# *The occurrence of ground water in boreholes in Kenya colony with notes on the geology of the chief formations (with five plates and a geological map)*

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SUBMITTED BY

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## PART I.

THE OCCURRENCE OF GROUND WATER IN BOREHOLES

IN KENYA COLONY

WITH

NOTES ON THE GEOLOGY OF THE CHIEF FORMATIONS.

(WITH FIVE PLATES AND A GEOLOGICAL MAP)

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## PART II.

NOTES ON THE GEOLOGY OF THE AREA ADJACENT TO THE ROAD

MARSABIT - MEGA

(NORTH KENYA - SOUTH ABYSSINIA)

WITH

PETROLOGICAL DESCRIPTIONS OF REPRESENTATIVE ROCK TYPES.

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## PART I.

# THE OCCURRENCE OF GROUND WATER IN BOREHOLES IN KENYA COLONY

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NOTES ON THE GEOLOGY OF THE CHIEF FORMATIONS.

(WITH FIVE PLATES AND A GEOLOGICAL MAP)

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# I- INTRODUCTION.

The compilation of this report was commenced as a spare time study while the writer was attached from the Gold Coast Regiment, R.W.A.F.F., to various Water Supply Units of the East Africa Command as a Geologist and Geophysicist between February 1941 and February 1944. It has been completed since his release from the Armed Forces to civil employment.

Numerous water supply investigations carried out by the writer in Kenya, Northern Tanganyika, Southern Abyssinia and British Somaliland convinced him that certain additions to the earlier work on Kenya Water Supply of Mr. H.L.Sikes,C.B.E. (Sikes 1934) could be made, and some of his deductions amplified or modified in the light of knowlwdge gained from the drilling of many new boreholes in various parts of the Colony.

It is hoped that this work may be of some value at a time when a good deal of interest is being expressed in the possibilities of closer white settlement of the Kenya Highlands as a measure of post-war reconstruction and development. In the most suitable climatic areas, closer settlement will necessitate additional water supplies for domestic and stock consumption. The majority of such additional supplies will most probably have to be produced by boring, and in the body of this paper results obtained in the past and probabilities for the future

are

are indicated for the main areas of the Colony.

For the two geological formations in which most boreholes have been drilled; the Basement Complex and the Kainozoic Volcanics, an attempt has been made to show probabilities both as to depth to water and relative yields at various depths. The method used is similar to that used by Frommurze for boreholes in South Africa (Frommurze 1937). This method consists of the plotting of curves of the frequency with which water is struck at any given depth and of the yields expressed as percentages of the total output at that depth, against the depth. Typical asymmetrical curves of the form

$$\frac{dy}{dx} = \frac{y(x+a)}{f(x)}$$

are thus produced, such as are used with irregularly varying quantities. It is possible that the curves plotted for certain large areas of the Colony will have to be modified to a certain extent when more boreholes have been drilled, but those for the more restricted areas like the Machakos-Sultan Hamud area of the Basement Complex rocks and the Nairobi area of the Volcanics should remain more or less constant.

Provisional Water Table Contour maps have also been produced for the Nairobi area where a considerable mass of information is available. The lack of a reliable contour map of the area necessitated reliance on height readings with an aneroid barometer on the various borehole sites; thus minor flexures in the subsurface contours

due

due to variations of surface topography are not shown on the maps, which must be regarded only as provisional frameworks.

Analytical tables are also given for the chief formations and localities. The card indexing of the results from all boreholes and the analytical work necessary for the preparation of the above mentioned tables, maps and probability curves has been done by the writer.

During the progress of the work many of the boreholes have been visited and the general geological features of the areas studied. It has also been possible to determine from an examination of samples collected by drillers of the more recent holes, many of which were sited by the writer, the nature of the strata passed through. For earlier holes, the records have been supplied by the Hydrological Section of the Public Works Department of Kenya, whose assistance in the investigation is gratefully acknowledged.

Increasing use has been made in recent years in Kenya of geophysical methods of prospecting for water, usually by means of the Evershed and Vignoles Geophysical Megger. To the accurate interpretation of the results obtained from the use or this instrument, much of the success of the new drilling may be attributed. By this time a considerable mass of information has been accumulated on the correlation of the Depth Resistivity Curves with their reflection in the strata passed through by boreholes drilled

on

on the tested sites. It is now possible to decide, by the use of such comparison curves for different areas and different geological conditions, the possibilities of any particular site without recourse to the somewhat complicated mathematical interpretation of the curves. This saves much time in the choice of sites in the field. It is well known ,however, that anomalies do occur in these curves, and that they are not infallible and must be interpretted in the light of accurate geological knowledge of the area under consideration; in other words, the geophysical investigations are merely an additional aid to the geologist in the selection of the most suitable sites for drilling. It is not proposed to discuss the question of type curves for separate areas since this will be of interest only to geologists and geophysicists working in these areas and not applicable to water-supply problems as a whole.

A total of 505 boreholes with an average depth of 269 feet is considered here, representing all records available up to October 1943. Many sunk since that date are not included here since completion reports were not to hand. Of the total holes sunk, 319 have been classed as successful, that is, they have a tested yield of more than 90 gallons per hour (90 g.p.h.) or a theoretical safe yield taken as two thirds of the tested yield , of 60 g.p.h. This gives a percentage success for drilling over the whole Colony of 63.2 . The average depth of the successful holes was 285 feet, water being struck at an average depth of

205 feet, under a hydrostatic head of 85 feet, thus bringing the average rest level to within 120 feet of the surface. The average tested yield of all boreholes was 1310 g.p.h., that is, an aggregate tested yield from all boreholes in the Colony of just over 10,000,000 gallons per day. Only 18 holes gave water which was too saline for use, while 168 boreholes gave less than 90 g.p.h. on test , making a total of 186 boreholes classed as unsuccessful, of which the average depth was 244 feet.

Most of the boreholes were drilled by the Public Works Department or by private drilling companies for farmers and native communities, but since 1940 many have been sunk by the military authorities.

These results are considered in detail in later sections of the paper according to their distribution in the main geological formations , and also, where possible, in more restricted areas within these formations.

## II- GENERAL GEOLOGICAL AND PHYSIOGRAPHICAL FEATURES.

The rocks of Kenya range in age from the pre-Cambrian Basement Complex to Recent deposits in the form of wind-blown sands, lake-shore deposits, alluvium and soils, and include representatives of most of the recognised geological systems, with the exception of rocks of Palaeozoic age. The Basement Complex and the Kainozoic Volcanics are the most widely exposed, covering in the aggregate about two thirds of the area of the Colony. The Jurassic and

and Miocene (?) also have a relatively wide distribution, while the other systems represented, ranging in age from Permian to Recent, are mainly restricted to a belt of country some 60 miles wide running parallel to the coast and immediately behind it.

The outcrop of the various geological formations is shown on the 1;2,000,000 map, which is a reduction from the"1:1,000,000 Provisional Geological Map of Kenya" compiled by the writer in 1941 and reproduced by the East African Survey Group, East African Command. Descriptions of the formations are given in later sections of this paper.

Sikes (1934) has likened the Colony physiographically to "a flat arch with its springings at different levels and its crown fitted with a sort of elevated gutter running longitudinally". The elevated gutter represents the Kenya section of the Rift Valley, the flanks of which, varying in general elevation from 6,000 to 13,000 feet, together with the lower slopes of Mt. Kenya (17,040 feet), form the well-known Kenya Highlands, one of the most suitable areas for white settlement in tropical Africa.

The Rift Valley is the outstanding topographic feature of Kenya and is a small part of the system of troughs which extends through some 50° of latitude from Palestine to the Zambezi. The evidence indicates that the rift system is essentially one gigantic structural feature.

The Kenya section of the Rift Valley averages some

45 miles in width and has a roughly north-south direction Within its boundaries occurs a wide range of geological and physiographical features, while naturally, over such a large area, climatological factors vary within wide limits. The flanks of the Rift Valley are usually tilted away from the margins of the main depression and hence give rise to predominantly exterior drainage conditions. The valley floor is split by a series of minor "en echelon " faults which break it up into a number of miniature rift valleys with narrow parallel blocks between. This type of structure is well seen from the top of the Kikuyu scarp, looking westwards towards the extinct volcano of Suswa.

The landscape of the Rift Valley is characterised by enormous masses of eruptive material, the earliest volcanics being soda-rich types probably extruded from fissures. Most observers are of the opinion that the faulting was initiated at the same time as the fissure eruptions, but that it continued for long after the fissure eruptions had ceased. The fissure eruptions were followed by more violent localised eruptions which formed great thicknesses of bedded ashes, tuffs and agglomerates.

Lake sediments, deposited in the formerly much more extensive lake system of the Rift Valley, are intercalated in many places with volcanic rocks, while Recent lake deposits also cover fairly large areas of the Rift Valley floor.

Topographic features of importance other than the great dome of the Highlands and the Rift Valley, are Mt. Marsabit, the Mathews Range, Mt. Kenya, the Huri Hills etc., and the widespread plains of the Northern Frontier District, the lava plains of Athi and Kapiti and the low-lying, gently undulating country underlain by Basement Complex rocks, which stretches westwards from the 60 miles wide coastal belt to the lower slopes of the Kenya Highlands.

The pre-Kavirondian volcanics and the overlying metamorphosed Kavirondian sediments with granitic intrusions, extensively developed on the west side of the Colony along the eastern shores of Lake Victoria, are not described in this paper since no boreholes have been sunk in them.

## III- GENERAL HYDROLOGICAL CONDITIONS.

In the greater part of the Colony there are two separate and distinct rainy seasons, the "long" rains from the end of March to about the end of June and the "short" rains for about six weeks between October and December. The mean annual rainfall varies in different localities from less than 10 inches in parts of the Northern Frontier District, to over 70 inches in the plateau country in the Lake Victoria rain belt. The settled areas of the Colony all average 25 inches or more per annum.

In the coastal belt the rainfall varies from 50 to 60 inches in the south to about 20 inches in the north

towards

towards the old Kenya-Italian Somaliland frontier. It also decreases inland from the coast and produces the arid plains, with a mean annual rainfall of 20 inches or thereabouts, which occur between the coastal belt and the Highlands. As the Highlands are approached, the rainfall increases gradually from 35 inches, as in the Nairobi area, to 60 inches at Molo, and, where in addition to the monsoonal rains, the influence of the Lake Victoria rain belt is felt, many places have a mean annual rainfall in excess of 70 inches. A break in the general increase from east to west occurs in the Rift Valley, in which, in general, the rainfall is only about 30 inches per annum. Parts of the N.F.D., for example , the Wajir and Mandera districts, receive just less than 10 inches per annum, while Lodwar receives only about 6 inches, the lowest recorded average for any station in the Colony.

From the foregoing it would appear that the settled parts of the Colony on the whole are well watered, but the rainfall is unfortunately very uncertain both in amount and seasonal incidence. Uniform conditions are maintained to a large extent over the low-lying coastal belt and the plains behind, but in the Highlands rainfall shows great local variations.

The surface drainage of the Colony may be conveniently divided into three main systems- (a) that draining eastwards to the Indian Ocean, (b) that draining westwards to Lake Victoria, and (c) the internal drainage of the

Rift

Rift Valley.

The most striking feature of (a) is that only two perennial rivers reach the Indian Ocean, the Tana and the Sabaki. Many other large streams have their origin in the volcanic Highlands but on reaching the plains mainly composed of Basement Complex rocks, their dry season flow is rapidly reduced , and, in most cases, soon disappears entirely. The streams of the westerly drainage system, which drainaan area of higher rainfall than the easterly one, do not diminish in volume as they pass from the Highlands towards their outlet in Lake Victoria. The Basement Complex rocks of this area yield more readily to weathering and the heavy soil mantle forms an excellent reservoir which supplements the dry season flow of the streams. This area is so well watered on the whole that very few boreholes have been necessary. The Rift Valley drainage system is entirely internal in that no stream entering it leaves it again at the surface, nor do any of the great lakes within it discharge outside it. Sikes calculated that 94% of the total rainfall offthe Rift Valley must be accounted for by evaporation from temporary pools, capillary movement through the soil, transpiration by vegetation, and absorption. Of these factors the last is no doubt the most important, and, as will be shown later, the percolating water must go down to great depths over most of the Rift Valley floor.

Springs are not on the whole of great importance in

Kenya

Kenya except in the volcanics, from which issue several of considerable magnitude, which are the sources of some of the major rivers of the Colony and their tributaries. Hot springs and heavily mineralised springs are common in certain parts of the Rift Valley, the outstanding examples of the latter being found in the Lake Magadi locality. Steam jets are also common, particularly in the Eburru locality near Lake Elmenteita, where in places the steam is condensed and the water used for human and stock consumption.

## IV- DESCRIPTION OF FORMATIONS.

### (a) THE BASEMENT COMPLEX.

In Kenya roughly one third of the surface area is occupied by rocks of the Basement Complex. From the Abyssinian border in the Moyale neighbourhood they extend in a belt varying in width roughly from 100 miles in the north to 70 miles in the south, to a position just short of halfway between Buna and Wajir, where they disappear beneath the Merti Beds. This area of Basement Complex rocks is bounded to the east by the Jurassics and to the west by the volcanics of the Dida Gulgalla.

The largest continuous outcrop of these rocks, forming roughly the central portion of Kenya in a belt running approximately north and south, is again bounded to the west by volcanics. From the southern end of Lake Rudolf, the western boundary runs roughly south to the neighbourhood of hood of Rumuruti, where the belt narrows due to the eastward extension of the lavas. The boundary then swings in an arc down to the Nanyuki locality and thence in a north-easterly direction to the Isiolo area. From here it runs northwards to just south of Archer's Post, where it swings off to the east and then crosses the Isiolo-Wajir road a few miles west of Garba Tulla. From here its boundary with the volcanics is highly sinuous, but with a roughly south-westerly trend , down to the Tanganyika border. To the east the rocks disappear beneath the Merti Beds, the boundary being roughly north and south. From about latitude 3° S. the eastern boundary is against the overlying Duruma Sandstone and crosses the K.U.R. Nairobi-Mombasa line in the neighbourhood of Mackinnon Road, passing southward from here to the Tanganyika border.

Lying on this main mass of Basement rocks are many smaller areas of volcanics. In some cases these are merely thin cappings on small prominences, as for example in the area bordering the Laisamis-Marsabit road. In other places for instance the Chulyu Hills, large masses of volcanics have been built up on the Basement Complex rocks, forming prominent topographical features.

The width of this main body of Basement rocks varies from about 110 miles in the north to just over 20 miles in the Garba Tulla area and then gradually widens again to some 200 miles at the Tanganyika border. The latter width is over-all and includes the isolated patches of volcanics overlying the Basement rocks.

A third extensive area of Basement rocks is located along the west side of the Colony, with its eastern boundary against the volcanics. From a water-boring point of view this area has so far been unimpottant since very few boreholes have been sunk in it. Many inliers of the ancient rocks also appear among the overlying lavas in various parts of the Colony.

The Basement rocks comprise a varied series of metamorphosed igneous and sedimentary types, the most characteristic of which is probably a gneiss composed mainly of microcline and XXXXXXXX quartz (Gregory 1921). Associated with this are biotite-and muscovite-gneisses and occasionally a horneblendic type.

The Turoka Series (Parkinson 1913) is a sub-division of the Basement Complex, the name being given to a series of altered sediments, now represented by granulitic quartzite, crystalline and flaggy limestone, graphitic-schist, kyanite-schist, biotite-schist etc., which are characteristically developed in the neighbourhood of the Turoka River in the Magadi area.

The Turoka Series is now known to have a very wide distribution in the Colony. Glenday and Parkinson (1926) note that there is also a series of metamorphosed sediments in the Suk Hills area, known as the Maripu Series, with contemporaneous ashes (the Marich Schists), thought to have been intruded by a magma originally having the

approximate

approximate composition of a syenite, but now forming quartz-horneblende schists. These rocks are associated with massive granitoid gneisses which make up such prominent hills as Dingeret, Maral and Latertum. Parkinson and Glenday point out that the metamorphosed sediments resemble the Turoka Series so closely in petrological character, that although the nearest definitely known occurrence of the latter series is south of Marsabit, some 200 miles away to the east, there can be little doubt of their general contemporaneity. If this correlation is valid, then these metamorphosed sediments are distributed over a belt of country some 700 miles in length by 250 miles in width. Similar rock types have also been reported by Parkinson from the Buna area of the N.F.D. of Kenya.

Quartz veins intrude the Basement rocks at various places, but so far very little mineralisation has been found in association with them. Pegmatite veins are everywhere common and in some cases attain widths of up to 900 feet, as in the area just south of Laisamis. Very little accessory mineralisation appears to be associated with the pegmatites except where they are intrusive into schists, but in some such areas, Roberts, of the 42nd. Geological and Geophysical Section, S.A.E.C., has found garnets up to one inch in diameter and hornblendes and tourmalines up to three inches in length. Other accessories, sometimes developed in fairly large amount in favourable localities, are biotite and muscovite. Attempts at mining the mica have been made in various parts of the Colony, but so far

with

with only very limited success.

Roberts, in an unpublished report, gives the following list of rock types noted by his party in the Basement Complex of the northern part of the Colony:-

Quartzite
Garnet-granulite
Biotite-para-gneiss
Biotite-ortho-gneiss with much quartz and felspar
Biotite-schist
Amphibolite
Hornblende-gneiss and schist
Garnet-biotite-schist
Garnet-hornblende-schist
Garnet-hornblende-biotite-schist
Calcite-tremolite stringers of unknown sedimentary or igneous origin
Talc rock
Pegmatite veins(rarely carrying 2-inch muscovite)
Quartz-tourmaline and quartz veins
Coarse-grained"granite" with 2-inch idiomorphic crystals of orthoclase
Several unidentified hybrid rocks where intrusives have mixed with the surrounding country rocks,

and states that " the biotite-gneisses......... are the predominant types, through which run the various schist bands which are exposed on the West Suk Plain..... More detailed work will probably prove the existence of at least two ages of sediments, followed by granitic intrusions. All the ancient sediments have been folded and contorted along a general north-south axis..... and into this altered mass has been injected the younger granites and its offshoots, the quartz and pegmatite veins."

The more elevated areas of Basement Complex rocks are chiefly made up of highly resistant granitic gneisses in sharp contrast to the low-lying, gently undulating country associated with the more easily eroded siliceous biotite-schist and gneiss. Examples of inselberg type

of

of scenery,produced where the granite-gneiss is surrounded by the more easily eroded schists,may be seen at Ngomeni near the Thika-Garissa road, between Archer's Post and Laisamis, near Kacheliba in the West Suk, at Loriguma and in many other localities. In these districts the inselbergs are only a few hundred feet above the old peneplain. Examples of old mountain ranges also generally of granitoid gneiss are to be found in the Ndoto-Matthews Range west of Laisamis, and on the Cherengani-Moroto-Muruanisigar Ranges between Kitale and Lodwar. The hilly broken country around Mwingi on the Thika-Garissa road appears to be a deeply-dissected peneplain on these massive crystalline rocks.

The characteristic surface features of areas underlain by Basement Complex rocks in Kenya, especially in the N.F.D., are wide-spread plains with a sandy soil which quickly loses its water during the dry season. In areas of low rainfall the vegetation consists of scattered tufts of dry and parched herbage in the dry season, and such drought-resisting trees as the spiny acacia and candalabra euphorbia. In the more humid areas, however, good agricultural land is found, as in the Machakos area, the Cherengani area north of Kitale and elsewhere.

From a water-bearing point of view, the crystalline rocks of the Basement Complex are of great importance since they are found over extensive areas and can usually

be

be relied upon to give steady, though possibly small, supplies of water. The more coarsely crystalline members, such as granites, are usually poor water-yielders and at any considerable depth are in general completely devoid of water. Boreholes in granitic rocks mainly rely on striking well-developed joints for their supplies. Such supplies are not often large, but exceptions to this have been noted. The joints are usually very irregular in size, direction and distribution, this being particularly the case with vertical and highly-inclined joints, the horizontal joints being generally slightly more regular. For this reason supplies from boreholes in close proximity to each other may vary considerably. The joints and cracks tend to become tighter and fewer with increasing depth and yields will normally be found to decrease accordingly. This is borne out by a study of the probability curves for the Basement Complex of Kenya (Plate I), a fuller discussion of which is given later.

Schists do not usually have such well-developed cracks and joints as the gneissic and granitic rocks and those which do occur are usually closed at a shallower depth. The finding of water in any quantity in such rocks depends on striking a decomposed or softer layer of coarser grain than usual below the water table. Where such occurs it is generally a bed of siliceous biotite-schist. This has a considerable distribution in the Colony as part of the Turoka Series and is usually well decomposed and open-grained

grained to considerable depths.

When choosing borehole sites in the Basement Complex it is wise to make use, where possible, of drainage lines leading from large catchments. Depth of decomposition is also of great importance, since water is more likely to be stored in decomposed material than in the more compact unweathered zone below, which carries its water, if any, in cracks and joint planes. One of the most useful and simple methods of determining the depth of decomposition is by use of the geophysical "Megger". This instrument also has its uses in determining the depth of any softer layers, such as biotite-schists etc., intercalated with the harder rock types. Bisset (1941) makes the interesting point that in granitic gneiss, decomposition of the felspars may result in the formation of enough kaolin to effectively prevent adequate recharge of any reservoir which exists below the weathered zone, by cutting down the infiltration of rainwater and also increasing the run-off.

## BOREHOLE RESULTS IN THE BASEMENT COMPLEX.

An examination of all available records of boreholes drilled in the Basement Complex of Kenya shows that out of a total of 160 holes drilled, 109 or 68.1% were successful. The average depth was 229 feet, while that of the successful holes was 236 feet, water being struck at an average depth of 139 feet, rising under pressure to within 82 feet of the surface, i.e. under and average hydrostatic

head

## SUMMARY OF ALL BOREHOLES IN THE BASEMENT COMPLEX.

| DEPTH TO WATER IN FT. | YIELD IN GALLONS PER HOUR AND NUMBER OF HOLES. | | | | | | | | | TOTALS | AVERAGE YIELD IN GPH. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-500 | 500-1000 | 1000-1500 | 1500-2000 | 2000-2500 | 2500-3000 | 3500-4000 | 4000-4500 | 4500-5000 | | |
| 0 - 50 | 4 | 2 | 2 | 1 | 2 | 1 | 0 | 0 | 0 | 12 | 1287 |
| 50- 100 | 11 | 6 | 3 | 6 | 1 | 1 | 0 | 1 | 1 | 30 | 1220 |
| 100- 150 | 14 | 8 | 3 | 2 | 1 | 1 | 0 | 0 | 0 | 29 | 762 |
| 150- 200 | 8 | 6 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 18 | 826 |
| 200- 250 | 2 | 2 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 8 | 1028 |
| 250- 300 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 707 |
| 300- 350 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 3 | 1200 |
| 350- 400 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 1520 |
| TOTALS | 44 | 27 | 13 | 12 | 5 | 5 | 1 | 1 | 1 | 109 | 1000 |

Table I.

head of 57 feet. The average tested yield of all borehole was 1,000 g.p.h. The attached tabular representation of the results (Table I) analyses the depth at which water was obtained and the yield at various depths. It is interesting to note that a high proportion of the holes struck water at a depth of less than 100 feet (12 holes between 0 and 50 feet averaged 1,287 g.p.h. and 30 holes between 50 and 100 feet averaged 1,200 g.p.h.). 47 holes struck water at between 100 and 200 feet and averaged 787 g.p.h. only. The number of holes striking water below 200 feet was small (20 only) and these averaged 990 g.p.h. with a maximum yield from one of the holes of 2,900 g.p.h. No boreholes reached water at a greater depth than 390 feet.

