these zones this unit shows well developed jointing, especially in the ortho-gneisses and granitoids.
The highly metamorphosed para-gneisses of unit X3 show very undeep, tight and poorly developed joints. The granulite bands and hornblende-gabbro veins show more fractures.
Also unit X4 consists predominantly of highly metamorphosed para-gneisses which are also poorly jointed. Locally the rocks are more brittle and and more fractured. This is demonstrated by the more frequent occurence of tors, usually built up by migmatites or granulites.
The gneisses of unit X5 show many joints which are relatively

well developed. Locally, and especially around the G-units migmatites occur which, in general, are well fractured. These fractured migmatites build up most of the tors in this unit. The migmatitisation grade of the migmatites is not high enough to make the rock brittle. The poorly fractured migmatites form the rounded, bare hills in this unit.
The para-gneisses in this unit which have not undergone high-grade migmatitisation-processes seem to have lower metamorphic grades than the other gneisses in the Chuka-South area.
The quartzites and schists of unit Q are the meta-sediments with the lowest metamorphic grades in the Chuka-South area. Only the quartzites show jointing. The schists only show cleavage parallel to their stratification. The joints are not very well developed and are only extended in the quartzite bands.
The granite- and granodiorite complexes of unit G1, which form the highest hills or mountains in the Chuka-South area, are merely poorly jointed granite massives. The highest parts of these complexes consist of granite "cores" with migmatites with only shallow joints and cracks, merely as a result of physical weathering, which give chemical weathering little chance to attack the rock. The lower parts between the peaks show a denser and better developed jointing pattern, demonstrated by the numerous granitoid tors in these parts of the unit.
Another granitoid unit, unit G2 which consists predominantly of gneissose granites, shows relatively more joints than the granites of unit G1. However these joints are still poorly developed.
The most and best developed joints in a granitoid unit are found in unit G3. This unit is built up by predominantly granitoid gneisses. These gneisses are well fractured. This is indicated by the relatively low position of this unit compared to the other granitoid units. The fracturing of this unit has given chemical weathering a chance to lower these rocks more than the less fractured granitoids. In the southern part of this unit less fractured granitoids form many ridges.
The basic rocks of the M-units are too poorly exposed to reveal detailed information about the jointing of these rocks. The few good exposures in these rocks show a very dense pattern of undeep and tight joints in the hornblende-gabbros. The chemical weathering has not widened the joints much. The joints are merely filled by a residual clayey material. Also the talc-tremolite rock shows a tight jointing. The granulites of the M-units tend to show more jointing towards the edges of the units. In the centres the granulites are poorly jointed and form the prominent outcrops.

In contrary to the Basement System rocks, where most joints are related to tectonic processes which once acted on these rocks, the joints of the volcanics all find their cause in the cooling, hardening, loss of steam, setting and shrinking of the lavas and lahars.
The lavas of unit V consist of phonolites and basalts. Every unit V comprises a single lava flow, so no well-fractured crusts of

quickly solidified lava between lava flows overlying each other could be found. As well as the basalts also the phonolites show a clear columnar jointing. The polygonal basalt columns have diametres of only a few decimetres. The phonolite columns show diametres from about one metre to even more. The jointing of the most north-western flow, a phonolite flow, is more regular and better developed than the jointing of the most south-western flow, which is also a phonolite flow. The jointing of the basalts has a clearly promotive influence on the rate of the chemical weathering of the basalts. The phonolites with their less developed jointing almost show no chemical weathering, except for some wider and deeper joints.
The lahars of the L-units show well develped continuous systems of steeply dipping, oblique joints. These major joints have spacings from a few to many metres. Smaller joints form the connections between these major joints. The jointing of the lahars shows not a clear pattern as there is in the lavas. The jointing pattern in the lahars seems to be determined by the varying composition of the lahar. The loose, porous lahars show no jointing. Where in the firm, massive lahars large boulders occur, the jointing is interrupted.
At the contacts of lahar flows with other lahars or lava flows never well fractured crusts as at the contacts of lava flows overlying each other are found. The contacts are very clear transitions, usually within a few centimetres.

The colluvial and fluviatile deposits of the C- and F-units are too young and not consolidated enough to show any deformation or jointing. Only some conglomerates in the F-units are indurated with secondary lime. These deposits have never undergone any tectonic or other deforming actions and show no fractures.

Iwlz2wlz

2.3. Geomorphology.

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 sub-parallel 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 which has an overall radial drainage pattern (see Fig. 9). 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 and are a part of the radial drainage pattern of the Mt. Kenya volcanic body (see Fig. 9).
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.

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.

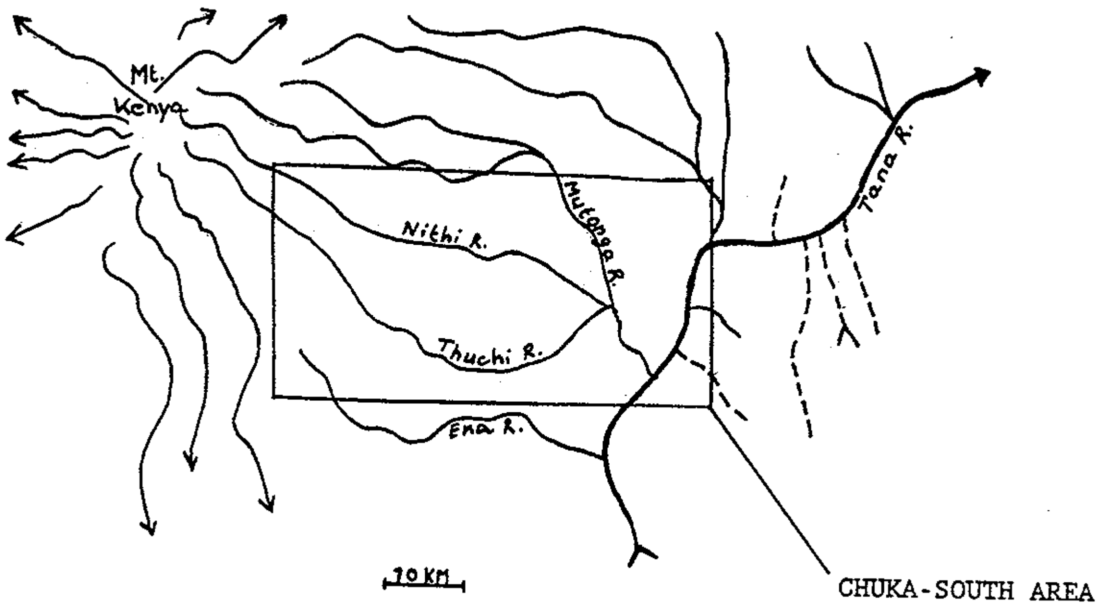


FIG. 9. -GENERAL DRAINAGE PATTERN OF THE EASTERN SLOPES OF MOUNT KENYA.

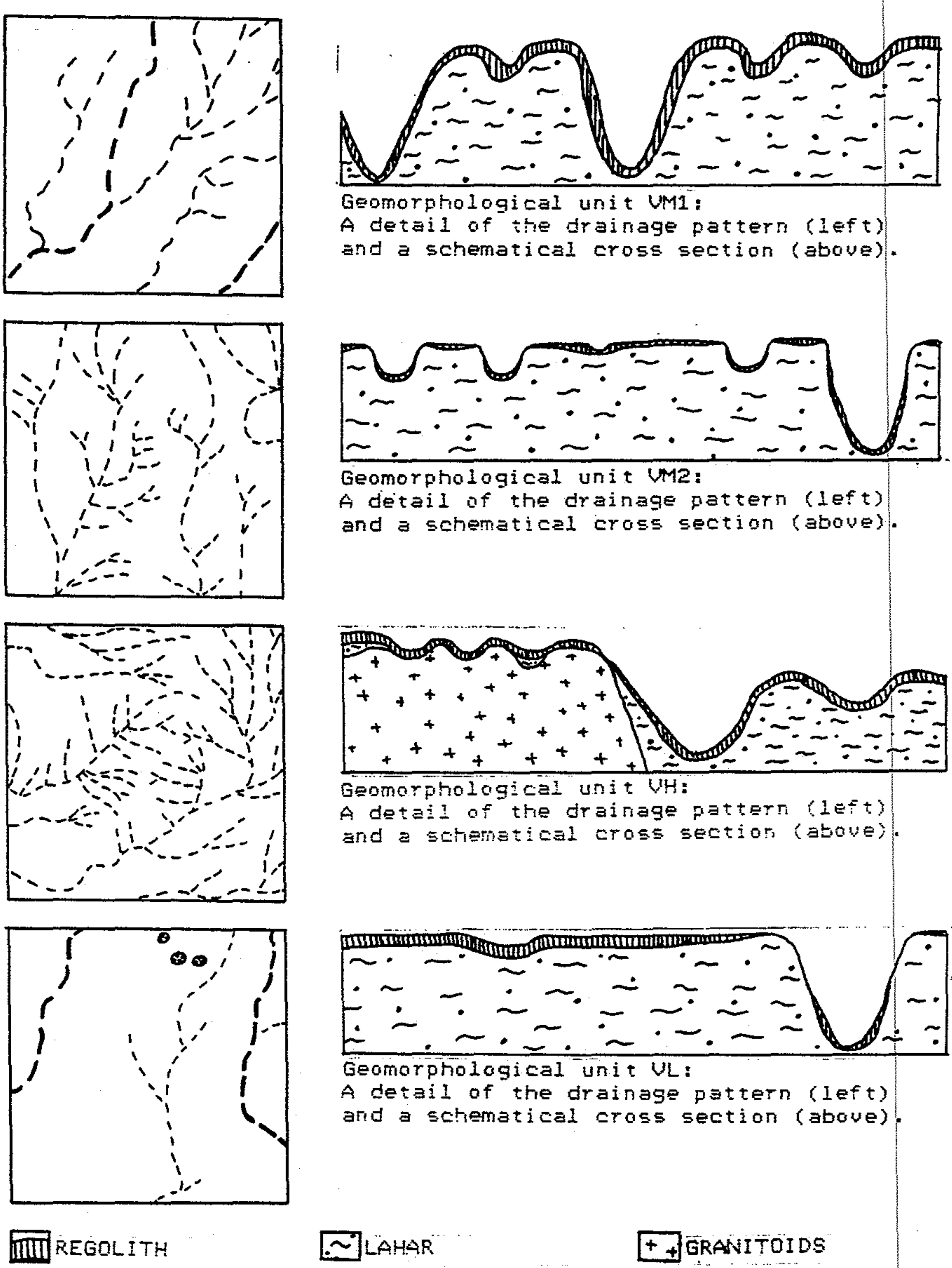


FIG. 10. -DETAILS OF THE DRAINAGE PATTERNS AND SCHEMATIC CROSS SECTIONS THROUGH A NUMBER OF LANDSCAPES OF THE VOLCANIC AREA.
(Scales: drainage pattern maps 1:100,000 cross sections 1:40,000)

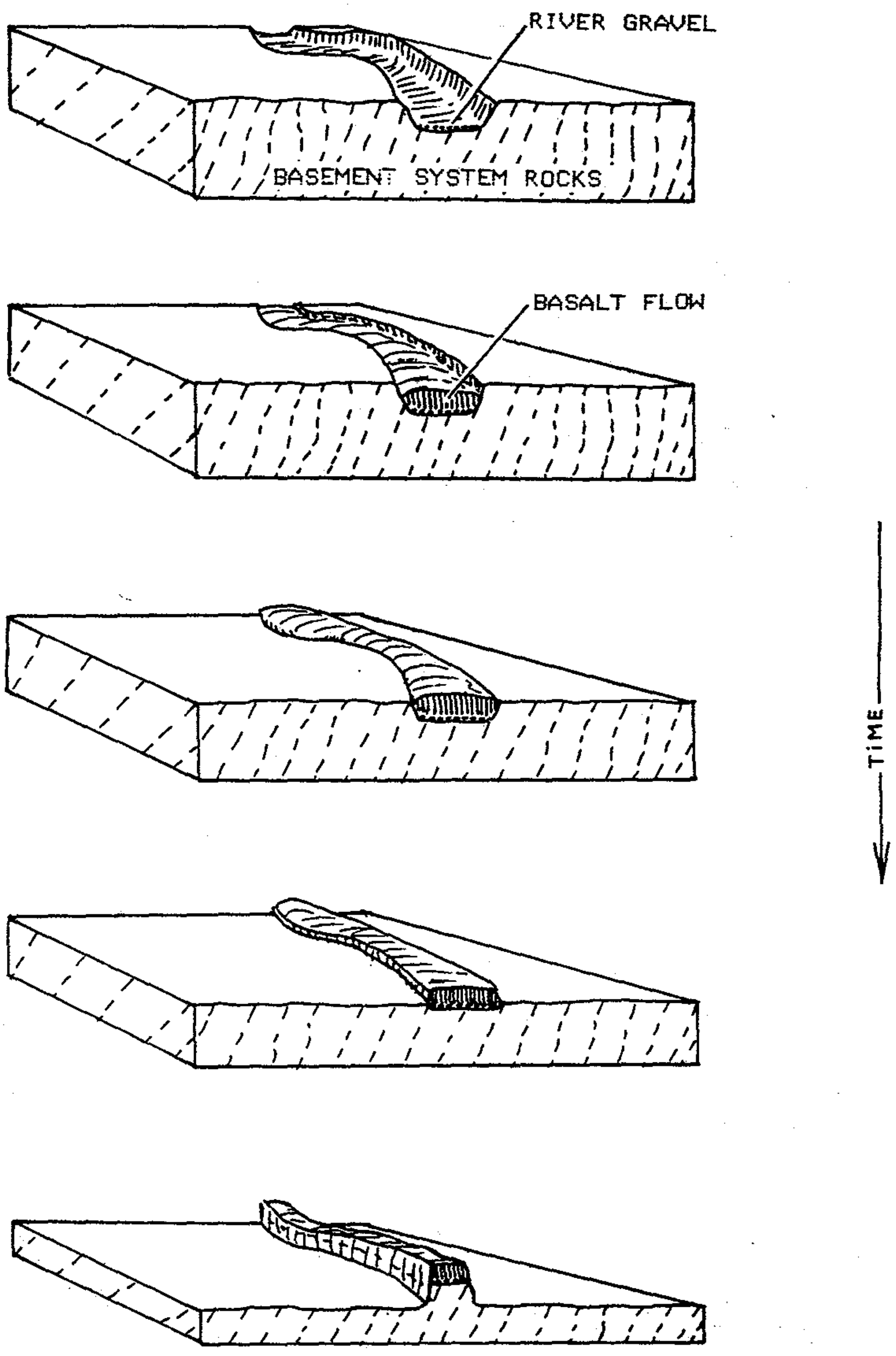


FIG. 11. -DEVELOPMENT OF A VOLCANIC RIDGE (VR) IN THE BASEMENT SYSTEM AREA BY A PROCESS OF RELIEF INVERSION.

The 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).
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%)

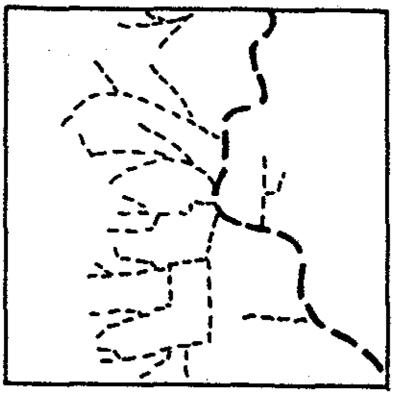
The flat Lowlands show some local dissections like erosion gullies, but the main character is flat. These areas are usually situated along rivers and are former river terraces. Locally remnants of the fluviatile deposits are found in this unit.

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).

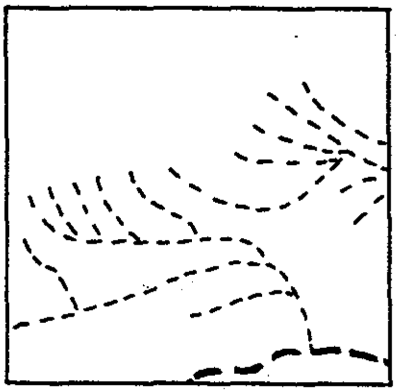
The hilly Lowlands BLh also can be subdivided.
Unit BLh1 has a dendritical drainage pattern. This area is generally situated higher than the surrounding Lowlands. The main rock types in this area are granodiorites and their accompanying migmatites (see Fig. 12).
Unit BLh2 has a more subparallel drainage 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).

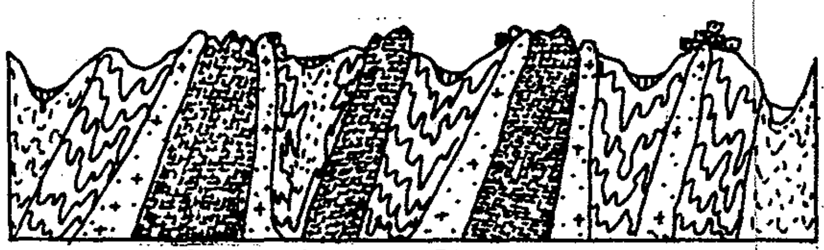
The Valley (BV).
In the Basement System landscape only one large Valley can be distinguished. It is the large Valley of Tana river. The Valley length-profile has an overall slope of some percents, and the slopes are up to 20%. In this Valley the Tana is following a straigth course since the river has 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.

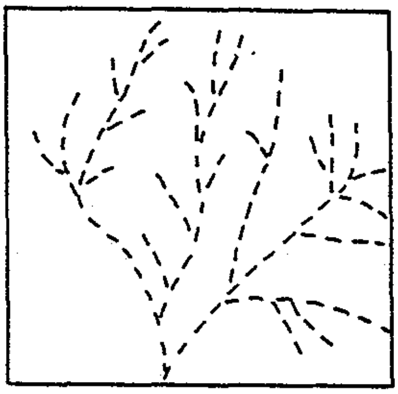


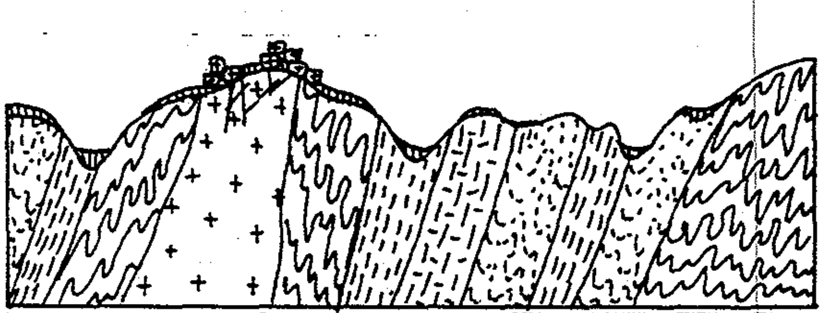
Geomorphological unit Blr1:
A detail of the drainage pattern (left)
and a schematical cross section (above).





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).

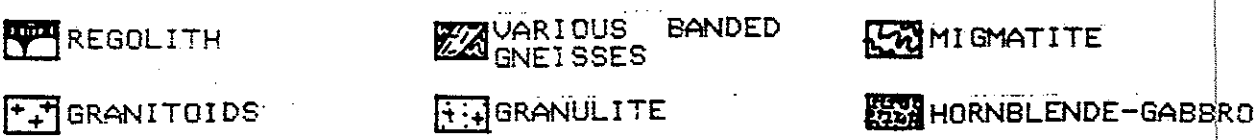
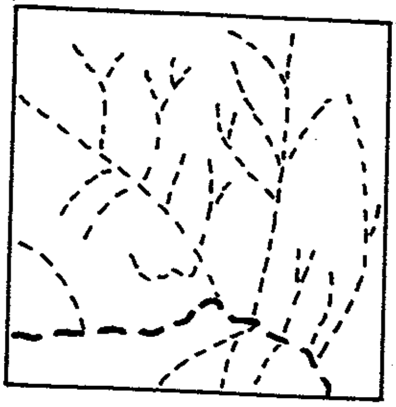
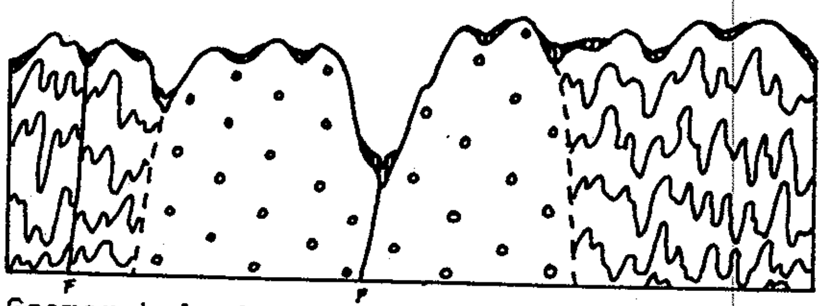
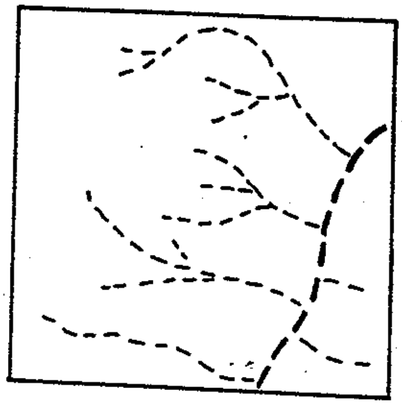


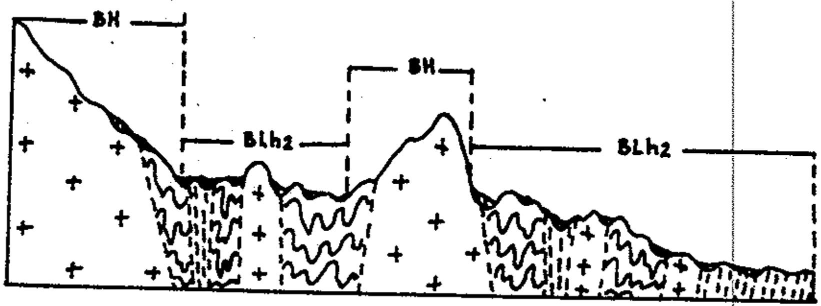
FIG. 12. -DETAILS OF THE DRAINAGE PATTERNS AND SCHEMATIC CROSS SECTIONS THROUGH A NUMBER OF LANDSCAPES OF THE BASEMENT SYSTEM AREA.
(Scales: drainage pattern maps 1:100,000 cross sections 1:40,000)





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. THE HYDROGEOLOGY OF THE CHUKA-SOUTH AREA.

In this chapter the petrography, structures, and geomorphology of each unit, together with some additional information, will be combined to give a description of the hydrogeological characteristics of the units of the hydrogeological map and to give an estimation of the liabilities of occurences of groundwater bodies or aquifers in these units. The conclusions about the occurences of groundwater and the indications of the best sites for procurement of groundwater should be considered as tentative because no test-drillings nor geophysical measurements could be carried out, except for a part of unit F2 as is described in chapter 5.

3.1. The Basement System.

The banded migmatitic gneisses complex (X):

X1: Small granulite hills. The granulites are non porous and poorly fractured so the permeability of these rocks is almost nil. This also restrains the chemical weathering so almost no regolith is developed on these hills. This unit forms small hills. This causes the unit to be well drained. Most of the rainwater runs to the surrounding units as an overland-flow. Very little water is stored in the few larger joints. A drought resistant vegetation is rooted in these larger joints and is capable to withdraw enough water to survive.
Only very limited amounts of groundwater can be expected in this unit. Probably the amounts are not worth exploration.

X2: A succession of various banded gneisses with granitoid bands which comprise hilly and rolling lowlands and the broad valley in which Tana river finds its bedding.
The gneisses and granitoids are well jointed. The regolith is not very thick but more sandy and better permeable than the regolith of most gneisses units of the Chuka-South area. This delivers the rainwater a good opportunity to infiltrate into the regolith and joint system. Also a lateral transport of groundwater from the granite mountains North-west and South-east of this unit should be expected. This makes this unit very liable to contain amounts of ground water worth mentioning. The best chances of striking groundwater in a drilling in this unit will be at the intersections of lineaments like in some right-angled bends of the rectangular drainage pattern.

X3: A banded gneisses complex which is rich in gabbro veins and granulites and which comprises subdendritically to subparallelly dissected lowlands. The rocks of this unit are practically non porous and also the fractures do not deliver a great permeability. Even where the fractures are better developed the feeding of the groundwater in these fractures is hindered. As in most Basement System units the regolith is absent to moderately thick. The soil structure is extremely instable. This causes the development of an impermeable crust during the rains.