These results have also been shown graphically as probability curves. A study of these curves (Plate I) suggests that the chances of obtaining water at depths greater than 270 feet are not great enough to warrant drilling to greater depths unless geological and geophysical indications are exceptionally favourable. Anomalies may have been produced in these curves because of the small number of results available for use, a factor which gives too much prominence to the deeper holes. Only 6.4% of the total number of successful holes gave water below 270 feet and these produce 7.6% of the total yield.

Only 4 boreholes in these rocks struck water in any quantity which was too saline for use. Two others struck

very

## SUMMARY OF BOREHOLES IN BASEMENT COMPLEX OF MACHAKOS-SULTAN HAMUD AREA.

| DEPTH TO WATER IN FT. | YIELD IN GALLONS PER HOUR AND NUMBER OF HOLES. | | | | | | | | TOTALS | AVERAGE YIELD IN GPH. |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0-500 | 500-1000 | 1000-1500 | 1500-2000 | 2000-2500 | 2500-4000 | 4000-4500 | 4500-5000 | | |
| 0 → 50 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 605 |
| 50- 100 | 4 | 3 | 2 | 4 | 0 | 0 | 1 | 1 | 15 | 1534 |
| 100- 150 | 7 | 5 | 1 | 1 | 1 | 0 | 0 | 0 | 15 | 740 |
| 150- 200 | 2 | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 9 | 878 |
| 200- 250 | 2 | 2 | 2 | 1 | 0 | 0 | 0 | 0 | 7 | 832 |
| 250- 300 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1000 |
| 300- 350 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 400 |
| 350- 4000 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 130 |
| TOTALS | 18 | 16 | 6 | 8 | 1 | 0 | 1 | 1 | 51 | 991 |

Table II.

very small amounts (20 to 30 g.p.h.) and are not considered here. These saline holes averaged 373 feet in depth, an average yield of 1,150 g.p.h. being obtained at 173 feet, rising under pressure to within 150 feet of the surface.

BOREHOLES IN THE BASEMENT COMPLEX OF THE MACHAKOS-SULTAN HAMUD AREA.

This area has been treated separately in the tables because a higher percentage success has been obtained here than in any other area of Basement Complex rocks in the Colony, and also because more boreholes have been sunk than in any other limited area of Basement Complex rocks.

The boreholes were drilled in both the Turoka Series (metamorphosed sediments)and the granitoid gneisses, but unfortunately there is insufficient evidence available to make possible a comparison in the yields and depths to water in the two distinct rock groups.

In all, 72 boreholes have been drilled in this area, of which 51 were successful, a percentage success of 70.8. The average depth of all holes was 233 feet, with that of the successful holes 243 feet. The average depth to water was 146 feet, a tested yield of 990 g.p.h. being obtained under an average hydrostatic head of 54 feet.

Table II shows that only three of the successful holes struck water below 250 feet and these averaged only 510 g.p.h., the highest yields being obtained from holes

striking

## SUMMARY OF BOREHOLES IN BASEMENT COMPLEX OUTSIDE MACHAKOS-SULTAN HAMUD AREA.

| DEPTH TO WATER IN FT. | YIELD IN GALLONS PER HOUR AND NUMBER OF HOLES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0-500 | 500-1000 | 1000-1500 | 1500-2000 | 2000-2500 | 2500-3000 | 3500-4000 | TOTALS | AVERAGES YIELD IN GPH. |
| 0 - 50 | 3 | 1 | 2 | 1 | 2 | 1 | 0 | 10 | 1434 |
| 50- 100 | 7 | 3 | 1 | 2 | 1 | 1 | 0 | 15 | 915 |
| 100- 150 | 7 | 3 | 2 | 1 | 0 | 1 | 0 | 14 | 780 |
| 150- 200 | 6 | 2 | 0 | 0 | 0 | 0 | 1 | 9 | 774 |
| 200-250 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 2400 |
| 250- 300 | 3 | 1 | 2 | 0 | 0 | 0 | 0 | 6 | 704 |
| 300- 350 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 1600 |
| 350- 400 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2910 |
| TOTALS | 26 | 11 | 7 | 4 | 4 | 5 | 1 | 58 | 1011 |

Table III.

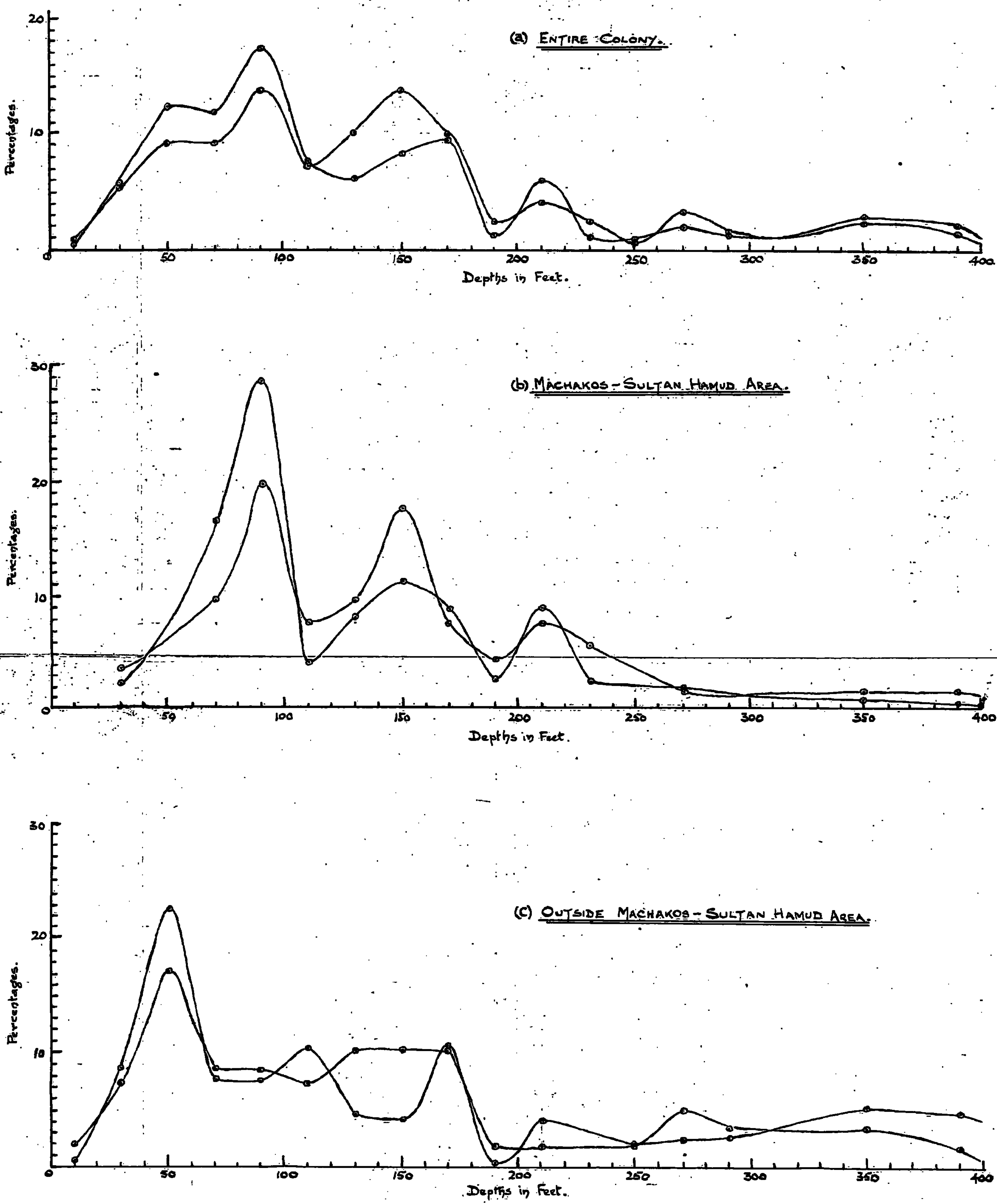


PLATE I. PROBABILITY CURVES – BASEMENT COMPLEX.

Probable depths to water.
Probable relative yields at varying depths.

striking water at depths of between 50 and 100 feet. The results are excellently illustrated in the probability curves (Plate Ib) which show that boring in this area to depths of more than 210 feet will be highly speculative. Most of the water occurs above 200 feet with high proportions of successful holes at 90 and 150 feet. Progressive tightening of joints with depth is also indicated by the lower average yield as depth to water increases. No boreholes in this area yielded water which was too saline for use.

A further analytical table (Table III) and probability curves (Plate Ic) are given for boreholes in the Basement Complex outside the Machakos-Sultan Hamud area. The value of the latter however, is doubtful, as they are scattered over an immense tract of country. The curves do however, exhibit similar tendencies to those of Plates Ia and Ib in that they show maxima at 60 feet vertical intervals, in this case at 50, 110 and 170 feet, with a smaller peak at 210 feet. Very few boreholes struck water below 210 feet and, as is the case for the results over the whole of the Colony, the small number available may have produced anomalies in the curves.

## IV (b)— THE DURUMA SANDSTONE SERIES.

In the area behind the coast from the Tanganyika border to some distance north of Mambrui is exposed a series of grits, sandstones, flagstones and sandy shales of terrestrial and lacustrine origin, named by Reichenbach (1896) the

the

the Duruma Sandstone Series. They occur in a belt, roughly parallel to the coast, some 35 miles in width and rising to a maximum elevation of some 1700 feet above sea level. They directly overlie the gneisses and schists of the Basement Complex to the west and are themselves overlain by Jurassic shales and limestones, or by Magarini Sands and coastal sands and corals to the east. To the north they disappear beneath the so-called Merti Beds which in this area are now also thought to be of Jurassic age.

Gregory (1921) classified the series as follows, the youngest beds being at the top of the table:-

(a) The Shimba Grits- coarse quartzo-felspathic grits with micaceous bands, layers of quartz conglomerate and beds of ferruginous sandstone. Wind-polished facetted pebbles suggest desert origin.

(b) Mazeras Sandstone- coarse felspathic grits interbedded with red, buff and white sandy shales, ripple-marked white sandstones interbedded with thick shales and cross-bedded sandstones.

(c) Mariakani Sandstones- flaggy fine-grained compact white sandstones, grey and yellow sandstones.

(d) Maji ya Chumvi Beds- hard shales and olive-green sandstones with bands of jointed sandstones.

(e) Taru Grits- coarse quartzo-felspathic grits interbedded with hard black shales; pebbles and sand grains derived from gneiss.

The Series ranges in age from the Permian Taru Grits to the Triassic Shimba Grits, and has not so far proved to be such an important water bearer as have similar arenaceous successions in other parts of the world, though it has not yet been intensively drilled.

Sixteen boreholes have been sunk in the Series, of which 13 have given supplies of potable water. Ten of the holes are in the Mariakani Sandstones and three of these, according to Sikes, probably entered the Maji ya Chumvi Beds. Borehole No.103 at Samburu started in the Maji ya Chumvi Beds and probably passed down into the Taru Grits while four other holes were drilled for the whole of their depth in the Maji ya Chumvi Beds. The Mazeras Sandstones have not yet been explored by drilling, but since springs issuing from them are fresh, it is likely that good supplies of potable water would be obtained from them.

Four boreholes, 2 in the Mariakani Sandstones and 2 in the Maji ya Chumvi Beds, struck large supplies of highly saline water at shallow depth, but by casing and grouting off these supplies and going deeper, good supplies of only slightly saline water were obtained. One of these holes, M/38, 7.4 miles from Mariakani Station, gave a small artesian supply (228 g.p.h.) of water which was at first charged with methane, but this gas later disappeared. Six boreholes sunk some years ago, which produced slightly saline water at first, have now become highly saline. The reason for this has not yet been explained. It may be that there is pollution of the lower water by more saline water from higher levels, or it may be due to

over-pumping

over-pumping, with consequent exhaustion of the fresh water layer lying above more saline water.

The average total yield of the 13 sucessful holes was 1,300 g.p.h. from a depth of 231 feet, the rest level being 58 feet. The average total depth of the holes was 305 feet.

## IV (c)- THE JURASSIC ROCKS.

Two main areas of Jurassic rocks are known in Kenya, one more or less parallel to the coast and overlying the Duruma Sandstone Series, and the other, which is of much greater extent, in the Northern Frontier District in the north-east corner of the Colony bordering Italian Somali-and and Abyssinia. Relatively little geologival work has been done on the rocks of the latter area, but Greg-ory collected a considerable amount of data on those of the coastal area near Mombasa, and sub-divided the rocks as follows:-

(a) Champamwe Shales- (Corallian). This is the uppermost of the four divisions of the Jurassic in the coastal area and is essentially an olive-green and yellow shale with calcareous and ironstone nodules, septaria and many ammonites and belemnites.

(b) Mititini Shales- (Oxfordian). Dark-grey to black unfossiliferous shales with calcareous nodules interbedded with half-inch layers of arragonite.

(c) Kibiongoni Beds-

(c) Kibiongoni Beds- (Callovian). These occur inland of the Miritini Shales and are characteristically shales, yellow micaceous sandstones, cherty mudstones and shelly sandstones. Some of them sandstones are strongly false-bedded and some show evidence of shrinkage cracks and rain pittings.

(d) Kambe Limestone- (Bathonian). This is the lowest member of the Jurassic in this area and contains three main types, the most abundant being a dark-grey unfossiliferous rock which may be sandy and contain pyritic nodules. The second variety is light-grey in colour and packed with massive corals, while the third, which is found interbedded with both the other types, is oolitic and pisolitic.

There has been some argument as to the relation between the Duruma Sandstone Series and the Jurassic rocks which overlie them, but Gregory favours an unconformity between the two series, rather than that the Kambe Limestone formed a passage bed between the Duruma Sandstones and the Jurassic.

Records of boreholes in the Jurassic beds of the north-east corner of the N.F.D. show that alternating bands of limestone, shale and sandstone are found down to depths of 400 feet along the Wajir-El Wak road (as at Wajir Bor and Mile 46) while nearer to El Wak, sandstones are penetrated for some considerable depth before passing into ing into limestones and shales. The sandstones, the Marehan type, have been referred by Busk (1939) to the Duruma Sandstones, but the borehole evidence disproves this correlation. They have been classed by other geologists as Cretaceous, but Dixey (personal communication) now suggests that they are Jurassic in age, since he has noted that the fossiliferous marine limestone passes up into them by alternation at the foot of the Marehan scarp of the Bamba Hills.

Water supplies in the Jurassic rocks of Kenya would appear to be on the whole extremely poor. Limestones are known to vary greatly under different conditions in their usefulness as aquifers, mainly due to the differences in the extent to which they have been subjected to the solvent action of percolating waters. It is well known that young limestones contain many voids between the individual calcareous fragments of which they are composed, but these usually become filled with calcareous cement deposited by solutions passing through the rocks. In this way, older limestones become compact and impervious except along cracks, caves and passages developed by solution along bedding planes and cracks. Unless such fissures or caves are struck in the drilling, it is unlikely that large supplies of water will be produced from boreholes in limestone, which accounts for the extremely sporadic occurrence of successful boreholes in this type of rock.

The second main division of the Jurassics, the shales, are

are amongst the worst water bearers of any type of rock. Shales, being formed by the induration of clays, have extremely fine particles with minute interstices. Under ordinary hydrostatic pressure they will not give up any water they do contain, but if joints and bedding planes are well developed in the zone of decomposition near the surface, small supplies may be obtained from this zone.

Two boreholes only were drilled in the Jurassics of the coastal belt. Borehole No. 107 at Vitengeni gave 875 g.p.h. of highly saline water at 136 feet, at the base of a shale bed above limestone. This was cased off and a supply of 350 g.p.h. of potable water was obtained at 386 feet, in sandstone which is possibly the Mazeras Sandstone of the Duruma Sandstone Series. Borehole No.173 at Kitenwangi gave 1,000 g.p.h. of saline water, unfit for use, at 190 feet in a sandy band in grey calcareous shale, and although drilling was continued to 550 feet, no supplies of fresh water were encountered.

The Jurassic beds of the coastal area are repeated by faulting and their actual thickness is not known, but there is no doubt that they are of considerable thickness. It is doubtful whether they could be penetrated economically from a water-boring point of view to reach the Duruma Sandstones below, except where they thin out towards their surface contact with the latter series.

Eight boreholes were drilled in the Jurassics of the N.F.D. and only one of these was successful, No.160 at

mile

mile 46 on the Wajir-El Wak road. This hole yielded 90 g.p.h. at 280 feet and 350 feet in thin sandstone bands in the shales. The rest level in this hole was 260 feet. Borehole No.169 at mile 76 on the same road gave a total yield of 50 g.p.h. and is classed as unsuccessful. Other holes were drilled to varying depths up to 400 feet without striking any water.

A summary of drilling in the Jurassics therefore shows only 20% success, the two successful holes averaging 401 feet in depth, with water at 368 feet, rising to within 200 feet of the surface.

## IV (d)- THE TURKANA GRITS.

Mr. A.M. Champion (see Campbell Smith 1938) has reported three distinct and rather widely separated areas of sedimentary rocks which are mainly felspathic grits and sandstones with minor developments of conglomerate, from the Turkana District, west of Lake Rudolf. The name Turkana Grits has been applied to this sedimentary series.

In the Labur Hills they rest on the Basement Complex and are themselves overlain by flows of amygdaloidal basalt or compact basalt which is either poor in olivine or entirely olivine free. The sediments in this area have also been described by Arambourg (1935) who named them the "Serie de Labur" and correlated them provisionally with the Adigrat Sandstones of Abyssinia. Fuchs (1939) points out that this correlation cannot stand, because

fossil

fossil trees found in these beds have shown them to be not older than Cretaceous and more probably to be of Oligo-Miocene age.

A second and more extensive outcrop occurs south of Kosekria and north of the Kagwalas River (Champion) and here the grits appear to be cut by microfoyaite dykes. At mile 74 on the Kalin-Lodwar road in this locality, Simpson of the 42nd. Geological and Geophysical Section, S.A.E.C reported "a fairly extensive deposit of sedimentary beds consisting of arkoses and conglomerates. Traversing these beds are a number of parallel dykes running roughly north and south." In Arambourg's map (1935) this area of grits is shown extending to the Kagwalas River and round the southern end of the Lothidok Hills. He also shows another area of grits to the south of the Turkwell River.

At Kosekria and six miles north of Kosekria Camp on the Kalodeke-Lokitaung road, Champion noted hard compact conglomerates, apparently at the top of the grits and sandstones. Pebbles in these conglomerates are said by Campbell Smith to be well-rounded and many of them are up to two centimetres in diameter. They consist mainly of pale-buff and greenish felsitic rocks set in a matrix of either angular fragments of felsitic or felspathic material in a dark base, or of ferruginous and calcitic material.

Roberts also reported conglomerates of this series from various localities, as at thirty miles north of Lodwar

and

and again at Taban and Loruth where flat-bedded conglomerates overlie lava of the augite-porphyry type. In the Taban-Loruth area, the conglomerate is finer grained than that nearer Lodwar and has been much more indurated by secondary siliceous solutions. Further proof of the circulation of these siliceous solutions is found in the valley 3/4 mile due south of Loruth, where angular pebbles of weathered gneiss have been cemented into a hard breccia. Roberts found a few felspar pebbles in the conglomerate, but insufficient to justify the name arkose. The scarcity of felspar and the rounding of the quartz grains and pebbles indicate that the conglomerates have had a long transportation history. Their provenance has not yet been determined.

Fuchs (1939) suggests that the Turkana Grits may be correlated with Gregory's Kamasian in its earlier restricted sense in the Lake Baringo area, which is probably of Miocene age.

The only borehole drilled in the Turkana Grits (SA/29 at mile 83 on the Kalin-Lodwar road) was not logged in detail but sandstone was reported throughout the whole of its depth (188 feet). Water was found at 94 feet, rising under pressure to within 90 feet of the surface. The tested yield was over 3,000 g.p.h. and it would appear that these sediments should prove a valuable source of borehole water supplies in the future.

## IV-(e)- <u>THE MERTI BEDS.</u>

## IV (e)- THE MERTI BEDS.

The series of nodular limestones, sandy, clayey and pebbly beds with minor gypsiferous developments, which covers a great part of the Northern Frontier District and the eastern part of Kenya, and is characteristically developed in the Merti area, has been named the Merti Beds. It has been assumed by many geologists who have visited these parts of the Colony that such deposits are only thin surface coverings upon Basement Complex gneisses and schists, but drilling has shown them to be some hundreds of feet thick over a great part of their outcrop.

Some 17 miles south-west of the Merti "dukas", an excellent cliff section of 250 to 300 feet in thickness has been reported and described by Roberts (unpublished report). This section shows a complete succession from the Basement Complex gneisses, through the Merti Beds, to a capping of lava which Roberts classified as a Pleistocene basalt. He observed that in this cliff section the pebbles of the gravel were extremely well-rounded, except immediately above the gneiss, indicating a long transportation history. No current bedding was observed, but the absence of dreikanter, desert varnishing and frosting, together with the poor grading, suggested that the beds had an aquatic (marine or lacustrine) ~~xxxgxx~~ rather than an aeolian origin. No fossils were found, but this may be accounted for by the fact that only the more robust types would be expected to be preserved in such coarse gravel deposits.

deposits. Fossil wood (as yet undetermined) has recently been found by Dixey in comparable beds in the Chalbi Desert, east of Lake Rudolf. No volcanic material has been observed in the sediments of the Merti area, the beds being made up entirely of gneissic debris.

The volcanics which cap the sediments in the Merti area have been classed by Roberts and others as Upper Pleistocene in age. This may well be correct in the case of the lavas of the plains, but where isolated hills (up to 400 feet above the level of the surrounding country) are lava-capped, it would appear that the lavas, and therefore the underlying sediments, are much older than this since denudation to a depth of 400 feet in Recent times is scarcely likely. It has been suggested that the sediments were laid down in the early Tertiary pre-volcanic pluvial period and possibly correspond in age with the Turkana Grits west of Lake Rudolf as described by Champion (1938) and Fuchs (1939). Recent work by Dixey, however, has led him to the conclusion that these beds in the main are merely a continuation of the Jurassic beds of the northeast corner of the N.F.D., with a change in facies from calcareous (as in the north-east corner) to arenaceous and argillaceous as represented by the sands, gravels, and clays developed in other areas. Dixey also suggests (personal communication) that roughly west of a line through Marsabit the sediments are of Miocene age. The fossil wood already mentioned may be of value in finally assessing the essing the age of these deposits.

Additional information regarding this series has been obtained from boreholes sunk in it during the course of military operations in East Africa in 1940 and 1941. The deepest hole was sunk at mile 245 on the Thika-Garissa road. Here 480 feet of alternating sands and clays were penetrated before drilling was stopped, and a very small quantity of highly saline water was obtained at the bottom of the hole. Several boreholes were sunk at intervals along the Garba Tulla-Wajir road in this formation. Most of them show limestone deposits, usually of a nodular nature, with intercalations of sandy beds, down to depths of 100 to 200 feet, followed by alternating sandy, clayey and pebbly beds. Boreholes SA/3, 38 and 61, the logs of which are shown below, are typical of holes in this locality.

SA/3- Lak Boggal.

| | | | |
|---|---|---|---|
| 0- | 3 | feet - | Sand |
| 3- | 35 | " | Soft Limestome |
| 35- | 200 | " | Soft quartzitic limestone |
| 200- | 270 | " | Quartzitic white clay |
| 270- | 280 | " | Red quartz sand |
| 280- | 310 | " | Limestone, clay and sand. |
| 310- | 325 | " | Red quartz sand and clay. |

SA/38- Ndeges Nest, 20 miles south of Wajir.

| | | | |
|---|---|---|---|
| 0- | 5 | feet- | Soil |
| 5- | 59 | " | Gravel and limestone |
| 59- | 131 | " | Sand and clay |
| 131- | 354 | " | Sand, clay and gravel. |

SA/61- Cross roads, Merti-Wajir-Arba Jahan-Habaswein.

| | | | |
|---|---|---|---|
| 0- | 3 | feet- | Soil |
| 3- | 25 | " | Hard quartzitic limestone |
| 25- | 90 | " | Quartzitic limestone |

| | | | |
|---|---|---|---|
| 90- | 116 | feet- | Sand and limestone |
| 116 | -245 | " | Sand and clay. |

Borehole M/4 at El Dera, on the Isiolo-Habasweim road (mile 93) penetrated the Merti Beds at 305 feet, passing at this depth into weathered biotite-gneiss of the Basement Complex. The log of this hole is as below.

| | | | |
|---|---|---|---|
| 0- | 3 | feet- | Top-soil |
| 3- | 90 | " | Sandy clay |
| 90- | 305 | " | Alternating sand and clay beds |
| 305- | 349 | " | Weathered biotite-gneiss |
| 349- | 408 | " | Hard unweathered gneiss. |

A small quantity (30 g.p.h.) of highly saline water was struck in the hard unweathered gneiss at 368 feet, the rest level being 358 feet.

In addition to the extensive outcrop of these deposits down the eastern side of the Colony, another wide-spread occurrence of similar beds is seen in the Chalbi Desert area, bounded to the east, north and west by volcanics and to the south by Basement Complex rocks. Good outcrops may beeseen adjacent to the new Marsabit-Mega road from mile 40 to mile 55 and are described in detail in the second part of this thesis.

Only one borehole was sunk in this area (SA/112), at mile 55, just below the low lava scarp, and yielded 1,200 g.p.h. of excellent quality water from a sandy conglomerate at a depth of 140 feet. The rest level was 135 feet.

Boring for water in these deposits has, on the whole, been singularly unsuccessful. Out of a total of 30 holes sunk, only 6 were successful, two produced water which

was

was too saline for use and 22 were complete failures, a percentage success of 20 only, which apart from that for the Jurassics, is the lowest recorded for drilling in any formation in Kenya. The average tested yield was 580 g.p.h. at an average depth of 249 feet. The average rest level was 237 feet and the average total depth 260 feet. The average depth of all the holes was 266 feet.

The six successful holes were :-

SA/112- mile 55 on the Marsabit-Mega road- 1,200 g.p.h. at 140 feet.

SA/69- Liboi- 400 g.p.h. at 290 feet.

SA/70- Galma Galla- 1,000 g.p.h. at 245 feet- saline but potable.

SA/98- Kolbio- 300 g.p.h. at 194 feet- saline but potable.

SA/68- Galma Galla- 200 g.p.h. at 270 feet- saline but potable.

SA/67- Hagadera- 620 g.p.h. at 357 feet.

It will be noted that of the 6 successful holes, three gave saline but potable water.

With reference to the Hagadera area, Simpson (unpublished report) states " At Hagadera fairly well-consolidated sandstone was encountered in borehole SA/67, yielding a good supply of fresh water. On the road to Liboi, which runs as far as Wardeglio on Lak Dera, these sandstones outcrop in the banks of the Lak, and specimens taken show them to be fine and coarse grits with frequent layers of conglomerate. The pebbles are mainly rounded quartz with occasional pebbles of gneiss so that the

sandstones

sandstones and conglomerates are mainly composed of granitic debris....... The beds differ entirely from the sands and clays of the Merti Beds to the north round Habaswein and may be Duruma Sandstones". The difference noted by Simpson does not affect the classification of these beds as Merti since those to which he refers in the Habaswein area are, as noted later, the products of resorting of the Merti Beds by the Uaso Nyiro River.

The majority of the successful holes were sunk either in or in the immediate vicinity of pans or dry luggahs. Dixey (personal communication) has pointed out in this connection that most of the larger pans are not merely haphasard depressions in the general level of the country, but are most probably cut-off meanders of an ancient river system. A certain amount of evidence in support of this view has been noted by the writer in the neighbourhood of the pans in the Gherille area on the Wajir-Bardera road, where a very varied assemblage of well-rounded pebbles was noted. These included gneiss, sandstone, quartzite, ironstone, quartz, chert etc., in addition to the more common nodular limestone fragments.

Considering the above facts it is not improbable that the meagre water supplies of the N.F.D. could be augmented to a certain extent by the drilling of boreholes suitably sited in some of the larger pans. A further point is that none of the holes so far drilled have been taken to any great depth. In this connection there is reason to

suppose

suppose that by suitable geophysical methods, the sub-surface topography of the underlying Basement Complex could be mapped in many areas. Boreholes put down in old valleys in this ancient land surface should have a good chance of striking water, though this might prove to be saline. It would of necessity entail drilling to considerable depths and would also require detailed preliminary geological and geophysical investigations.

## IV (f)- THE HABASWEIN DEPOSITS.

These deposits, very similar in general character to the Merti Beds, are found on each side of the Uaso Nyiro River in the neighbourhood of Habaswein. The are, in all probability, the products of resorting of the Merti Beds by this river as it shifted its course from time to time during earlier periods of its history. Roberts suggests that the fine dust which is so prevalent in this area may be classified as a weathered or possibly unconsolidated loess with a non-calcareous cement. Many mollusc remains of the Turritella type are, however, found in this material, and it ~~is~~ therefore seems much more likely that it is an eluvial or alluvial silt.

In this area a certain amount of success has been obtained by drilling. Out of a total of 18 holes drilled, 6 were successful, averaging 550 g.p.h. at a depth of 64 feet, the average rest level being 54 feet. The average depth of all the holes sunk was 100 feet, the deepest,

(dry)

(dry) being 237 feet. The drillers'logs are unfortunately not detailed, all showing only top-soil and then alternating sands and clays to the bottom of the holes. Four of the boreholes classed as unsuccessful would have yielded water if an effective method of separating the water from running sand could have been devised. Further supplies could no doubt be developed if necessary in this area by drilling both up and down this old stream course.

## IV (g)- THE KAINOZOIC VOLCANICS.

A great part of Kenya Colony lies in a volcanic zone extending from Abyssinia to Nyasaland, in which volcanic activity has been more or less continuous from possibly as early as Cretaceous times to the present day: Isolated volcanoes and numerous steam jets and mud volcanoes are still active in several localities in the Rift Valley.

During this immensely long period of vulcanicity, lavas and pyroclastics were spread over emormous areas of the Colony, and the two highest mountains of Africa, Mts. Kilimanjoro and Kenya, were built up. The eminent suitability of the Kenya Highlands for white settlement is due not only to its pleasant climate but also because the weathering of the volcanics in the more humid areas has produced a very fertile soil which constitutes the most highly productive agricultural land in the Colony.

The volcanics of Kenya may be divided into three

main

main areas, within which smaller divisions may be made, while several other smaller and less important areas occur in various parts of the Colony.

The first main area considered is in the Turkana District of the far north-west corner of the Colony between Lake Rudolf and the Uganda border. To the west the rocks are bounded by the Basement Complex, while to the east they are masked by the alluvium of Lake Rudolf. From north to south the extent of this portion of the volcanic field is from the Abyssinian border to about latitude 3° North. The continuity of outcrop over the area is broken by patches of Basement Complex and Turkana Grits, as in the Todenyang-Lokitaung area, and by Turkana Grits again in the Khosa and Loupi River localities. Large spreads of river alluvium and swamp deposits occur in the north-central portion and in the Kagwalas and Turkwell River areas in the south.

A comprehensive series of rock types collected from this area by Mr. A.M.Champion has been described by Campbell Smith (1938) who found the southern portion to be made up of a series of olivine-basalts, olivine-nephelinites and phonolites of the Kenya type of Gregory's Laikipian division. Younger phonolites and trachytes were followed by Reeent extrusions of basanites and olivine-basalts. The northern part of the area shows a series of basalts followed by pantelleritic trachyte and rhyolite, the relation of which to the rocks of the south is uncertain.

Arambourg

Arambourg (1935) described another series of basalts from the Lothidok Hills (roughly the east-central portion of the area) which he classified as Laikipian and which may be identical with those described by Campbell Smith.

The second large area of volcanics is found in the northern part of the Northern Frontier District, bounded to the east by Basement Complex rocks. The eastern boundary runs from 16 miles west of Moyale on the Abyssinian Frontier in a south-westerly direction to the neighbourhood of latitude $3^{\circ}.15'$ N. and longitude $39^{\circ}$E. whence it follows a roughly southerly direction to about latitude $1^{\circ}45'$ N. Here the boundary has a sinuous course to the west-north-west, passing the foot of the Marsabit "scarp" some 14 miles south of Marsabit and across to latitude $2^{\circ}$N., longitude $37^{\circ}.35'$ E. Here a long tongue of Basement Complex rocks and sediments of the Chalbi Desert breaks the continuity of outcrop up to latitude $3^{\circ}.50'$ N. before the volcanics are again encountered as a wide band along the eastern shores of Lake Rudolf. Many isolated plateaux are also capped by volcanics in the N.F.D. outside the main area as described above, as for instance the Merti Plateau and many others of greater or less extent on both sides of the Archer's Post-Marsabit road.

Very little detailed petrological work has so far been done on the volcanic rocks of this particular area, though numerous general traverses have been made from time to time, usually with the object of attempting to find

means

means of increasing the water supplies of the arid barren area. Such traverses have been carried out by Parkinson and various members of the Hydrological Section of the Public Works Department of Kenya, while more recently a great deal of reconnaisance work has been done by members of the 42nd.Geological and Geophysical Section, S.A.E.C., and 41st.(E.A.)Water Supply Company, including the writer.

The area round Marsabit is typical of the whole of this great volcanic field; isolated cones of ash and agglomerate rise above the general level of the plain, on which highly-vesicular olivine-basalts form low ridges, while large blocks of similar material are scattered over the intervening areas. The harder and more resistant basalts make up the flat or gently undulating country, while the softer ashes and agglomerates usually stand out as low hills and cones. Since the relatively soft and unconsolidated pyroclastics form the main topographic features it is obvious that they must be considerably younger than the lavas themselves , which Fuchs(1929) mapped as Upper Pleistocene in age. As the Huri Hills are approached, the country is covered with large lava boulders and flat-topped ridges of highly-vesicular basalt. This lava type breaks up into large,roughly rectangular blocks rather than into rounded boulders as produced by the less vesicular type. The vesicles in many instances have a lining of crystalline calcite. It is suggested that the lava tongues are the end phase of the fissure eruptions in this locality

when

highly viscous material carrying a high percentage of volatiles was erupted. In these ridges are also seen many roughly circular shafts some 6 to 8 feet in diameter which are possibly late dry explosive vents. In the Huri Hills, ash and agglomerate cones increase in number and the peaks of this range are all formed of this material. Their lower slopes consist of a fine-grained olivine-basalt carrying small idiomorphic olivines in a fine-grained black ground-mass.

Microscopic examination by the writer of several specimens of the two main lava types shows that they are of normal olivine-basalt, with the more vesicular types possibly grading towards ankaramite.

The lava-capped plateaux previously mentioned, the Merti Plateau and several others in the neighbourhood of Laisamis, often rise to a height of 400 feet above the surrounding country, which itself may be either of Basement Complex rocks or lava. The lava caps may directly overlie Basement Complex rocks or sedimentary beds of the Merti type. It is obvious therefore, that the lava caps must be of considerably greater age than the lavas of the plains, since erosion must have removed at least 400 feet of material between the extrusion of the lava of the caps and that of the plains.

Many definite volcanic cones and craters, from which bombs and lapillae of various crystalline rock types have been ejected, occur in this area. Notable among the ejectamenta

are

amenta are unfoliated granites and coarse-grained ultra-basic types collected from points as far apart as Magada and Tass in Southern Abyssinia, Marsabit Mountain and the Mgombe Crater near Isiolo. Only the ultra-basics from the Magada-Tass area have been examined microscopically, and they show a wide range of rock types, including olivine-pyroxenite with garnet(almandite), augite-peridotite, augite-peridotite with garnet, dunite, amphibole-olivinite and amphibole-olivinite with garnet, but in hand specimen at least, those collected from the other localities mentioned are similar.(See Part II of this thesis for details of the above rocks).

The third and by far the largest continuous spread of volcanics in the Colony stretches from the north-west side of Lake Rudolf down through the whole length of the Kenya Highlands, bounded along its western margin by Basement Complex rocks, to the Tanganyika border, some 20 miles west of Lake Natron. The eastern margin of the mass follows a roughly southerly direction from the south end of Lake Rudolf towards Maralal and Rumuruti where it swings away to the south-east to some few miles north of Nanyuki. Here a large tongue spreads north-east through Isiolo and Archer's Post, and thence follows the Uaso Nyiro River to the neighbourhood of Chandler's Falls before swinging round to the Garba Tulla area. From this locality the margin follows a southerly line to Chuka and thence east of the K.U.R. Nairobi-Nanyuki line to the west side of Donyo

Sabuk. A narrow tongue follows the east side of the Athi River from this point as far south as Tsavo, while the margin of the main mass swings to the east of Nairobi, through Athi River township, to Kapiti Plains Station on the K.U.R. Nairobi-Mombasa line. From here the boundary follows a sinuous line with a general south-westerly trend to the Tanganyika border at the north-west corner of Lake Natron. This eastern border abuts entirely against Basement Complex rocks except in small isolated localities a few miles east and south of Nairobi, where lake sediments outcrop beneath the volcanics.

The general succession and petrology of the volcanics of this area have been described by Prior, Gregory, Sikes and others, so only brief reference to them will be made when dealing with borehole results in different parts of the area.

Other large isolated masses make up the Chulyu Hills, Mt. Kilimanjaro and Mt. Elgon, while other smaller occurrences are found along the eastern shores of Lake Victoria in the area south of Kisumu.

Bailey Willis (1936) points out that this volcanic region is distinguished structurally from other eruptive areas associated with the formation of Rift Valleys in that the earlier lavas issued mainly from fissures, the isolated volcanoes of this age being mainly incidental. Later, the great cones of Kilimanjaro and Kenya were built up. Such cones as Menengai, Suswa, Longonot etc., are probably of

fairly

fairly recent age, since the weathering of the soft material has so far been slight. It would appear that the earlier lavas, have, in the main, risen through the Basement Complex along steeply dipping fissures, and have spread out on reaching the surface to cover the Basement rocks with an enormous thickness of extrusive material.

Gregory (1921) classified the volcanic rocks of East Africa generally as ranging in age from the Upper Cretaceous to the Upper Pleistocene. His dating of the older representatives, from the Upper Cretaceous Kapiti Phonolites to the Miocene Laikipian basalts and augitites , is based mainly upon his interpretation of the age of; (a) the torrential gravels in the vicinity of the Kavirondo Gulf of Lake Victoria, in which fragmental remains of Dinotherium hobleyi were found and which he considered to be of Miocene age (see also Oswald 1914), and (b) the so-called Kamasian Lake Beds in various parts of the Rift Valley. Willis (1936) is of the opinion that the fossil in (a) above has in fact been transported and redeposited in Pliocene Beds, but Kent (1944) proves conclusively that the beds containing the fossil are of Miocene age and overlie an older agglomerate which he thinks is of Early Tertiary age, resting directly on the Basement Complex. Leakey and Solomon, working on the Kamasian Beds which Gregory classed as Oligocene find, from the evidence of palaeolithic implements collected from certain of the beds, that they must be of Pleistocene age, while other

beds

beds in which no implements have been found are consider- to be not older than Miocene.

Much work remains to be done on these rocks and the intercalated sediments before they can be definitly dated but all the available evidence indicates only that the earliest agglomerate is older than Miocene and there appears to be no direct evidence that the Kapitian and Doinyan are pre-Miocene in age.

GENERAL WATER BEARING PROPERTIES OF THE VOLCANIC ROCKS.

Tolman (1937 p.309) classifies the factors governing groundwater movement and accumulation in lavas under three heads :-

(a) Vertical permeability due to fractures,

(b) Horizontal porosity and permeability in horizons containing openings due to flow and gas expansion during solidification, and

(c) The occurrence of impervious horizons and dykes.

Massive unfractured lava is impervious and a good example of this is the Kapiti phonolite of Kenya, which so far has proved to be practically useless as a water bearer and yielder in boreholes. This is the oldest of the Kainozoic lavas of Kenya and in isolated instances it has been possible to penetrate it to reach the underlying Basement Complex rocks, which have yielded water in a greater or lesser degree. In other cases water has been obtained from old weathered land surfaces between successive flows. Examples of this will be discussed later.

Of the other lava types, the more basic varieties, such as basalts, are usually the most useful water bearers. The fracturing of such rocks, due to volume shrinkage on devitrification, is appreciable, and these fractures not only provide adequate entry for the water above the water table but also freely yield up their water from interconnecting fractures below the water table. In addition to the shrinkage fractures, the basal portions of the various flows often have a bouldery habit due to the rolling over of the rapidly cooled upper surface of the viscous lava to the under side as the front of the flow advanced, again tending to produce a very free water channel. Furthermore, the weathered surfaces between the various flows and the greater solubility of the commoner minerals of the basic lavas tend to produce greater porosity and permeability in them than in the more acidic types.

Rhyolites and other acidic types often remain vitreous on solidification, and thus have a smaller number of less well-developed shrinkage fractures than the more basic varieties, but on the other hand, they contain more gas openings and thus amygdaloidal and scoriaceous textures are more common. On the whole, however, these rocks are less useful as water bearers than the basic types.

Pyroclastic rocks (ashes ,tuffs, and agglomerates) which make up a large proportion of the volcanics of Kenya, have two distinct water-bearing properties depending mainly on their mode of deposition. Sometimes the

finer

finer grained beds are deposited, after being cooled by their passage through the air, in compact masses without resultant cooling cracks. Such deposits form impervious layers and inhibit the passage of water to lower beds. Due to their compactness, they are usually dry below the weathered zone, or at any rate do not readily yield any water they may contain. Such beds are, however , of importance when underlying more porous beds in depth, by virtue of their impervious nature.

In the other extreme case, great thicknesses of only loosely consolidated pyroclastics may be so porous as to allow water to percolate to such a depth as to make its recovery by boreholes uneconomic. This type of occurrence is common in certain parts of the Rift Valley, where it is probable that ground water descends to such a depth that it becomes vaporised and rises to the surface again as steam from the numerous fumaroles which are of such widespread occurrence in this part of Kenya. Thus the pyroclastics as a whole are of speculatative value as water bearers. Isolated instances where they have proved to be useful are discussed later.

Of major importance from the water supply point of view are the numerous old land surfaces between the lava flows and the interstratification of old lake sediments with the volcanics in various parts of the Colony.

Apart from the conditions of deposition, subsequent weathering, fracturing,etc., mentioned above, the occurr-

ence of

## SUMMARY OF ALL BOREHOLES IN THE VOLCANICS.

| DEPTH TO WATER IN FT. | YIELD IN GALLONS PER HOUR AND NUMBER OF HOLES. | | | | | | | | | | | TOTALS | AVERAGE YIELD IN GPH. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-500 | 500-1000 | 1000-1500 | 1500-2000 | 2000-2500 | 2500-3000 | 3000-3500 | 3500-4000 | 4000-4500 | 4500-5000 | 5000-5500 | | |
| 0- 50 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 3390 |
| 50-100 | 8 | 2 | 4 | 0 | 0 | 4 | 1 | 0 | 0 | 0 | 2 | 21 | 1637 |
| 100-150 | 7 | 3 | 5 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 20 | 1360 |
| 150-200 | 4 | 2 | 3 | 3 | 1 | 2 | 0 | 3 | 0 | 0 | 0 | 18 | 1760 |
| 200-250 | 10 | 6 | 3 | 2 | 4 | 2 | 0 | 1 | 0 | 0 | 0 | 28 | 1210 |
| 250-300 | 7 | 2 | 4 | 2 | 5 | 4 | 1 | 0 | 0 | 1 | 0 | 26 | 1656 |
| 300-350 | 7 | 3 | 3 | 4 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 20 | 1195 |
| 350-400 | 4 | 2 | 2 | 3 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 15 | 1232 |
| 400-450 | 2 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 1 | 0 | 0 | 8 | 1381 |
| 450-500 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1155 |
| 500-550 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 720 |
| 550-600 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1440 |
| 600-650 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1800 |
| 700-750 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 300 |
| TOTALS | 50 | 23 | 27 | 19 | 17 | 16 | 3 | 5 | 2 | 3 | 2 | 167 | 1502 |

Table IV.

ence of ground water in the volcanics is dependent on several other factors such as topographic and rainfall features. It is, therefore, somewhat difficult to generalise on conditions for the lavas as a whole, but it has been possible to make certain deductions for areas where drilling has already been carried out on a fairly intensive scale.

## RESULTS OF DRILLING IN THE VOLCANICS OVER THE WHOLE COLONY.

An examination of all available records shows that 245 boreholes have been sunk in these rocks to an average depth of 304 feet. Of these, 167 or 68.2 % have been successful, drilled to an average depth of 327 feet, with water struck at 248 feet, rising under pressure to within 147 feet of the surface, i.e. under an average hydrostatic head of 101 feet. The average tested yield was 1,500 g.p.h., the total tested yield therefore being theoretically over 6,000,000 gallons per day.