This crust makes plantgrowth difficult and makes infiltration of the rainwater almost impossible. Most of the rainwater runs off to the gullies and dry riverbeds as an overland flow. According to infiltration measurements this run-off can comprise more than 80% of all rainfall. The little amount of water infiltrated into the regolith usually does not percolate deeper than about 50 cm. Most of this infiltrated water evaporates during the dry season before it can infiltrate deeper into the fracture system. Also a part of the water in the regolith flows off as a through-flow towards the lower parts, usually the dry riverbeds. Here a aprt of this through-flow water comes near the surface and evaporates. This is demonstrated by the amounts of secondary lime and other salts in the banks of the wadis. The dissolved salts are taken up by the water from the weathering gneisses and precipitate when the water evaporates (see Fig. 13). This process still seems to take place, but the thick calcium-carbonate banks (or petrocalcics) are probably formed during former, wetter periods.
The poor percolation of the water through the regolith means the fracture system can not be supplied very well with rain-water. Probably some feeding of the groundwater in the fracture systems takes place in the dry rivers. Most rivers prefer to find their riverbed in less resistent zones e.g. well fractured zones. The water from the surroundings running down to the wadis easily infiltrates into the sandy riverbeds. From these sandy riverbeds the water easily can infiltrate into the fractures. The water in the wadis will only flow as a real river when the whole riverbed is completely saturated and more water is supplied to the wadi.
The above is applicable for the units X4 and X5 too. It means the feeding of the groundwater in the fractures of these units is very limited. Also a lateral feeding of the groundwater from higher areas is not very plausible.
The gabbro veins and granulite bands in unit X3 are not extended and continuous enough to cause a drive-up of the groundwater. All together should be concluded the amounts of groundwater in unit X3 should be considered as very limited. When drilling at lower spots or in the valleys of the wadis, especially when these wadis form straight lines which can indicate stonger fractured zones, finding of higher amounts of groundwater should not be excluded.

X4: This unit resembles unit X3 in most characteristics. Distinguishing is the higher amount of granulites with accompanying migmatites and the lower amount of gabbro veins in this unit. The physiography of this unit is the same as in unit X3 but in unit X4 more tors appear. These tors are merely built up by migmatites and granulites. Where the tors appear the rocks are more fractured. Also the migmatites and gneisses surrounding unit X1 appear to be more brittle and more fractured near these granulite hills. Although the same problems with respect to the infiltration of the rain water into the regolith occur as in unit X3, the better developed fracturing is more promising for finding groundwater. Probably also some water flows from the higher lahar area in the West via the colluvial deposits into the fracture system of this unit.

X5: Complex of hornblende-, biotite-, and hornblende-biotite gneisses and migmatites with dolerite veins. The gneisses between and around the G-units are intensely migmatitised. Most of the gneisses and migmatites are well jointed. The large North-west to South-east directed fault South-east of Ishiara seems to continue in south-eastern direction into the migmatites and gneisses of unit X5.
Because the deformation and metamorphic grade of the gneisses in this unit seems to be less than the average of the gneisses in the Chuka-South area, the permeability of these gneisses probably is a little higher than the average. Still the permeability of the para-gneisses is too low to let these para-gneisses be more than a marginal aquifer. Also the feeding with water of the rock and its fractures meets the same problems again as unit X3 andX4. Erosion caused by the high run-off percentages has resulted in a similar landscape as it has in unit X3 and X4. The density and depth of the gullies in this unit is much higher than in the other units. This indicates the run-off is even more severe in this unit.
The dolerite veins do not seem to be capable to increase locally the amounts of water stored in the fractures since these veins are very thin, not continuous over reasonable distances and strongly fractured.
The best chances of striking groundwater in this unit will be found in
the fault zone South-east of the G1-unit. The granodiorite which is dissected by this fault has a somewhat higher position than the surrounding X5-unit. This implies that the groundwater in the fault will flow from the granodiorite towards the gneisses area. The necessity of making a borehole here is arguable since the perennial Ena river almost runs through the fault zone.

Q: The quartzites and muscovite schists. These rocks are almost impermeable. The quartzites are poorly permeable, due to their jointing. The quartzite bands are intersected by the impermeable schists so no continuous joint system excists in this unit.
The unit forms a hill and a flank of another hill area. This causes this unit to be well drained, so no groundwater should be expected here.

The granitoid complexes (G):
G1: The granites and granodiorites. The granites form high hills or mountains e.g. the Kijege-, Kierera-, and Mumoni-Forest. A similar North-South range peaks up through the lahars in the western part of the Chuka-South area. For the greater part these hills are covered with volcanics now. The granodiorite area South-west of Ishiara forms a hilly area which is a little more elevated than the surrounding lowlands. This area has not built

up a mountain or hill like the other parts of the G1-unit, but it forms a sub-parallel dissected hilly part of the lowlands.
The eastern granite mountains and the granodiorite intrusion show some large faults and numerous lineaments which not could be proved to be large joints or faults.
The granite mountains receive higher amounts of rain due to their higher topographical position (see also Chapter 1).
Where present the regolith of the granites and granodiorite is more sandy and better permeable than the more loamy soils developed on the gneisses. The regolith is too thin to store amounts of groundwater worth mentioning. This implies the faults in the granites and granodiorite can be supplied with water infiltrating through the regolith and through smaller joints. That these faults contain water is proved for the fault which runs through unit G1 in north-western direction to Chiokariga. A spring occurs where this faults leaves the high granite massive. This spring supplied most people from Chiokariga with water until the water-pipe line was finished. The chemical data of this water show high amounts of dissolved salts. The high amount of Si-ions in the water is striking (for chemical data see appendix 2). This suggests the water was taken up in the fracture system of the rock for a fairly long time and does not originate from the regolith. Also the fact that, according to the local people, throughout the whole year there is a constant supply of water, with only a minor increase during the rainy season suggests the spring-water originates from the fault-zone and not from the regolith.
The small granite peaks amidst the Mt. Kenya volcanics show no faults, large joints or other lineaments, so no groundwater should be expected here.
The spots in unit G1 where it is most liable to strike water when making a bore-hole are located on the fault-zones, preferably at the lowest parts of these zones, or at the intersection of these faults with other lineaments e.g. large joints.

G2: Gneissose granite hills which show better developed jointing than the granites and granodiorite of unit G1. The water can easily infiltrate into theses joint systems through a sandy, permeable, but thin regolith. Although the jointing is better developed in this unit compared to unit G1, the physiography does not favour the storage of large amounts of water in these joints. First the areage of this unit is too small to store large groundwater bodies and secondly the unit consits of isolated hills. These small hills are well drained due to their relief and permeable regolith. The run-off on these hills is not very high. Most water flows through the regolith and shallow joints to the adjecent areas, and contributes to the water supply of the well developed joint systems of the surrounding units G3 and X2. That lateral water transport, or through-flow, through the regolith takes place in this unit is indicated by the occurence of secondary calcium-carbonate in the regolith of the lower slopes of this unit. This through-flow is supposed also to take place in the regolith of the granitoid hills of other units, but there it could not be proved by the occurence of secondary salts as in unit G2. The process of precipitation of the secondary calcium-carbonates in unit G2 is the same as in the gneisses area as described above (see X3). The only difference is that in this unit the secondary salts do not occur as concretions or petrocalcics but as soft mottles and more diffuse precipitates.

G3: This is an extended area built up by granitoid gneisses, located West of the Kijege-Kierera Forest granite mountain ridge. The unit comprises a hilly lowland. Most gneisses are granitoid para-gneisses, but numerous granitoid ortho-gneisses and granites form small hills and ridges in this landscape. The granites and granitoid gneisses are well fractured. The regolith is, as usually in the granitoid areas, sandy and permeable. Also the physiography of this unit is favorable for the supply with water of the fracture systems. The unit is a relatively low area bordering the high mountain ridge in the East and, due to the general eastwardly slope of the Basement System in the area, a somewhat higher gneisses area in the West. Especially from the East a lateral contibution to the water supply of this unit can be expected.
No large faults or zones with more than general joints could be proved to excist in this unit, so it is difficult to indicate preferable spots for bore-holes in this area. In general can be said the best spots are the lowest parts of the area, preferably where concentrations or intersections of lineaments occur.

M: The gabbroic-ultramafic complex. The jointing of these rocks is not very clear. It seems the fracturing is only poorly developed. Only one fault could be recognised in this unit.
The poor fracturing and the fact that this unit builds up hills with only very shallow regolithes does it make unlikely this unit contains large amounts of groundawater. The best chances of finding groundwater in this unit occur in the fault-zone in the M-unit in the centre of the area. Other areas likely to be water bearing are the granulite border-zones of large M-units like Njuguni Forest and the elongated North-South ridge. These two hill complexes have clear border-zones of granulites. These granulites show locally better developed joints. This in combination with the fact that these granulite are situated at the lower slopes of these hill complexes offers a better opportunity for the granulite zones to be water bearing. In general highly-metamorphosed para-gneisses, of which granulites are the most extreme example, are no good aquifers. This means the possibly present groundwater bodies in granulites will have a very limited extension and importance.

For a general view on the water-cycle in a part of the Basement System area see Fig. 14, a schematic cross section through a part of the Basement System.

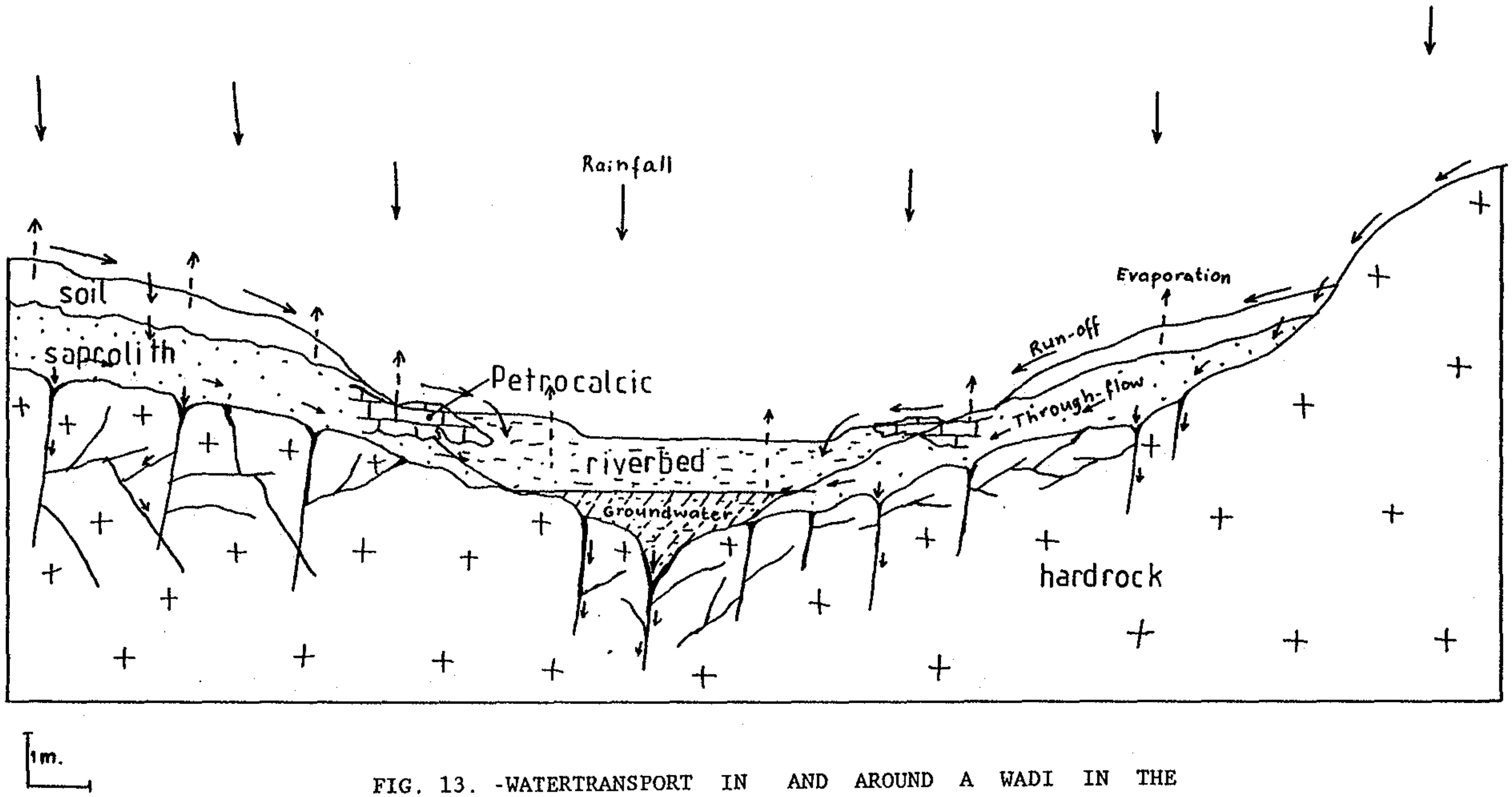


FIG. 13. -WATERTRANSPORT IN AND AROUND A WADI IN THE BASEMENT SYSTEM AREA.

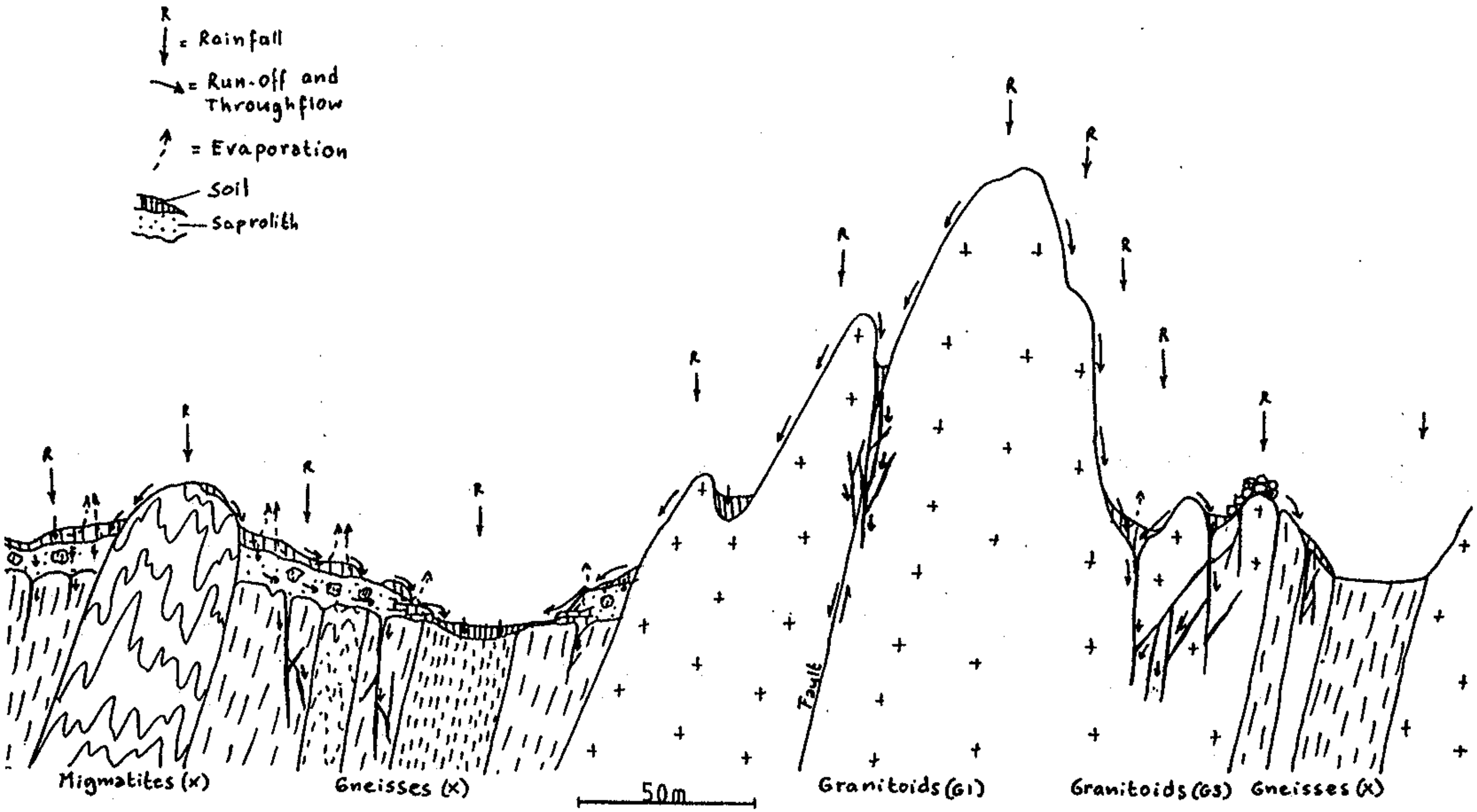


FIG. 14. -GENERAL WATERTRANSPORT IN THE BASEMENT SYSTEM AREA

3.2. The Volcanics.

V: The lava flows. These flows form the tops of the volcanic ridges and plateaus in the Basement System area. The development of these ridges and plateaus has already been described in chapter 2.3. The erosion which has caused the relief inversion has also caused a varying thickness of the lava cap. The maximum thickness of the lavas is about 6m. The average thickness is only about 2m. This in combination with the fact the lava flows have only a limited extension does not make it very liable the lava flows are bearing large groundwater bodies. The basalt plateaus East of Njuguni Forest and East of Munguni Forest have a somewhat greater extension, a flat topography and a relatively thick soil cover. This in contrary to most of the flows which are narrow, arching and not covered with soil. This offers the basalt plateaus the best opportunity to be water bearing areas.
Where present under the flows, the gravel acts a drain for the water infiltrated into the joints of the lava . The gravel deposits are too thin and have a too highly elevated position to be aquifers themselves.

The lahar-lava complexes (L):
L1: This lahar-lava complex consists mainly of lahars and a few enclosed lava flows. The lahars are built up by a succession of numerous lahar flows, each flow varying in thickness from a few metres to over ten metres. The contact zones between the lahar flows overlying each other are very limited in thickness and do not give the lahars any special hydrological characteristics. Locally some remains of soils between the lahars do occur. These paleosols can be of importance as a concealing deposit of an aquifer. The paleosols are aquicludes but are not very liable to be aquifers themselves due to their limited thicknesses and small extensions.
Most of the lahars are covered with a very thick regolith. Most of the regolith consists of a deep, red clay soil. This soil has a very permeable, stable structure. The regolith is an aquifer with a variable importance. It usually contains an amount of groundwater which increases during the rainy season. The rate of the downward movement of the groundwater in the regolith usually is diminished at the transition to the less weathered lahars. In the area with sloping lahars an important throughflow of water in the regolith over this transition zone is the result. This causes the occurence of many seepage zones where the regolith is cut by river valleys, road-cuts, near the depressions and at the scarps. Where the lahars are less sloping the water can not flow easily away through the regolith. Here the stagnation of the groundwater causes a temporarely higher groundwater table. The level of this groundwater table is high during the rainy season and lowered during the dry season. This fluctuation has caused the development of laterites in these flatter areas. This laterite

can be diffuse, but continuous in the weathering lahars, or occur as ironstone-gravel, the so called murram. The murram is fairly permeable, but the former type is almost impermeable.
This difference in hydrology of the sloping and flat lahars is one of the main differences between the sloping lahars (Lla) and the plateau-like lahars (Llb).
It is supposed the plateau-like lahars are older than the sloping lahars (Veldkamp&Visser, 1986), but this is not reflected in a better development of the joints of the plateau-like lahars.
The lahars themselves are porous, but not very permeable. The loose, porous lahars are very poorly sorted and have a very low permeability. The firm, massive lahars are also poorly sorted and have a lower porosity but as a whole these lahars are better permeable due to the high amounts and high density of the joints in these lahars. In this extended joint system high amounts of water are stored. Aquifers occur at several depths everywhere in the lahar area. The best aquifers occur in the sloping lahar area. The plateau-like lahars are partly too thin to contain more than marginal aquifers.The thickness of the plateau-like lahars varies from a maximum of about 200 m at the western border of this unit, if it is supposed the Basement System under the volcanics has a more or less general level of about 1,000 m, slightly increasing towards the West (the pre-volcanic pliocene etch-plain), to only a few meters at the eastern edge of the unit.
The thickness of the sloping lahars varies from about 200 m to more than 1,000 m. In this enourmous lahar pile various aquifers at several depths do excist. This is indicated by the six bore-holes in the sloping lahars. These bore-holes were not made at special selected sites but just at the spot where the water was needed. In every bore-hole water was struck between depths of 7 m (probably regolith-water) to 120 m. In some bore-holes two water-struck-levels were present. The water-rest-levels were between 5 m and 76 m (see Fig. 17). The yields of these bore-holes varied from 2.3 to 18.6 m3/h, averaging 6.8 m3/h. Most of these bore-holes are out of use now. This is not caused by a natural decrease of the yields of these bore-holes but mereely a result of collapsing of the walls of the bore-holes, possibly due to insufficient casing of the holes.
The water in the lahar aquifers slowly flows parallel to the dip of the volcanics. Some aquifers are cut by river valleys or by the scarp at the eastern edge of the volcanic area. Here not only springs or seepage-zones occur in the regolith but also in the less weathered lahars. Although also some springs occur at the Basement System contact, which forms a barrier for the percolating water in the lahar, most springs occur at higher levels e.g. South and East of Kanyambora. The springs in the not weathered lahars only yield very small amounts of water. Estimated yields are much less than 1 m3/h. The yields of the springs in the regolith are much higher during the rainy season. During the dry season these yields are almost nil, while the springs in the unweathered lahars still yield some water.
The chemical composition, as determined with field test kits, of

the riverwater in the lahar area and of the water from the regolith is the same. The water from the lahars has a much higher conductivity and amounts of dissolved salts (see Appendix 2). This suggests the rivers are mostly fed by a through-flow with water from the regolith. The yields of the lahar springs and the chemical composition of the water from these springs suggests the water infiltrated into the lahars has a long staying period in the lahars. Mr. Vazak, of the Water Resources Assessment Project of the Ministry of Waterdevelopment, suggested staying periods of the water in the lahars up to ten thousands of years. Also the possibility of occurences of fossil water in the lahars should be taken into account. The lahars originally were containing very high amounts of water. Probably not all the water evaporated from the consolidating lahars but was partly enclosed in the lahars. This conate and juvenile water still can be present in the lahars. For a general view on the water movements in the L1-lahars see Fig. 15 and 16.
Concluding can be said the unit L1a contains the highest amounts of groundwater. It is not of great importance where a drilling site is selected in this unit. Almost every test drilling is liable to strike water. In unit L1b the best chances of striking water are in the western parts of this unit. Also here it is difficult to indicate the best drilling sites.

L2: Lahars overlying a granite/granitoid complex. This third group of lahars shows no remarkably different characteristics than the lahars of the other L-units, but in this unit the underlying Basement System has a great influence on the hydrology. The granites and granitoids built up high hills or mountains in the pre-volcanic pliocene etch-plain. These hills are a part of a granite hill range comparable to the Kijege-Kierera Forest range. This implies the volcanics now covering these hills have thicknesses less than those of the surrounding volcanics. The thicknesses of the volcanics of unit L2 vary from almost nil to about ten metres at some spots. Locally the lahar is completely weathered. At these spots the regolith is unusually thick for a regolith covering granitoids. Here the drainage pattern reflects the drainage pattern of the covered Basement System rocks.
The very limited thicknesses of the lahars of unit L2 diminish the possibilities of occurences of groundwater in this unit. Contemporarely (during the rainy season) the regolith does contain some groundwater. The granitoids under the lahars are probably of the same type as the granitoids which peak up through the Mt. Kenya volcanics (part of unit G1). As described for unit G1 these granitoids are not very liable to contain groundwater. So these areas can better be avoided when selecting a site for a bore-hole which should yield reasonable amounts of water.

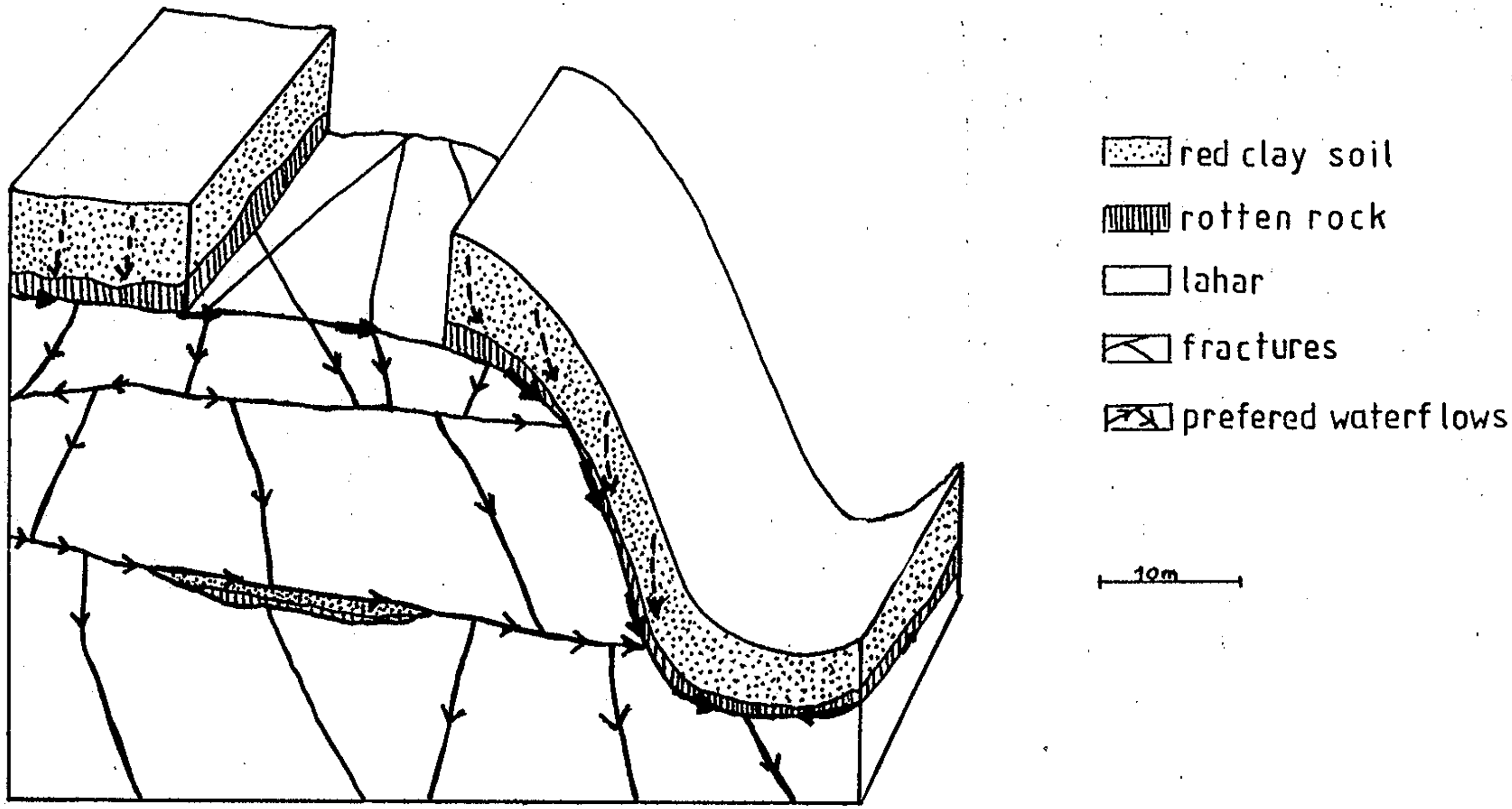


FIG. 15. -WATER TRANSPORT IN THE SLOPING LAHAR AREA.