Table IV analyses these results from the point of view of the depths at which the main supplies were struck and the yield of holes at these depths. It will be noted that most of the boreholes struck water between 50 and 450 feet (156 of the successful holes fall within these limits), while 74 struck water between the narrower limits of 200 and 350 feet. Below 450 feet not only does the number of successful holes fall off rapidly but also the average yield, which falls to 1,000 g.p.h. for 8 holes below this depth. It will also be noted that high yields are

SUMMARY OF BOREHOLES IN THE VOLCANICS OUTSIDE THE NAIROBI DISTRICT.

| DEPTH TO WATER IN FT. | YIELD IN GALLONS PER HOUR AND NUMBER OF HOLES. | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-500 | 500-1000 | 1000-1500 | 1500-2000 | 2000-2500 | 2500-3000 | 3000-3500 | 3500-4000 | 4500-5000 | 5000-5500 | TOTALS | AVERAGE YIELD IN GPH. |
| 0- 50 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 3890 |
| 50-100 | 7 | 1 | 4 | 0 | 0 | 4 | 1 | 0 | 0 | 2 | 19 | 1751 |
| 100-150 | 4 | 3 | 5 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 16 | 1346 |
| 150-200 | 1 | 1 | 3 | 3 | 1 | 2 | 0 | 3 | 0 | 0 | 14 | 2153 |
| 200-250 | 9 | 5 | 1 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 19 | 901 |
| 250-300 | 6 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 10 | 862 |
| 300-350 | 3 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 711 |
| 350-400 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 992 |
| 400-450 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2000 |
| 550-600 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1440 |
| 700-750 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 300 |
| TOTALS | 33 | 13 | 17 | 7 | 5 | 9 | 2 | 4 | 2 | 2 | 94 | 1436 |

Table V.

are not common, only 15 holes producing quantities in excess of 3,000 g.p.h., of which 2 gave yields of over 5,000 g.p.h.

The probability curves (Plate III) show very little of interest since they represent a comparatively small number of holes in a large area. It will be seen that the figure of 450 feet for the falling off in the number of successful holes and the average yield is reduced to 410 feet.

Further analytical tables and probability curves (Table V and Plate III) are given, from which the results of the successful holes in the Nairobi area (see separate section later) have been abstracted from the results for the whole Colony. These show that outside the limited Nairobi area, 156 boreholes have been sunk of which 94 or 60.3 % were successful. The average depth of all these holes was 269 feet, the successful holes averaging 267 feet. Water was struck at an average depth of 197 feet under a pressure head of 78 feet, bringing the rest level to within 119 feet of the surface. The average yield was 1436 g.p.h., slightly less than the average for the whole Colony. From the table it will be seen that holes striking water at depths of less than 200 feet gave higher yields than holes below that depth, while the greater proportion of holes reached water above 350 feet (81 out of a total of 94). The probability curves show the same results graphically, though the explanation of the major

dips

dips at 110 and 170 feet in both curves is not apparent.

DETAILED DRILLING RESULTS IN THE VOLCANICS.

Having set forth above the generalised results for drilling in the volcanics over the whole Colony, the smaller separate areas will now be dealt with in rather more detail in the following order:-

(1) The Northern Frontier District, including Turkana, the Dukana area, Marsabit-Huri Hills area and the Isiolo-Garba Tulla area.

(2) The Nanyuki area.

(3) The Plateau Lava districts, including Laikipia, the Uasin Gishu and the Athi River-Kapiti Plains area.

(4) Examples of lava-buried valleys,eg. Taveta and Makuyu areas.

(5) The Rift Valley proper and the Kinangop Plateau.

(6) The Nairobi area.

(1) The Northern Frontier District.

Thirty boreholes have been sunk in a widely scattered area in this district, and 13 of these gave successful results, averaging 193 feet in total depth. The average depth to water was 111 feet, the rest level being 74 feet and the average tested yield 1,140 g.p.h. The low percentage of successes in this area is no doubt due to the fact that all the boreholes were sunk by the military authorities during the opening stages of the East African Campaign and paign and many holes were, therefore, drilled in localities where the chances of success in any case were low, but where water was urgently needed and drilling the only possible means of obtaining it. Several holes too were abandoned at shallow depth when the forward movement of troops no longer necessitated the providing of water supplies at these particular points.

In the Turkana District 14 boreholes were sunk to an average depth of 219 feet, and of these, 8, averaging 194 feet in depth, were successful. Water was struck at an average depth of 100 feet, rising under pressure to 65 feet, the average tested yield being 750 g.p.h. Two boreholes, however, at Taban and Kalin, yield 2,000 and 2,600 g.p.h. respectively and account for the bulk of the water obtained. With these abstracted from the total, the other 6 successful holes, yielding an average of only 230 g.p.h. are all located in the Lokitaung area. The 6 unsuccessful holes are ranged along the Kalin-Lodwar road and average 252 feet in depth.

In the Dukana area, 3 boreholes were all unsuccessful averaging 114 feet in depth. It seems likely that these holes would have had a fair chance of success if they had been taken deeper, since though this area is somewhat arid, there are several well-defined water courses and drainages which may well have considerable quantities of water still stored in open-textured beds of tuff and agglomerate below the well-jointed basalts.

In ...

In the Marsabit-Huri Hills area, 7 boreholes were sunk, averaging 250 feet in depth. Of these only 1 was successful, sited at the southern foot of the Marsabit "scarp", where water to the extent of 600 g.p.h. was struck at 233 feet in old lake sediments lying immediately below the lavas. The unsuccessful holes were in the thick beds of extremely porous tuffs and agglomerates of Marsabit Mountain and the Huri Hills. More suitable sites exist in the area between the northern foot of Marsabit and the southern slopes of the Huri Hills, where the volcanics could be penetrated to reach the underlying sediments. The area is, however, completely useless from an economic point of view, being a barren wilderness of tumbled black lava boulders with no vegetation, so it is unlikely that additional water supplies will be required here in peace time. The nomadic Boran, grazing their herds on the sparse vegetation of the Chalbi Desert, gain their supplies of water mainly from small springs issuing from the base of the basaltic lavas at their junction with the underlying sediments.

Six boreholes in the Isiolo-Garba Tulla area average 180 feet in depth, and of these, 4, averaging 173 feet, were successful. Water was struck at an average depth of 102 feet in these holes, rising under pressure to 59 feet and producing an average of 2,050 g.p.h. on test. The successful holes were all sited close to Isiolo, the water being produced from bedded tuffs and sediments below the

main

mani lava flows. Two of the holes gave slightly saline water but this was still potable. The two unsuccessful holes were drilled at mile 30 and mile 45 on the Isiolo-Garba Tulla road to depths of 182 and 183 feet respectively, and there appears reason to believe that if they had been carried deeper they would have given a certain amount of water.

(2)- The Nanyuki Area.

Here, in the neighbourhbod of Mt. Kenya, 11 holes have been sunk averaging 227 feet in depth. Eight of these were successful averaging 233 feet in depth. Water was struck at an average depth of 200 feet, rising to 130 feet under pressure, and giving an average tested yield of 1,210 g.p.h. Sikes (1934) published the results of drilling in this area up to 1932. Subsequent drilling has yielded similar results. Water occurs either in weathered Kenyte lava or in coarse morainic or fluvio-glacial material, derived from the former glaciers of the mountain, interbedded with the lava flows.

(3)- The Plateau Lavas of Laikipia, the Uasin Gishu and the Athi and Kapiti Plains.

The plateau lavas, consisting mainly of successive flows of nephaline phonolite, which appear to have welled up quietly from huge fissures along the flanks of the Rift Valley, cover very large areas of Kenya. Since the

run-off

run-off is very high in these rocks, due to their extremely compact and solid nature, it is necessary to provide water supplies for stock by boring. These phonolites are very poor water bearers, but weathered surfaces between successive flows, when struck below the general water table of the district, have often given good supplies.

Of the 48 holes sunk in these rocks in widely separated areas, 30, averaging 288 feet in depth, have been successful. Water was struck at an average depth of 208 feet under a pressure head of 106 feet, the average tested yield being 1,060 g.p.h.

Laikipia is the high plateau country rising from the east side of the Rift Valley from Kedong in the south to the Lake Baringo area in the north. It varies in altitude from 5,000 to 7,000 feet, stretching eastwards towards Mt. Kenya. To the south it is bounded by the Kikuyu uplands and to the north passes towards the southern end of Lake Rudolf via the Thomson's Falls-Rumuruti area. Phonolites, basalts and phonolitoid kenytes make up the mass of the Laikipia plateau, but subordinate occurrences of pyroclastics are found near the centres of extrusion. Twenty four boreholes have been sunk in this area to an average depth of 317 feet, and of these, 17 were successful, averaging 300 feet in depth. Water, averaging 840 g.p.h. on test, was struck at 212 feet under an average pressure head of 100 feet. Pressure heads of up to 270 feet have been encountered in this locality and one borehole ( C/ 226), in the Thomson's Falls area, actually gave a small artesian supply.

supply. Four boreholes gave an aggregate yield of 9,000 g.p.h. thus reducing the average yield of the 13 remaining holes to 400 g.p.h. The logs of the successful holes indicate that the main supplies of water were struck in old land surfaces between the lava flows or in weathered zones in the lavas immediately below such surfaces. Minor supplies have also been obtained from rare fracture planes in the usually compact phonolites.

The Uasin-Gishu plateau (Eldoret-Kipkabus area) is essentially similar geologically to the Laikipia plateau but lies on the opposite side of the main Rift Valley. Only seven boreholes have been sunk in the plateau lavas in this area ; five were successful, averaging 297 feet in depth. Water was struck at 235 feet under an average pressure head of 183 feet, the highest noted being 290 feet. The tested yield of the holes averaged 1,290 g.p.h. Of the two unsuccessful holes, one was abandoned at 37 feet and the other was only taken to 242 feet, which is barely below the average depth to water in this locality.

The Athi Plains and Kapiti Plains area, situated just south and south-south-east of Nairobi , is similar geologically to the two areas described above, except that its general elevation is less and the lavas here are almost exclusively of Kapiti phonolite. Here are wide plains of gently undulating nature, well grassed and supporting huge herds of game of all descriptions. Of the 17 holes drilled to an average depth of 209 feet, 8 were

successful

successful, averaging 248 feet feet in depth. Water was struck at 177 feet, rising under pressure to 112 feet and averaging 1,400 g.p.h. on test. The 9 unsuccessful holes averaged 175 feet in depth and of these, 5 were abandoned before reaching a reasonable depth.

The Athi River locality had been, up to quite recently, regarded as unpromising for boring, but in 1942, of 5 holes drilled by the military authorities some three miles along the Kadjiado road from Athi River, 3 gave excellent results and one of the unproductive holes was abandoned at very shallow depth (47 feet). More recently, additional attention has been focussed on the area by the highly successful borehole between Liebig's Factory and the river which tapped an artesian supply of some 10,000 g.p.h. This borehole must, however, be regarded as a special case, being sited (within half a mile of a borehole which gave only 250 g.p.h.), on what appears to be the downthrow side of a fault of considerable magnitude in the Kapiti phonolite. The younger volcanics and lake sediments exposed on the hillside on the Nairobi side of the river dip towards this fault and this no doubt accounts for the quite unusually high yield and true artesian character of this borehole. The results from this hole have not been included in the general analysis of results since complete details were not to hand when this report was written. It is possible that similar sites may be found in this area in the neighbourhood of the fault, the extent of which has not yet been determined.

(4) Taveta and Makuyu Areas.

These two areas, though widely separated, have been treated together because the conditions under which borehole water supplies are found are similar in both instances, in that Basalt flows have filled old stream valleys in the pre-existing land surface. (see also Sikes 1934). At Taveta the water is found in soft tuffs and sediments below a bouldery basalt flow of the Kilimanjaro lavas. Six boreholes were sunk, of which four were successful, one was abandoned at 50 feet and the other silted up after striking water. The successful holes averaged 122 feet in depth, water being struck at an average depth of 102 feet and rising to 60 feet, with an average tested yield in excess of 3,000 g.p.h.

At Makuyu a basalt flow filled an old valley in the Basement Complex gneisses and the water is obtained from a bouldery bed in the basalt above the gneiss. One hole only of the four drilled here was a failure and that was presumably sited outside the main valley. The other three holes were all high yielders, and two of them, in close proximity to each other, pumped by air-lift methods, gave 122,000 gallons per day continually and this only lowered the general water table by 2 feet. The average depth of these holes was 156 feet, water being struck at 75 feet and rising to between 2 and 13 feet of the surface.

Similar occurrences may be expected in other parts of the Colony and will be of great value when found.

(5) The Rift Valley.

The section of this great topographic feature dealt with here is mainly within the trough itself, from the neighbourhood of Kedong in the south, through Naivasha and Nakuru, to the southern end of Lake Baringo in the north. Certain holes which fall just outside this main area have been included (eg. at Njoro and the Mau) since conditions there are essentially similar to those of the main trough. Other boreholes in the Kikuyu-Limoru area, which should properly have been included, are dealt with later, in the section on the Nairobi area, as they fall more naturally into that section in view of the locality treatment of results adopted here. Boreholes on the southern edge of the Kinangop plateau have also been treated separately (following Sikes), since they fall outside the main Rift Valley drainage system. Other boreholes drilled in the the Rift Valley for the whole of their depth in lake sediments are also dealt with later.

In all, 45 boreholes of an average depth of 331 feet are considered here. Of these, 29 were successful to an average depth of 329 feet, water being struck at and average depth of 247 feet, rising under pressure to 161 feet and yielding an average on test of 1,410 g.p.h. The unsuccessful holes averaged 340 feet in depth. The percentage success for drilling over the whole area is fair, but in many individual areas where water is urgently required geological conditions are such as to almost entirely preclude the chances of even small supplies being obtained from

from boreholes. Such areas are those where soft, porous and relatively unconsolidated ashes and tuffs extend to great depths with no impervious beds to hold up the water before it reaches a depth at which it is likely to be vaporised. The deepest borehole in the Colony (C/115), on the Kijabe-Narok road some 20 miles from Kijabe Station, is a case in point. This hole was drilled to a depth of 320 feet through alternating beds of soft lavas and sediments without striking any water and the temperature of the borehole is said to have been high. Another boreholes (on the Mt.Margaret Estate) , was carried to 727 feet before striking water (300 g.p.h) which rose to 700 feet, making it uneconomic to pump. This small supply was struck in the first relatively hard lava encountered, a rhyolite, overlain by alternating beds of pumice, tuffs, agglomerates and silty and clayey beds. In such areas, which are very common in the Rift Valley, the chances of striking water at a moderate depth, where it is not found in the superficial deposits, are entirely dependent on the intersection of some relatively impervious bed of lava or tuff below the soft porous beds. Geophysical investigations should be of great assistance in locating such sites.

Several boreholes in the Rift Valley and along its flanks have struck steam or draughts of hot air and it has been found without exception,that after such conditions have been encountered, deeper drilling does not produce water.

The Kedong Valley area has not been productive of good drilling results since only three of the eight holes drilled produced water and even these only gave supplies of the order of 300 to 400 g.p.h., the conditions encountered being similar to those dealt with in some detail above. North of this however, in the vicinity of Lake Naivasha, greater success has been obtained, with high average yields. Six of the 8 holes drilled in this locality were successful, averaging 2,200 g.p.h. from an average depth of less than 100 feet. All the holes obtained their water either from old lake sediments or fairly coarse-grained pyroclastics resting on more impervious beds of solid lava. Their proximity to Lake Naivasha no doubt accounts to a large extent for their high yields at such shallow depths. The two unsuccessful holes failed to strike any solid impervious layer down to depths of 320 and 520 feet respectively.

In the Nakuru area, 10 holes have been sunk of which 6 were successful. It should be pointed out that 4 of the successful holes were sunk in a very small area on the flats of the Ngosur stream at the foot of the extinct Menengai volcano. In other parts of the Nakuru area no great success has been obtained from boring, as the conditions are similar to those in the previously described Kedong area.

The Njoro area has given good results, 8 out of 10 holes being successful, though in most cases a greater depth than usual (300 to 570 feet) had to be drilled before success fore success was attained.

The Rongai area produced small supplies from three of the four boreholes sunk ( 100 to 250 g.p.h.) but none of the boreholes was taken to more than medium depth ( 350 feet), except the unsuccessful one which was drilled to 466 feet. Boreholes in the Mau Summit area gave similar results.

Sikes (1934) has described the results of 5 boreholes on the Kinangop Plateau. He points out that this area differs from most other parts of the Rift Valley in that the rhyolites, trachytes and tuffs of Laikipian age have not been appreciably affected by the later Naivashan faulting. Only one borehole was successful and its yield was low (450 g.p.h.). Sikes suggests that since the Kinangop is an area of high rainfall it should be possible to meet the water requirements of places where surface supplies are inadequate, by suitably sited shallow wells or dams.

(6) <u>The Nairobi Area.</u>

The area now to be considered is some 20 to 25 miles square with the Nairobi Municipality situated roughly in its centre. It may be considered as a small segment of the gently rising plateau from the Athi River in the east to the main eastern flank of the Rift Valley in the west, and varies in general elevation from 5,400 to 7,500 feet. The drainage of the area has a roughly east to east-south-east trend, ie, from the direction of the Rift Valley flank towards the Athi River. The streams are on the

whole

whole small, though running for the most part in large valleys. Moreover many of them are seasonal, and hence the provision of additional water from boreholes in this thickly populated area is of great importance. The higher elevations, as in the Kikuyu and Limoru districts, are better watered generally than the lower-lying areas of the east, and therefore, additional supplies are not so urgently required, although a considerable number of boreholes has been sunk to augment surface supplies for minor industrial and domestic purposes.

Sikes, in his excellent paper (1939) on the geology of the country surrounding Nairobi, points out that the volcanic sequence in this area is notably complete in comparison with other portions of the Rift Valley ramp, since all divisions are represented from the basal Kapiti phonolite to the products of modern vulcanicity. In general, successively younger volcanics are encountered in passing westwards from the Athi River to the Rift Valley flank. The general succession is as below, the youngest beds being at the top of the table:-

5. Pyroclastics.
4. Limoru Trachyte.
3. Nairobi Trachyte.
2. Athi Plains Phonolite.
1. Kapiti Phonolite.

The Ngong Basic Series, locally developed in the Ngong Hills in the south-west corner of the area, is intermediate in age between the Athi Plains Phonolite and the Nairobi Trachyte. With all these lavas are associated more

or

or less important beds of pyroclastics and the existence of many old land surfaces between individual flows is evidence of the long period during which these flows were extruded. This is particularly noticeable in the case of the break between the Kapiti Phonolite and the Athi Plains Phonolite, where typical lake sediments with sub-aqueous tuffs have been proved by boreholes in the south-east and east-central portions of the area to reach thicknesses of over 300 feet, without any intercalated lava flows.

The petrological characters of the lavas have been described in detail by Sikes (1939) and reference to them will, therefore, only be made in so far as they affect the water bearing properties of the rocks.

The Kapiti Phonolite is not exposed in the area under review but has been intersected in at least one borehole here.

The Athi Plains Phonolite, exposed over much of the south-east and east-central portion of the area, with tongues fingering up several valleys away from the main outcrop, is, like the Kapiti Phonolite, not a good producer from boreholes. Meagre supplies have been obtained occasionally from the very infrequent cracks and fissures in the rock but in no case have they been of importance. The lava is, in hand specimen, a fine-grained tough dark-grey rock (called by Sikes the Nairobi Phonolite) and differs only in appearance from the Kapiti Phonolite in having smaller and less conspicuous phenocrysts of felspar and nepheline. Boreholes in this formation rely for their water on the sub-aqueous tuffs and lake sediments below the lava. The core of a shot-drill hole recently drilled some three miles east of Nairobi on the Nairobi-Nanyuki line of the K.U.R. , shows that the phonolite is divided into several flows with ~~the~~ products of weathering between them. The flows individually are thin near the top of the formation but increase in thickness lower down. After passing through the lava, about 100 feet of fine-grained sub-aqueous tuffs and ashes were intersected before reaching the typical lake beds, which are mainly composed of interbedded fine-and goarser-grained sandy beds with minor developments of bentonitic material. A detailed study of the core could not be made by the writer as the hole was completed only a short time before he left East Africa. Other shot-drill holes are projected for the same locality and should be of great assistance in the elucidation of several of the problems of succession and petrology of both the lavas and the sediments.

The Ngong Basic Series is made up of a varied assemblage of basic lavas, tuffs and agglomerates in the Ngong Hills and foothills east of them. The basic volcanics range from nephelinites to basanites, basic tephrites, and phonolitic tephrites and are thought by Sikes to correspond to Gregory's Lower Laikipian division of older basalts, which make up much of the Aberdares, Settima and western Laikipia. In common with other basic volcanics, these lavas are usually good water bearers, and excellent results have been obtained from drilling in them.

Apart

Apart from their well-weathered and fissured nature, there are also numerous old land surfaces between the various flows which give good supplies under suitable conditions.

The Nairobi Trachyte, with its associated tuffs and minor developments of agglomerate, covering roughly a third of the area in the centre, disappears eventually beneath the younger flows of Limoru Trachyte in both westerly and northerly directions. The individual flows of the trachyte are usually thin and have some old land surfaces between them, but tuffaceous intercalations form the major separations between the flows. The trachyte varies greatly in hardness in different bands and presents certain difficulties in drilling, for which it does not compensate in the amount of water it produces. As a water bearer it is extremely poor and boreholes have yielded, on the whole, disappointing results. Occasional holes have given good supplies from old land surfaces but these cases are exceptional, particularly in the immediate vicinity of Nairobi.

The Limoru Trachyte is the best water bearer of all the lavas of the area and is exposed over most of the western and northern portions. It is essentially a porphyritic trachyte containing poikilitic quartz in small amount in the groundmass. The porphyritic crystals of alkali felspar are stumpy in habit, set in a pale-grey groundmass. This rock weathers easily, becoming light-grey to almost white in colour. Even when fresh it is relatively soft and drilling in it is quick and easy.

Associated

Associated with it are ejectamenta of various types and old land surfaces between individual flows are common. In the Kiambu area these trachytes cap many ridges, while deeply-incised stream beds expose the underlying Nairobi Trachyte in many places.

A total of 89 boreholes is considered in this section with an average depth of 367 feet. Of these, 73 holes or 82.0 % to an average depth of 404 feet, were successful. Water was struck at an average depth of 312 feet under a pressure head of 129 feet, thus bringing the average rest level to within 183 feet of the surface. The average tested yield was 1,586 g.p.h. Of the 16 unsuccessful holes 11 were abandoned before reaching the depth at which water could be expected, and this is reflected in the figure of 198 feet for the average depth of the unsuccessful holes.

The summary of results for the successful holes (Table VI) shows that a high proportion obtained their water between 200 and 400 feet (50 out of 73) and these averaged 1,700 g.p.h. on test. Five holes gave yields in excess of 3,000 g.p.h.

The probability curves (Plate IIC) are of interest, as they show that over the area as a whole, the highest probable yields (and also the highest probability of obtaining water) are between the depths of 250 and 320 feet. This is mainly due to the excellent results obtained by drilling through the Athi Plains Phonolite into the lake sediments below. The continuation of the curves below this point is again made up chiefly of holes in the same formation, where

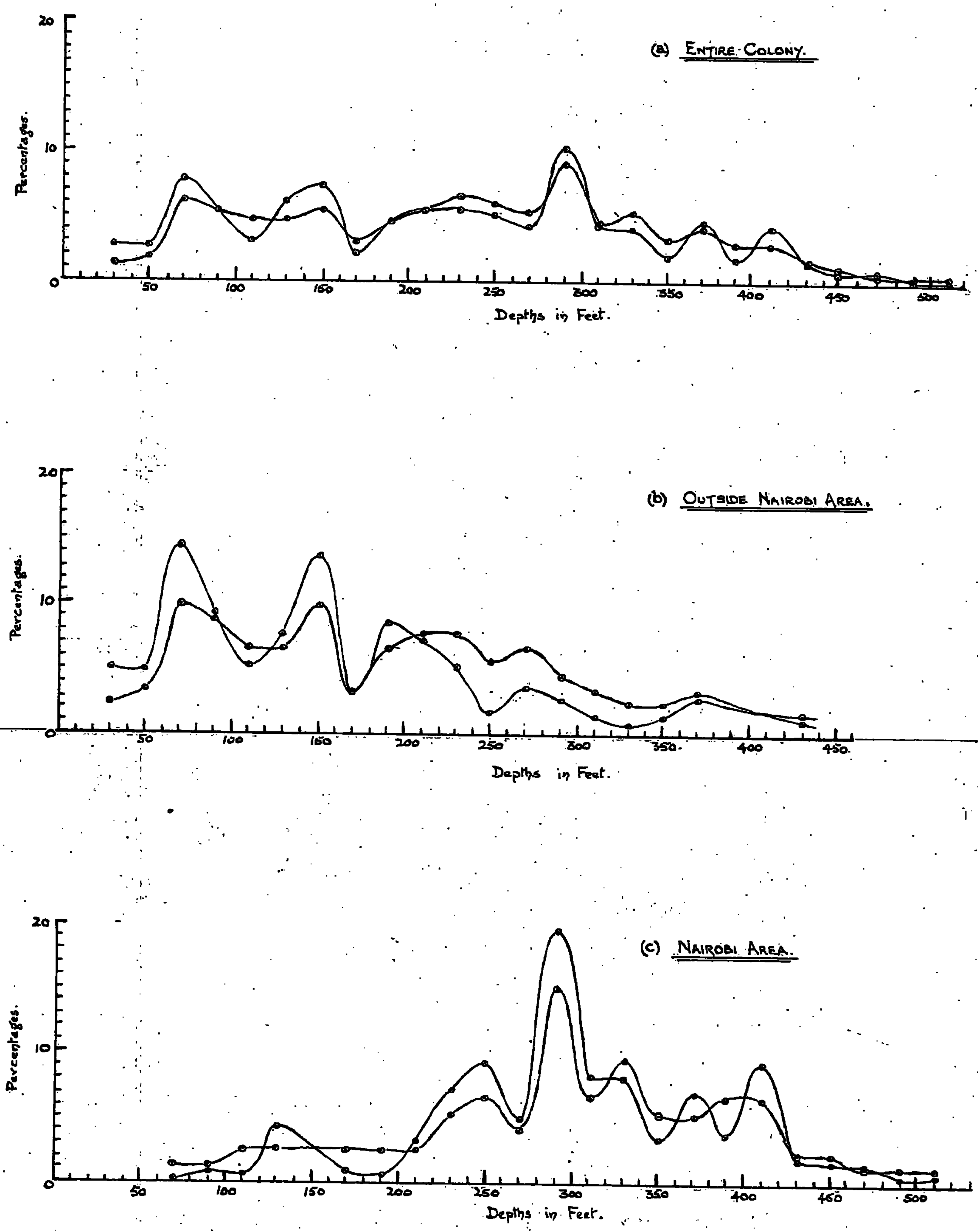


**Plate II. Probability Curves – Volcanics.**

o——o Probable depths to water.
o——● Probable relative yields at varying depths.

where greater thicknesses of both Nairobi Trachyte and Athi Plains Phonolite had to be penetrated before reaching the water-bearing lake sediments., and also to a less degree the higher areas of Kiambu and Limoru, where the water table is relatively deep. The curves for depths less than 250 feet mainly represent in their higher levels results in the Nairobi Trachyte,and lower down in the Limoru Trachyte of the Kabete area. The results from the Ngong Basic Series are scattered throughout the curves from 100 to 400 feet.

A more detailed areal analysis of the results for the main sub-divisions may now be given.

(a) Athi Plains Phonolite area underlain by lake sediments.

(b) The Langata area.

(c) The Nairobi Trachyte area in the western section of Nairobi.

(d) The Ngong-Karen area.

(e) The Kabete area.

(f) The Kikuyu-Limrou-Kiambu area, north and north-west of Nairobi.

(a) <u>The Athi Plains Phonolite area,</u> as previously stated, occupies the east-central and south-eastern portion of the main area, and, in addition to the phonolite, also includes , in its south-western section, some overlying Nairobi Trachyte and pyroclastics (eg. the Civil Aerodrome area). A total of 21 boreholes has been sunk here,

of

of which 2 only, abandoned at 64 and 136 feet respectively are classed as unsuccessful. The average depth of the successful holes was 443 feet, water being struck at 337 feetunder an average pressure head of 125 feet, bringing the rest level to within 212 feet of the surface. The average tested yield of these holes was 1,690 g.p.h. As a general rule it has been noted, in the central portion of this section at least, that water is encountered after passing through anything from 80 to 120 feet of fine-grained , rather argillaceous material below the phonolite, in the more open sandy beds. The shot-drill core previously mentioned shows that in that particular hole, this unproductive layer beneath the phonolite is made up of compact fine-grained sub-aqueous tuffs. It may reasonably be assumed that the beds in the other holes are of a similar nature, though from the comminuted samples from percussion drilled holes, differences in the beds below the lavas are difficult to detect. The deepest hole in these beds was taken to 653 feet, the main supply of water (1,800 g.p.h) not being obtained till a depth of 650 feet was reached, although a small supply (300 g.p.h.) was obtained at 100 to 123 feet, near the base of a bed of pyroclastics overlying the Nairobi Trachyte. The Athi Plains Phonolite was intersected in this hole at 257 feet and continued to 404 feet, at which depth the fine-grained tuffs, which here appear to have attained a greater thickness than usual , were encountered.

This portion of the Nairobi area is, therefore, exceptionally good ionally good for the siting of boreholes with a more than reasonable hope of obtaining good supplies, though the average depth at which water is struck is somewhat greater than for other areas, with the exception of Langata.

(b) The Langata Area has so far proved to be extremely difficult. A total of 9 boreholes has been sunk to an average depth of 287 feet. Of these, 3 only were successful to an average depth of 492 feet, water being struck at 383 feet, rising under pressure to within 203 feet of the surface, with an average tested yield of only 300 g.p.h. The 6 unsuccessful holes averaged 170 feet in depth, three of them being abandoned at very shallow depth (47,50 and 71 feet). All these boreholes start in the Nairobi Trachyte or its associated pyroclastics, and with the exception of one,(and even in this case the record is doubtful), do not strike the lake sediments. It seems possible from a study of the Water Table Contour Map (see later) that deeper holes than usual, say to 700 feet, might be successful in reaching these sediments, in which good supplies are to be expected. It may be, however, that the sediments do not extend as far west as this, but as there is at present no definite evidence either for or against this, it would be worth while to experiment with a deep borehole. The low yield of the producing holes in this area is due to the fact that both the trachyte and the phonolite are too compact and unfractured to make good aquifers.

(c) The Trachyte area west of Nairobi. is somewhat

similar

similar to the Langata section except that a slightly greater percentage success has been obtained. Six holes were drilled to an average depth of 368 feet, and of these 4, averaging 417 feet were successful. Water was struck at an average depth of 293 feet, rising to 155 feet and giving an average of 470 g.p.h. on test. The average yield is low, as might be expected from the formation in which the holes were drilled, but as in the Langata area, deeper holes might be expected to reach the lake sediments, if these are present, or an old land surface between the Athi Plains Phonolite and the Kapiti Phonolite, either of which should give greater yields than the phonolite or trachyte.

(d) The Ngong-Karen area has given uniformly excellent results; 13 holes have been sunk to an average depth of 282 feet and of these, 9, to an average depth of 325 feet, were successful. Water was struck at 236 feet, rising under pressure to 108 feet and yielding an average of 1,120 g.p.h on test. Of the 4 unsuccessful holes, 2 were abandoned at a depth less than that at which water would be expected and the other two were sited close to the main eastern boundary fault of the Rift Valley, and somewhat outside the main Ngong area. The results from this area again show that basalts and other similar basic volcanics are usually good water bearers, because of their easily weathered and well-fissured nature. In addition, the thinness of the individual flows and the large number of old land surfaces encountered in them have added apprec-

iably to

iably to the yields of individual boreholes.

(e) The Kabete area falls in the larger area (f) below but since a special set of geological conditions applies, it is considered separately. Six boreholes, all successful, have been sunk. Their average total depth was 369 feet, with the main supplies struck at an average depth of 247 feet, rising to within 82 feet of the surface under pressure, the average tested yield being 2,470 g.p.h. Two of the holes, one not deep enough to tap the large supplies struck in the other holes, and the other at the eastern end of the section, produced only 500 and 400 g.p.h. respectively, the other four holes thus having the high average yield of 3,480 g.p.h. An intensive drilling campaign has recently been started in this area with the object of augmenting the Nairobi Municipal Water Supply and preliminary results are as good if not better than those described above.

It appears that several flows of the soft, easily weathered and well-jointed Limoru Trachyte occupy a pre-existing valley in the old land surface, the overturned nose and upper surface of the first flow forming a bouldery mass on the old valley floor, which still acts as a drainage channel from higher elevations. In the more westerly section where the trachyte is thicker, boreholes pass through a larger number of old land surfaces and cut a greater number of fractures than they do in the east where the flows thin out. This is reflected in the much

higher

higher yields of holes in the west than those in the east.

(f) The Limoru-Kikuyu-Kiambu area has given good results; of the 26 holes which have been sunk, only 4 were unproductive. Three of these were drilled to very shallow depths (67,74 and 109 feet), and could not have been expected to reach water. It is possible that these three holes, Nos. 5,7 and 8 , drilled some 7 miles from Nairobi on the Fort Hall road, would have struck lake sediments if carried deeper. They have been included in this section, however, since they are somewhat outside the proved area of sediments. The other unsuccessful borehole, No.71, in the Kikuyu Native Reserve, was drilled to a depth of 623 feet and is the only recorded hole in which the Limoru Trachyte, here present to a depth of 400 feet, has not produced water in good quantity. The 22 successful holes averaged 371 feet in depth, water at the rate of 1,730 g.p.h. being struck at an average depth of 294 feet under a pressure head of 90 feet. This area is mainly one of Limoru Trachyte and its associated pyroclastics resting on a foundation of Nairobi Trachyte, the water being, as usual, obtained from the well-fissured Limoru Trachyte or old land surfaces between the various flows.

The Provisional Water Table Contour Map No.1 (Plate VII) shows the generalised sub-surface contours of the base of the Athi Plains Phonolite against the underlying fine-grained pyroclastics and lake sediments as far as they can be deduced from the evidence at present available. Outside able . Outside the 5,200 foot contour line there is, so far, no evidence of the continuation of these pyroclastics and lake sediments except to the east and south-east where they outcrop between Embakasi and Athi River. This does not necessarily mean that they do not exist west and south of this line, but if they do, they have not yet been reached by boreholes. This would be quite natural in view of the general rise in surface level to the west, and the increasing thickness of the superimposed volcanics which would have to be penetrated before reaching the level at which the sediments might be expected to occur. Comparison of the confined water level contours with those of the base of the Athi Plains Phonolite shows that the thickness of the unproductive layer at the base of the phonolites varies considerably, and indicates that the fine-grained sub-aqueous tuffs were laid down upon a somewhat uneven surface of lake sediments, generally deeper in the centre than on the margins , as would naturally be expected. The Athi Plains Phonolite later flowed over a fairly even surface, the only depressions shown being one in the neighbourhood of Ruaraka in the north-east corner, and another underlying the Civil Aerodrome area in the south-west.

A detailed surface contour map will no doubt show, when more evidence is available, that the confined water table contours swing up streams and down ridges, i.e. they will reflect the surface topography.

It is also noted (Plate IV~~III~~) that the static and confined water table contours are closer together in the northern half of the area than they are in the south, the measured gradients being approximately as follows :-

Northern section-Confined water contour 1:26
Static water contour 1:35

Southern section-Confined water contour 1:72
Static water contour 1:84

The same observation applies to the general surface gradient — northern section 1:53 and southern section 1:111. It has been noted too that the main spreading effect on the contours occurs on a line marking approximately the southern limit of the flows of Limoru Trachyte. Spreading also occurs in the north-east corner where the Limoru Trachyte thins out against the underlying Nairobi Trachyte.

The Road Map ~~No. 2.~~ (Plate X) shows the approximate location of the boreholes on which the evidence for the compilation of the water table contour maps is based.

The foregoing analysis of the results of drilling in the Nairobi area shows that the portion of the whole in which drilling has so far given poor results is small and restricted to that section having thick flows of Nairobi Trachyte exposed at the surface. This area is roughly south of the Kabete road from Kabete Station eastwards to the Show Ground and southwards to the Langata-Mbagathi area, in the form of a rough rectangle measuring some 5 miles from east to west and 6 miles from north to south.

It

It is thought likely by the writer that even this area would prove to be a useful producer if deeper boreholes than usual, say to 700 or 800 feet, were drilled. Pumping however, from such depths may be a matter of some difficulty even though the pressure head, particularly in the centre of the area, is likely to be higher than the average outside this restricted section.

Other portions of the Nairobi area give an unusually high percentage of good yields from depths of less than 400 feet.

## IV (h)- THE LAKE SEDIMENTS.

Reference has already been made to the existence of old lake sediments interbedded with the volcanics at several differnet horizons and also, in the case of the younger deposits of the Rift Valley, overlying the volcanics. Although the number of boreholes considered in this section is small, many successful holes credited to the volcanics should properly be placed in this series, since the bulk of their water is derived from it.

A considerable amount of work has been done on the lake deposits of Kenya by such workers as Gregory, Leakey, Nilsson, Solomon and Fuchs, but the correlation of the beds in different parts of the Colony is still not satisfactorily settled. Other problems awaiting solution are the age of the older members of the series and the reconstruction of the physical geography and climatic conditions at ions at the time they were deposited.

These lake deposits have a wide distribution in Kenya from Lake Rudolf in the north to the Tanganyika border in the south and also occur sporadically outside the confines of the Rift Valley. Similar lake beds are known in Tanganyika, Uganda and Nyasaland.

Gregory's type area for the oldest lake beds seen by him in Kenya, the Kamasian Beds, (1921 p.199) is at the foot of the Kamasian Range west of Lake Baringo. From their position here in relation to the volcanic sequence, he placed them in his Nyasan division which he considered to be of Oligocene age. The beds here are fine-grained silts and clays interbedded with coarse gravel and bouldery beds, the pebbles of which are derived from older lavas, the whole series being laid down in what he called Lake Kamasia. They are overlain by basalt and trachyte flows. Similar beds exposed in the walls of the Njorowa Gorge south of Lake Naivasha were thought by Gregory to have been formed in the southern end of this great lake or in a contemporary independent lake. Both series were tentatively correlated by him with the Karungu Beds of the Kavirondo Gulf of Lake Victoria. Leakey (1934) suggested an even greater lake than that of Gregory to account for the very widespread distribution of the lake beds — a lake stretching from the north end of Lake Rudolf to the south of Lake Natron and divided from a further southward extension through Lakes Eyasi and Manyara, by a narrow

strip

strip of high ground. An arm of this lake opened out from the southern end and spread out to include Lakes Victoria, George and Albert. The deposits on which Leakey based his conception are now known to be of widely differing ages in various parts of the area, and, as Nilsson had previously pointed out (1932), the many discordances indicate that they were deposited in a series of lakes rather than in one lake.

The age of the Kamasian Beds is still uncertain. Gregory, as stated above, considered them to be of Oligocene or possibly Lower Miocene age, but all the available evidence indicates that they are not older than Miocene and that a considerable part of the series is Pleistocene in age (see also p. 48 ).

According to Leakey (1935), the Kamasian period closed with a period of dessication which coincided with great earth movements producing faults with a throw of over 2,000 feet in many places. This was followed by a second pluvial period known as the Gamblian, during which more lake beds were deposited, and later still by two so-called post-pluvial wet phases known as the Makalian and Nakuran, the latter being post-Pleistocene in age. The Gamblian and Makalian are both Upper Pleistocene. This concept of pluvial periods to account for the former existence of much more extensive lakes than those of the present day in Kenya has been used by Wayland (1932 and 1933) to account for the rise in level of these lakes in

the

the past, with special reference to Uganda. He was followed by Leakey and Solomon in their work in Kenya and Tanganyika, who interpreted the observed phenomena on the same lines. Solomon (1939 ,p.40),however, now considers this hypothesis to be entirely unnecessary and says that much of his recent work in East Africa forces him to the belief that many of the phenomena ascribed by Wayland to climatic agencies may just as easily be explained by earth movements. He points out that a comparitively small change in rainfall would be competent to produce great alteration in the area of lakes like the present day Lake Naivasha and Nakuru as is indicated by the recession of both these lakes in the present century; also that the height of the Gamblian sediments in this area above the present lake levels may well be due to post-Gamblian earth movements, the importance of which were previously underestimated. He considers, however, that the older Kamasian sediments may have owed their origin, particularly in the case of the torrential gravels and boulder beds, to greatly increased rainfall conditions, though Lake Kamasia itself must have owed its origin to physiographic rather than climatic factors.

The lake deposits associated with the Gamblian, Makalian and Nakuran phases are mainly of fine-grained material, and contain extensive deposits of diatomite at more than one horizon. It is in these later lake deposits that most of the boreholes considered in this section

have

have been sunk.

The question of the comparative age of the extensive series of lake deposits underlying the Athi Plains Phonolite in the Nairobi area introduces a complication into Gregory's classification (followed by Sikes 1939) of the age of the volcanic beds here. If, as stated by these two writers, the Athi Plains Phonolite is Doinyan in age, it follows that the lake deposits are older than Nyasan, ie. older than the oldest Kamasian seen by Gregory. It would appear far more likely that the phonolite is the base of the Laikipian series of Gregory rather than a representative of the Doinyan, in which case these lake deposits, composed of sandy beds and bentonitic clays overlain by fine-grained tuffs of sub-aqeous origin, would represent Gregory's Kamasian.

The lake beds as a whole, from the Kamasian to the more recent Nakuran beds, have been proved by drilling to be extremely useful water-bearers, giving usually higher-than-average yields at comparatively shallow depths. Nine holes have been sunk in them apart from those previously mentioned which started in the volcanics and passed down into the older lake beds below. Of these, 8 were successful with an average depth of 326 feet. Water was struck at an average depth of 242 feet under an average hydrostatic head of 114 feet, the average tested yield being 1,900 g.p.h.

Further detailed research into the relations of the lavas and the lake sediments of various ages should open up up possibilities for successful boring where at the moment good results have been difficult to obtain.

Work along these lines has already been initiated in the Colony and should be of great value in the future.

## IV (i)- PLIOCENE TO RECENT DEPOSITS OF THE COASTAL AREA.

This section deals with the Recent sand dunes, sands and clays, Pleistocene coral limestone, the Kilindini Sands and shales of Pleistocene age, the Pliocene shell crag and Magarini Sands which overlie the Jurassic shales and limestones of the coastal area. This area has been upraised in stages to at least 80 feet above sea-level in certain places, and it was probably the last of these uplifts which raised the Pleistocene coral limestone above the water level, thus killing the corals which formed it.

Sixteen boreholes have been sunk in these deposits, 7 of which gave supplies of potable water. The remaining 9 holes all gave water too saline for use. Two of the successful holes, drilled at the Government Station at Kilifi, north of Mombasa, also gave saline water at depths of 115 and 147 feet respectively, but when this was cased off and drilling continued, brackish but potable water was obtained at depths of 250 and 256 feet respectively. Two other successful holes were sunk in the Kilifi district, both giving supplies of the order of 3,000 g.p.h. on test. The remaining 3 successful holes were sunk in the coral limestone of Mombasa Island and gave excellent

results

results at shallow depth but with very low pressure heads.

The average depth of the successful holes was 149 feet with water struck at an average depth of 142 feet, rising under pressure to within 36 feet of the surface. The average tested yield was 2,250 g.p.h.

Two deep boreholes, Nos. 18 and 58, which were unsuccessful, are thought by Sikes to have passed down into the Jurassic shales, though the driller's logs are not sufficiently detailed to prove this. On stratigraphical grounds, however, he suggests that the transition was probably at a depth of between 200 and 300 feet.

Large supplies of fresh water are also obtained from shallow wells in the coastal area in all these various rock types, the main producer being the coral limestone, while important, though usually small, supplies are also obtained from thin layers of fresh water lying on the salt water in the coastal sand dunes in many places.

## V- SUMMARY OF BORING STATISTICS FOR THE VARIOUS GEOLOGICAL FORMATIONS?

As will be seen from the accompanying schedule of boreholes (Table VII) , the majority of the boreholes drilled were sited in either the Basement Complex or the Kainozoic volcanics (160 and 245 in number respectively), leaving 100 other holes distributed amongst the rest of the formations. In these two groups the percentage successes

are

SUMMARY OF INFORMATION FOR ALL BOREHOLES FOR WHICH RECORDS ARE AVAILABLE.

| Geological Formations | Basement Complex | Duruma Sdstn. | Jurassic | Merti Beds | Habaswein Beds | Turkana Grits | Kainozoic Volcanics | Lake Beds | Pliocene to Recent-Coast | TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|
| Total number of Boreholes | 160 (68) | 16 (7) | 10 (2) | 30 | 18 | 1 | 245 (31) | 9 (6) | 16 (10) | 505 (174) |
| Aggregate footage of all Boreholes | 36574 | 5394 | 2756 | 7986 | 1810 | 188 | 74581 | 2896 | 3616 | 135801 (43957) |
| Average depth of all Boreholes | 229 | 338 | 276 | 266 | 100 | 188 | 304 | 322 | 266 | 269 (251) |
| Number of successful Boreholes | 109 (52) | 13 (6) | 2 (1) | 6 | 6 | 1 | 167 (44) | 8 (6) | 7 (2) | 319 (111) |
| Aggregate footage successful Boreholes | 25680 (10983) | 3961 (1478) | 803 (443) | 1560 | 407 | 188 | 54640 (13659) | 2588 (1506) | 1046 (524) | 90873 (28602) |
| Average depth of successful Boreholes | 236 (211) | 305 (248) | 401 (443) | 260 | 68 | 188 | 327 (310) | 326 (251) | 149 (262) | 285 (258) |
| Average depth tp water | 139 (154) | 231 (226) | 368 (386) | 249 | 64 | 94 | 248 (245) | 242 (150) | 142 (253) | 205 (197) |
| Average depth to Rest Level | 82 (85) | 53 (74) | 200 (146) | 237 | 54 | 90 | 147 (154) | 128 (101) | 36 (111) | 120 (111) |
| Average Hydrostatic Head | 57 (69) | 173 (151) | 168 (240) | 12 | 10 | 4 | 101 (91) | 114 (49) | 56 (142) | 35 (86) |
| No. of Boreholes giving water too saline for use | 4 (1) | 2 (0) | 1 (1) | 2 | 0 | 0 | 0 | 0 | 9 (8) | 18 (10) |
| No.of Boreholes giving less than 90 g.p.h. of test | 47 (15) | 1 (1) | 7 (0) | 22 | 12 | 0 | 78 (37) | 1 (0) | 0 | 168 (53) |
| Average depth of unsuccessful Boreholes | 219 | 478 | 244 | 268 | 117 | - | 230 | 308 | 236 | 244 (244) |
| Average Yield in Gallons per Hour | 1000 | 1300 | 240 | 580 | 550 | 3000 | 1502 | 1900 | 2253 | 1310 (1180) |
| Average yield in gallons per day | 24000 (24144) | 31200 (28816) | 5760 (8000) | 13920 | 13200 | 72000 | 36050 (31844) | 45600 (40360) | 54070 (24800) | 31440 (28335) |
| Total yield in gallons per day. | 2620600 (1271450) | 405600 172900 | 11520 (3000) | 84000 | 79200 | 72000 | 6020400 (1401120) | 364800 (242160) | 378500 (49600) | 10035000 (3145230) |
| PERCENTAGE SUCCESS | 68.1 (76) | 81.3 (86) | 20 (50) | 20 | 33 | 100 | 68.2 (54) | 39 (100) | 41 (20) | 63.2 (64) |

Table VII.

are practically identical (68.1 and 68.2 respectively).