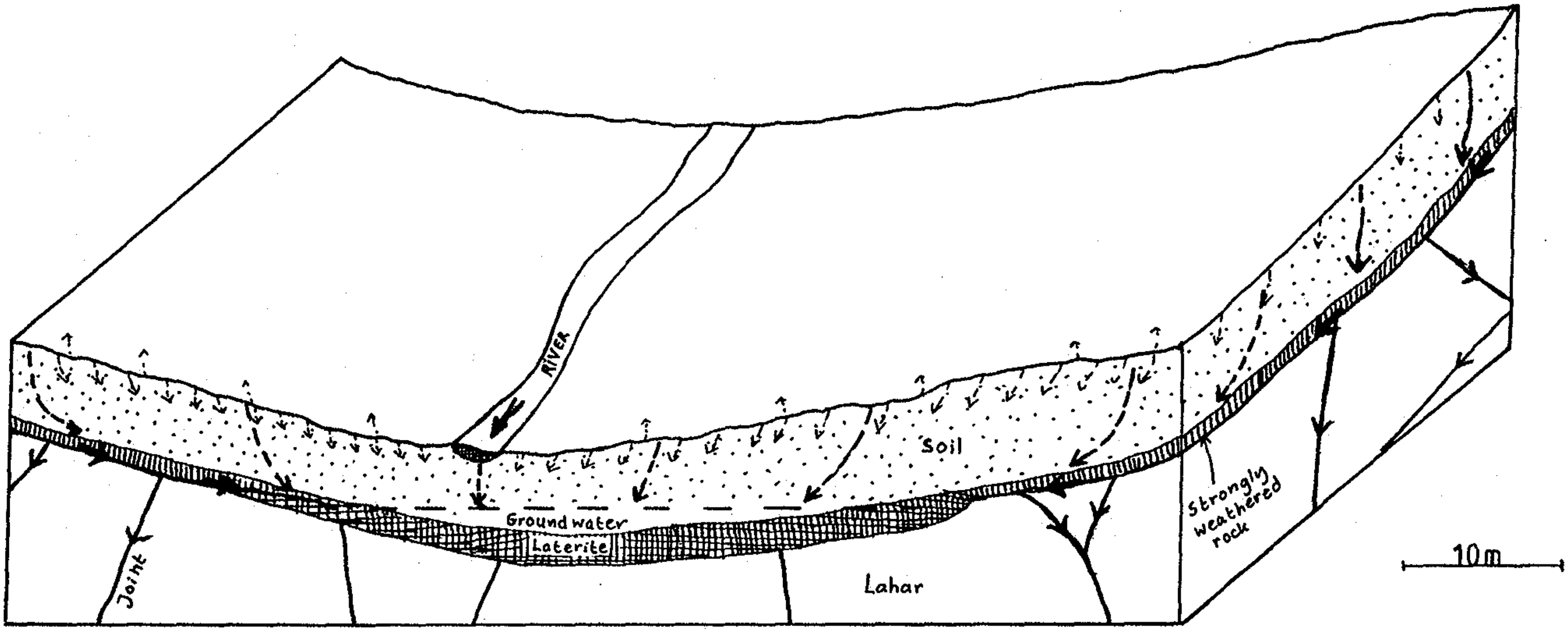


FIG. 16. -WATER TRANSPORT IN THE PLATEAU LAHARS.

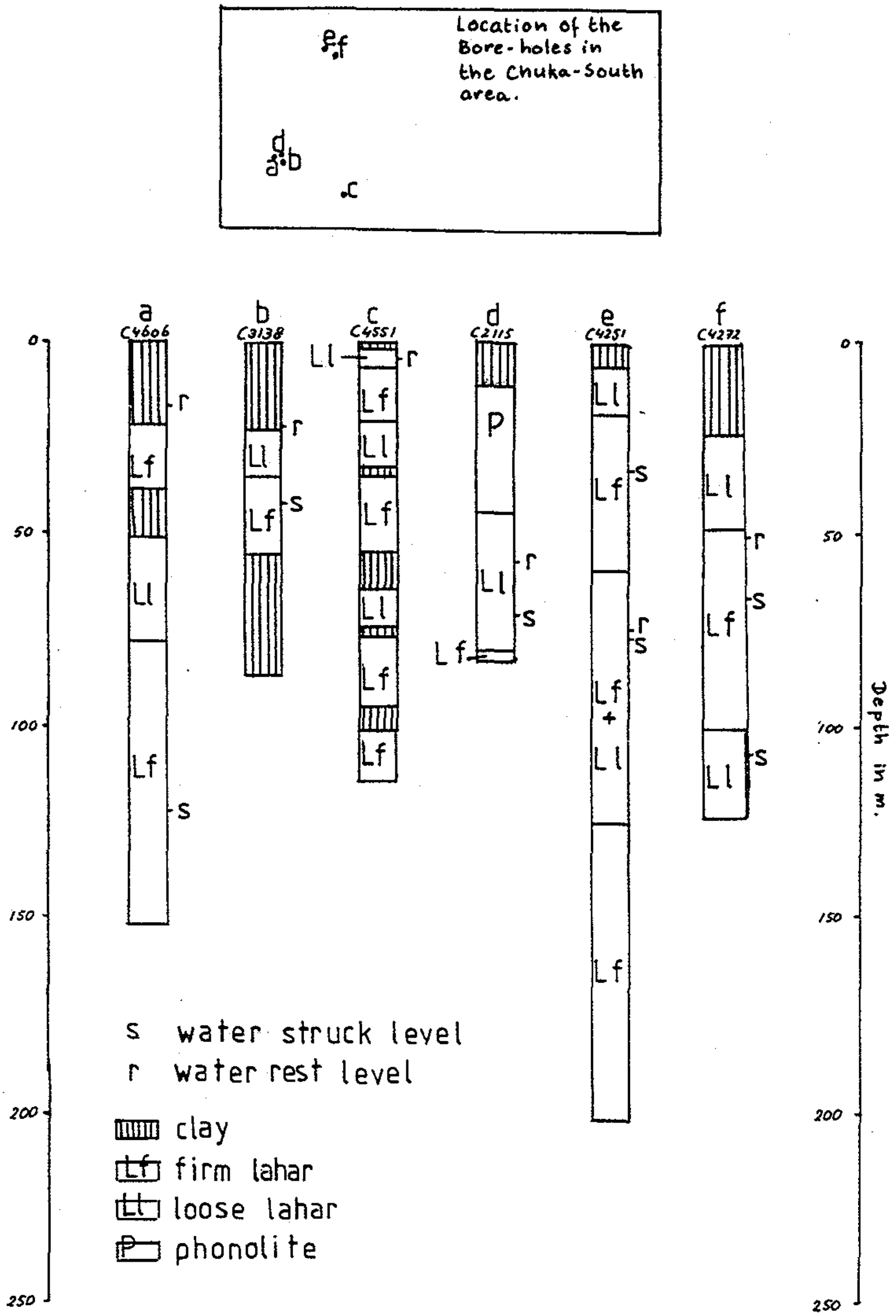


Fig. 17. -SIX BOREHOLES IN THE VOLCANIC AREA

Borehole no	Location	map coordinates	elevation in m	depth in m	wsl m	wrl m	yield m3/h
c4606	Kyeni	99545-3425	1500	151	120	15.5	4.08
c3138	Kyeni	99548-3426	1500	86	42	22	2.27
c4551	Karurumo	99483-3495	1240	113	7	5	18.6
c2155	Kyeni	99551-3422	1520	83	70	60	7.7
c4251	Muthambe	99695-3521	1410	201	75	76	2.8
c4272	Muthambe	99699-3511	1410	123	106	50	5.5

3.3. The colluvial and Fluviatile deposits.

C: The colluvial deposits. Together with the fluviatile deposits these deposits are the most recent in the Chuka-South area. Both are built up by the debris of all units named above.
The colluvial deposits form the transition from most of the volcanics to the Basement System rocks and from some M-unit hills to the surrounding Basement System rocks. This unit consists of sloping areas of non-sorted, unconsolidated debris of the volcanics or the rocks of the gabbroic-ultramafic complex. On the lower slopes also other types of Basement System rock is present. The groundwater in these units is merely the water which runs off the higher volcanic or ultramafic rocks, or the water which seeps from these rocks into the colluvium. Due to the small extent of the two M-unit hills surrounded by colluvium, the amount of water running off these hills into the colluvium will not be high. The amout of water seeping from the ultramafics into the colluvium can be regarded to be nil. So no amounts of groundwater worth mentioning can be expeceted in this part of unit C.
The situation for the C-units bordering the V-units is almost similar.
This all is fairly different for the C-units at the eastern edges of the lahar area. Here the colluvium covers a part of the scarp and other steep edges of the lahar area. As described for the L-units, locally at these edges springs or seepage-zones occur. Most of the water from these springs and seepage-zones infiltrates into the colluvium. A part of the out-flow points, where the groundwater flows out of the lahars, is covered with colluvium. At these spots seepage-zones in the colluvium occur. These places are usually indicated by the occurences of a vegetation or crops which need a constant supply of water.
The water in the colluvium is transported downwards parallel to the slope the colluvium is covering. Where Basement System rocks form a heightening under the colluvium, locally small springs in the colluvium do occur (see Fig. 18).
The water supply from the lahars and the fresh soil material of this unit make the colluvial slopes along the lahar area a more suitable place for farming than the adjacent, lower Basement System area, as long as no machines are applied. If the water supply is high enough for procurement of water is arguable.

The Fluviatile deposits (F):
F1: The terrace deposits. As noticed before this unit does not completely excist of terrace materials. It is merely a flat area with a thick regolith which once was covered with terrace deposits from which more or less extended remains are found in this unit. These remains consist merely of unconsolidated gravel and boulder deposits. Locally the gravels are consolidated by secondary lime. The terrace remains are too thin or have too small extensions to be groundwater bearing.

The rest of the Fl-units, which are flat and have thick regolithes thanks to the former covering with terrace materials, have a greater importance to the occurences of groundwater. The regolithes are fairly permeable, so the rainwater can deeply infiltrate into the regolith. This water is better protected against evaporation than the water in the shallow regolithes of the gneisses. The water taken up in the regolith does not undergo far going lateral displacements due to the flat topography of the unit. This water probably merely contributes to the water supply of the ground water in the joints of the underlying Basement System rocks. This may cause higher amounts of groundwater in these rocks compared to the adjecent rocks.

F2: The riverbed deposits. These merely sandy deposits with strongly varying depths are regularly supplied with water from adjecent areas. This supply can be a through-flow or an overlandflow (see also description of unit X3). If the riverbed deposit is deep enough, or if the river is a perennial river (like Tana river), the water in the riverbed is well protected against evaporation and can be stored there for long periods. During the rainy season, when the supply of water of the intermittent rivers increases, the supplied water is taken up by the riverbed deposits until these are saturated. If more water is supplied then, a river starts to flow.
The deposits in this unit usually contain high amounts of groundwater. For more detailed information about the occurence of this water in such a deposit and about the build up of that deposit see chapter 5, a detailed study of a part of unit F2.

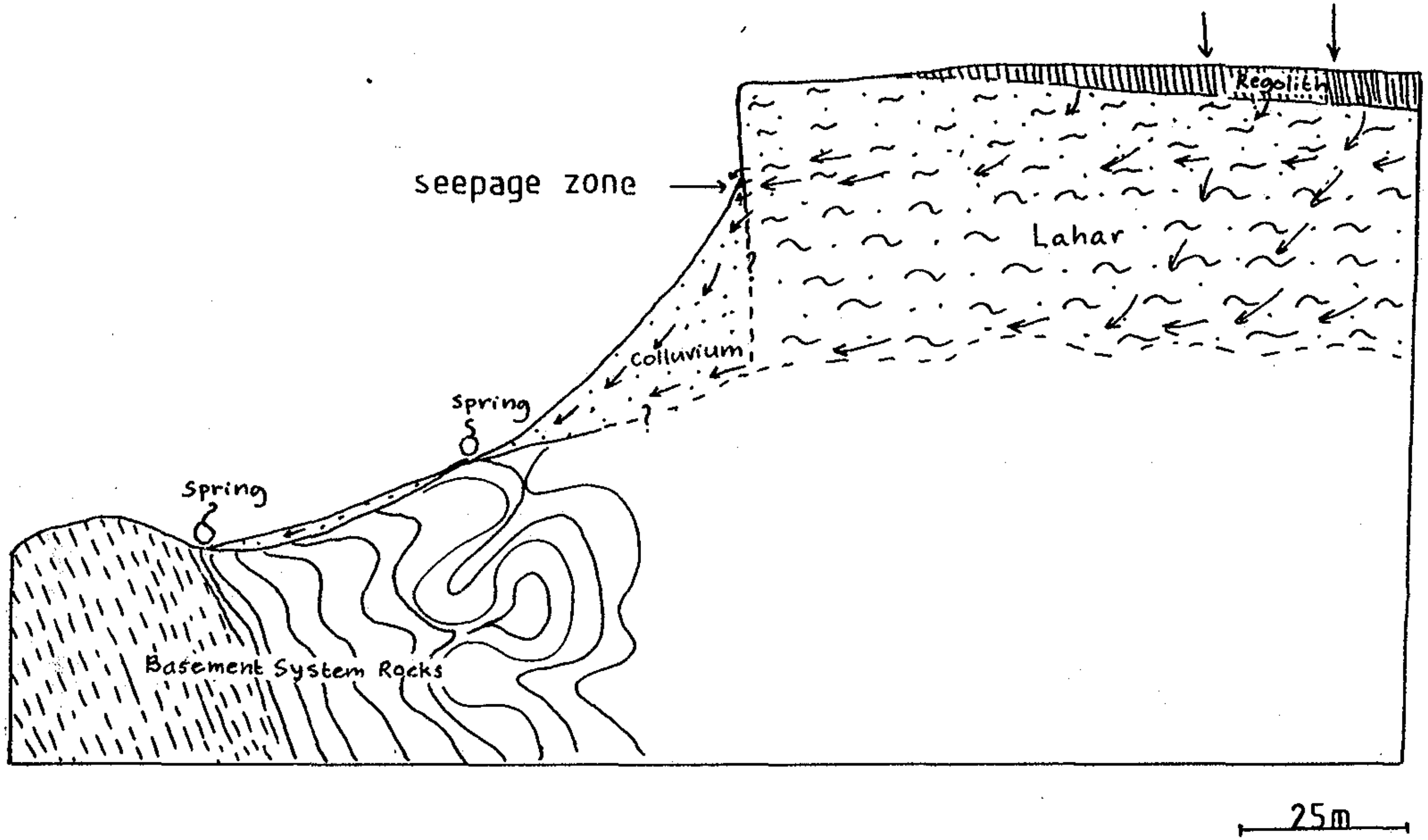


Fig. 18. WATERTRANSSPORT IN THE BOUNDARY ZONE OF THE VOLCANIC - AND BASEMENT SYSTEM AREAS

4 WATER-SUPPLY AND POSSIBILITIES OF IMPROVEMENTS.

4.1 Water supply

The water supply is very important in the survey area. To a large extend the agricultural development is limited in the area due to a lack of water for the crops, people and cattle.
Four types of water supply are of importance in the area. These types will be discussed in the next paragraphs. For the distribution of the types of water supply over the survey area see Fig. 19.

4.1.1 Surface water.

A number of perennial rivers cross the area. Tana River is the largest of these rivers. The perennial rivers are the most important sources of water in the area. The amounts of water are sufficient throughout the year but the distances to the rivers can be long. Most of the rivers have come a long way down the slopes of Mt.Kenya before they enter the Basement System area. There are many population centres along these rivers. This causes dangers for the public health situation especially in the Basement System area.
The conductivity of the water of the perennial rivers is very low throughout the whole year. This indicates that there is hardly any danger of salinisation of the drinkingwater.
The potable water in the volcanic area is usually derived from surface water. The water inlets are mostly in or near Mount Kenya forest from where extended waterpipes-lines start. Most people of the western part live near a tap (see Fig. 19). The people who do not fetch water from the rivers themselves which they carry home in containers or drums by man or ox power.
Also some waterinlets are located in the dense populated areas. These are inlets of private waterpipes for hospitals and missions. These inlets are better protected than the forest inlets. The inlets in the populated zones are indirect via a shallow well near the river and those in the forest are direct from the river (see Fig. 20).
One water pipe line extends through a large part of the Basement System area. It has its inlet in Thuchi River, a few kilometers west of Ishiara. This water is treated with chemicals and flows through a water pipe line via Ishiara to the East and northeast. This water work is extended now to Tana River and almost to Kanjuki, a small village near the confluence of Mara and Nithi river.
The surface water of Thuchi River is used for irrigation in the only irrigation scheme in the area near Ishiara.

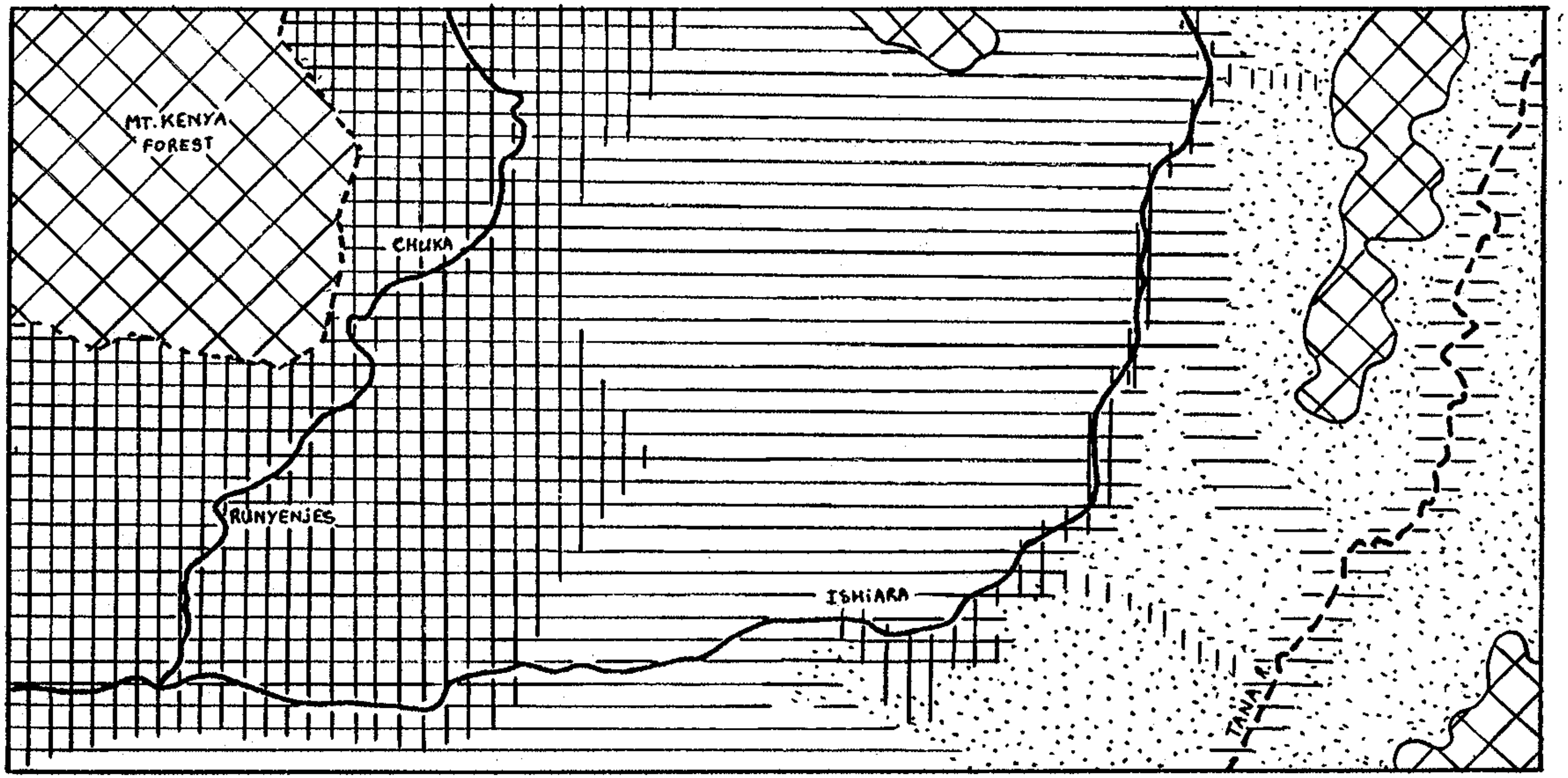


Fig. 19. -TYPES OF WATER SUPPLY IN THE AREA

uninhabited areas

waterpipe lines

surface water and springs

shallow wells

waterpipe lines, surface water and springs

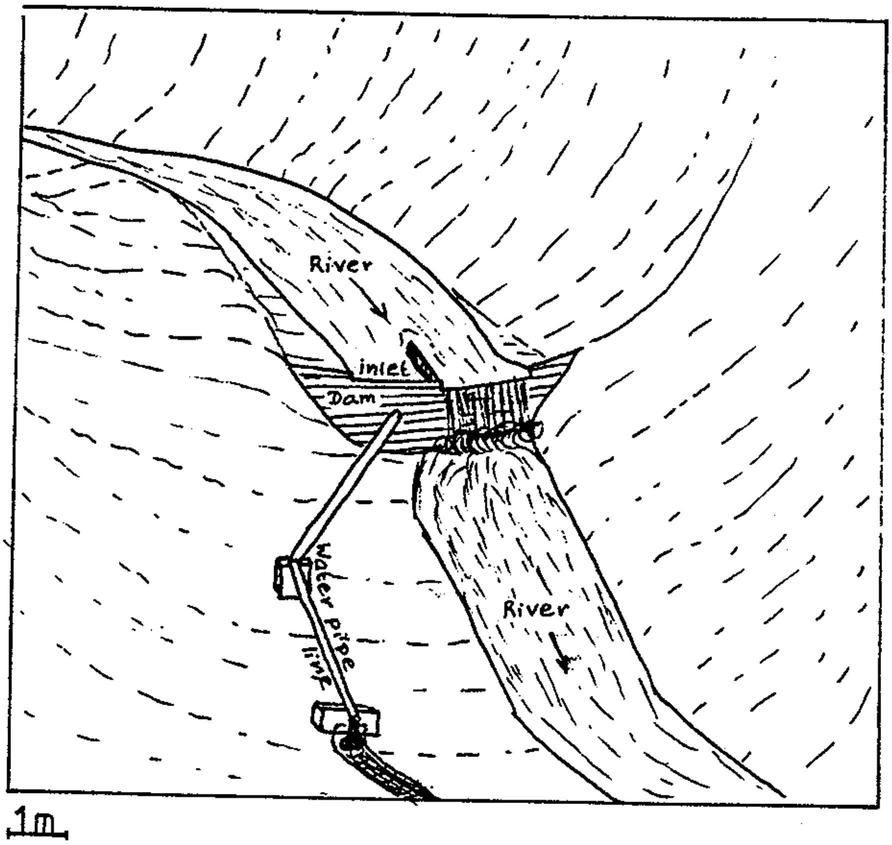


Fig. 20. -WATERINLET IN PERENNIAL RIVER IN MOUNT KENYA FOREST.

4.1.2 Near surface water

The near surface water is important especially in areas where surface water is too remote and where near surface water is available. Most of the near surface water is collected from shallow, hand-dug wells in the riverbeds of the wadis in the Basement System area.
The depth of these wells varies from half a meter to two meters (during the dry season).
Other places to fetch water are the depressions in the volcanic area which are oval concave depressions which often form swamps (usually only seasonal swamps). The water from these depressions is non-saline. The conductivity is very low which indicates a regular flush of fresh regolith water. People dig holes at the higher side of the depressions. In these holes the water accumulates quickly (during the rainy season) and the people collect this water in containers.
In the volcanic plateau-like area some shallow wells were dug for the watersupply of some schools. These wells are about 10 m deep and yield considerable amounts of water throughout the whole year (a yield of 3m3/h was mentioned by one of the Fathers of the mission of which some schools are a part). These wells also have a low conductivity which indicates a regolith origin. The bottom of most of these wells is at the laterite on which water accumulates.
The sandy and gravelly beds of the largest wadis in the eastern part of the survey area always contain water even during the dry years. In these wadis the same well is used for fetching drinking water, washing, coocking and for watering the cattle. Especially in the area East of Tana river there are very large wadis and almost no perennial rivers. A detailed survey of a wadi in this area was carried out and described in chapter 5.