In the 109 successful holes in the Basement Complex, water was struck at an average depth of 139 feet under an average hydrostatic head of 57 feet, the average tested yield was 1,000 g.p.h. Four boreholes in the formation gave water too saline for use.

In the 167 successful holes in the volcanics, the average depth to water, average hydrostatic head and average tested yield are all considerably higher than in the Basement Complex, the relevant figures being 248 feet, 99 feet and 1,500 g.p.h. No borehole in this formation gave water too saline for use.

In the Duruma Sandstone Series, 16 holes were drilled of which 13 were successful, though now, due either to overpumping or polution by saline water at shallow depth, the water from six of the originally successful holes has become too saline for human consumption. Two other holes in this formation gave saline water when first drilled.

The Jurassics of the coastal area and the Wajir-El Wak area of the Northern Frontier District gave very poor results, two holes only of the 10 drilled being successful and these produced an average of only 240gph.

The only hole drilled in the Turkana Grits gave a yield in excess of 3,000 g.p.h. (the maximum capacity of the test pump used), at a depth of 94 feet, but with a hydrostatic head of only 4 feet.

The Merti Beds and Habaswein Deposits (which are simply resorted Merti Beds) have yielded poor results, 12 holes only of the 48 drilled being successful. These deposits are now thought to be of Jurassic age in the eastern section and of Miocene age in the western section as a result of recent work by Dr. F. Dixey. Two boreholes in the Merti Beds produced water too saline for use. The average depth of the 12 successful holes was 164 feet, water being struck at an average depth of 156 feet, rising under pressure to 145 feet and yielding on test an average of 567 g.p.h.

The Lake Sediments, in which 9 holes were drilled, gave 8 successful results with the high average yield of 1,900 g.p.h. from an average depth of 242 feet, under a hydrostatic head of 114 feet. As previously stated, many holes considered under the heading of the volcanics should properly be placed in this section since their water is derived from the lake sediments, but it has been found more convenient to classify them in the formation in which they were drilled at the surface.

In the Pliocene to Recent deposits of the coastal area, 7 boreholes of the 16 drilled were successful, the remainder giving large quantities of highly saline water. The average depth to water in these deposits was 142 feet the rest level being 86 feet and the average tested yield 2,250 g.p.h. Large amounts of water are also drawn from these deposits by means of shallow wells all along the coast.

It will be seen from the above summary of results that borehole supplies in the Colony as a whole are of potable quality, 18 holes only yielding water too highly mineralised for use, as against 319 yielding potable water. The majority of the saline holes were drilled near the coast.

Supplies from individual boreholes are not high but this is to be expected from the prevailing geological conditions, which are not conducive to the formation of artesian basins of any magnitude. Locally, artesian conditions do exist, as recently proved near Athi River. Strictly speaking, all the borehole supplies are artesian in character in that they all have a positive hydrostatic head, but only three cases are known in which the water rose above ground level naturally.

In addition to the summary of results to date, figures are given in parenteses for comparison purposes, which indicate results obtained to 1932 (compiled from Sikes 1934). A consideration of both sets of figures shows only minor variations in the general averages, except that subsequent boring has increased the figure for average daily yield by some 3,000 gallons per day. This increase is mainly due to the raising of the figure for the average yield of holes in the volcanics by some 4,200 gallons per day. The percentage success for drilling in the latter formation has risen from 54 to 63 while that for the Basement Complex has fallen from 76 to 68.

It is to be expected that as more detailed knowledge of geological and hydrological conditions for the various formations is accumulated, greater percentage success will be obtained in most of the geological formations in the Colony, by the elimination of unsuitable and unlikely sites by the geologist or geophysicist concerned with their choice.

## VI- ACKNOWLEDGMENTS.

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# PART II.

## NOTES ON THE GEOLOGY OF THE AREA ADJACENT TO THE ROAD

## MARSABIT - MEGA

## (NORTH KENYA - SOUTH ABYSSINIA)

## WITH

## PETROLOGICAL DESCRIPTIONS OF REPRESENTATIVE ROCK TYPES.

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# CONTENTS.



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## I- INTRODUCTION.

The Marsabit-Mega road forms the most direct link between the north-central portion of the Northern Frontier District of Kenya and the south-central portion of Abyssinia, and is part of the main north road from Nairobi to Addis Ababa. From Marsabit, roughly 100 miles south of the border, the road runs in a north-north-westerly direction to the southern slopes of the Huri Hills in the neighbourhood of Kalacha, where it swings to the north-north-east through these hills to the border at Mt. Furroli and from thence some 35 miles to Mega in Southern Abyssinia.

The following notes were compiled from observations made on the geology while geophysical work in connection with the siting of boreholes was being carried out at various points along and adjacent to the new road alignment in February 1941, during the course of the East African Campaign. A considerable number of representative rock specimens were sliced and microscopically examined at the Department of Mines and Geology, Nairobi.

## II- GENERAL GEOLOGY.

From Marsabit to mile 40, the road passes over a volcanic area, and after leaving the neighbourhood of Marsabit Mountain at about mile 12, the country becomes, in general, flat and uninteresting, the only topographic features being isolated cones of ash and agglomerate and occasional

occasional low flat-topped ridges and tongues of blocky scoriaceous lava. Fuchs (1939) mapped all these lavas as Upper Pleistocene basalts. The harder and more resistant basalts form the flat or gently undulating country, while the softer ashes and agglomerates usually stand out as low hills or cones. Since the pyroclastics are, on the whole, relatively soft and unconsolidated, but yet form the main topographic features, it is obvious that they must be younger than the basalts. Sand dunes are in process of formation from mile 35 to mile 40, above the lavas, the sand apparently being derived from the sedimentary area immediately to the north.

At mile 40, in the neighbourhood of Maidahad, the road leaves the volcanics and traverses sediments to mile 55 with no appreciable change in level at the boundary. To the east of the road, the lavas overlie the sediments, and have a thickness of about 40 feet at the end of the flows. This area of sediments is gently undulating and falls away gradually to the west to the general level of the Chalbi Desert. Some of the ridges crossing it have a thin skin of scattered residual lava boulders but the whole area may be mapped as sediments older than the lavas. The sediments are massive and probably flat-bedded, and are extremely variable in composition. Well-consolidated sandstones, grits and pebbly grits, which in places become almost conglomeratic, make up the greater part of the outcrop, but there are also numerous small

lenticular

lenticular bodies of blood-red fine-grained jasper intercalated with the sediments. Similar material is present as pseudo-veinlets, together with spherical concretionary growths of yellowish-brown amorphous siliceous material. These occurrences appear to be solution deposits, probably from hot springs, which have in part replaced the sediments. The finer grained sandstones are mainly composed of sub-rounded clear or iron-stained quartz grains, while, as the material becomes coarser, the proportion of angular quartz increases. The pebbles in the pebbly grit vary from perfectly rounded to angular and many appear to be dreikanter. There are also occasional rounded pebbles of somewhat decomposed, fine-grained, purplish-blue material which appears to be a lava.. Unfortunately all specimens of this material collected were too decomposed for microscopic examination. Pebbles, mainly of quartz, and up to two inches in diameter , are scattered over a considerable part of this area and were presumably derived from the more pebbly facies of the sediments. At the foot of the lavas east of the road at mile 45, is a fairly extensive surface deposit of yellowish-brown amorphous material carrying scattered quartz grains which are usually small, sub-rounded and iron-stained. It is hard but extremely brittle and has probably been deposited from a hot spring issuing from the base of the lavas.

The sandstones show many small, polished and apparently slickensided surfaces which possibly indicate small

scale

scale faulting or slumping during consolidation. No fossils were found in this locality so an accurate age determination is difficult. They appear to be younger than the Turkana Grits found west of Lake Rudolf and thought by Fuchs to be of Miocene age, and are definitely younger than the earlier lava flows, since lava fragments are found in them. It seems likely that they correspond to the Lower and Early Middle Pleistocene Lake Beds in Fuchs classification (1939) since they are followed by at least one further period of vulcanicity. This view is supported by the recent discovery by Dixey of mammalian remains in similar beds not far to the south-west of this occurrence which, according to him, belong to the upper part of the Lower Pleistocene (personal communication).

At mile 55 near Maikona, the road leaves the sediments and again passes on to volcanics, with a rise of 30 to 40 feet. For some considerable distance onwards the country is flat and featureless, covered with large lava boulders, and with occasional tongues and low flat-topped ridges of highly-vesicular blocky lava which breaks up into roughly rectangular blocks rather than into the more usual rounded boulders produced by the weathering of the less vesicular type forming the flat country. It would appear that these lava tongues are the latest phase of the plateau type of extrusion in this locality, with the material originally in a highly viscous state and containing a higher percentage of volatiles than the older types.

Vesicle

Vesicle fillings of calcite are common in the lavas and the ridges also show many small circular shafts, some six to eight feet in diameter, which may be late dry explosion vents.

Ash and agglomerate cones become more common as the Huri Hills are approached and the peaks of this isolated range are all formed of pyroclastic material. On the southern slopes of the Hills, the commonest lava type is an olivine-basalt with an extremely fine-grained black groundmass carrying small euhedral phenocrysts of olivine. Along the top of the range and down its northern slopes the basalts are of a highly-vesicular slaggy type, the vesicles of which have been flattened and elongated by the movement of the lava. The lavas continue along the flat, low-lying country from the foot of the Huri Hills to the border, where the inselberg mass of granite which forms Mt. Furroli and Mahier emerges through the lavas. In hand specimen this granite is usually a fresh-looking, coarse-grained biotite type but finer-grained and probably marginal types are also present. The isolated masses of Ulan, Elle Dimtu and Kwial are also of granite, while smaller occurrences are scattered south of Furroli.

From the top of the low col between Furroli and Mahier, the ground falls away gently for several miles down to a broad lava plain, but the granites are again in evidence some 5.5 miles from the top of the col. Isolated cones of ash and agglomerate and ridges of highly-vesicular basalt

basalt stand out from the flats and these features increase in number about 15 miles from Furroli, producing a very broken topography. Just south of Magada, basalts carrying roughly spherical xenoliths of pale-green, coarsely crystalline dunite and augite-peridotite occur. About 0.5 mile west of the road at Magada is a circular crater some 300 feet deep, narrowing from about 1,200 yards in diameter at the top to some 700 yards at the bottom. The lake at the bottom of the crater is highly saline and marked on the topographic map as a soda or salt mine. From the middle of the lake rises a mud cone with a blow-hole in its centre which appears to have been recently formed, The odour of sulphur dioxide is clearly noticeable from the lip of the crater, while on its outer slope ejected blocks of various rock types occur, including granites similar to those of Furroli and basalts with ultra-basic xenoliths.

A few miles north-east of Magada the Pass scarp is reached, rising steeply for some 1,300 feet, after which there is a further gentle rise for several miles to the foot of the steep Mega hills. The scarp itself is guarded by three large cones with craters which have, in all probability, been formed along a fault plane or plane of weakness roughly parallel to the main fault of the scarp. The road is cut in volcanics to the top of the scarp but immediately to the east, across a sharp little gully, gently dipping gneisses form the whole height of the scarp.

This

This would appear to indicate a second fault roughly at right angles to the scarp fault. The volcanics are a series of ashes , agglomerates and basalts with abundant large green coarsely crystalline xenoliths, while the gneiss is a hornblendic type which does not appear to have been subjected to any great pressure and deformation. Small pegmatite veins are common in the gneiss, with biotite as their main constituent.

From the top of the main scarp to within some 5 miles of Mega, narrow tongues of bouldery basalt cross the road and all fade out at short distances east of it. From this point to the foot of the Mega hills, gneiss outcrops are common and these rocks underlie all the gently undulating country in this neighbourhood. Volcanics are again in evidence near Mega, but as the Mega sheet was not available at the time of the examination, this area was not mapped. The volcanics here, however, are similar to those seen west of the road above the scarp and to those on the plains between Furroli and Tass, and are, in all probability, younger than the lavas of the scarp itself.

## III- PETROLOGY.

### (a) The Granites of Furroli and Magada and the Granite-gneiss of the Tass Scarp.

Specimens HK/8 and HK/9 are typical of the principal types of the acid plutonics making up the masses of Furroli, Mahier, Elle Dimtu and Kwial, which project as rugged

rugged-toothed ridges through the volcanics.

HK/8 is in hand specimen a coarse-grained glomeroporphyritic leucocratic rock with small sporadically distributed clots of biotite making up a maximum of 5% of the rock. Felspar phenocrysts up to 5 mm. in length are common and occasionally reach a length of 2 cm. In thin section the rock is seen to be of interlocking granular texture with quartz and felspar in roughly equal proportions. The quartz is usually water-clear but occasionally contains parallel strings of bubbles and minute inclusions. The inclusions appear as hexagonal colourless crystals with high relief and straight extinction, suggesting zircon or apatite. The felspars are microcline, perthite and oligoclase, the first two being somewhat cloudy and the latter quite clear. The oligoclase is slightly less common than the microcline and shows a maximum extinction angle in sections perpendicular to 010 of 9$^{o}$ with $\mu$ greater than canada balsam and less than that of quartz, indicating that its composition is $Ab_{74}An_{26}$. Biotite, which is pleochroic from yellowish-brown to pale-green to dark-green, is the only mafic mineral present and shows some alteration to chlorite. This alteration is associated with a certain amount of magnetite and reddish-brown haematite. Quartz and felspar are poikilitically intergrown with the biotite which is always much corroded. Accessory minerals present are mainly iron ores in small

corroded

corroded crystals and aggregates, togetehar with occasional idiomorphic or slightly rounded zircons. This rock is classed as a quartz-rich biotite-granite.

HK/9 is much finer grained than the rock just described and is a sugary leucocratic type with more biotite which is spread evenly throughout the rock. Alteration of both felspars and biotite has proceded much further than in the previous specimen. Quartz and felspar are again present in roughly equal amount and make up some 75% of the rock. The felspars include kaolinised orthoclase, microcline, perthite and oligoclase, all of which are twinned. The alkali felspar is relatively less in amount than in HK/8. Biotite is the only mafic mineral and is extensively altered to give ragged masses of chlorite with associated magnetite. The accessories are zircon and magnetite, the general grain size of the former being less than in HK/8. This rock is a fine-grained potassic biotite-granite and is probably a marginal type.

HK/10, which is similar in hand specimen to HK/9, was collected from the outer slopes of the Magada crater and is apparently an ejected block from this crater. In thin section quartz and felspar occur in approximately equal amount and make up some 80% of the rock. Microcline is the predominant felspar, accompanied by very little perthite and not more than 2% of oligoclase. The microcline is slightly cloudy and sometimes encloses smaller sub-rounded quartz grains showing a reaction rim

of

of clear felspar (probably orthoclase) between themselves and the microcline. Highly corroded separate fragments of quartz enclosed in the felspars are optically continuous over considerable areas. Biotite is present only in minor amount and is usually chloritised. Magnetite, mostly primary, forms some 15 % by volume. A little secondary magnetite is associated with the chloritised biotite. Zircons are more abundant than usual; they occur in and around the borders of the idiomorphic magnetite. This rock is a biotite-microcline-granite.

The fine-grained leucocratic hornblende-granite-gneiss of the Tass Scarp is somewhat similar in appearance megascopically to the above granites. It is represented by specimen HK/26, which has a tiny veinlet of quartz and biotite through it and shows prominent banding of the mafic minerals. Microscopically the rock is seen to be fairly coarsely xenomorphic granular in texture, with quartz and microcline as the dominant constituents, quartz being slightly in excess of the felspar. Smaller grains of oligoclase occur interstitially, while perthitic intergrowths of microcline and quartz are common. The microcline usually shows cloudy alteration products. The main mafic constituent is a pleochroic brown to dark-green hornblende with extinction angle Z $\wedge$ c of 15°. A little brown biotite is developed and its slight alteration to chlorite is associated with a little magnetite. Plentiful idiomorphic

or

or slightly rounded colourless zircons and rarer rutile which encloses zircons, are present as accessories. Magnetite is also present in slight amount.

(b) The Basalts between Mile 55 and Mile 30.

The two specimens described below are typical of the two main types occurring along this stretch of road. HK/3 was collected near the Kalacha road junction and is a fine-grained, dark-grey vesicular type with phenocrysts of dark-green glassy olivine up to 3 mm. in length. The vesicles are lined with calcite. In thin section, phenocrysts of serpentinised olivine and tiny laths of clear twinned plagioclase felspar are set in a cryptocrystalline matrix of magnetite and small, usually subhedral, prisms of pale yellowish-green pyroxene. Olivine phenocrysts show euhedral to subhedral corroded forms with almost always a serpentinised zone round their borders and sometimes along irregular cracks. Magnetite is present in such sections. The olivine has a 2V of about 90° but appears to be optically negative. Pyroxene is present in large amount in the groundmass. It is an optically positive and non-pleochroic augite with an extinction angle $Z \wedge c$ of 43°. The felspar laths are not as prominent as the pyroxene; they are clear and glassy and have a maximum extinction angle in sections perpendicular to 010 of 27° and $\mu$ greater than canada balsam, indicating labradorite of the composition $Ab_{50}An_{50}$. Much magnetite is also

also present in the groundmass and a certain amount is enclosed in the olivines, while granular calcite is common in vesicles. No felspathoids were seen in the rock which may be claased as a normal olivine-basalt.

Specimen HK/5 was collected from the lower south-eastern slopes of the Huri Hills and is a heavy dark-grey basalt with slightly larger olivine phenocrysts than HK/3 (up to 1 cm. in leggth), set in a cryptocrystalline matrix. Vesicles are not common in this rock. In thin section both olivine and monoclinic pyroxene are seen to form phenocrysts, with the pyroxene slightly less common than the olivine. The groundmass is much finer grained than HK/3 and, though it appears to be made up of the same minerals (labrødadorite, augite and magnetite), the individual crystals are too small for optical determination. The olivine phenocrysts show few signs of alteration and are usually of greater size than the pyroxene which only rarely poikilitically encloses them. Small cavities with serpentine borders and lined with calcite are occasionally seen in the olivine phenocrysts. The pyroxene generally shows euhedral form and is slightly pleochroic from purplish-brown to pale-yellow with absorption $X > Y > Z$. Many crystals have a rim darker and more pleochroic than the central portion. The mineral is optically positive with an extinction angle $Z \wedge c$ of $42^{\circ}$ and is, therefore, a titaniferous augite. The augites show a tendency towards crystallisation in radiating groups from centres of

olivine

olivine or granular masses of calcite, and the majority of them appear to have crystallised at a later stage than the olivine. Calcite is common as irregular granular masses and much of it is no doubt secondary. The rock is classed as an olivine basalt possibly tending towards ankaramite.

The differences between the two types may be summarised as below :-

| HK/3 | HK/5 |
|---|---|
| Vesicles common. | Vesicles rare. |
| Olivine phenocrysts serpentinised. | Olivine phenocrysts not serpentinised. |
| Augite phenocrysts absent. | Augite phenocrysts common. |
| Groundmass fine-grained. | Groundmass very fine-grained. |

Chemical analyses are not available so it is impossible to say to what extent the chemical compositions reflect the differences noted microscopically.

(c) <u>The Basalts with Ultra-basic Xenoliths from the Tass Scarp.</u>

The hurried nature of the reconnaissance in this area made it impossible to carry out any detailed study of the field relations of the various volcanics. The xenoliths in the lava appear to be of common occurence since specimens have been collected also from the Magada Crater, the Alge area some 100 miles north of Mega, the lower

southern

southern slopes of Marsabit Mountain and from the neighbourhood of the Mgombe Crater north of the Isiolo-Garba Tulla road some 100 miles south of Marsabit. Only the specimens collected from the Tass Scarp have been examined microscopically, but in hand specimen, those from the other areas are similar. Selected specimens from the Tass Scarp are described below.

UK/20 is an extremely fine-grained , dark-grey, highly-vesicular slaggy type with xenoliths of pale-and dark-green glassy crystalline material in which there is a certain amount of reddish-brown haematite staining. Occasional phenocrysts of olivine, up to 3 mm. in length, are present in the basalt, while one felspar phenocryst of rectangular section about 1 cm. in length was also noted. The groundmass of the basalt is extremely fine-grained and almost opaque in thin section except with high magnification when it is seen to be augitic, liberally sprinkled with magnetite, and with rare small olivines and microliths of twinned plagioclase felspar. The augite is pale brownish-green in colour. Olivine phenocrysts, the larger ones usually much corroded and the smaller ones generally euhedral and little corroded , are present in the groundmass. It is suggested that the badly corroded individuals may be relics of crystals stoped from the olivine-rich xenoliths, while the euhedral crystals have crystallised from the basalt magma. Euhedral augite phenocrysts, fewer

and

and smaller than the olivines, and less corroded, are also present; they consist of a zoned, slightly pleochroic titaniferous type.

The xenoliths are essentially diopsidic pale-green augite and olivine, the augite being approximately twice as common as the olivine. Brown almandite garnet is present to the extent of 3 to 5 % by volume. The augite is non-pleochroic with 2 V about 60°, optically positive with extinction angle Z∧c of 40°. The olivine is optically negative with 2 V near 90° and shows no serpentinisation. The garnets usually show a kelyphitic rim of granular augite. One plate of a colourless mineral which was not positively identified showed the following optical properties :- lamellar twinning well developed and a tendency to cross-hatching noted at high magnification, straight extinction, a silky appearance with low order greys and yellows between crossed nicols, low birefringence with μ greater than canada balsam and less than olivine, biaxially positive with 2 V between 60° and 70°, no cleavages but irregular cracks. It encloses garnet and olivine and in this particular section is adjacent to the basalt contact with the xenolith. Another colourless or very pale-green mineral is present in small amount, which shows grey polarisation colours, μ greater than canada balsam, optically negative, 2 V near 90° and extinction angle Z∧c of 9°. It is probable that this mineral is tremolite, the highest extinction angle Z∧c of which

does

does not appear in this section (see later description of HK/25). Tongues of the groundmass have penetrated the xenolith along crystal boundaries and irregular cracks but there is little evidence of alteration due to this except the deposition of black iron ores in the adjacent olivines. Small trains of gas bubbles and black ores are common in the olivines and less common in the pyroxenes; they appear to be connected with tongues of basaltic material. The borders of the crystals against the lava are highly crenulate, suggesting that a certain amount of magmatic corrosion has taken place. Crystal stoping by the magma from the xenolith is also obvious, the olivines appearing to have suffered more in this respect than the pyroxenes.