4.1.3. Groundwater.

Only at one place procurement of groundwater from the hard rock is known to take place in the Basement System area. Near Chiokariga water from a spring is catched in a tank for storage and feeding a water pipe line. This water is saline to some extent during the dry season. The spring is on the footslope of the granite hills East of Ciokariga. The water originates from a fault which in the granite massive. The fault is fed with water from the granite mountains, which catch more water than their surroundings because of their high topography. The water percolates down the fault zone and is transported by gravity to the spring.
Another groundwater source are the 6 boreholes in the volcanic area (see Fig. 17). These bore holes are usually belong to a school or mission. Some of these boreholes have stopt functioning. They had average yields of 6.8 m3/h. For one borehole the conductivity of the groundwater was measured. The conductivity appeared to be as low as the surface water of the

rivers in the volcanic area.

4.1.4 Rainwater.

Since a long drought period during the last few years caused many epidemics, spread by the surface water in the area, a lot of new built buildings like schools and dispensaries have got storage tanks for catching and storing rainwater which flows from the roof. This water can be used as drinking water during the dry season. This method of water conservation is not yet widespread in the area.

4.2 Possibilities of improvements

4.2.1 Surface water

In the volcanic area the water quality is a point of greater concern than the water quantity. In this area more than enough water is available throughout the whole year. In the Basement System area the quantity is also very important.
In the dense populated areas the risk of infection by the surface water with contagious diseases like cholera is very high but risk of infection is even higher in the less dense populated areas downstream, especialy during the dry season.
Since more than 80% of the potable water is derived from surface water there is a general danger for the public health. Also shallow wells can get contaminated easily especially near schools where sometimes many latrines are located next to the wells.
The best improvements are to protect the water inlets of the waterpipes better. A good protection of such an inlet is to take the water via a filter, e.g.taking in water via a shallow well near the river. The surrounding soil is acting as a filter. This has as disadvantage that it will cost some extra money. Another improvement is to move the inlets of the water pipe lines further up-stream into the Mount Kenya forest. This has become more necessarely since recently a new 150m wide strip of forest has been cleared cultivated.
Before entering the Basement System area most of the perennial rivers come a long way down the slopes of Mount Kenya. Upstream there are dense populated areas which certainly have poluted the water. Therefore treatment of the surface water with chemicals or filtering is neccesary before distribution by a waterpipe lines into the Basement System area.
Still there are a lot of places were the people have to fetch water from the rivers .During the long dry seasons epidemics of cholera and dysenteria occur in these areas. One way to prevent epidemics is to supply information to the local people how they should treat infected water (e.g. by boiling) and how to prevent infection. This supply of information already takes place everywhere dangers for the public health develop during the dry seasons, but this information does not reach everybody yet.

4.2.2 Near surface water

The near surface water, which often is the only water source in remote places such as Kitui district, is also very sensible for waterbased and related diseases. In these places the shallow wells in the wadis are the only water source in fairly large areas. In these shallow wells the people fetch drinkwater, wash themselves and water the cattle.

In Konyu wadi e.g. around 400 animals are watered daily in the same shallow wells as where the people fetch water and wash themselves. At the end of the dry season the whole area around the shallow wells is scattered with manure which easily can mix with the water. This way of managment of the wells does not improve the puplic health situation of that area.

Some posible improvements here are better information for the people how they must treat infected water and how to manage the water distribution. This may need radical changes in the livestyle of the people which is probably difficult to achieve.

Another improvement is the construction of so-called subsurfacedams, earthdams or drainpipes.

Sub surfacedams are dams constructed below the riverbed surface to improve the storage capacity of the riverbeds. The principle and construction of a subsurface dam are shown in Fig. 21 and 22. Earthdams are dams in the rivers to increase the amount of sediments behind the dams to increase the storage-capacity of the riverbed. Drainpipes are used to drain the water in the riverbed and to collect the water downstream in a pond or storage tank. These drainpipes can also be used together with a subsurface dam or an earthdam.

The advantages are the higher amounts of water which can be supplied and the easier way to fetch it.

Disadvantages are in general that more water attracts more people and cattle which will cause overgrazing in the surrounding area and this will lead to other problems like erosion and/or overpopulation. Technically an earthdam will last less longer than a subsurface dam (some earth dams are easily washed away). The drainpipes can easily choke up and the waterstorage in tanks is not without the danger of contamination of the stored water. All these improvements will not last forever and do cost money to build and maintain them.

Probably the best advice in these situations will be to leave it the way it is and to try to improve the excisting sytems. Often radical changes turn out as a worsening after some time.

The shallow wells in the volcanic area are usually much deeper and better protected by a clay layer of several meters. Less cattle uses the wells. Most cattle in the volcanic area is zero-grazing cattle: the fodder and water is brought to the cattle. The grazing cattle is usually watered at rivers. Therefore the risk of contamination of the wells by the cattle in the volcanic area is less than in the sandy shallow wells in the Basement Sytem area. A more serious problem in the volcanic area is contamination by wrongly situated latrines. Usually the clayey regolith forms a good protection against this form of infesting of the water.

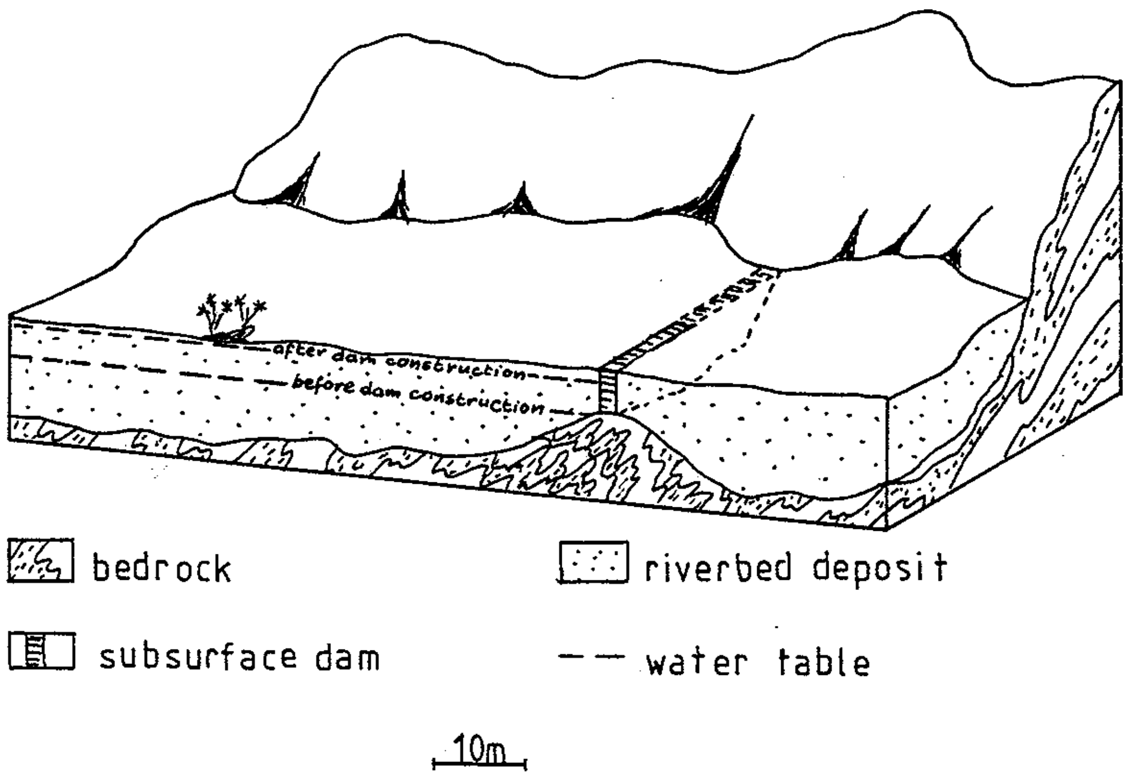


Fig. 21. -SUBSURFACE DAM IN WADI.

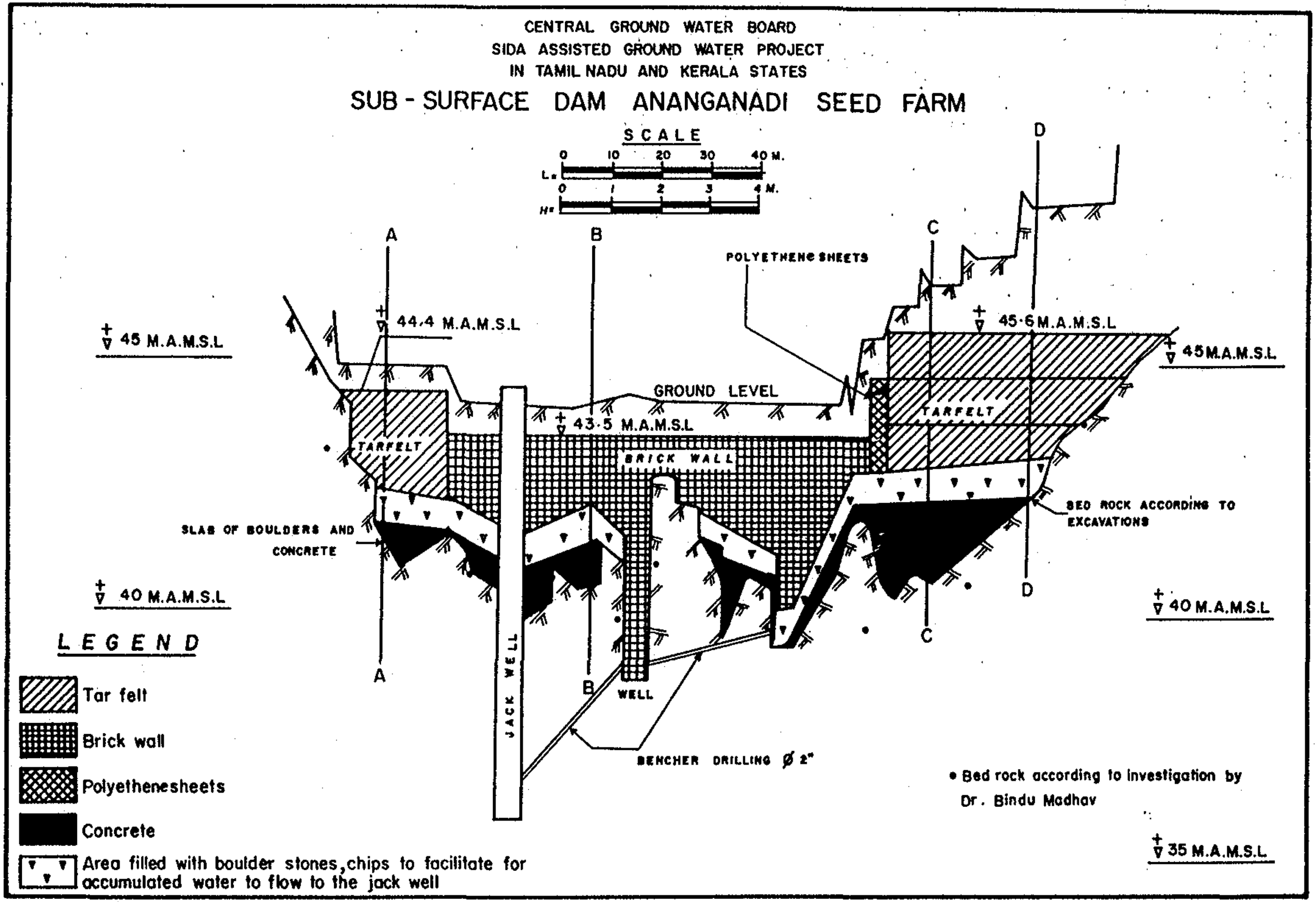


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Fig. 22. -CONSTRUCTION PLAN OF A SUBSURFACE DAM IN INDIA.

(Fig. from 20.)

4.2.3 Groundwater

Drilling boreholes is expensive. No only the drilling but also the pump which is needed to pump up the water costs a lot of money.
In the Basement System area there is always a serious risk that bore-holes will not give sufficient yields. The most promising areas to drill are the more jointed and faulted areas in the Basement System rocks and the lahar area.
However these areas are usualy situated near the perennial rivers and at those spots no bore holes are urgently needed. It is always possible that these boreholes stop yielding in after some time due to collapsing of the borehole walls or due to insufficient supply of water to the borehole.
Thererfore boreholes are not the most appropriate solution for the general water supply of the whole area, but for small-scale use by missions hospitals and schools they give a well protected source of clean water. Public taps from a bore hole can attract too many people and cattle, who can destroy the surrounding area of such a well. The maintenance of boreholes and the pumps and the fuel for the pumps do cost a certain amount of technical support and money. It is cheaper to use surface water and let it be transported by gravity where possible.
The water from the fault near Chiokariga is better protected against possible contamination since the feeding of this fault is situated in an uninhabited and protected forest reserve. The water from the spring is catched in a fairly well protected basin. This water will not be used very much anymore in nearby future since a waterpipe line has already reached Chiokariga. The springs in the plateau-like lahar area are not very much used to collect drinking water since these springs are usually located near the large perennial rivers. These small springs are not artificially protected against any contamination. At some springs the water flows from the springs over the lahar and is usually continuously flowing what gives contamination little chance to spoil the water. The springs which are prefered for procurement of water are springs which feed small ponds in which the containers can be filled easily and quickly. These ponds are easily contaminated.
The groundwater delivers the most healty kind of water in the area but the ways of procurement of this water should also be save.

1wlz2wlz

5. A CASE STUDY IN KONYU WADI

5.1 Introduction

The Konyu wadi is situated in Kitui district and is a intermittent contributary of Tana river (see Fig 23). The mapcoordinates of the survey spot are 99534-3867 of the topographical map 122/4 of Kenya 1:50.000.
During the first weeks of January 1986 a part of Konyu wadi was surveyed in detail with geoelectrical measurements.
The purpose of the survey was to gain insight in the build up of a large wadi and the waterstorage in its riverbed and to make an attempt to estimate the carrying-capacity of the wells at the survey spot.
This spot was chosen since there is a local shallow watertable. The wells at the survey-spot are intensively used by the nearby living people for their water supply.

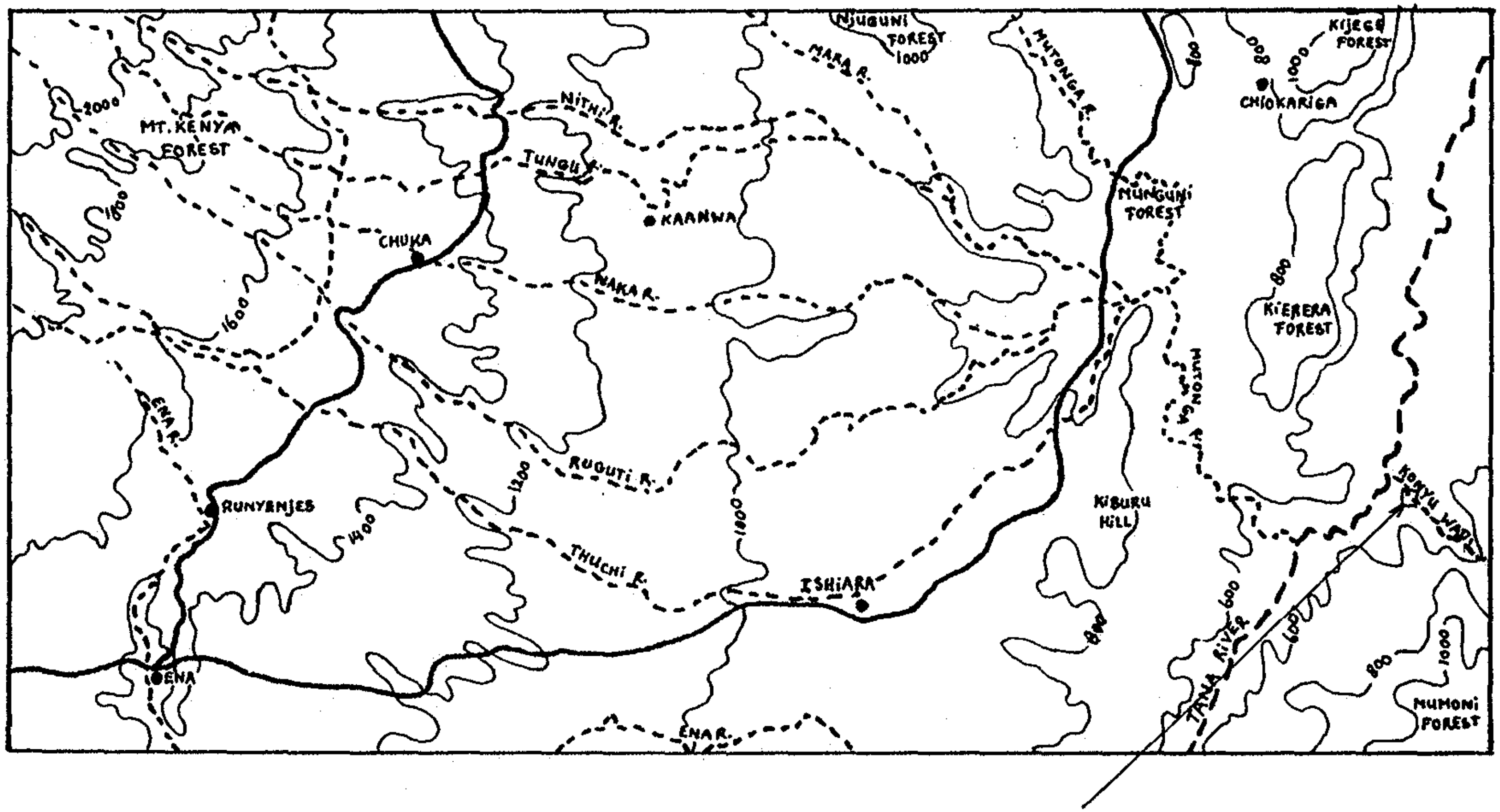

Fig. 23. -LOCATION OF THE CASE STUDY AREA IN KONYU WADI

5.2 Physiography and hydrology

The Konyu basin is divided into three sections, the upper, middle and lower basin (see Fig 24). This subdivision was made with regard to the physiographic characteristics.
The upper Konyu basin is situated in the Mumoni mountain complex. Mumoni is a large mountain complex (BM on geomorphological map) and more than 1500 m high.
The Konyu has steep V-shaped valleys in the upper basin. Where the Konyu is leaving the Mumoni mountain complex and entering the Lowlands (BLrl on geomorphological map), the so called middle Konyu basin starts.
In the middle Konyu basin the river has a straight course. The valley has slopes which are less steep and along some parts of its course the Konyu has built up terraces. These terraces have a maximum width of 50 m and a maximum length of 100 m . In the middle basin the riverbed has a width of about 100 m . Where the Konyu is leaving its straight course the survey spot is situated. A few kilometres further down-stream, where Konyu wadi is entering the Tana valley (BV on geomorphological map), the lower Konyu basin starts.
The lower basin has not a large extension and comprises only the Konyu valley. Here the Konyu valley is much narrower and has a more gorge like appearance than the middle basin valley. At this confluence a large sandridge (more than 3 m high) is situated. This sandridge is only partly blocking the Konyu. These sandridges are common at the confluences of wadis with larger wadis and rivers.
The drainage pattern is partly dendritical (upper basin) and partly rectangular (middle and lower basin). All river incisions are intermittent.
When it starts raining the Konyu will not immediately flow like a river. The riverbed has to become saturated first. This may take some time. When the riverbed is saturated the Konyu can discharge enormous amounts of water at once. Water levels of 4 to 5m were estimated in the middle Konyu basin by driftwood in treetops. This water is completely saturated with clay, sand and stones. The specific density of such a mixture is so high that even large boulders easily can be transported.
The rentention time of most of the rainwater in the Konyu basin probably is only a few hours. This is certainly true for the middle and lower basins where high run-off percentages and severe erosion occur. The retention time for the upper basin is considerable higher since the fairly dense natural vegetation will prevent excessively high run-off.

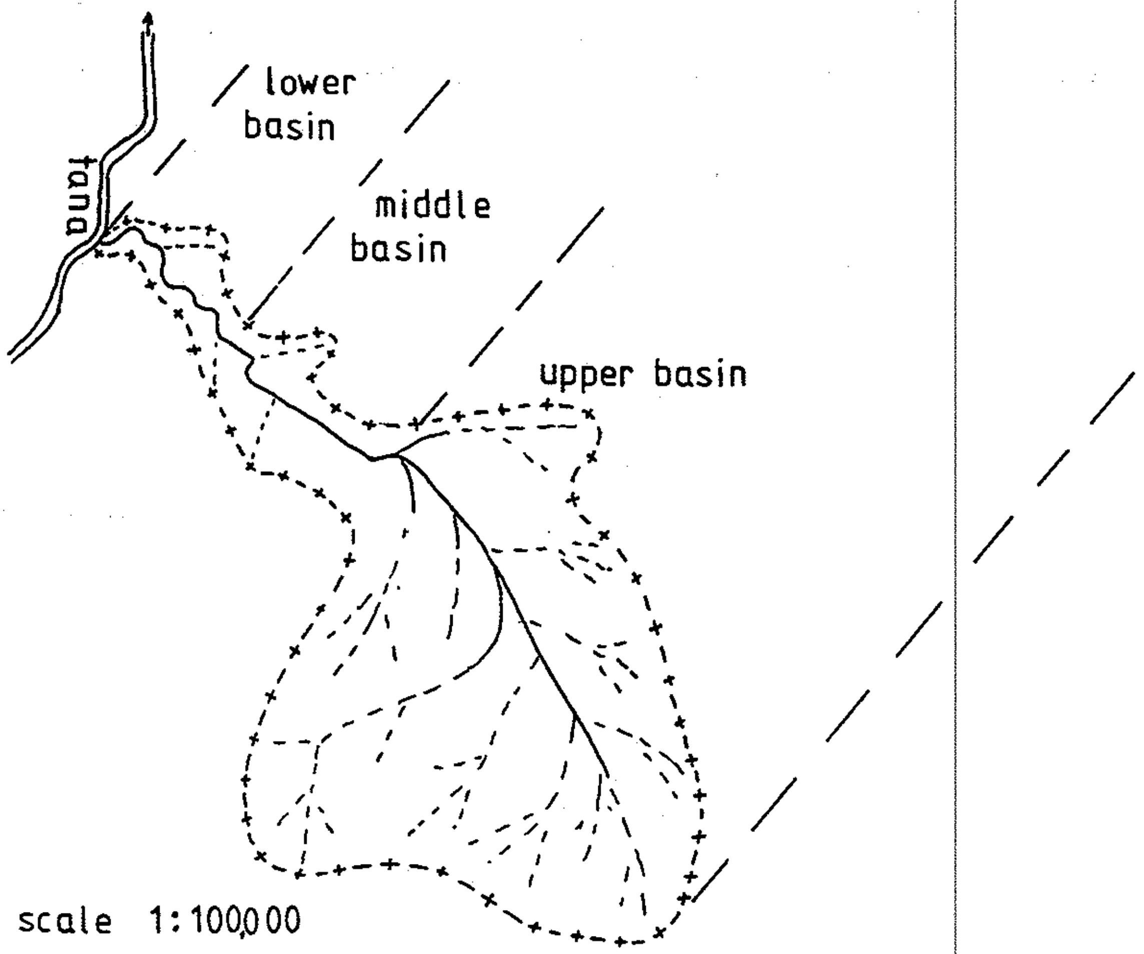

FIG. 24. -SUBDIVISION OF THE KONYU BASIN.

5.4 Regional geology

The Konyu basin is situated in the Basement System area. This area consists of several smaller units (see hydrogeological map, Appendix 3). The upper Konyu basin is situated in unit G1. This unit comprises granites and granitoid gneisses. The middle and lower Konyu basins are situated in unit X2. This geological unit consists partly of various migmatitic gneisses, often with amphibolitic and granitoid gneisses bands. Generally the gneisses are more migmatitic near unit G1.

In the middle Konyu basin the riverbed has a straight south-eastwardly to north-westwardly course and at one spot (the survey spot) the Konyu is making a staight-angled bend. This suggests that the Konyu is following structures of the rock e.g. faults or joints . Not only Konyu wadi is following a straight course, also its contributaries do so.

Along the Konyu (midddle basin) narrow elongated terraces are found. These terraces have thicknesses varying from 2 to 8m along the riverbed. The terrace deposits are poorly sorted mixtures of sand and clay with some stone and boulder layers. These deposits strongly resemble the riverbed deposits.

The riverbed deposits are also a poorly sorted mixture of sand clay and gravel, with some stone and boulder layers. The deposits are locally very rich in black heavy minerals.

5.3 Climate and vegetation

The upper Konyu basin is situated in an area with an average annual rainfall varying from 800 to 900 mm. This amount is considerable higher than in the surrounding area. These higher rainfall figures are caused by the higher altitude of the upper Konyu basin at the Mumoni mountain complex .
The middle and lower Konyu basins are receiving an average of 600 to 700 mm/year.
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 starts in October and ends in December with November as its wettest month.
In the Konyu basin, which comprises about 66 km2, most of the rain is distributed over a few very heavy showers. It is not uncommon an amount equal to the average annual rainfall is concentrated in one shower lasting only a few hours.
Only during those very heavy rains the Konyu is carrying water. Most of the year the Konyu is a dry sandy riverbed.
The mean annual temperature of Konyu basin is 24-30oC.
These high temperatures are also contributing to the high annual potential evaporation which is about 2100 mm in the Konyu basin.

The vegetation was originally closely related to the climate and geology.
On the Mumoni mountain complex some remnants of a natural forest are preserved. Along the middle and lower Konyu basin almost no natural vegetation is preserved. In this area we can find a shifting cultivation cycle and grazing which have strongly reduced the vegetation since the population has become more sedentary. The main crop in this cycle is millet. Due to a shortened shifting cultivation cycle and an increasing amount of grazing cattle during the fallow period, the run-off and erosion have increased. This higher run-off has certainly lowered the water retention time in the basin, which has caused higher and shorter discharge peaks in Konyu wadi when flowing.

5.5 Hydrogeology

Aquifers in the Konyu basin can be located in the hardrock (fractured rockzone), in the regolith and in nonconsolidated deposits.
Since the regoliths around the survey are very shallow, varying from 0 to a few metres in thickness, no extended aquifers are expected in the regolith.
Noncosolidated deposits are present as terraces the riverbed. The most favourable condition would be if the terrace and riverbed deposits were well connected. Unfortunately this is not the matter. The riverbed is only poorly connected with the higher situated terraces (see Fig 25). The water which is transported in the terraces, locally seeps out at the contact zone with the underlying Basement System rocks. At these seepage zones salts accumulate and petrocalcics are formed. The main salt is $CaCO_3$ but also considerable amounts of NaCl are found among these secondary salts . The NaCl-rich seepage zones are used by the cattle as a saltlick.

The regolith is not extended and thick enough to be an aquifer. The terraces are also not extended or thick enough and its relatively high topographical position is not favourable to form an aquifer.
These observations only leave the riverbed deposits and fractured rock zones as a possible aquifer.
A fractured rock zone was not observed in the Konyu basin , but since the Konyu is probably fracture related one can expect a fractured zone in the hard rock below the riverbed-deposits.

A locally very shallow watertable was observed at the survey spot (see Fig. 26). To explain this shallow watertable two possible theories were developed:
1. The shallow watertable is caused by a natural subsurface dam. In this case the subsurface dam is expected in the bend of the Konyu.
2. The shallow watertable is caused by an extra water addition of seeping water from a fractured zone under the riverbed-deposits. This can be expected since this should be the lowest part of the possible fractured zone. The Konyu probably is leaving this lineament because this zone is getting less fractured and less easily to incise downstream.
In order to find out which theory is valid for the Konyu situation and to get a more general insight in the build up of the wadi some geoelectrical measurements were carrried out.

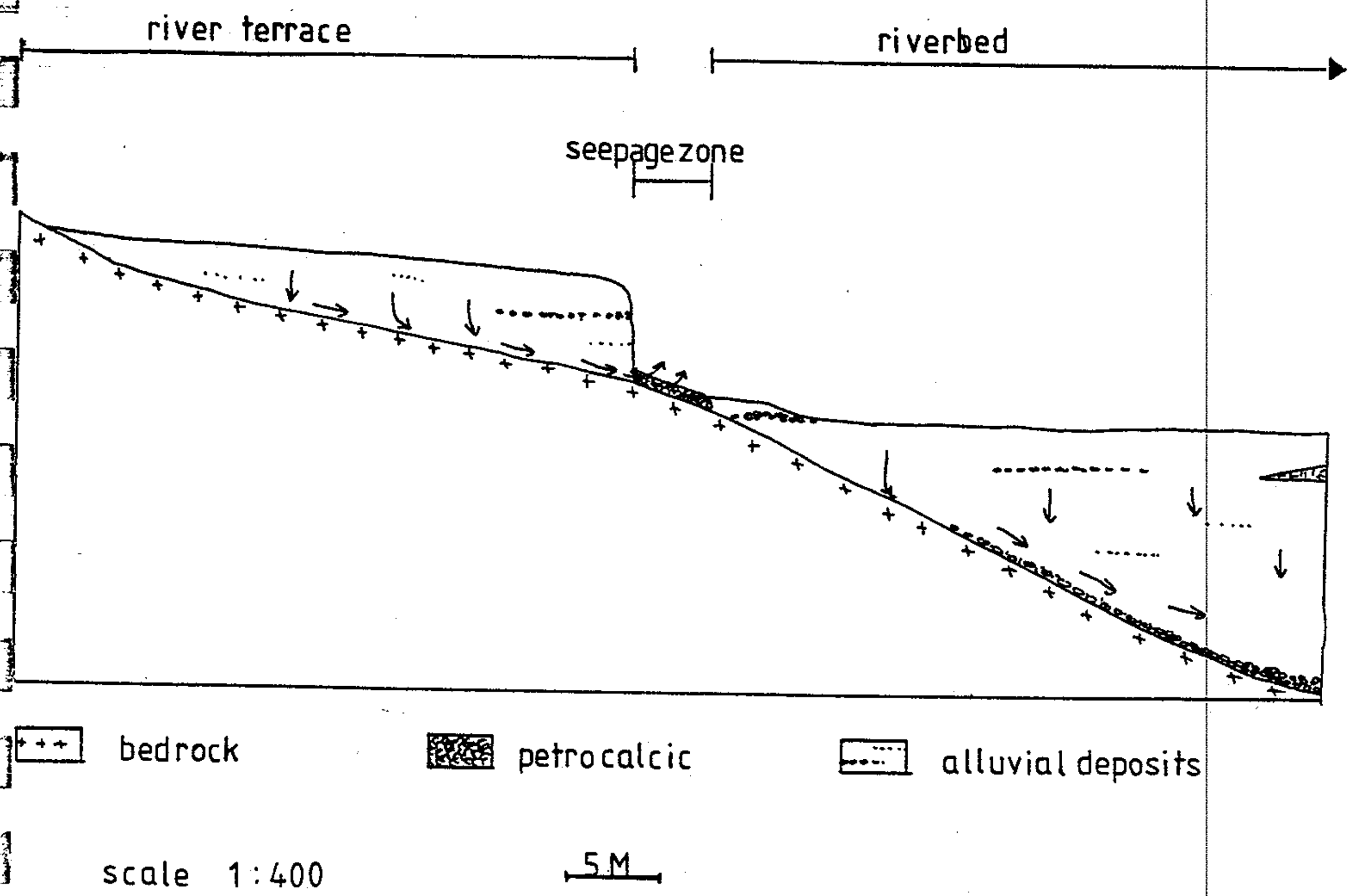

FIG. 25. -THE SEEPAGE ZONE ALONG THE TERRACES OF KONYU WADI.

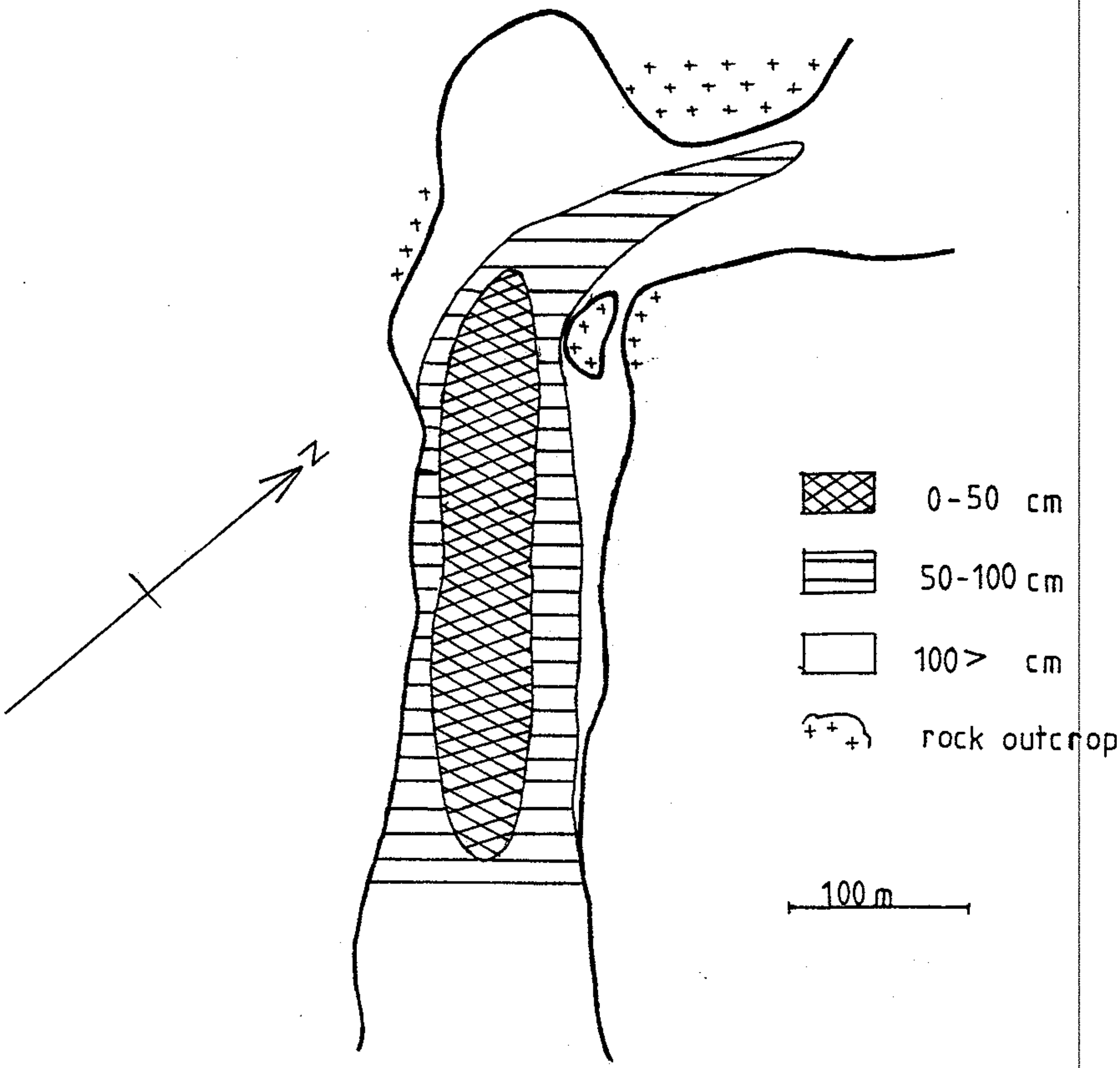

FIG. 26. -MAP OF THE WATERTABLE DEPTH IN KONYU WADI.

5.6 The geoelectrical measurements and their interpretations

The method of geoelectrical survey used in the Konyu wadi is the resistivity method. For more detailed information about this method in general and the ways of interpreting the measurements see Appendix 1.

The measurements were carried out along two types of arrays (for the locations of the arrays at the survey spot see Fig. 27).
Schlumberger soundings were made along 4 arrays to obtain absolute data about the deposit thickness and build up of the deposits at four spots.
Measurements along 5 Wenner-arrays were used to get information about the three-dimensional build up of the deposits of the Konyu, by deriving cross sections and resistivity maps from these data.

The Schlumberger soundings
The Schlumberger soundings are interpreted with help of a computer program. This program calculates the thicknesses and resistivities of the different layers in the profile.

When one looks at the four Schlumberger electrical sounding curves, one sees the curves are those of a three-layer model (see Fig. 28+29+30+31 in which the figure left gives the electrical sounding curves (dashed line) and the computer interpretations of these curves (straight lines)). This reflects the following build up of the profiles in general:
First there is a toplayer with a higher apparent resistivity as the layer below . This second layer has the lowest apparent resistivities. The deepest layer has very high apparent resistivities. These layers have the following interpretation: a dry toplayer of riverbed deposits above the watertable, followed by a layer of saturated riverbed deposits and down in the profile we have the bedrock with the highest apparent resistivities. In each of these four soundings we can distinguish these three layers. When one compares these interpretations, a general decrease of deposit thickness in downstream direction can be seen. The bedrock depth is changing from 10m below the surface to less than 2m downstream. This observation supports the subsurface dam theory.

The Wenner measurements
The Wenner measurements are interpreted by making apparent resistivity cross sections and maps. The cross sections are derived with the help of the rule-of -thumb that the apparent resistivity at x metres is measured depth when the potential electrode distance a is x metres. With this rule we can combine each resistivity value with to a certain depth and when one changes the potential electrode distances from 2.5m to 5m to 10m one can draw a apparent resistivity cross section. When the resistivity values of one depth are plotted in the middle of the positions of the potential electrodes on a map one can draw an

apparent resistivity map for a certain depth.
Along five Wenner arrays the resistivities were measured with three potential electrode distances (2.5, 5, 10m). Four Wenner cross sections were drawn and two apparent resistivity maps for the two most relevant values of a (a=5 and 10m) were drawn.
The low resistivities indicate deposits rich in water and/or clay. The deposits rich in gravel and coarse sand show higher resistivities. The bedrock gives the highest resistivities. These interpretations have always been checked and completed with some augerings (see Appendix 6).

The cross sections:
The cross sections will be discussed in downstream direction (see Fig. 27 for location of the arrays and the cross sections).

Cross section W4 (see Fig. 28).
This profile has low resistivities throughout the whole profile which indicates a deposit thickness of at least 10m (the maximum depth of the cross sections). This is also supported by the Schlumberger sounding which indicated a depth of about 10 m in the centre of the riverbed. The auger got stuck for unknown reasons at 3.10 m in several attempts.

Cross section W1 (see Fig. 29).
This profile has generally higher apparent resistivities than W4. The cross section has the highest resistivities at the borders of the riverbed, and the lowest resistivities at the centre of the riverbed. This suggests the thickest deposit is situated at the centre. This impression is supported by the augering data. These data yielded a bedrock depth 1.60m at 15m of the northern riverside, 15m from the southern riverside a depth of 2.55m was found. At the centre the auger got stuck at 3.75m for unknown reason. The Schlumberger sounding revealed a depth of about 3.50m.

Cross section W2 (see Fig. 30).
This cross section has its lowest resistivities South of the centre. The deposit depth in the centre was according to the Schlumberger sounding about 5m. This is supported by the augering which reached a depth of 4.75m. The highest resistivities are found near the northern riverside, the auger reached at 15m from the northern side a depth of 0.90m. At the southern riverside the resistivities are generally lower and the augerhole at 15m from this riverside reached a depth of 3.00m which is considerable deeper. These observations support the idea that the shape of the burried bedrock is one of a a-symetric valley.

Cross section W3 (see Fig. 31).
This cross section is completely different from the other three cross sections. Its resistivities are very high throughout the whole profile. One can distinguish three zones with relative low resistivities, especially 20m from the northern riverside. At 15m from this riverside augering yielded a profile rich in clay. Such

a clay rich profile was not found anywhere else.
This part of the cross section has the lowest resistivities, which gives the indication of a deeper gully, or reflect the influence of the clay body in the measurements.
The influence of this clay layer is also visible in the Schlumberger curve. This layer probably caused the flatter part in the raising side of the curve. It had a resistivity lowering influence on the curve when the current electrodes were spread far enough to let the current be effected by the clay body.
All three zones with lower resistivities were checked with augerings. Although one expects the most northern zone to be the zone with the thickest deposit cover, the augering yielded the contrary so the very low resistivities should be considered as an effect of the clay body. The deepest part is the zone about 15m from the southern riverside (3.30m), followed by the central zone which yielded a depth of 2.20m in augerings and 1.80m in the Schlumberger sounding. The clay rich zone revealed a depth of 2.10m.
In general one can say that the W3 cross section yields deposit thicknesses with are considerable lower than the cross sections located up-stream. Therefore the cross section location might be considerated as the location of a natural subsurfacedam.

The apparent resistivity maps

Along the axis of the river in the middle of the riverbed complementary measurements along Wenner-arrays were done for a = 5 and 10m.
From the Wenner data the two most relevant resistivity maps were drawn. For a is 5m and 10m two maps are compiled.
The a = 5 (or a = 10m) map indicates roughly the resistivities at 5m depth (or 10m depth), this is certainly not exactly true but it gives a very accurate estimation as prooved by augerings.
As well the a=5m (see Fig. 32) and the a=10m map (see Fig. 33)indicate a gully (or a greater deposit depth) with a straight course. This gully is getting gradually shallower in down-stream direction.
The natural subsurface dam is situated at the bend of the river. Here the resistivities show a sudden increase. The most striking fact is the straight course of the gully and the fact that it is exactly following the course of the lineament which is formed by the straight course of the wadi. This gully is also clearly recognisable on the deposit thickness map derived from the augerings (see Fig. 34 and 35).

The overall interpretation
From the resistivity-maps, combined with the cross sections and other observations, a schematical build up of the survey spot can be drawn (see Fig. 36).
Konyu wadi is following a lineament perpendicular to the local strike of the different gneisses bands. The riverbed is getting shallower down-stream, but its deepest part is always along the lineament. When the Konyu is changing its course to parallel to

the strike, the deposit thickness is only a few meters. This zone is a natural subsurface dam.

The subsurface dam theory is supported by the fact that the geoelectrical measurements prooved the existance of such a dam.

The fractured zone theory is also supported by some facts.
First there is the fact that the deepest parts of the riverbed are along a lineament. This could indicate a fracture.
Second there is the fact that the shallow water table seems to be related to the deepest parts of the riverbed (along the lineament) and that this shallow watertable is situated above (during the survey generally at -0.30m) the top of the natural subsurface dam (at about -2m).
Third there is the fact that the water from the survey spot which was analysed with field-test-kits showed some simularities with a analysed water sample from a fault spring.
Some analysed data are listed below (see Appendix 2 for complete list of chemical data).

name	conductivity S/cm	pH	tot.(mg/l) hardness	Ca(mg/l) hardness	SiO2 mg/l
Konyu	10,7*10-3	8.5	171	103	25
fault	3,3 *10-3	7,3	86	34	13
wadi	3,9 *10-3	8	975	428	2
Tana	0,1 *10-3	8	51	34	25

The ratios of the concentrations give a slight indication of a possible fault origin of the surface water at the survey spot in Konyu wadi because these ratios are the same for the water from the fault and for the water from Konyu wadi. The water of Konyu wadi looks like fault water which has become more concentrated by evaporation. Both have the combination of a high conductivity, and a high silica concentration.
The best overall conclusion is that we have the situation in which both theories are valid. There is a natural subsurface dam and extra feeding of water from the fractured zone along the lineament below the riverbed deposits.
This combination results in a situation were sufficient water is available for long rainless periods.

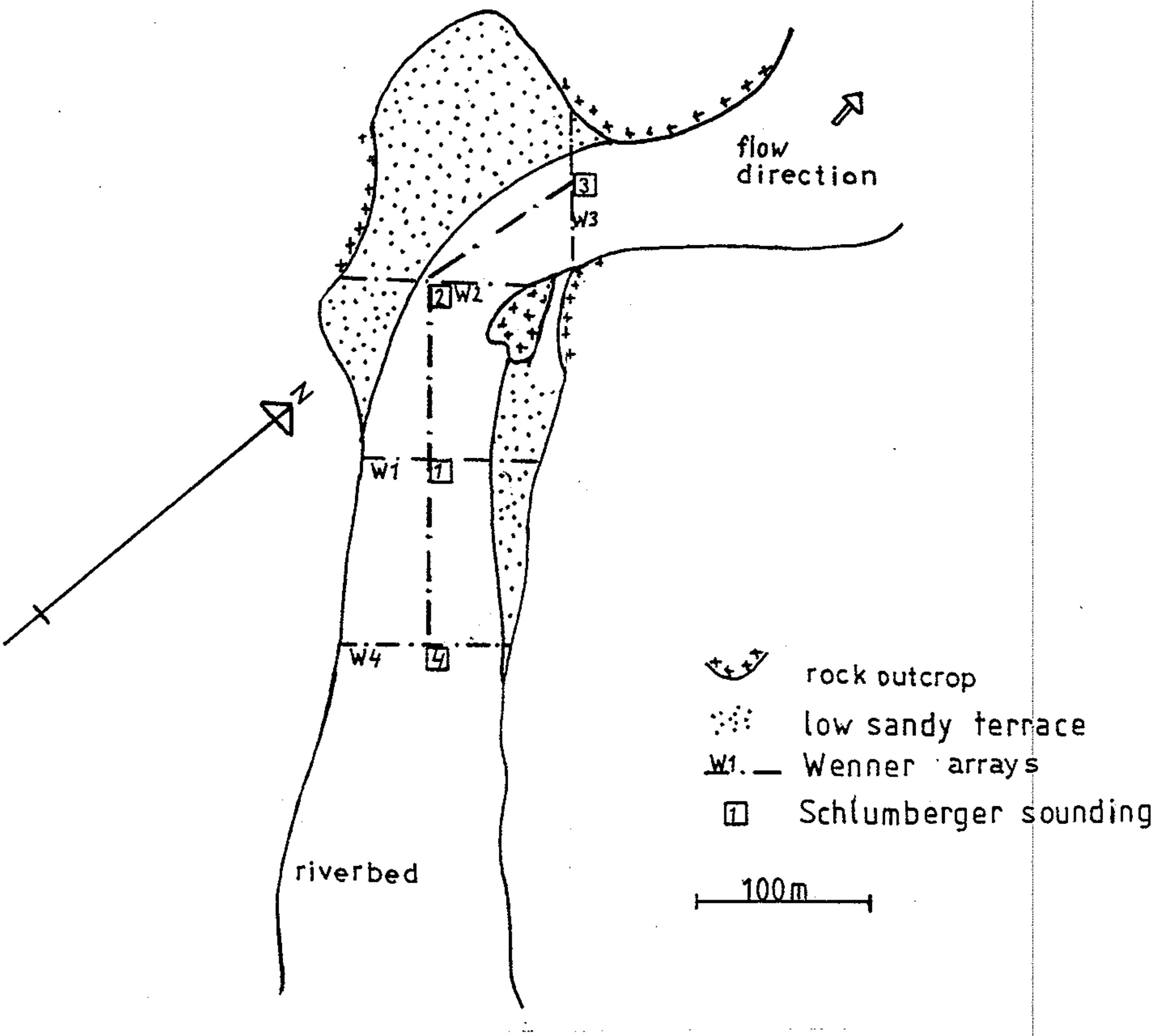

FIG. 27. -SITUATION SKETCH OF THE CASE STUDY AREA AND LOCATIONS OF THE GEOELECTRICAL ARRAYS.

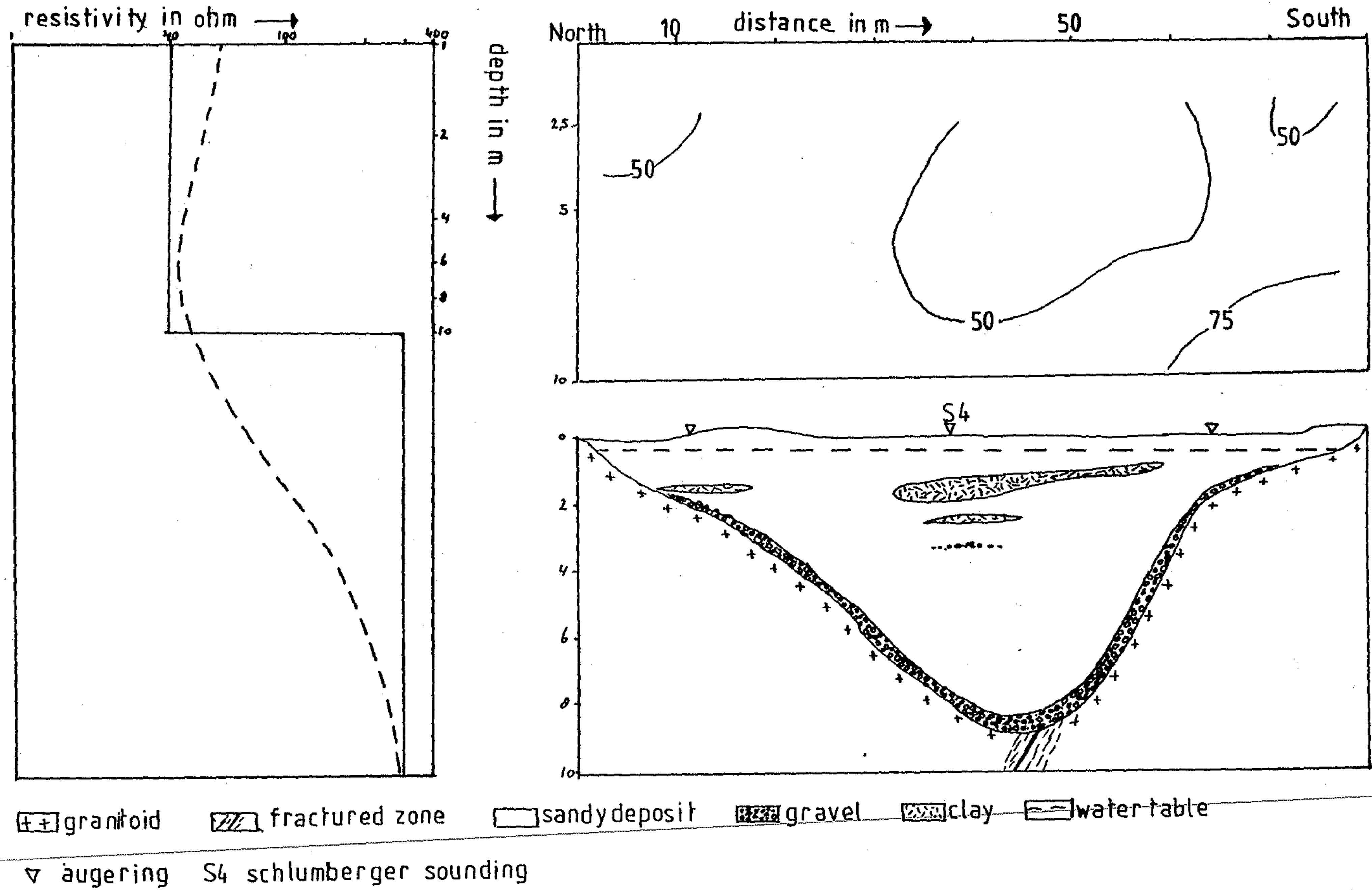

FIG. 28. -SCHLUMBERGER SOUNDING S4 AND WENNER SOUNDINGS-CROSS-SECTION W4 AND THEIR INTERPRETATION.