The xenolth is referred to GORDUNITE or OLIVINE-PYROXENITE with GARNET, while the enclosing lava is an OLIVINE-BASALT or possibly ANKARAMITE.

HK/21 is a dark-grey, extremely fine-grained basaltic type with phenocrysts up to 5 mm. in length of glassy green olivine and small xenoliths of dark bottle-green coarsely-crystalline material. Microscopically, the groundmass is greyish and cryptocrystalline, rich in tiny stumpy greyish-green pyroxenes and black ores. Under high magnification microliths of clear twinned plagioclase felspar may be distinguished but are too small for positive identification. This felspathic material is definitely subsidiary to iary to the pyroxene and iron ores. The olivine phenocrysts are usually corroded but show little evidence of other alteration. A dusty rim of black iron ore is usually developed round the edges of the corroded crystals. The mineral has a 2V near 30° and is optically positive, suggesting a composition of 87 % forsterite and 13 % fayalite. Phenocrysts of slightly pleochroic titaniferous augite are also present though in smaller amount than the olivine. Tiny rectangular inclusions having high relief and oblique extinction give this mineral a dusty appearance.

The xenolith is a coarsely xenomorphic granular mixture of olivine and monoclinic pyroxene in roughly equal proportions, with accessory garnet and magnetite. Alteration of the original constituents of the rock by invading tongues of the magma has not proceeded to any appreciable extent but magmatic corrosion of the olivines directly bordering the lava has produced crenulate margins to this mineral and the deposition of black ores gives a dusty rim in such cases within the olivines. Strings of inclusions of bubbles and minutely crystalline black ores appear to be connected with the invading tongues of the lava. The pale-green pyroxene is a non-pleochroic variety showing good cleavage, 2V just above 60°, optically positive and with extinction angle $Z \wedge c$ of 40°, i.e. a diopsidic augite. A few elongated sections and squarish basal sections of dark-brown garnet were noted. Its refract-

ive index

ive index is between 1.788 and 1.808 (nearer the latter) indicating that it is the almandite variety. Accessory magnetite occurs in both the olivine and augite.

The Xenolith is an AUGITE-PERIDOTITE and the enclosing lava an OLIVINE-BASALT.

HK/22 is identical in hand specimen with HK/21 and in thin section shows only minor differences. The augite phenocrysts of the basalt, which are of a zoned and slightly pleochroic type, with extinction angle Z∧c of 30°, show less corrosion than the olivines which are often little more than skeletal forms. Occasionally the olivine has a rim of radially disposed finely-granular augite. The groundmass is again augitic with a liberal sprinkling of black ores and some microliths of clear twinned plagioclase felspar showing a maximum extinction angle in sections perpendicular to 010 of 24° and $\mu$ greater than canada balsam, ie. andesine, $Ab_{57}An_{43}$. Interstitial to the above is a colourless mineral showing no twinning or cleavage, with $\mu$ just less than canada balsam and grey interference colours. No other optical properties could be determined because of the extremely small size of the crystals but the mineral is possible orthoclase.

The xenoliths are mainly small, some 2 cm. in diameter and the chief difference in composition between these and the previous specimens is the increase in the amount of almandite. The crystals of this mineral are also larger than in previous specimens and often assume a lobe-like

form

form and usually have an opaque black rim and a patchy kelyphitic zone of finely-granular augite. It is suggested that the opaque border and kelyphitic zone are associated with the alteration of the garnet, liberating magnetite and forming the granular augite from the remaining constituents of the garnet. The olivines are clear, colourless and show no serpentinisation. Small trains of gas bubbles and black ores, which increase in size and amount as the margin of the xenolith is approached, appear to indicate introduction from the lava and are not confined to cracks and cleavages in the minerals of the xenolith. The pyroxene is pale-green, pleochroic to almost colourless, optically positive with 2 V about 60$^{\circ}$, and with extinction angle $Z \wedge c$ of 48$^{\circ}$, i.e. in the diopside-hedenbergite series. This mineral, on the borders of the xenolith, usually has a rim of finely-granular alteration material which is too fine-grained to determine. Bordering cleavages and cracks along which thin tongues of the lava magma have invaded the xenolith, the pyroxene occasionally assumes a darker green colour, possibly indicating a slight enrichment in iron. The invading tongues of magma in some instances widen out to lobe-like forms inside the xenolith, usually replacing olivine, small highly corroded fragments of which remain enclosed in the basalt.

The xenolith is an AUGITE-PERIDOTITE with GARNET, and the enclosing lava OLIVINE-BASALT.

HK/24 megascopically is a heavy dark-grey, finely

vesicular

vesicular lava with olivine phenocrysts up to 4 mm. in length. It encloses one large xenolith of green glassy crystalline material about 5 inches in diameter. In thin section the augitic groundmass of the lava is finer grained and more vesicular than in previous examples. Plagioclase microliths are present in greater amount and usually are of greater size than previously noted (more like those of HK/2). The felspar is clear and twinned with a maximum extinction angle in sections perpendicular to 010 of 32° and $\mu$ greater than canada balsam, indicating labradorite about $Ab_{40}An_{60}$. The olivine phenocrysts are smaller and the pyroxene phenocrysts less common than in previous examples.

The xenolith is made up mainly of large anhedral olivines with a little very pale-green diopsidic augite. Accessories are small cubes of magnetite, rare dark-brown garnet and small rectangular zircons which are pleochroic from pinkish-brown to straw-yellow to almost colourless. Tongues of the groundmass have entered the xenolith along crystal boundaries and cracks and often swell out into bulbous forms, replacing both olivine and augite, small residual fragments of which are seen in the invasive material. Small subsidiary tongues branch from the main channels and pass into the olivines, decreasing in size until they become mere trains of gas bubbles or minutely crystalline black iron ores. The margins of the xenolith are highly crenulate and have a dusty appearance imparted

to

to them by the deposition of finely-crystalline black ores. Some carbonate has been formed in the xenolith.

This xenolith is a DUNITE enclosed in OLIVINE-BASALT.

HK/25 in hand specimen is a spongy, highly vesicular type purplish-brown in colour, enclosing a xenolith of similar type to those previously described but with its constituent minerals stained reddish-brown. In thin section, small circular vesicles showing no mineral lining make up some 50 % of the lava section, the groundmass of which is reddish-brown. Phenocrysts of highly altered olivine and pseudomorphs after olivine , with less common zoned titaniferous augites are present. The groundmass is again augitic and has tiny twinned microliths of clear plagioclase felspar determined as Andesine, $Ab_{63}An_{37}$, which occasionally show a rough flow arrangement round the vesicles. Much haematite is present in place of the usual magnetite. Many of the olivine phenocrysts have been almost completely altered to pleochroic reddish-brown to yellowish-brown iddingsite, together with reddish-brown haematite and a little finely-granular black magnetite. The most intensely altered phenocrysts commonly have a narrow rim of unaltered colourless olivine. Where the olivine is not completely converted, the iddingsite zone shows ragged margins against the central core of residual olivine while the unaltered olivine rim shows sharp margins with the enclosed iddingsite. Edwards (1938) ob-

served similar

served similar phenomena and suggested that iddingsite is only found in rocks having an iron-rich final fluid. The rim of unaltered olivine is explained as being due to the setting up of a reverse reaction in the equation—

| <u>OLIVINE</u> | | <u>IDDINGSITE</u> | | <u>MAGNETITE</u> |
|---|---|---|---|---|
| $3(MgFe)O.SiO_2$ | $\longrightarrow$ | $MgO.Fe_2O_3.3SiO_2.4H_2O$ | $\longrightarrow$ | $Fe_2O_3.FeO$ . |

In the forward reaction progressive addition of iron is needed throughout together with silica and water in the second stage. This, Edwards considers, takes place during the period of concentration of the volatiles immediately prior to the extrusion of the lava. The volatiles are released on extrusion and the forward reaction can no longer proceed, but is reversed, thus forming the second generation olivine rim which has no facilities for alteration. This olivine would presumably be of the same age of crystallisation as the olivines of the groundmass.

The xenolith has a coarse xenomorphic texture, being made up of about 50 % olivine or its alteration products, together with roughly equal amounts of pale-green augite and colourless tremolite. The tremolite has similar optical properties to the tremolite in HK/20 except that it extinction angle $Z \wedge c$ is $15^{o}$. Accessories are rare dark-brown garnet (probably almandite) and cubic black ores. The olivines show a similar type of alteration to those of the groundmass of the basalt except that generally the alteration has not proceeded so far. Iddingsite is

most

most common near the margins of the xenolith and starts along cracks and crystal borders and from these spreads into the olivine crystals. Much finely-granular, reddish-brown haematite is also seen, especially in the altered olivines. The whole of the marginal area of the xenolith has been broken up and shattered by lava tongues which form a ramifying network extending some distance into the xenolith. The process of crystal stoping is well demonstrated here by fragments of the marginal olivines preserved in the lava. Again the pyroxene and amphibole have been affected to a smaller degree than the olivines. Subsidiary veinlets from the lava tongues pass into the olivines and eventually the felspar microliths and augite disappear, leaving only nets of finely-granular black ores. Near the centre of the xenolith these themselves fade out into a train of gas bubbles or a single line of tiny twig and lobate forms of black ores which progressively decrease in size to the limit of visibility. Marginally the xenolith is also greatly enriched in iron where black ores pass directly into it from the lava along mineral cleavages and irregular cracks.

The xenolith is an AMPHIBOLE-OLIVINITE or AUGITE-TREMOLITE-PERIDOTITE enclosed in an OLIVINE-BASALT.

HK/27 in hand specimen is a dark slate-grey, finely vesicular lava with green crystalline xenoliths up to 2 cm. in diameter and isolated glassy bottle-green olivine phenocrysts up to 4 mm. long. In thin section the groundmass

is

is fine-grained and more felspathic than other specimens except HK/24. The felspar is labradorite, $Ab_{45}An_{55}$, which occasionally shows ophitic intergrowths with the augite of the groundmass . The augite usually occurs in small yellowish-brown prisms. Other minerals present in the groundmass are much magnetite and rare small olivines. Olivine occurs abundantly as phenocrysts which are unaltered except for the deposition of a slight amount of iron ores round their edges and along irregular cracks. It does , howerver, show some signs of embaymentx and corrosion. Rare euhedral microphenocrysts of colourless to purplish-brown titan-augite are present, but most of the pyroxene is found in the groundmass. The xenolith is similar in texture and grain size to previous examples and is made up of 75 % olivine and 25 % colourless to pale-green augite with an extinction angle $Z \wedge c$ of 46°. Small tongues of the invading lava occasionally spread out into bulbous forms within the xenolith. Such areas appear to be more augitic than the main mass of the lava. The only effect of the invading material on the xenolith is a certain amount of corrosion along its margins and the deposition of black iron ores.

The xenolith is an AUGITE-PERIDOTITE and the lava an OLIVINE-BASALT.

HK/28 is part of a large xenolith almost 2 feet in diameter, of a green, coarsely-crystalline, granular olivine-rich rock in a highly vesicular lava. The rock also contains green tains green augite and a little finely divided dark-brown to black garnet. The thin section contains some 50 % of clear colourless olivine, occasionally showing slight signs of serpentinisation, 30 % of very pale-green augite (2 V about 60$^{o}$ , optically positive and extinction angle Z c of 46$^{o}$) and a lesser amount of the colourless mineral referred to tremolite (cf. HK/20 and HK/25), with 2 V near 90$^{o}$, optically negative and with extinction angle $Z \wedge c$ of 19$^{o}$. Almandite is also present to the extent of some 3 to 5 % and shows the usual kelyphitic rim of granular augite occasionally associated with magnetite. Accessory magnetite is also present in the xenolith which shows no signs of alteration by the lava magma.

This rock is an AMPHIBOLE-OLIVINITE with GARNET or AUGITE-TREMOLITE-PERIDOTITE with GARNET.

(d) Summary of Petrology of (c).

The foregoing petrological descriptions are summarised in Table II and it appears that the xenoliths are representatives of the two series:-

(a) Dunite—Augite-peridotite—Olivine-pyroxenite and

(b) Dunite—Amphibole-olivinite (or Augite-tremolite-peridotite ), with up to 5 % of almandine, as shown below:-

Olivine-pyroxenite

↓

Olivine-pyroxenite + Garnet
35 % Olivine, 60 % Augite, 5% Garnet.

Augite-peridotite
75 % Olivine, 25 % Augite.
50 % Olivine, 50 % Augite.

↓

Augite-peridotite + Garnet.
50 % Olivine, 45 % Augite, 5 % Garnet.

DUNITE
95 % Olivine
5 % Augite

Augite-tremolite-peridotite + Garnet
or
Amphibole-olivinite + Garnet
50 % Olivine, 30 % Augite, 15 % Tremolite,
5% Garnet.

↑

Augite-tremolite-peridotite
or
Amphibole-olivinite
50 % Olivine, 25 % Augite, 25 % Tremolite.

Facilities for the carrying out of chemical analyses and detailed micrometric measurements were not available so that evidence of a complete gradational series cannot be established.

The enclosing lavas show variations in the amounts of augite, olivine and felspars and in the composition of the felspars. They have all been classed as olivine-basalts but it is considered possible that more detailed

petrological

TABLE I - SUMMARY OF PETROLOGICAL DESCRIPTIONS OF PART III (c).

| HK/20 | HK/21 | HK/27 | HK/22 | HK/24 | HK/25 | HK/28 |
|---|---|---|---|---|---|---|
| ENCLOSING LAVA | | | | | | |
| Gm. augitic with black Fe. ores & rare small ols. & tiny microliths plagioclase (n.d.). | Gm. augitic with black ores, no. ols. & microliths of plagioclase (n.d.) | Gm. augitic with black Fe. ores, rare ols., microliths of labradorite $Ab_{45}$ larger and commoner | Gm. augitic with black ores, no ols. & tiny microliths plag.-Andesine $Ab_{57}$ Interstitial orthoclase.(?) | Gm. augitic with black ores, no ols. microliths Labradorite- $Ab_{40}$ commoner & larger. | Gm. augitic with red haematite, no ols. microliths Andesine $Ab_{33}$. | NO LAVA SECTION. |
| Corroded phenocrysts ol. | Corroded phenocrysts ol. | Corroded phenocrysts ol. | Corroded phenocrysts ol., occasional tiny augites radial to ols. | Smaller corroded phenocrysts ol. | Corroded phenocrysts ol. pseudomorphed by iddingsite. | |
| Euhedral titan-augites. | Euhedral titan-augites, $Z \wedge c = 40^\circ$. | Micro-phenocrysts augite rare. Olivine slightly serpentinised. | Euhedral titan-augites $Z \wedge c = 33^\circ$. | Augites rarer. | Augites rarer. Iddingsitisation very pronounced, haematite replaces usual magnetite. | |
| OLIVINE-BASALT | OLIVINE-BASALT | OLIVINE-BASALT | OLIVINE-BASALT | OLIVINE-BASALT | OLIVINE-BASALT | |
| XENOLITHS | | | | | | |
| 35 % Ol., 60 % Aug. $Z \wedge c = 40^\circ$ 3-5% Almandite with kelyphitic rims. | 50 % Ol., 50 % Aug. Aug. $Z \wedge c = 40^\circ$. | 75 % Ol., 25 % Aug. Aug. $Z \wedge c = 46^\circ$. | 50% Ol., 45% Aug. $Z \wedge c = 48^\circ$, 5% Almandite with kelyphitic rims. | 95% Ol., 5% Aug. | 50% Ol., 25% Aug. $Z \wedge c = 45^\circ$, 25% Tremolite $Z \wedge c = 15^\circ$. Enrichment in Fe. very pronounced. Olivine partly iddingsitised. | 50% Ol., 30% Aug $Z \wedge c = 46^\circ$, 15% Tremolite $Z \wedge c = 19^\circ$, 3 - 5% Almandite with kelyphitic rims |
| Accessories:- Tremolite, black Fe. ores, colourless polysynthetic twinned mineral with straight extinction, $2V = 30^\circ - 70^\circ$, optically negative, $\mu$ between 1.54 & 1.66. | Rare almandite-no Kelyphitic rims, black Fe. ores | Fe. ores | Fe. ores | Fe. ores, rare almandite, no kelyphitic rims, pleochroic zircons. | Rare almandite, Fe. ores. | Fe. ores. |
| OLIVINE-PYROXENITE WITH GARNET (ref. GORDUNITE). | AUGITE-PERIDOTITE | AUGITE-PERIDOTITE. | AUGITE-PERIDOTITE with GARNET. | DUNITE. | AMPHIBOLE-OLIVINITE. | AMPHIBOLE-OLIVINITE with GARNET |

petrological and chemical work would show them to have affinities with the Absarokite-Shoshonite series of Holmes' and Harwood's Bufumbira Memoir (1936), though orthoclase has not been positively identified in any section. Changes in the original composition of the lava magma have no doubt been effected by the absorption of some of the xenolithic material.

In conclusion I wish to express my thanks to the Commissioner of Mines and the officers of the Mining and Geological Department of Kenya who provided facilities for the cutting of slices, microscopic examination and the use of the Library.

## IV- REFERENCES TO LITERATURE.

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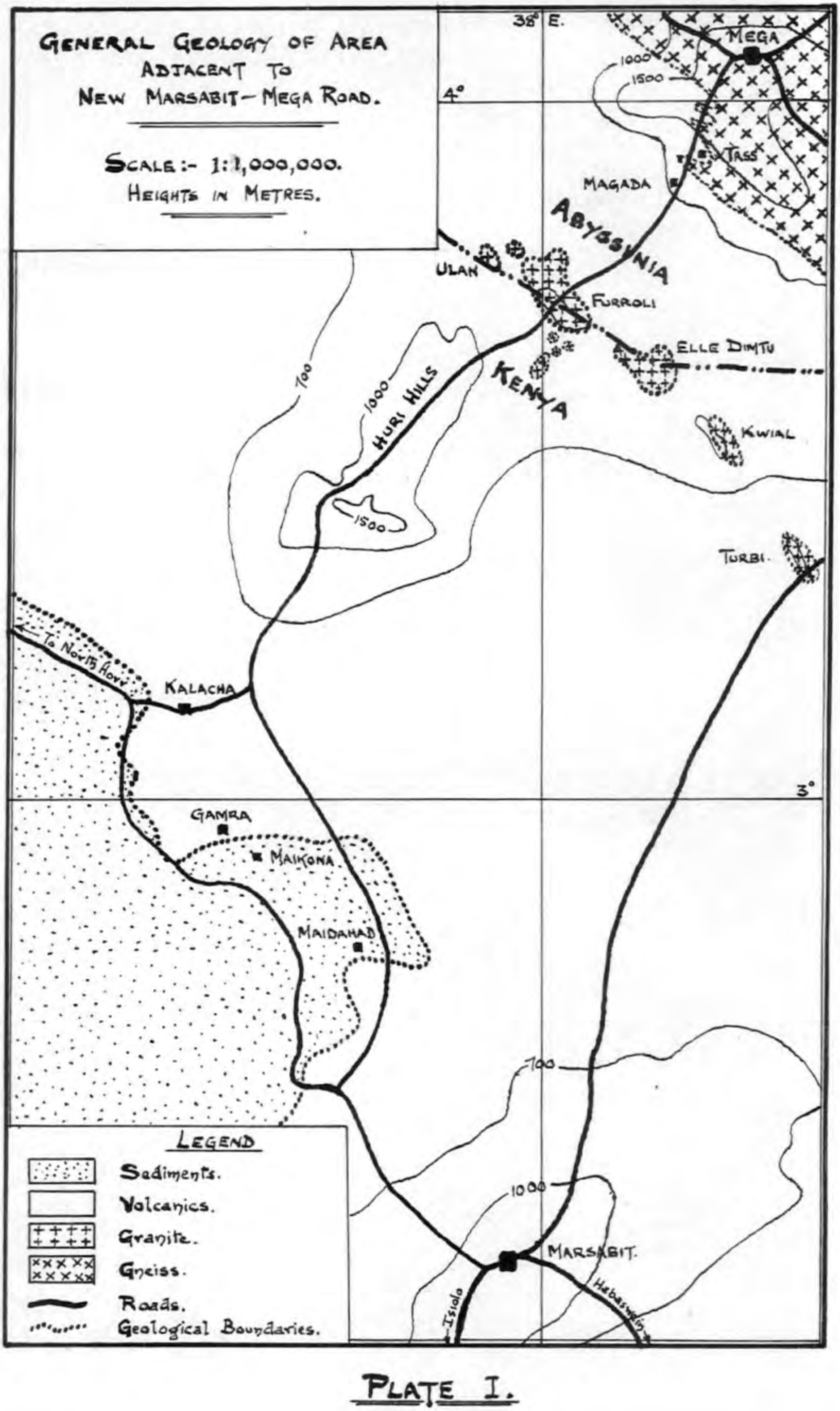
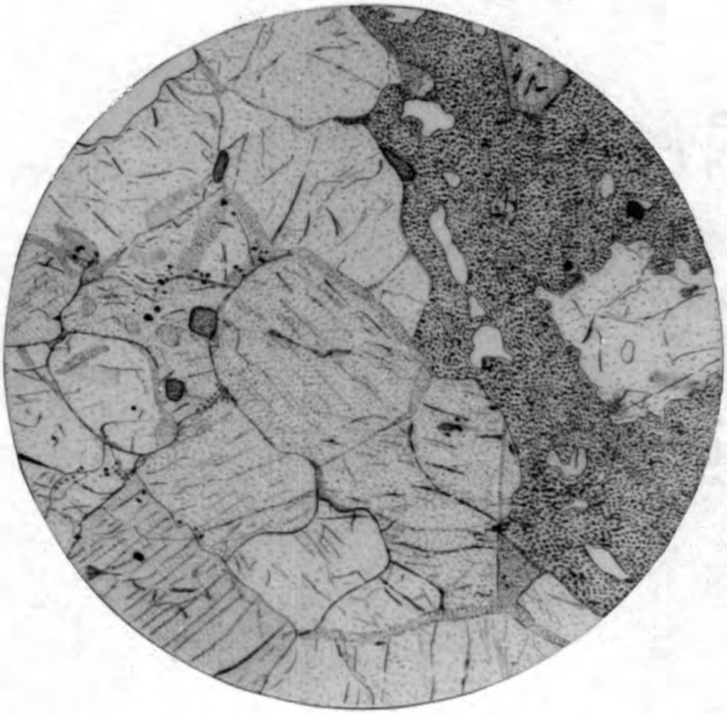

GENERAL GEOLOGY OF AREA
ADJACENT TO
NEW MARSABIT – MEGA ROAD.
SCALE :- 1:1,000,000.
HEIGHTS IN METRES.
38° E.
4°
3°
MEGA
1000
1500
TASS
MAGADA
ABYSSINIA
ULAN
FURROLI
ELLE DIMTU
KENYA
KWIAL
700
1000
HURI HILLS
1500
TURBI.
To North Horr
KALACHA
GAMRA
MAIKONA
MAIDAHAD
700
1000
MARSABIT.
Isiolo
Habaswein
LEGEND
Sediments.
Volcanics.
Granite.
Gneiss.
Roads.
Geological Boundaries.