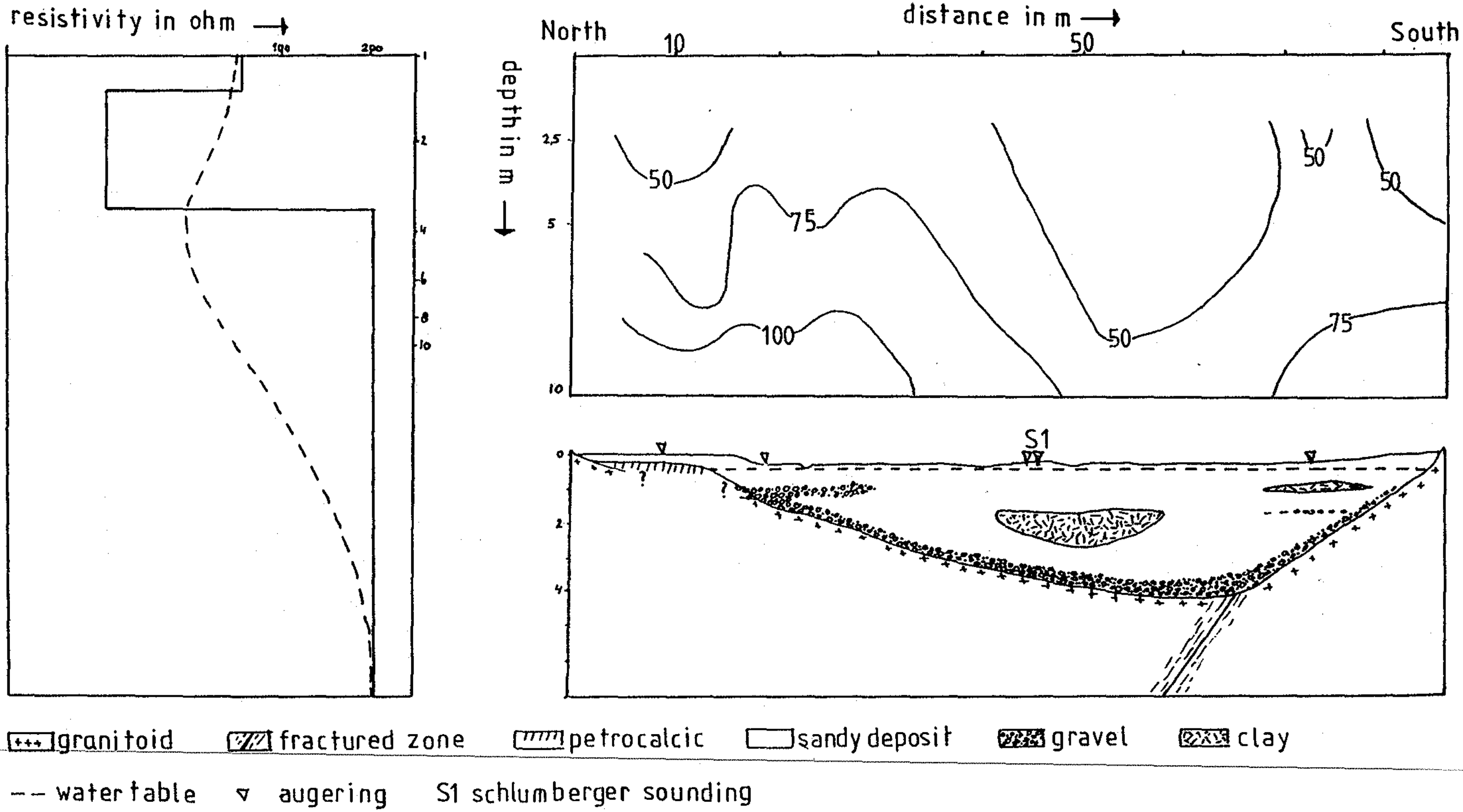

FIG. 29. -SCHLUMBERGER SOUNDING S1 AND WENNER SOUNDINGS-
CROSS-SECTION W1 AND THEIR INTERPRETAION.

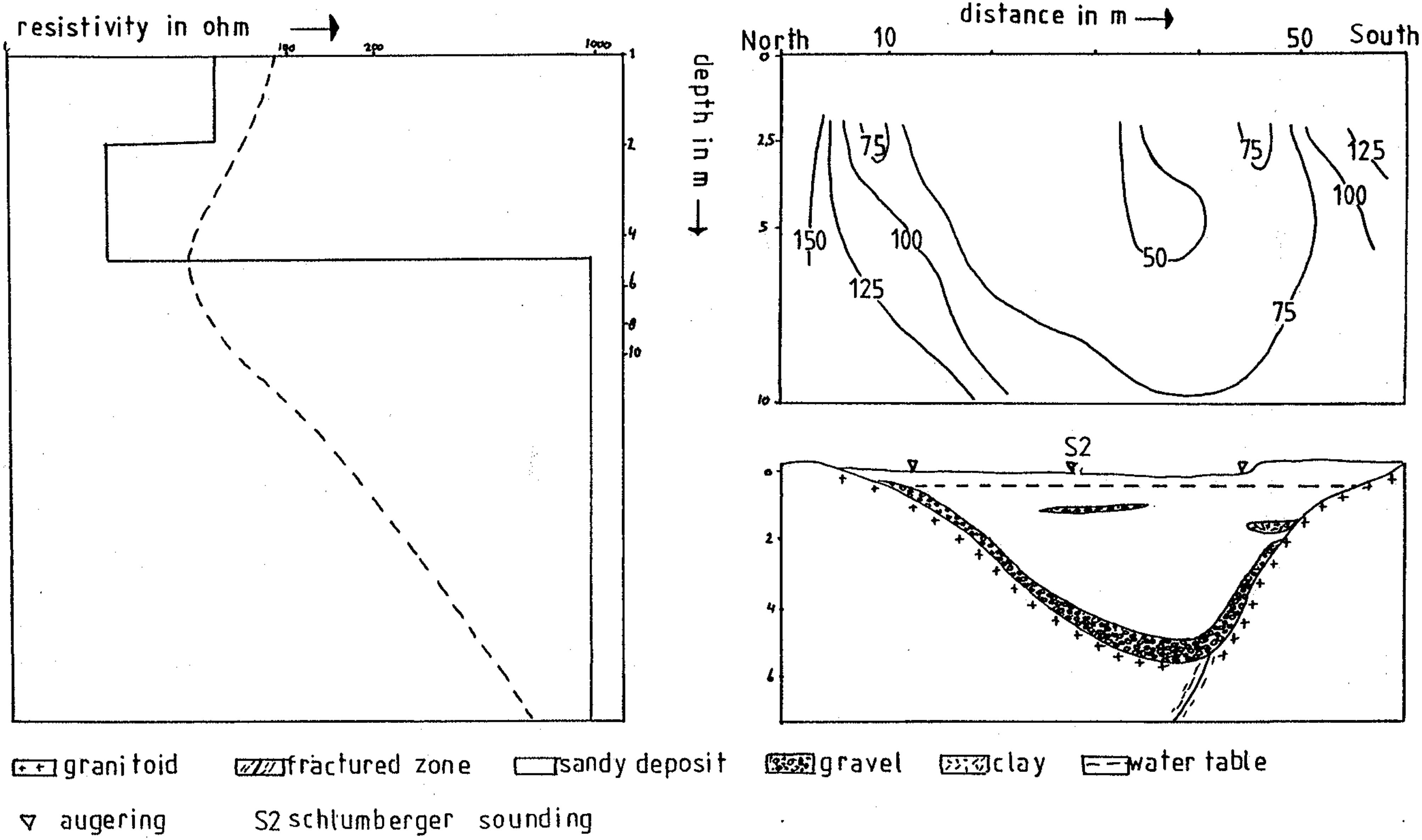

FIG. 30. -SCHLUMBERGER SOUNDING S2 AND WENNER SOUNDINGS-
CROSS-SECTION W2 AND THEIR INTERPRETATION.

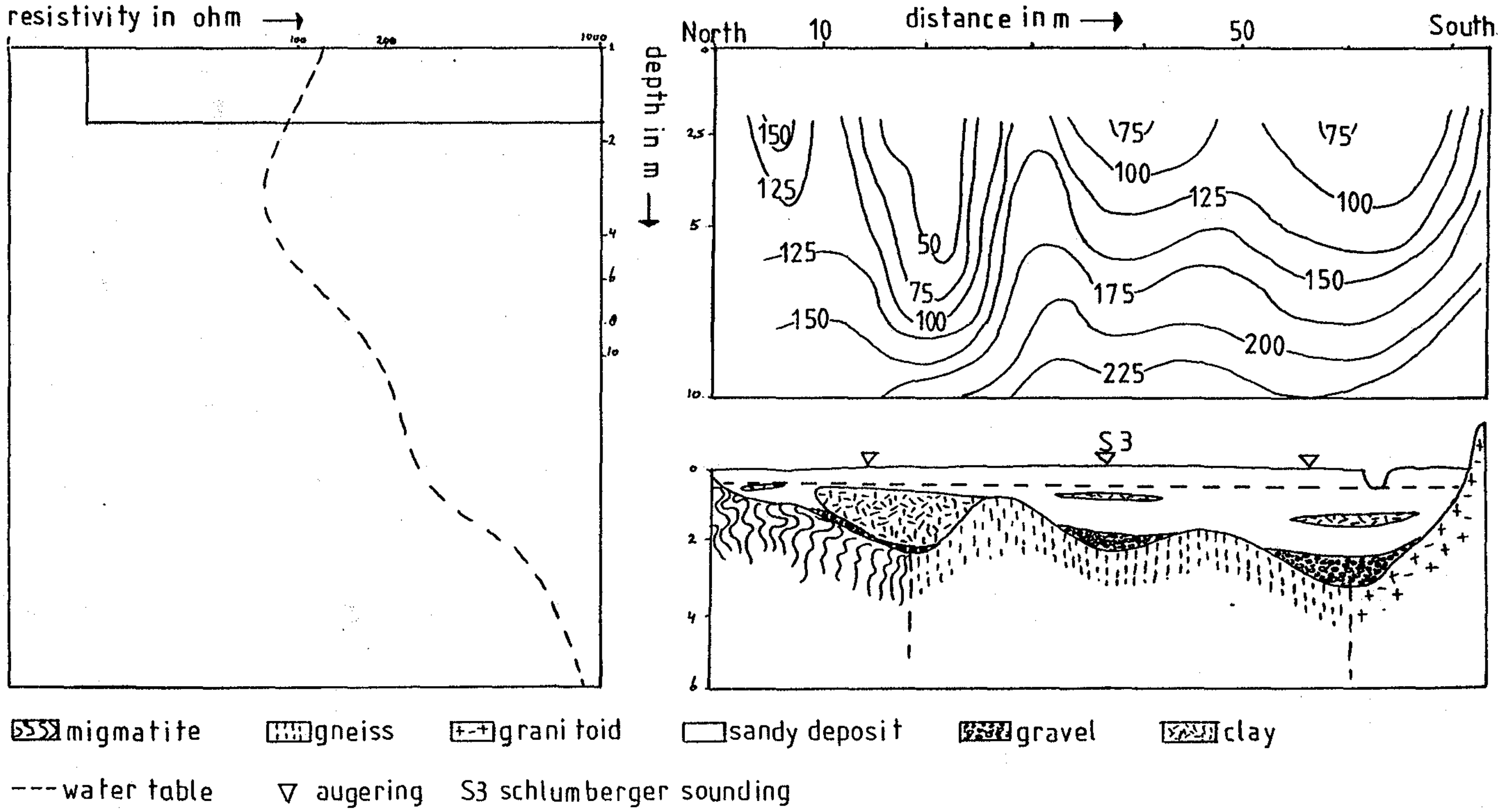

FIG. 31 -SCHLUMBERGER SOUNDING S3 AND WENNER SOUNDINGS-CROSS-SECTION W3 AND THEIR INTERPRETATION.

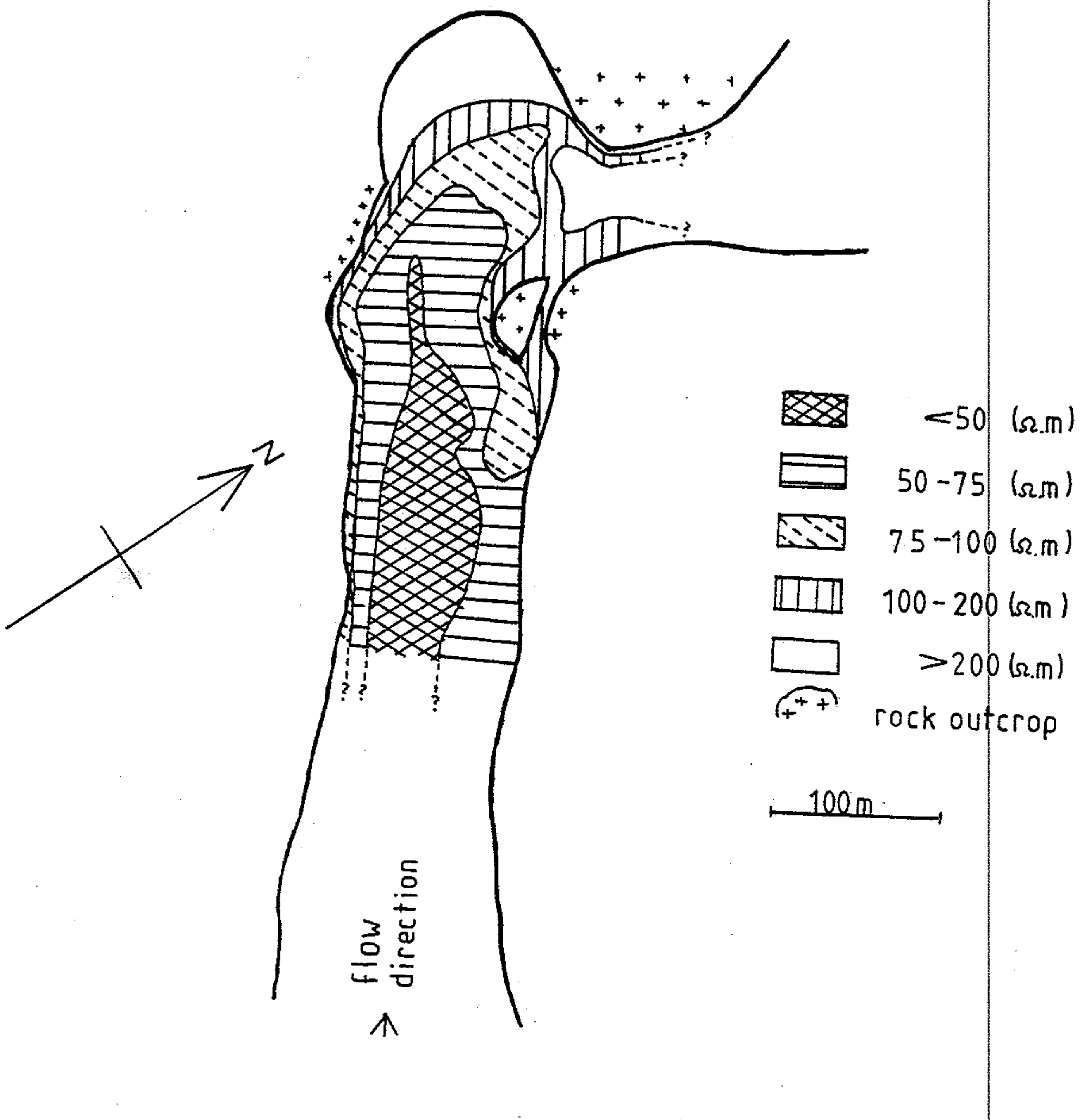

FIG. 32. -APPARENT RESISTIVITY MAP WITH A=5m.

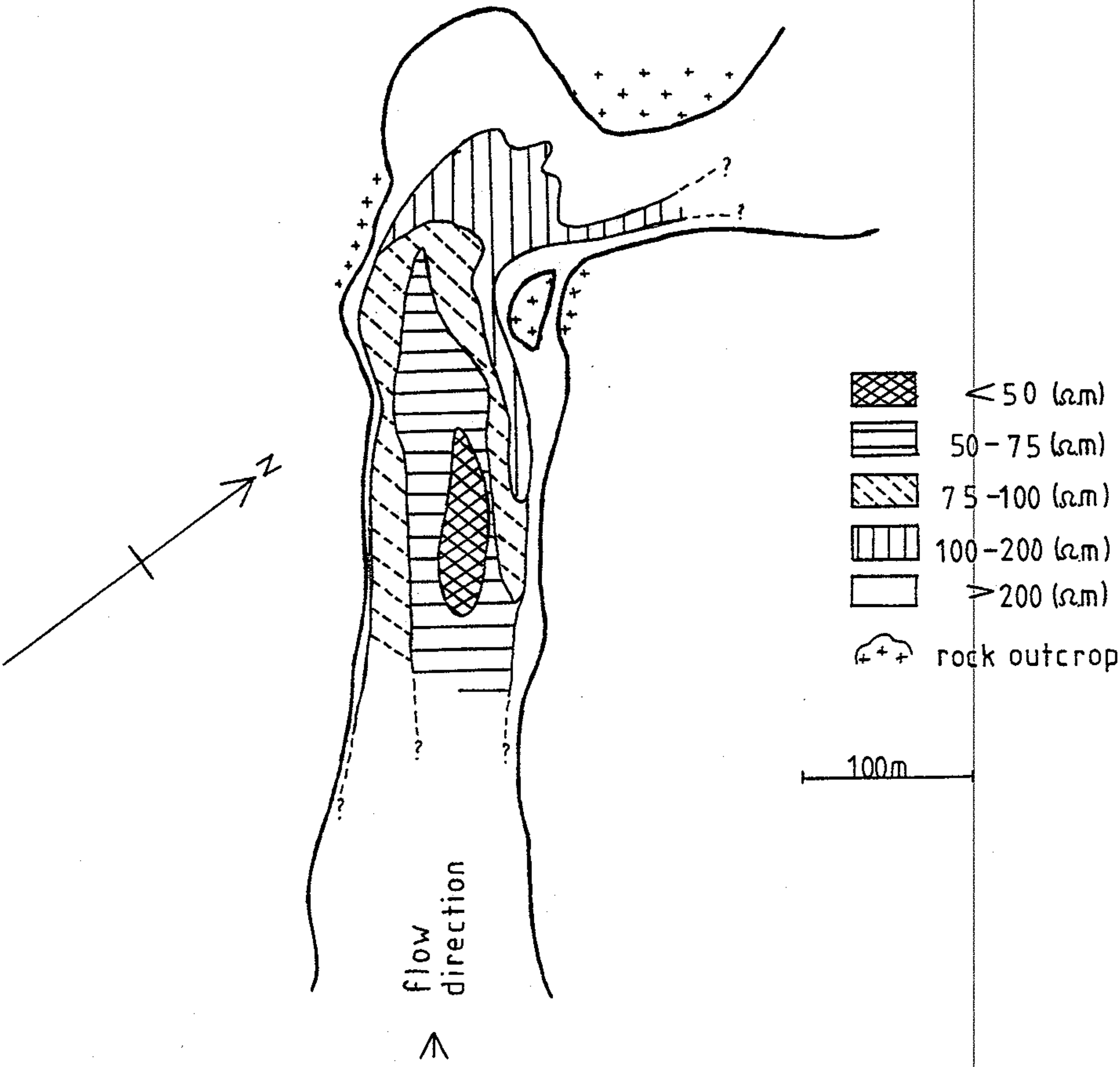

FIG. 33. -APPARENT RESISTIVITY MAP WITH A=10m.

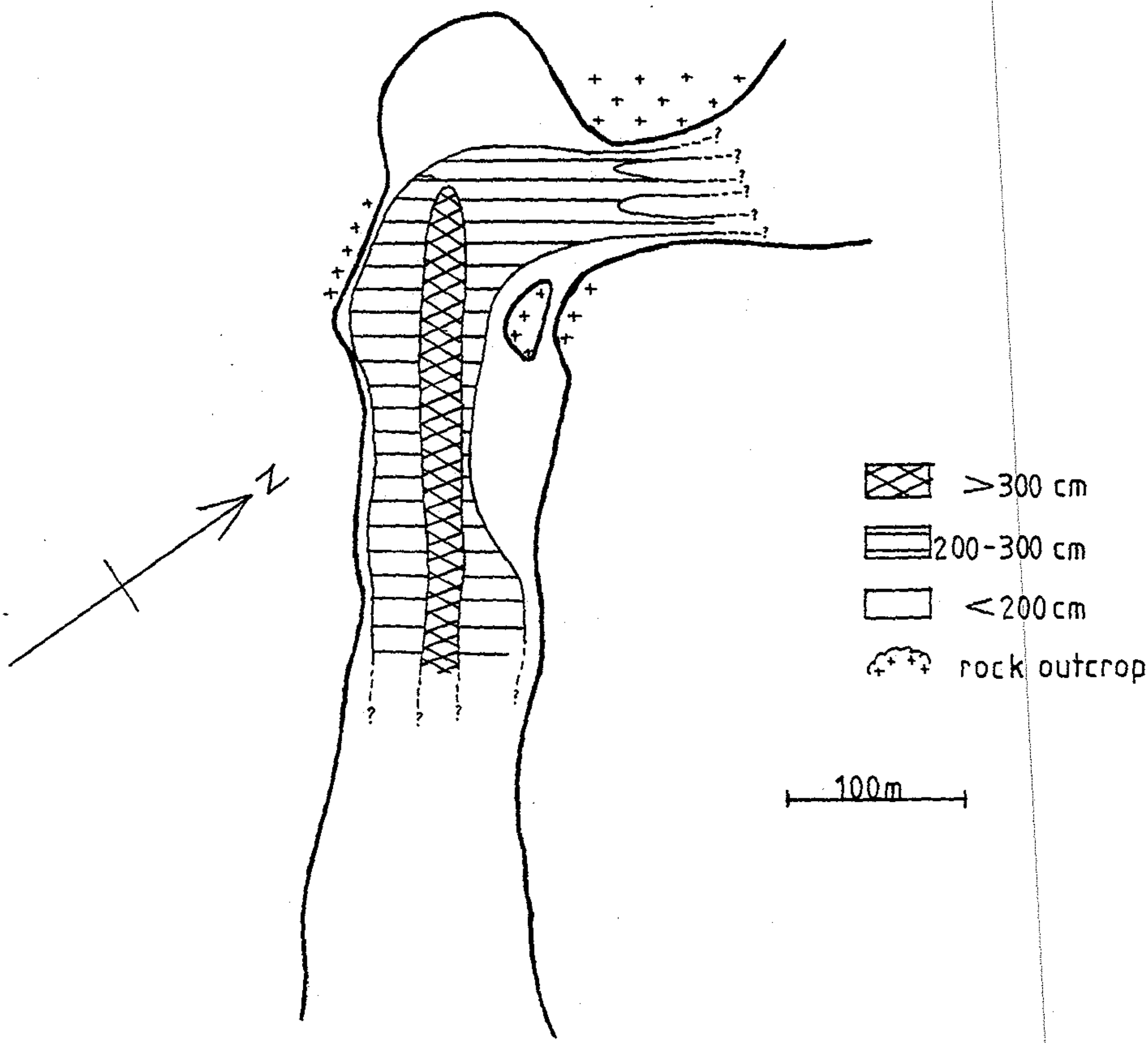

FIG. 34. -RIVERBED DEPOSIT THICKNESS MAP.

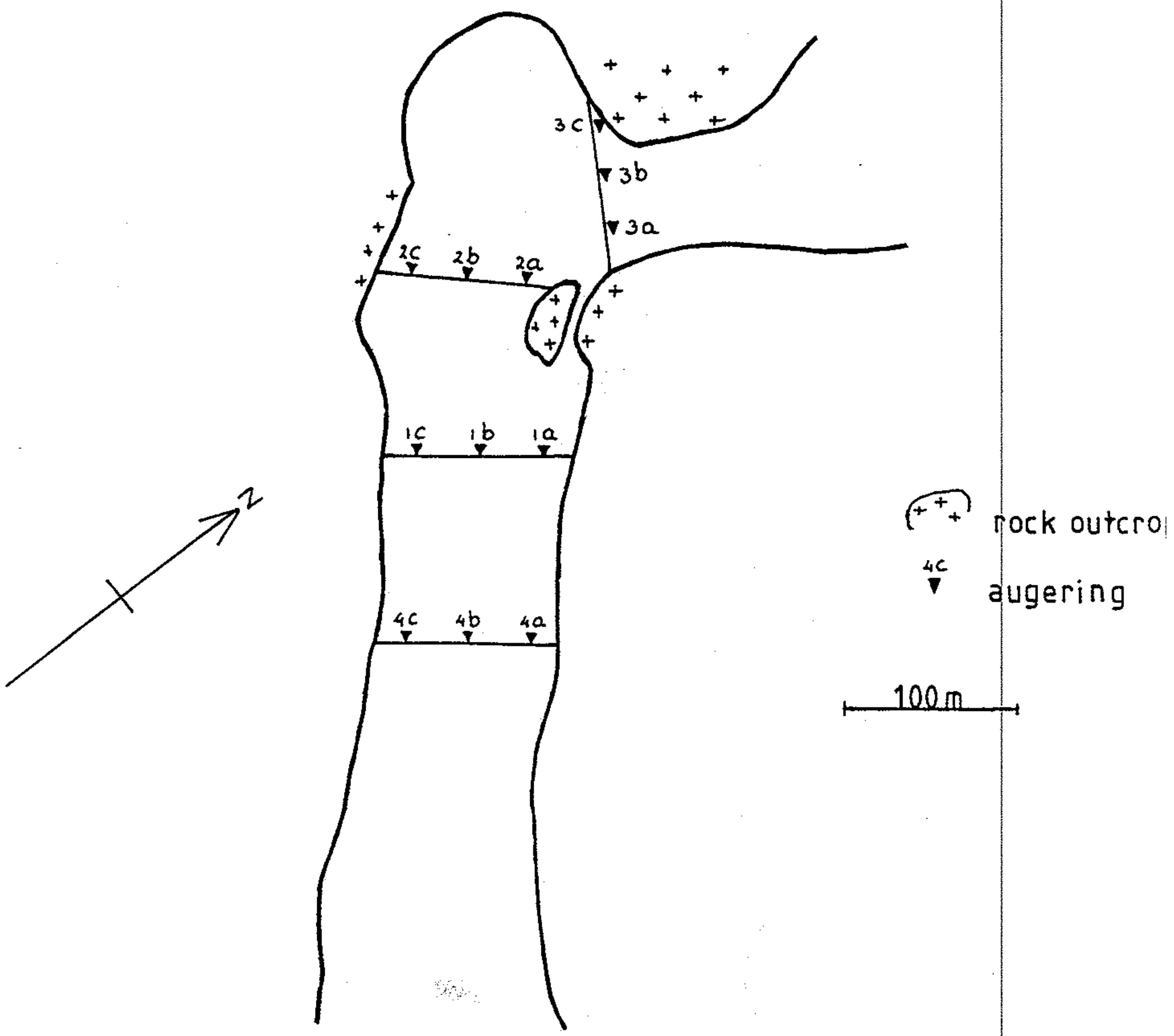

FIG. 35. -LOCATIONS OF THE AUGERINGS IN KONYU WADI.

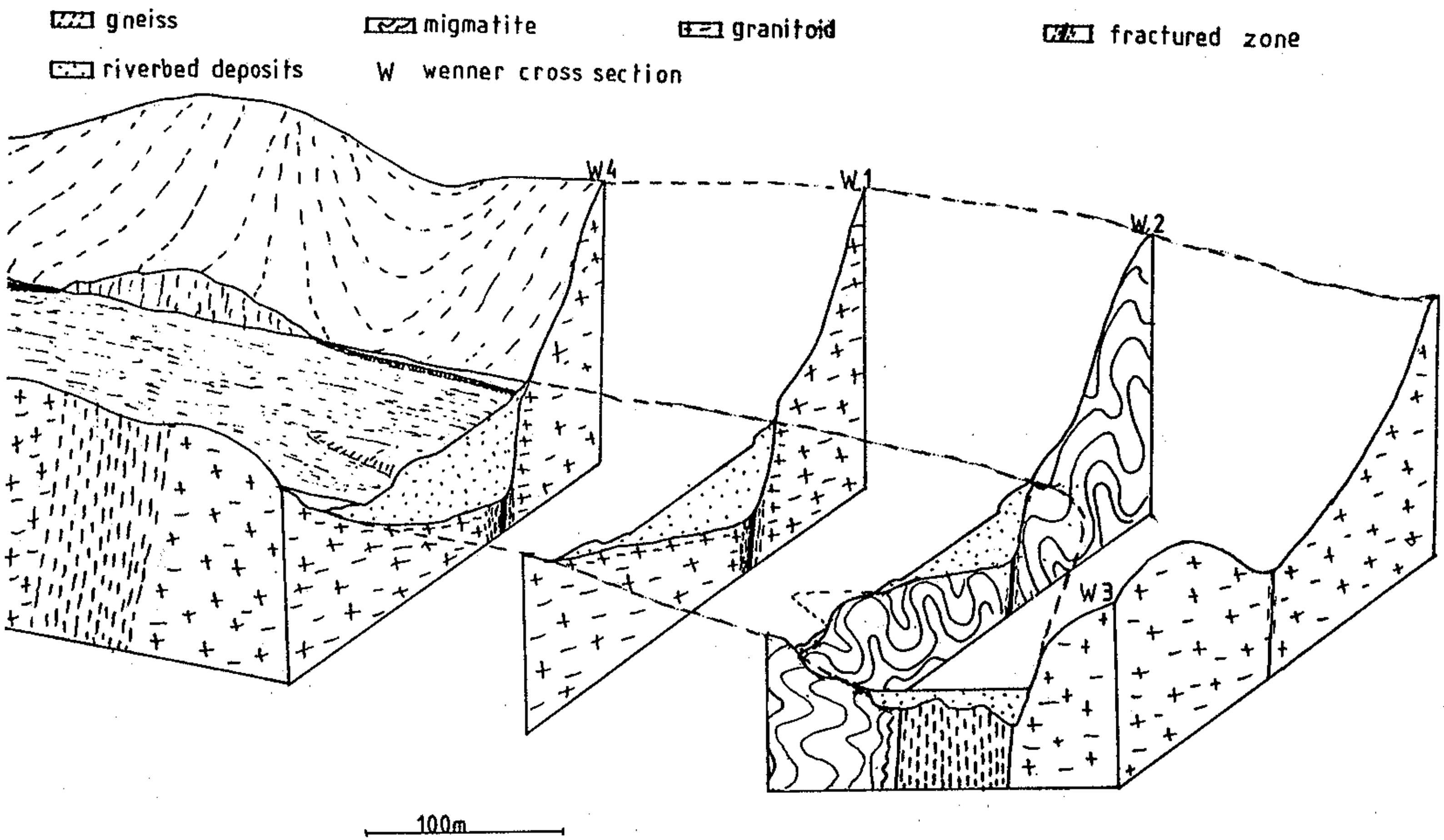

FIG. 36. -SCHEMATIC OVERALL INTERPRETATION OF THE BUILD UP OF KONYU WADI AT THE SURVEY SPOT.

5.7 The watersupply and possible improvements

The watersupply

The survey spot is one of the most important water suppliers of the surrounding area. Especialy the people upstream the Konyu depend on the spot for their watersupply.

The Tana is the most important watersupplier of the area downstream the survey spot.

At the survey spot daily 400-500 cattle and goats are watered and about 50 people come to fetch water and wash. These people are not the only ones who depend on the Konyu for their watersupply, also the relatives of the women who fetch water for their families depend on the Konyu for their water supply. A rough estimation of the number of people depending on this water supply is about 200 people.

The waterfetching is only done by women. The water is fetched from hand-dug shallow wells. These wells vary in depth with the seasons from 0.5 to 2m (during extremely dry years).

The water fetching is always done in one way:

First the women empty the shallow well with a buyu (a split gourd, see Fig. 37) and throw this water around the well.

Second they wait for the fresh water to refill the well.

Then this clear water is fetched carefully (otherwise it will become muddy) with the buyu and poured into a container or gourd. This water is carried to the homesteads for their family there. Usually the women carry about 20 liters, sometimes over several kilometres.

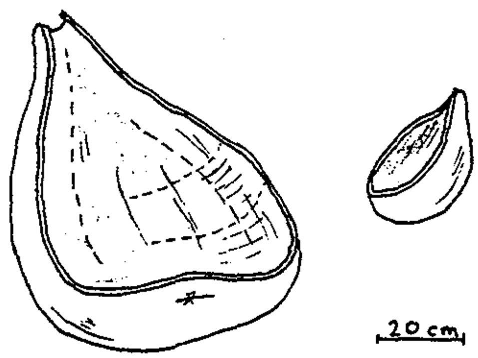

FIG. 37. -BUYU (OR CIUGA), A SPLIT GOURD USED FOR WATER FETCHING.

The herds from the neighbourhood are also watered in the Konyu at the survey spot. Most of the animals are goats and zebus, but also some donkeys are watered at the survey spot. These animals are watered in the same wells as where the people take their

water or wash themselves. This does not seem to improve the public health situation of the area.
There is some kind of a social division in the use of the wells. This division is probably made to seperate the sexes when washing (see Fig. 38). The most western well is only used by women and children this is also the well were most of the water is fetched and also the well where the women wash themselves. The most eastern well is the mens well. In this well no water is fetched, it is only a washing-well where also most baboons come to drink. The central area with many wells is used by both sexes and mostly by the cattle and goats. The cattle destroys these very shallow wells every day and therefore these wells have to be dug out every day again.
According to the local people there is always sufficient water available at the survey spot. Even in 1983-1984 when it did not rain for one year (two rainy seasons). During that extremely dry year they had to dug the wells to 2m deep.
This indicates a high carrying-capacity of the wells at the survey spot. Interesting to know is the amount of water that can be stored in the riverbed behind the natural subsurface dam.
This resevoir is the lineament related gully below the top of the subsurface dam. Its depth at the survey spot is varying from 10 to 3.5 m, since the subsurface dam is situated at 2m depth the resevoir has a depth of 8 to 1.5m.The gully is at least 300m long and 25m wide.
These figures give a total volume of the reservoir of about 37,500 m3 only at the particular survey spot. The porosity of these poorly sorted deposits is about 15%. This yields an amount of 5,600m3 water in the reservoir. This is only a very rough estimation, only to get an impression of the amounts of water available.
This water source is daily used by about 400 animals and 200 people which are 200 units of 1 man and 2 animals.
For each unit there is 28m3 of water to spend during the dry period, when it is assumed that there is no additional feeding of water, and the people will be able to extract all available water.
When this period is 400 days (one year) each unit can spend 70 liters a day which is probably just sufficient to survive the drought. That droughts of 400 days are not uncommon was demonstrated in the early 1980s.
The amount of water available is only a rough estimation by which the evaporation losses were not calculated nor the extra amount people and cattle and game attracted to this spot during periods of drought.
This estimation may indicate that there is a considerable addition of water from the fractured zone since during a period of one year without rain the people had to dug only 2m to get sufficient amounts of water.
Two metres depth is just the depth of the top of the subsurface dam this indicates that the people never have used water from the reservoir lower than the top of the subsurface dam during the extremely dry year 1983-1984.

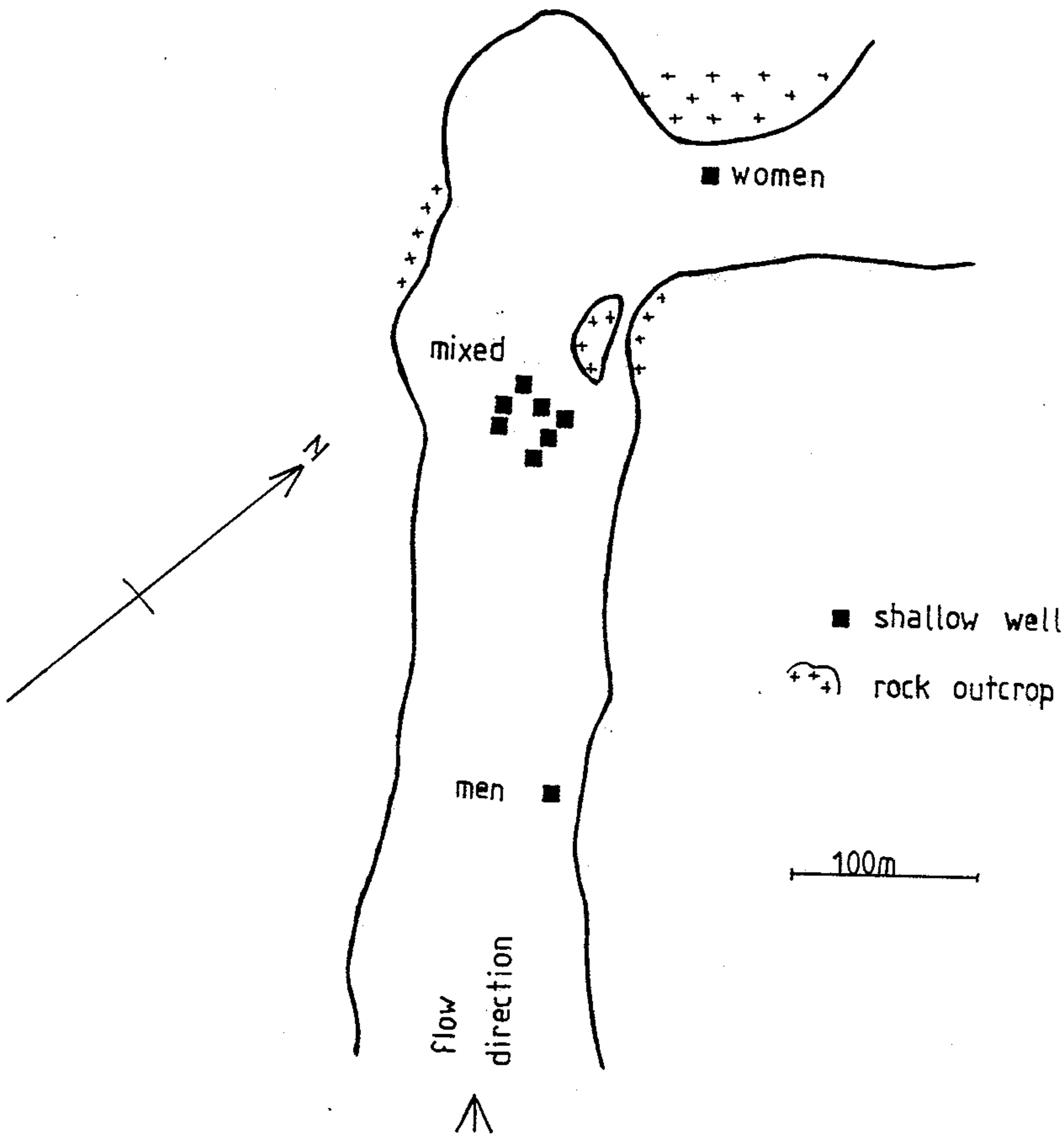

FIG. 38. -SOCIAL DIVISION OF THE WELL USE IN KONYU RIVER.

Possible improvements.
It seems to be clear that the way the water from the Konyu is used is not the most perfect one from a public-health point of view. When the use of the wells is compared with the use of the same kind of shallow wells in wadis by e.g. the Samburu in the more arid, more northererly regions some differences can be seen. The wells in more arid regions are always garded and protected by a bush fence. The wells are much larger and need to be dug less often and are maintained during longer periods. A fact is the necessity of fencing the wells is much higher is some parts of e.g. Samburu land since more game like elephants, buffaloes etc is present in those regions. The fenced wells seem to have some advantages. The labour which has to be used for repairing the wells is less and the unprotected wells seem to cause a less healty situation. On the other hand one unprotected and probably contaminated well is never used long. By digging new wells the people always get freshly filtered water. When a protected well gets contaminated and the water is not completely removed before filling a container or drinking, this contamination can last longer and increase in the well.
The mangement of the wells at the Konyu wadi maybe is one of the aspects of the shallow wells which can be improved, especially during long dry periods when the wells will certainly attrack more cattle and people, but no hasty conclusions should be drawn that the management of the wells is not good.
A real improvement can be to increase the amount of water stored in the riverbed e.g. by building a subsurface dam or an earth dam. Also other possibilities to extract more water from the wadis are listed in chapter 4. A disadvantage of the increased amount of water available is that it will attract more people and cattle and that it will cause a higher rate of sedentarity of the people. This will cause a higher density of people and cattle around the wadi. This higher density will cause more overgrazing and therefore cause more erosion along the local grazing routes. Also the construction and maintaince of water works costs money.
A disadvantage of using the water from the riverbeds of intermittent rivers is the fact this water usually becomes more saline during the dry season. What effects this more saline water has is not known for the Konyu.
Since the Konyu always seems to have supplied enough water for the amount of people and cattle depending on it now it is probably better not to change the present situation to radically.

occurences of groundwater in the gneisses are found in unit X5, especially in the zone which seems to be a continuation of a fault in an adjacent G1-unit. The worst possibilities of finding groundwater in the X-units are in unit X1, the small granulite hills. A problem in the whole gneisses area is the poor permeability of the regolith. The top soil tends to form impermeable crusts which favours extremely high run-off percentages. The little amount of rain-water which infiltrates into the regolith usually does not percolate deeper than 50 cm. The most of this water is evaporated during the dry season or transported to the riverbeds of the wadis in a through-flow. Only very small amounts of the rain-water will percolate through the regolith into the fracture system of the underlying rock. Also lateral addition of water to the groundwater in the fracture systems of the gneisses is only very limited. This does not favour the occurence of large amounts of groundwater in the X-units.

Unit Q has a topographic position and build up which make the posibilty of finding groundwater in this unit very limited.

The occurence of groundwater in unit G1 is limited to the faults in this unit. That these faults do carry water is demonstrated near Chiokariga, where a spring is fed by a fault. Unit G2 offers almost no possibilities for groundwater bodies. The unit merely consists of small hills which are isolated and not well fractured. The water running off the hills of unit G1 and G2 partly feed the water occurences in the fractures on unit G3. This best jointed granitoid unit also has the most favourable topography to offer the best chances of all G-units to contain groundwater bodies. Also the feeding of the fracture systems of the granitoids with water percolating through the regolith is not such a great problem as it is in the gneisses areas. The shallow regolith is more sandy and better permeable.

The M-units offer little chances of finding groundwater in these units. The topography of these units, the shallow, poorly permeable regolith and the lack of well developed fractures in these units do not favour the chances of finding groundwater here. Maybe very limited amounts of groundwater can be found in the fairly wide granulite border zones around the largest M-units, although granulites are not very good aquifers in general.

The lavas do not contain aquifers. All lava flows are single flows which are too thin and too well drained to contain groundwater.

The lahars mostly form very thick deposits with very thick and permeable regolithes. As well in the regolithes of the L-units as in the lahars themselves large amounts of groundwater can be found. The thickest lahar deposits and the most aquifers are found in sub-unit L1a. High amounts of groundwater can be found here. The further eastwards one goes in sub-unit L1b, the smaller the chances of occurences of aquifers become. Almost no groundwater can be expected at the eastern border of the lahars, where the lahar thickness is almost nil.

Unit L2 comprises areas where a thick regolith originating from lahars is covering granitoids. Some water can be expected in

these regolithes during the rainy season, but the undeep granitoids prevent the occurences of important aquifers in this unit.
The colluvial deposits do contain some water which easily infiltrates into these deposits which form the foot-slopes of the volcanics and some of the ultra-mafics. The colluvium around the lava flows and the ultra-mafics is not very liable to contain large amounts of groundwater. More important amounts are found in the colluvium bordering the lahars. Locally a lateral supply of water from the lahars causes the occurence of considerable amounts of groundwater in the colluvium what is reflected by the tillage of crops which need a constant supply of water.
Some of the fluviatile deposits also offer good possibilties of groundwater occurences. The terrace deposits in unit F1 do not contain amounts of groundwater, but in the areas which were once covered with these deposits and now form the largest part of this unit, are covered with thick regolithes and have a flat topography, so the infiltration of rain-water into the regolithes and the underlying rock is favoured. It is very probable these units will contain higher amounts of groundwater than the surrounding X-units.
Unit F2 comprises a few very large riverbeds. One riverbed is that of Tana river. Of course the riverbed of this perennial river is always saturated. The other F2-units are the riverbeds of large wadis. These riverbeds usually contain water at various depths.

The water-supply.
Four sources of water are of importance in the survey-area. These sources are surface water, near-surface water, groundwater and rainwater.
Most surface water is taken from the perennial rivers. It is fetched with gourds or other containers and some water-pipe lines have their inlets in these rivers. Most taps from water-pipe lines are found in the western part of the area. The surface water from the perennial rivers can be contaminated by the time it reaches the eastern part of the area. The best locations (with respect to the infection danger) for the water-inlets of pipe-lines are in the uninhabited areas of the Mt.Kenya forest or in wells in the riverbed beside the river.
The near-surface water is taken from wells which in the volcanic area are usually a number of metres deep in the regolith. This water is usually free of contaminations. In the eastern part of the area many shallow wells are dug in the riverbeds of wadis. At some spots these shallow wells supply water throughout the whole year. The shallow wells are easily contaminated.
Groundwater is taken from a few bore-holes in the lahars and from some springs in the lahars and granites. This water is usually free of contaminations except when the spring-water is collected in small pools.
Rainwater is catched in the eastern part of the area in large tanks which collect the rainwater from the roofs of schools and other large buildings. This water can be a fairly save supplement

or source of water. This way of water conservation is new in the survey area and not very wide-spread yet.

Possible improvements of the water supply.
There are no increases of the amount of surface water desirable in the area. Improvements can be made with respect to the public-health e.g. the type and location of inlets of the water-pipe lines and information supply.
The amount of the water in the wadis can be increased by building sub-surface dams or earth dams. The protection of the wells as well in the volcanic as in the Basement System area can be increased.
An increased amount of bore-holes which deliver save water also can be an improvement, but the drilling of bore-holes and the maintenance of these bore-holes and pumps do cost considerable amounts of money.

Case study in Konyu wadi.
Konyu wadi is an intermittent contributary of Tana river. A small part of this wadi was surveyed with geoelectrical measurements to gain insight in the build up of the wadi and to explain the local shallow water table at the survey spot. This water table is very important for the local people and their cattle.
Schlumberger soundings and measurements along Wenner arrays were carried out. As reference and to check the measurements also augerings were done. The soundings were processed into cross sections and apparent resistivity maps which gave insight in the build up of the wadi at the survey spot. The riverbed deposits depth varies from about 10m upstream to about 2m in the right-angled bend of the wadi. This decrease of deposit depth can be considered as a natural sub-surface dam. This is one important fact by which the shallow water table can be explained. Another aspect of the wadi is a straight gully in the bedrock under the deposits. This gully follows the straight course of the largest part of the Konyu at the survey spot. This suggests a fault or strongly jointed zone in the rock under the deposits. From this zone, which most down-stream end is at the survey spot, a seeping of water into the riverbed deposits is possible. This can be a second explanating factor for the shallow water table. It can also explain why the water table usually, also during extreme dry periods, is above the top of the natural sub-surface dam.
An estimated amount of water in this gully revealed there is probably enough water in it to supply water to the amount of people and animals who make use of the wells at the survey spot now, during a dry period of about 400 days.

1w1z2w1z

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APPENDIX 1. SURVEY METHODS

A 1.1. General.

The survey in the area began with a geological survey. First satellite images of the area and the surrounding areas were studied. These images were studied to get an impression of the geology and geological structures of the area and their relations to those of the surrounding areas. Structural elements as large joints, faults and other lineaments were indicated on the interpretation. With help of the satellite image possible water occurances can be detected like at large faults, in areas with many intersecting joints, transitions from volcanic to crystalline rocks etc.
After this first study aerial photograph interpretations were made. Aerial photographs, scale 1:50,000, were available for the whole area. From these photographs a geological fieldmap was derived. Information from fieldwork carried out for a soil survey in the same area by the authors of this report and other peolple was gathered and plotted on the fieldmap and the aerial photographs. Later more fieldchecks were made. The boundaries and the legend were adapted to this information.
Hand specimens were collected from all the map units for making thin sections and microscopical examination. A macroscopical lithological description of the rock types was given. The results of this geological survey are reported in "The Geology of the Chuka-South area (Kenya)" by the authors of this report (see 30 in list of references and literature used).
A second stage in the hydrological survey was deriving a hydrogeological map from the geological map with making use of the information about the hydrological features of the rocks gained by studying numerous exposures, seepage zones and springs. Additional information on the aquifers and deeper geology of the volcanic area was also gained from bore hole logs obtained from The Ministry of Water Development of the Republic of Kenya.
Information on the water supply of the area was gathered from officials from the ministry named above working in the area, missions, hospitals, from questioning people living in the area and from own observations.
Watersamples were taken on several spots and from several sources throughout the area. These samples have been analysed with preliminary methods to give some chemical classification of these samples.
A geoelectrical survey was carried out in a part of a large wadi East of Tana River (see chapter 5 of this report). A large number of people and their cattle depend on the water stored in the river bed of this wadi during the dry seasons especially when no rain falls during the rainy seasons like in the years 1983 and 1984. Work is done in several wadis to improve the water storage capacity of the sand bed. Background information on the geoelectrical methods used is given in the next paragraph.

A 1.2 Geoelectrical Methods.

The method used is the Resistivity Method. A low frequency current was introduced into the ground via two electrodes.
The potential difference between a second pair of electrodes is measured. The four electrodes can be arranged in any of several possible patterns. From the characteristics of each arrangement, the current and the potential difference the resistivity can be calculated.
For the model of a point electrode emitting a current I in a semi-infinite medium, which is the simplest Earth model, and with the current and potential electrodes on the Earth surface, the resistivity is given by the equation

$$V = \frac{\rho \cdot I}{2\pi \cdot \overline{AM}} \qquad (1)$$

where V is the electrical potential and $\overline{AM}$ is the distance on the on the Earth surface between the current electrode A and the potential electrode M.
When two current electrodes, A and B, and two potential electrodes M and N are used and the potential difference V is measured between measuring electrodes M and N, we get

$$\rho = \left[\frac{2\pi}{\frac{1}{\overline{AM}} - \frac{1}{\overline{BM}} - \frac{1}{\overline{AN}} + \frac{1}{\overline{BN}}} \right] \cdot \frac{\Delta V}{I} \qquad (2)$$

The factor $\left[\frac{2\pi}{\frac{1}{\overline{AM}} - \frac{1}{\overline{BM}} - \frac{1}{\overline{AN}} + \frac{1}{\overline{BN}}} \right]$ is the geometric factor and usually designated by the letter K. Therefore:

$$\rho = K \cdot \frac{\Delta V}{I} \qquad (3)$$

If the medium is inhomogenous and (or) anisotropic then the resistivity from equation (3) is called the apparent resistivity.
Apparent resistivity = ρ .
The apparent resistivity depends on the electrode configuration and the characteristics of the subsurface materials as true resistivities, layer thickness, angles of dip and anisotropic properties. This offers the possibility of electrical sounding of profiles. The method is based on the fact with increasing space between the current electrodes the electrical current penetrates deeper into the medium. With larger current electrode spacing the potential measured between M and N will be stronger influenced by the deeper layers of the profile.

Four electrical soundings were made along the axis of the wadi. The electrode configuration used for the electrical soundings is the Schlumberger Array: four electrodes are placed along a straight line on the Earth surface with

$\overline{AM} = \overline{AB}/2$, $\overline{NB} = \overline{AB}/2$ and $\overline{AB} \geqslant 5\overline{MN}$

Now equation (2) can be written as

$$\bar{\rho}_s = \pi \ (\overline{AB}/2)2 \cdot \frac{E}{I} \qquad (4)$$

where $E = \lim_{\overline{MN} \to 0} \frac{\Delta V}{\overline{MN}}$ = electrical field.

Here $\bar{\rho}_s$ is a function of $\overline{AB}$ only as long as $\overline{MN}$ and I are kept fixed. The apparent resistivity is plotted as a function of AB/2 on log-arithmic-coordinate paper. This curve is called an electrical sounding curve.

- The interpretation of electrical sounding curves.

All Schlumberger curves produced with the measurements in the wadi indicate the wadi river bed is a three layer medium. This can be concluded from the number of kink points in the curves. For a medium of three layers with resitivities $\rho 1$, $\rho 2$ and $\rho 3$ there are four possible combinations of the values of $\rho 1$, $\rho 2$ and $\rho 3$. These are:

$\rho 1 > \rho 2 < \rho 3$	- The Bowl or H-type section
$\rho 1 < \rho 2 < \rho 3$	- The A-type section
$\rho 1 < \rho 2 > \rho 3$	- The K-type section
$\rho 1 > \rho 2 > \rho 3$	- The Q-type section

In our case we only had to deal with the H-type section. The three layers can be considered horizontal and homogenous.

The electrical sounding curves can be given a quantitative interpretation by using so called Master curves to calculate the layer thicknesses and by calculating the apparent resistivities of the layers by using the Gosh method. In the case of this survey a computer program was used for comparing curves given by the computer with the sounding curves. After comparing the computer curve can be changed by adapting the curve characteristics after which a new comparism can take place etc. This cycle repeats as long as necessary until the curves fit. For the best fitting curve the computer calculates the layer characteristics for the model which belongs to the curve. The results of these soundings and their interpretations give a picture of the composition of the wadi river bed. The river bed

is build up by three layers, the top layer is thin and has a relatively high apparent resistivity, the second layer in this succession is thicker and has the lowest apparent resistivity, the third layer has an infinite thickness and the highest apparent resistivity. With the knowledge of augerings made in the wadi these three layers could be interpreted as a thin dry top layer consisting of sand and some gravel, the second layer of water saturated sand with some gravel and clay and the third layer is the hard rock.
For the electrical soundings see Fig. 28+29+30+31. For their interpretation see also chapter 5 of this report.

After the electrical soundings, measurements were done with the electrodes in a Wenner array. In this electrode configuration the four electrodes A, B, M and N are placed at the surface along a straight line so that:

$$\overline{AM} = \overline{MN} = \overline{NB} = a$$

For this array equation (3) reduces to:

$$\bar{\rho}_w = 2\pi a \frac{\Delta V}{I}$$

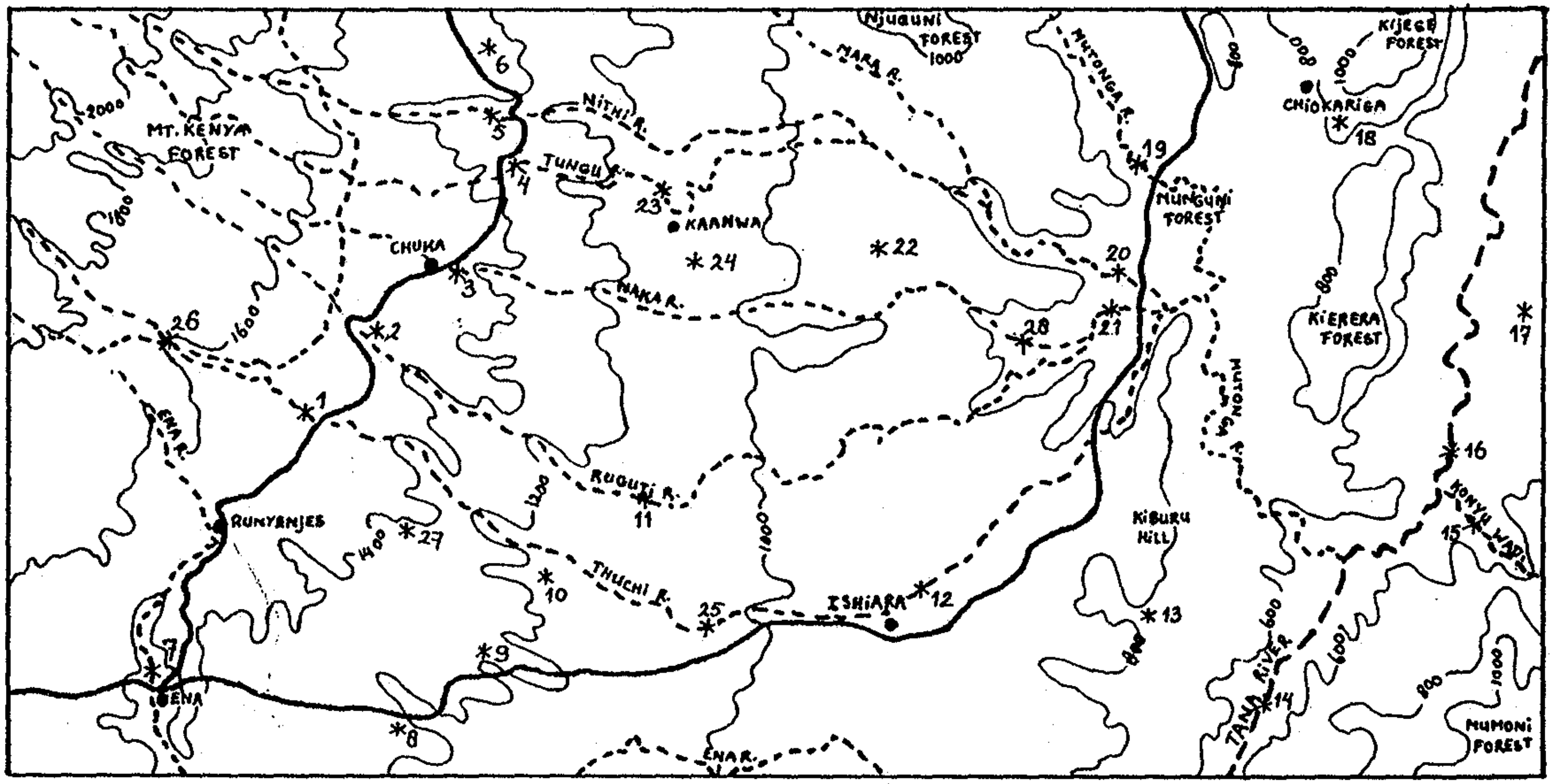
Thus the resistivity is a function of the distance variable a. The measurements with this Wenner array is used on four straight lines across the wadi. After each measurement the whole array was replaced along these lines with a distance a. The values used for a are 2.5 m, 5.0 m and 10.0 m. The distances 5.0 m and 10.0 m were also used for measurements along the axis of the wadi.
From these 244 Wenner measurements two apparent resistivity maps were derived, one for a=5.0 m and one for a=10.0 m. (See Fig 5,5,1,2 and 5,5,1,1) The values for a=2.5 m were too much influenced by the effects of the dry top layer to be usefull for making an apparent resisitivity map. The values obtained with a=2.5 m were used later to delete the effects of the dry top layer on the measurements with a=5.0 and 10.0 m.
Four resitivity sections were drawn for four cross sections through the wadi. The position of the middle of the array in the wadi was plotted on the horizontal axis of the section and a was plotted on the vertical axis as a parameter for the depth. On the cross point of these two points the measured apparent resistivity belonging to these coordinates was plotted in the section. Trough the section lines of equal apparent resistivity were drawn (see Fig. 28+29+30+31).
Sections like these can be used for gaining qualitative information on the occurrances of e.g. faults, buried troughs, clay bodies etc. The sections made for the wadi indicate a deeper "channel" in the hard rock along the midddle line of the wadi. This deeper part is filled up with water saturated sand and becomes less distinctive and deep downstream which means the water in this deeper part can be stored here (see also chapter 5 of this report).

To check the outcomes and to get the possibility of giving the measurements quantitative interpretation twelve augerings were made. With a riverside auger a hole was made until the ground water level was reached. In this hole a spiral auger was turned into the ground . The resistance the auger got during the augering could be correlated with the occurences of layers consisting of sand, sandy clay, clay and gravel which the auger met on its way down. The augerings were continued until the hard rock was reached. The depths of the hard rock under the sediment of the wadi were also plotted on a map of the wadi from which a sediment depth map could be derived (see Fig. 34). This map gives the same picture of the wadi as the apparent resistivity maps: a deeper part along the axis of the wadi which finds its end at the turn made by the wadi downstream.
For further interpretations and conclusions about the measurements see chapter 5 of this report.

APPENDIX 2.
CHEMICAL PROPERTIES OF SURFACE, NEAR SURFACE AND GROUNDWATER.
(Total and Ca hardness ,SiO2 ,SO4 ,Cl and NO3 in mg/l)

NO	WATER TYPE	COORDINATES MAP 122	CONDUC *10-6S	pH	TOTAL hardn.	Ca hardn.	SiO2	SO4	Cl	NO3
1	Surf.	99575-3445	59.7	7.4	17	17	1	<50	30	0
2	Surf.	99611-3451	85	7.3	51.3	34	2	55.2	121	0.6
3	Surf.	99630-3490	32.5	6.9	17	17	5	<50	30	0
4	Surf.	99630-3510	42	6.8	17	17	2	<50	30	2
5	Surf.	99685-3511	110	7.7	17	17	2	<50	30	0
6	Surf.	99710-3495	80	7.7	17	17	3	<50	30	0
7	Surf.	99479-3382	43	7	17	17	11	<50	30	0
8	Surf.	99469-3482	95	6.9	35	17	3	<50	30	0
9	Surf.	99484-3506	82	6.8	35	17	2	<50	30	1
10	Surf.	99521-3522	42	6.9	17	17	9	<50	30	0
11	Surf.	99550-3553	62	-	-	-	-	-	-	-
12	Surf.	99510-3652	28	7.5	17	17	15	<50	30	0
13	N.surf	99507-3740	3890	8	975	428	2	>50	455	0
14	Surf.	99480-3790	110	8	52	34	25	<50	61	0
15	N.surf	99533-3866	10700	8.5	171	102	25	>50	152	0
16	Surf.	99551-3850	106	7.5	51	34	25	<50	30	0
17	N.surf	99610-3888	14200	-	-	-	-	-	-	-
18	Ground.	99697-3807	3300	7.3	86	34	15	<50	61	0
19	Surf.	99662-3745	87	6.5	17	17	2	<50	61	0
20	Surf.	99623-3742	78	7.5	17	17	1	<50	61	1
21	Surf.	99616-3741	78	7.4	17	17	11	<50	30	0
22	Ground.	99648-3666	12960	7.5	375	188	0	>55	61	0
23	Surf.	99650-3572	48	7.1	17	17	2	<50	61	2
24	Ground.	99644-3575	139	7.1	34	34	0	<50	30	0
25	Ground.	99502-3584	72	7	17	17	1	<50	30	0
26	Surf.	99605-3385	53	-	-	-	-	-	-	-
27	N.surf	99535-3463	45	6	17	17	5	0	30	0
28	Surf.	99603-3710	106	7.4	34	17	16	<50	30	0

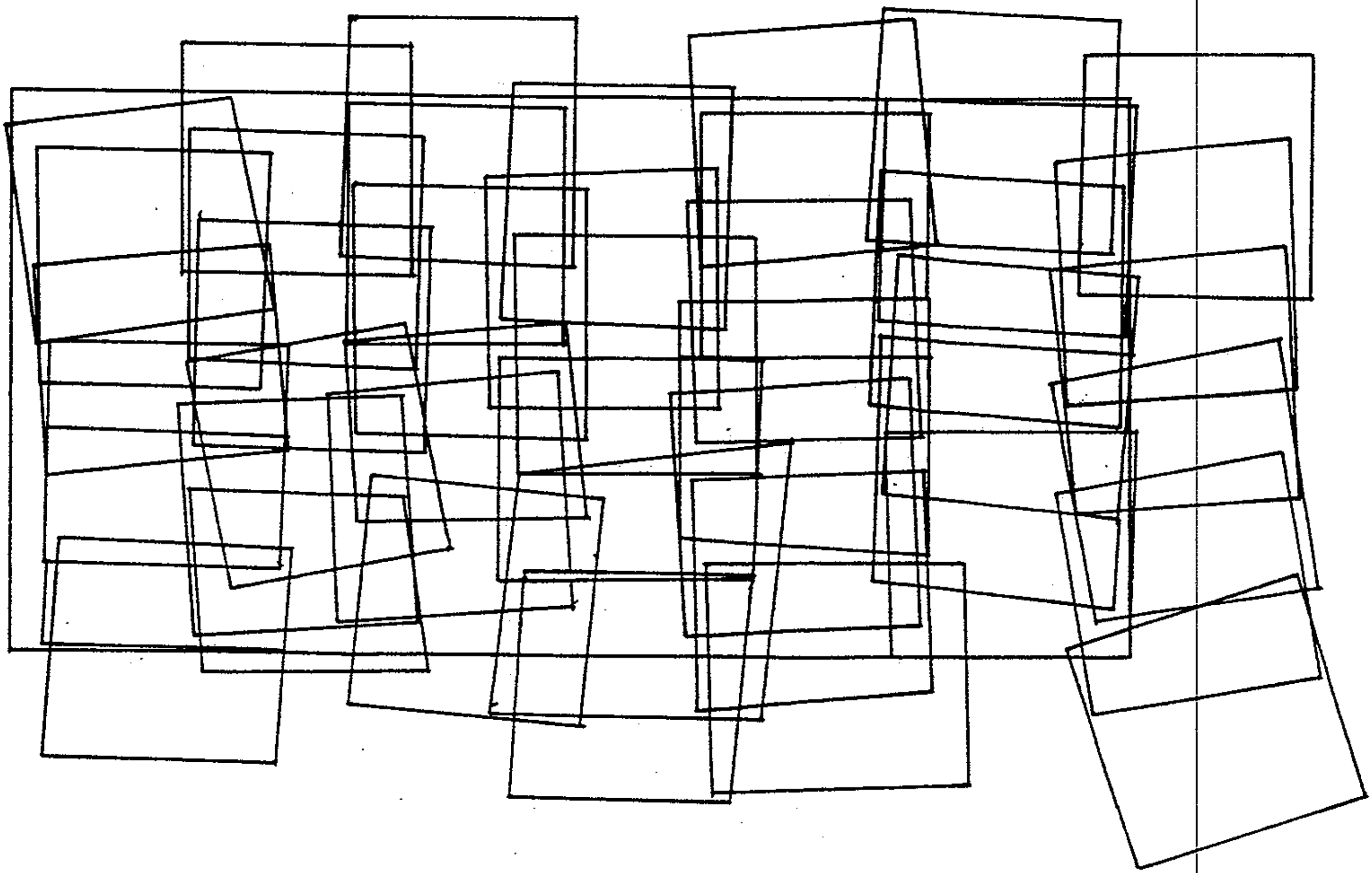
(Ground.=Groundwater; Surf.=Surface water; N.surf.=Near surface water)



LOCATION OF WATER SAMPLING SPOTS (*)

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			ISHIARA			TSEIKURU
I	II	III	I	II	III	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	93	184
				31		

1wlz2wlz

APPENDIX 6.

THE AUGERINGS IN KONYU WADI

---

augering no:	1a (14 m from river side)	
description:	0 - 30 cm	sandy clay
	30 - >	petrocalcic

augering no:	1a (22 m from river side)	
description:	0 - 30 cm	sand (unsortened)
	30 -150 cm	stony sand
	150-160 cm	less stony sand
	160->	rock or stone

---

augering no:	1b (middle river)	
description:	0 -130 cm	sand (unsortened, water struck 30cm)
	130-150 cm	sandy clay
	150-180 cm	sand
	180-190 cm	stony sand
	190-220 cm	sandy clay
	220-310 cm	sand
	310-	auger stucked for unknown reason.

augering no:	1b (middle river)	
description:	0 -150 cm	sand (unsortened, water struck at 30 cm)
	150-260 cm	sandy clay
	260-370 cm	sand
	370-375 cm	stony sand
	375-	auger stucked for unknown reason.

---

augering no:	1c (14 m from river side)	
description:	0 - 60 cm	sand (unsortened and gravelly, water struck at 50 cm)
	60 -140 cm	sandy clay
	140-170 cm	sand
	170-180 cm	stony sand
	180-210 cm	sand with some stones
	210-220 cm	sand
	220-250 cm	sandy clay
	250-255 cm	stony sand
	255->	rock or stone.

---

augering no:	2a (14 m from river side)	
description:	0 - 50 cm	sand (unsortened, water struck at 50 cm)
	50 - 90 cm	stony sand
	90->	rock

---

augering no:	2b (middle river)	
description:	0 -110 cm	sand (unsortened, water struck at 50 cm)
	110-150 cm	sand less gravelly
	150-190 cm	sandy clay
	190-400 cm	sand
	400-420 cm	sandy clay
	420-460 cm	stony sand
	460->	rock or stone

---

augering no:	2c (14 m from river side)	
description:	0 - 50 cm	sand (unsortened)
	50 - 60 cm	gravel
	60 - 80 cm	clay
	80 -150 cm	sandy clay (water struck at 130cm)
	150-160 cm	stony sandy clay
	160-230 cm	sandy clay
	230-290 cm	sand with some clay
	290-300 cm	stony sand
	300->	rock or stone

---

augering no:	3a (14 m from river side)	
description:	0 - 30 cm	sand(unsortened)
	30 - 50 cm	stony sandy clay
	50 -210 cm	sandy clay (water struck at 180 cm)
	210->	rock.

---

augering no:	3b (middle river)	
description:	0 - 30 cm	sand (unsortened)
	30 - 40 cm	stony sand
	40 - 80 cm	sandy clay (water struck at 80 cm)
	80 -220 cm	sand with clay
	220->	rock.

---

augering no: 3c (14 m from river side)

description:

0 - 70 cm	sand
70 - 80 cm	stony sand
80 -100 cm	sandy clay
100-200 cm	sandy clay (water struck at 150 cm)
200-280 cm	sand with clay
280-290 cm	stony sand
290-295 cm	sand
295-300 cm	stony sand
300-310 cm	sand
310-330 cm	stony sand
330->	rock.

---

augering no: 4a (14 m from river side)

description:

0 - 40 cm	sand (unsortened)
40 -100 cm	sand more gravelly, water struck at 80 cm.
100-110 cm	stony sand
110-140 cm	sand
140-170 cm	sandy clay
170-200 cm	sand
200-220 cm	stony sand
220->	rock.

---

augering no: 4b (middle river)

description:

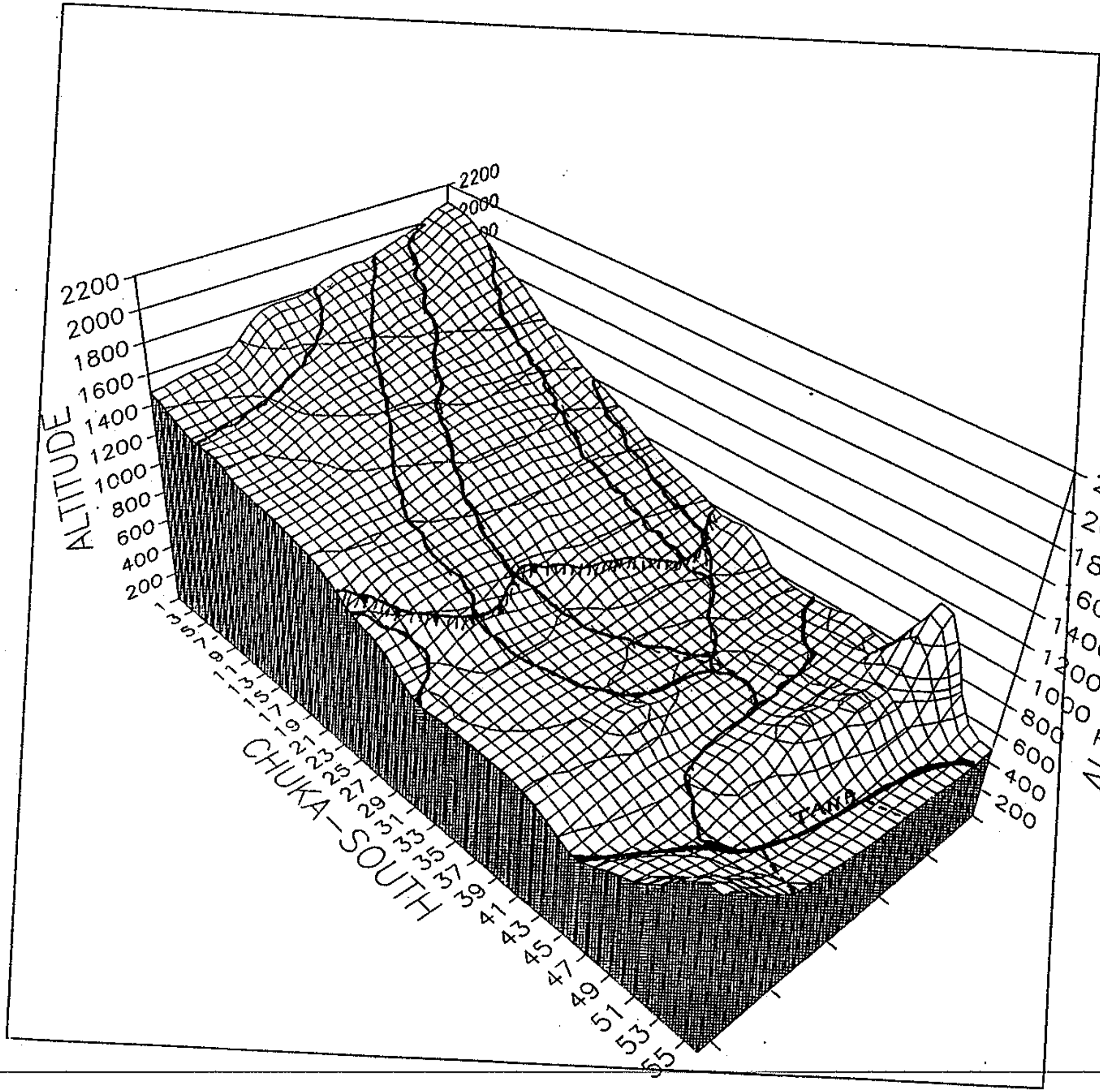
0 -110 cm	sand (unsortened, water struck at 40 cm)
110-160 cm	sandy clay
160-180 cm	sand
180-190 cm	sandy clay
190-220 cm	sand
220-230 cm	stony sand
230-290 cm	sand
290-310 cm	stony sand
310->	rock or stone.

---

augering no: 4c (14 m from river side)

description:

0 - 60 cm	sand (unsortened, water struck at 50 cm)
60 -140 cm	sandy clay
140-150 cm	sand
150-160 cm	stony sand
160->	rock or stone.


ALTITUDE
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
CHUKA-SOUTH
TANA

APPENDIX 4: THE LEGEND OF THE GEOMORPHOLOGICAL MAP.

<u>Volcanic landscape:</u>			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
<u>Basement System landscape:</u>			B
Mountains			BM
Hills			BH
Footslopes			BF
Lowland area			BL
	Flat		BLf
	Rolling		BLr
		rectangular dissected	BLr1
		subparallel dissected	BLr2
		subdendritically to sub-parallel dissected	BLr3
	Hilly		BLh
		dendritically dissected	BLh1
		subparallel dissected	BLh2
Valley			BV
Present Riverbed			BR