PLATE I.

PLATE II.



HK/21 x 36 (Ordinary light. Camera Lucida drawing).

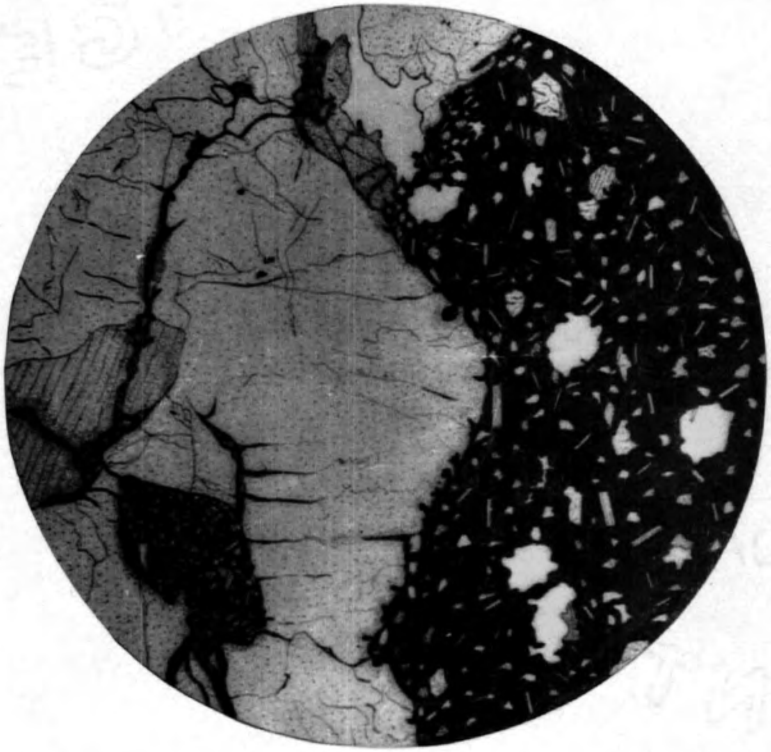
AUGITE-PERIDOTITE xenolth in a finely vesicular OLIVINE-BASALT. Xenomorphic olivines and augites(diopsidic), slightly altered along cracks and crystal boundaries near the border by invading tongues of the lava groundmass. Deposition of black iron ores on the border of the xenolith gives a dusty appearance to the olivines. Corroded phenocrysts of olivine and euhedral zoned titan-augites set in an augitic groundmass with much iron ore and occasional microliths of plagioclase felspar. Accessory almandine in xenolith.

PLATE III.

EK/22 x 36. (Ordinary light. Camera Lucida drawing).

AUGITE-PERIDOTITE xenolith in fine-grained OLIVINE-BASALT. Xenomorphic olivines and augites slightly altered along cracks by invading material from the groundmass of the lava. Black rimmed almandine with patchy kelyphitic bands common in the xenolith. Little accessory iron ore. Corroded and skeletal olivine phenocrysts common in basalt with zoned titan-augites smaller and rarer, set in an augitic groundmass, heavily sprinkled with iron ores and some microliths of plagioclase felspar.

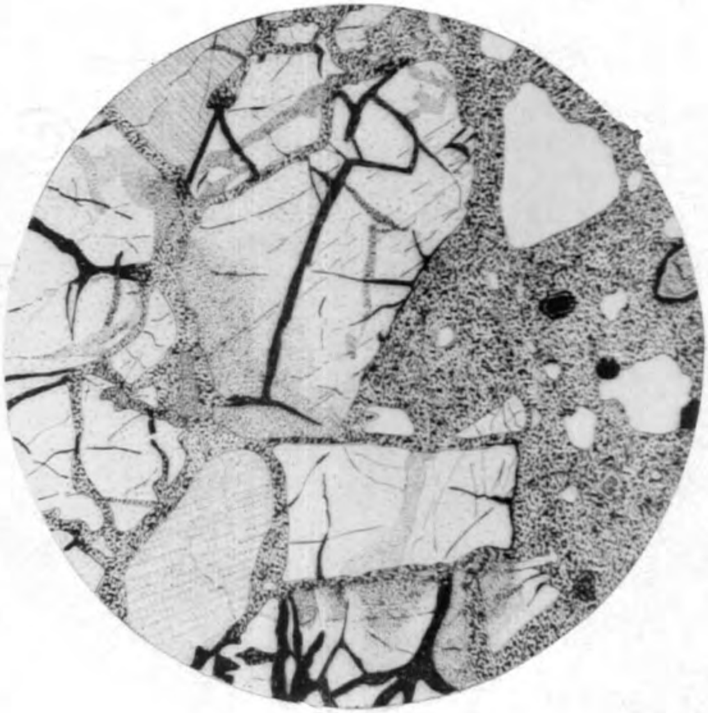
PLATE IV.



HK/24 x 38. (Ordinary light. Camera Lucida drawing).

DUNITE xenolith in vesicular OLIVINE-BASALT.
Tongues of the lava groundmass have invaded the xenolith along cracks in the olivines. Deposition of iron ores along borders of these tongues and strings of gas bubbles into the olivines. Augitic groundmass heavily sprinkled with ores and shows corroded phenocrysts of olivine with microphenocrysts of titan-augite and microliths of plagioclase felspar.

PLATE V.



HK/25 x 35. (Ordinary light. Camera Lucida drawing).

AMPHIBOLE-OLIVINITE (or AUGITE-TREMOLITE-PERIDOTITE) xenolith in highly vesicular OLIVINE-BASALT. Tongues of the lava groundmass have invaded the xenolith along the crystal boundaries of the olivines. The tongues fade out into iron ores as they pass further into the xenolith. Alteration of the olivines to iddigsite and the depositio of haematite well developed. Strong deposition of black iron ores on the margin of the xenolith and crystal stoping prominent. Augitic groundmass heavily sprinkled with haematite, shows iddingsitisation of olivine phenocrysts with rim of second generation olivine bordering almost completely altered phenocrysts. Also rare microliths of plagioclase felspar and microphenocrysts of second generation olivine.

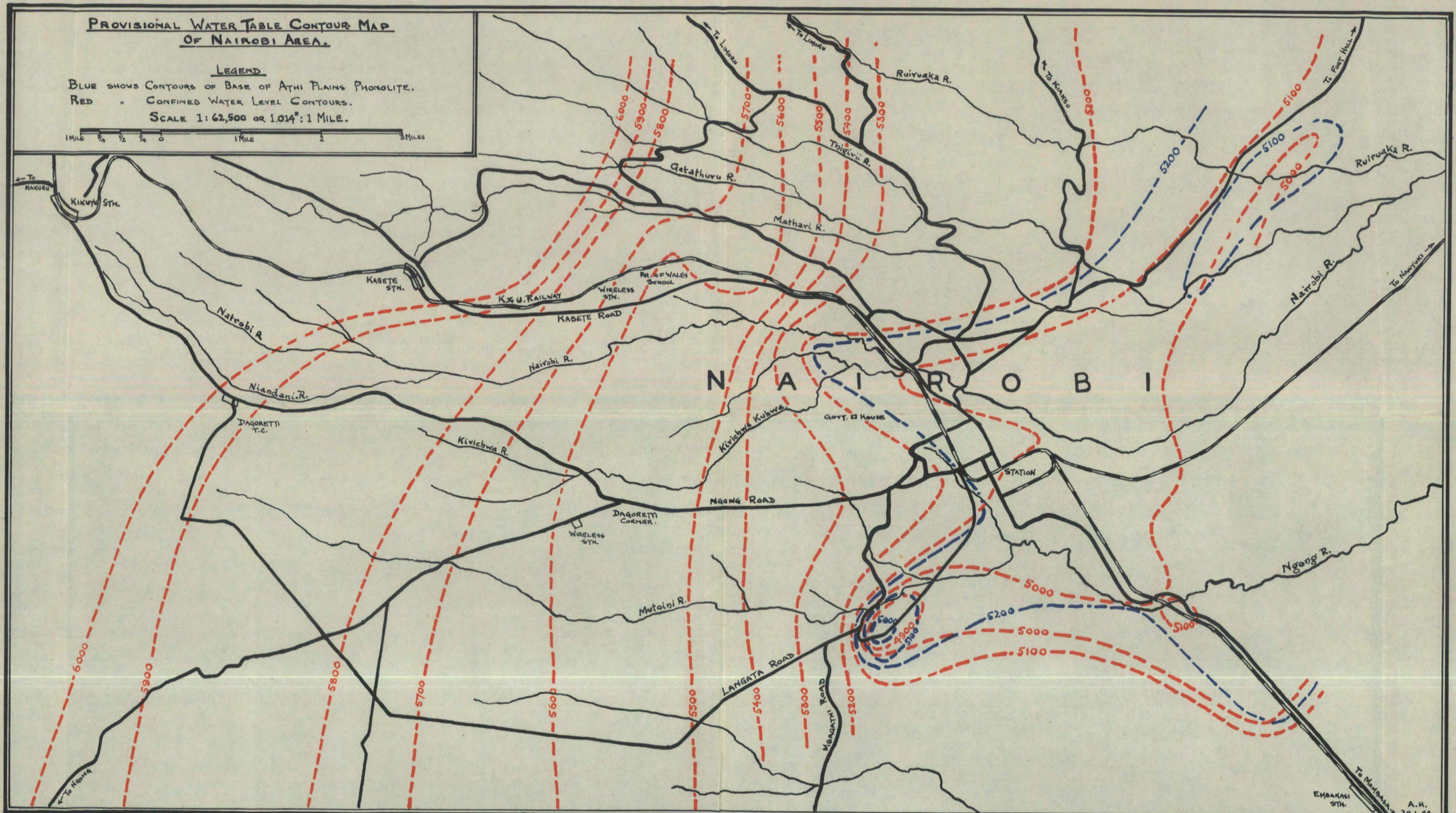



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PLATE III.

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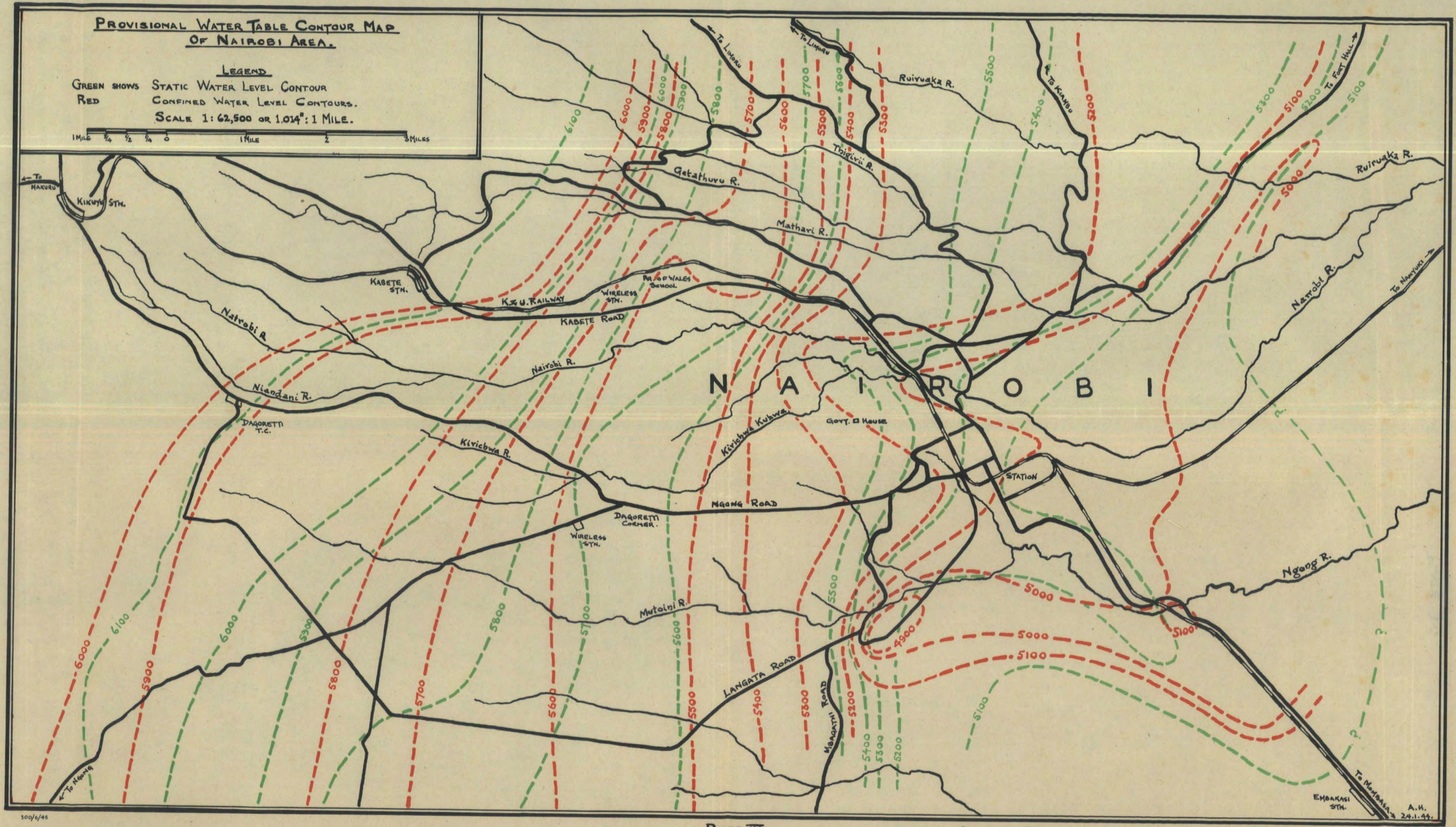


**Plate IV.**

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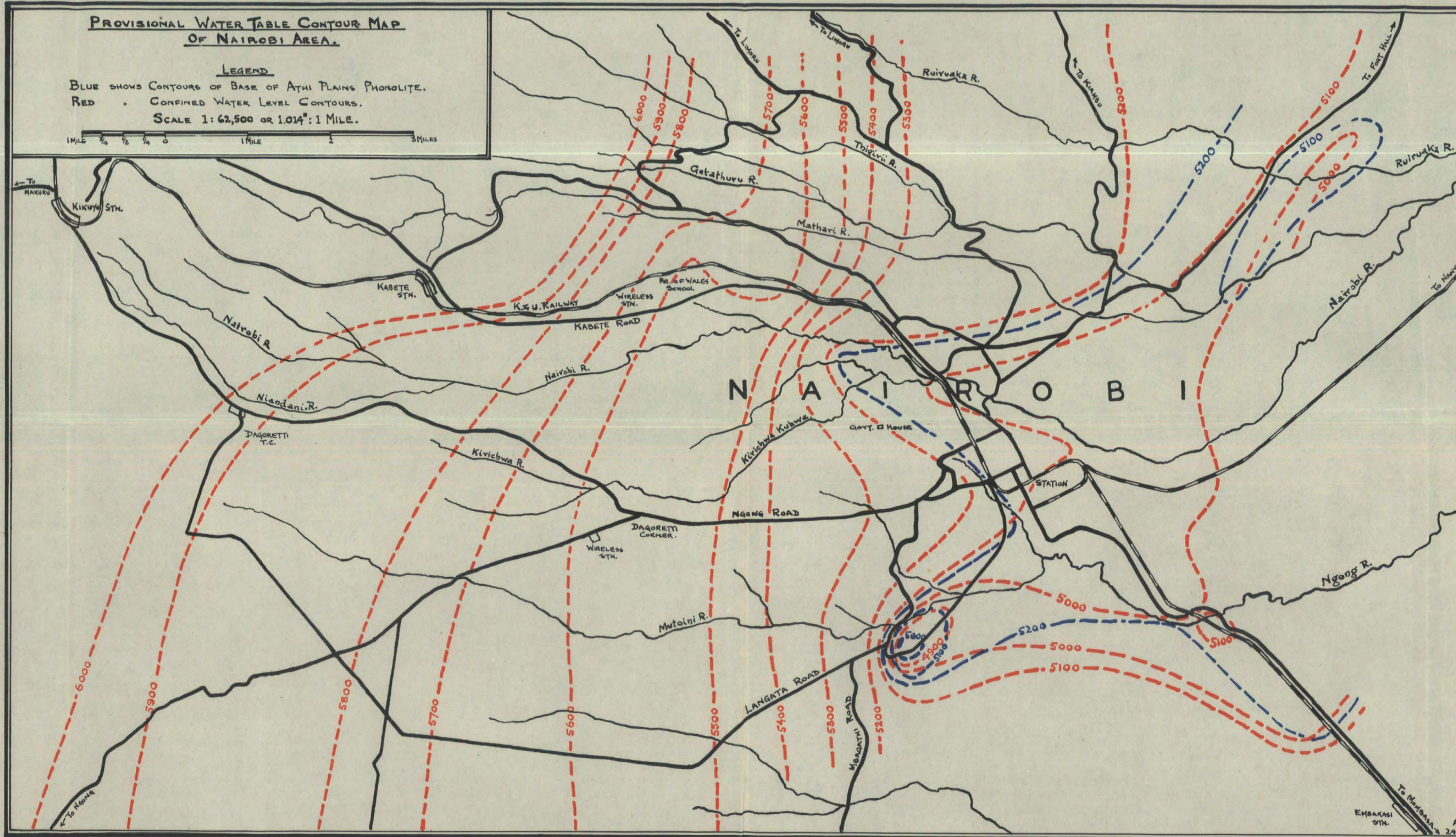


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Plate III.

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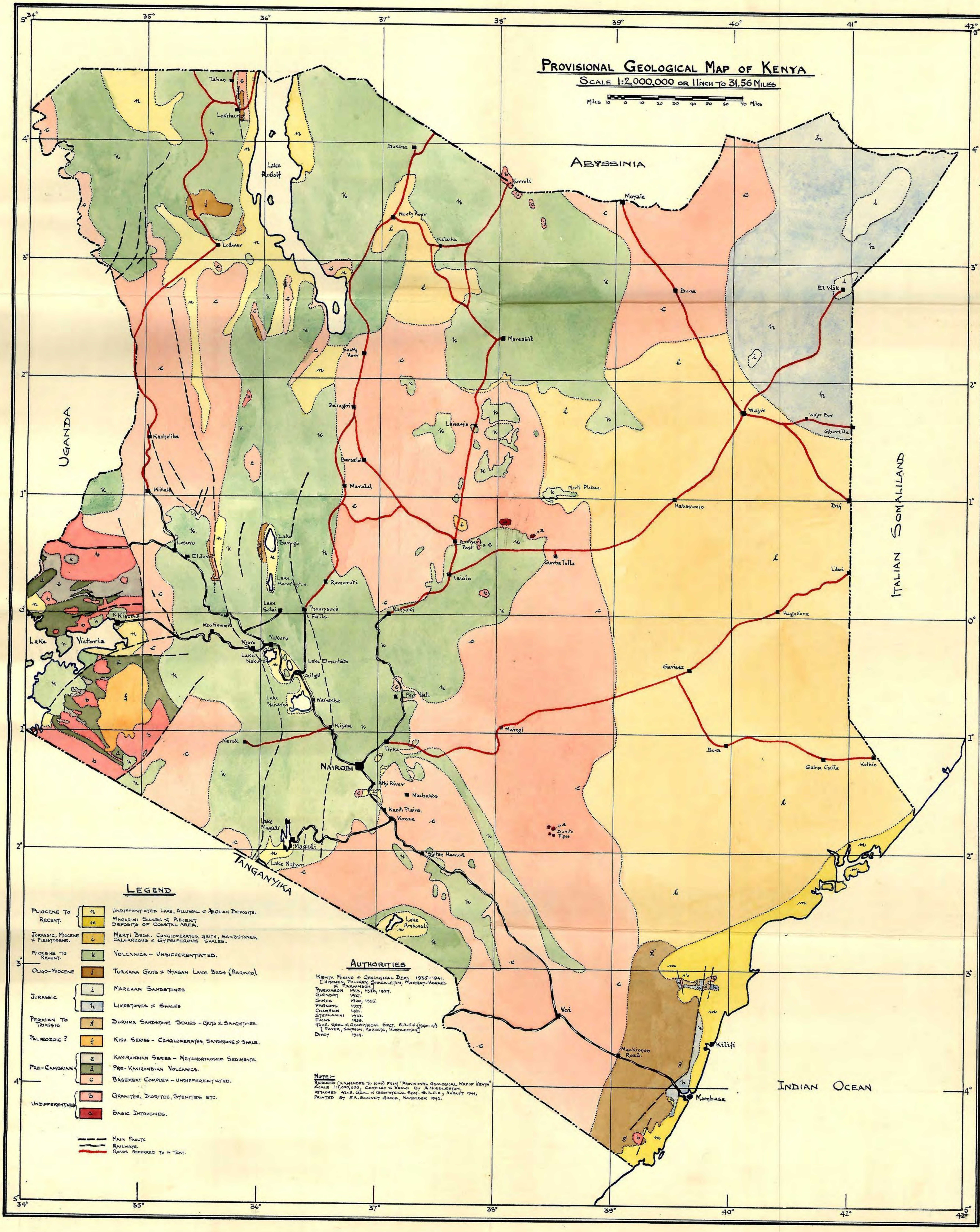

Provisional Geological Map of Kenya
Scale 1:2,000,000 or 1 Inch to 31.56 Miles
Miles 10 0 10 20 30 40 50 60 70 Miles
Abyssinia
Uganda
Italian Somaliland
Tanganyika
Indian Ocean
Lake Rudolf
Lake Victoria
Nairobi
Mombasa
Legend
Pliocene to Recent. n Undiffentiated Lake, Alluvial & Aeolian Deposits.
m Magarini Sands & Recent Deposits of Coastal Area.
Jurassic, Miocene & Pleistocene. l Merti Beds. Conglomerates, Grits, Sandstones, Calcareous & Gypsiferous Shales.
Miocene to Recent. k Volcanics – Undifferentiated.
Oligo-Miocene j Turkana Grits & Nyasan Lake Beds (Baringo).
Jurassic i Marehan Sandstones
h Limestones & Shales
Permian to Triassic g Duruma Sandstone Series – Grits & Sandstones.
Palaeozoic ? f Kisii Series – Conglomerates, Sandstone & Shale.
Pre-Cambrian e Kavirondian Series – Metamorphosed Sediments.
d Pre-Kavirondian Volcanics.
c Basement Complex – Undifferentiated.
Undifferentiated b Granites, Diorites, Syenites etc.
a Basic Intrusives.
Main Faults
Railways.
Roads Referred to in Text.
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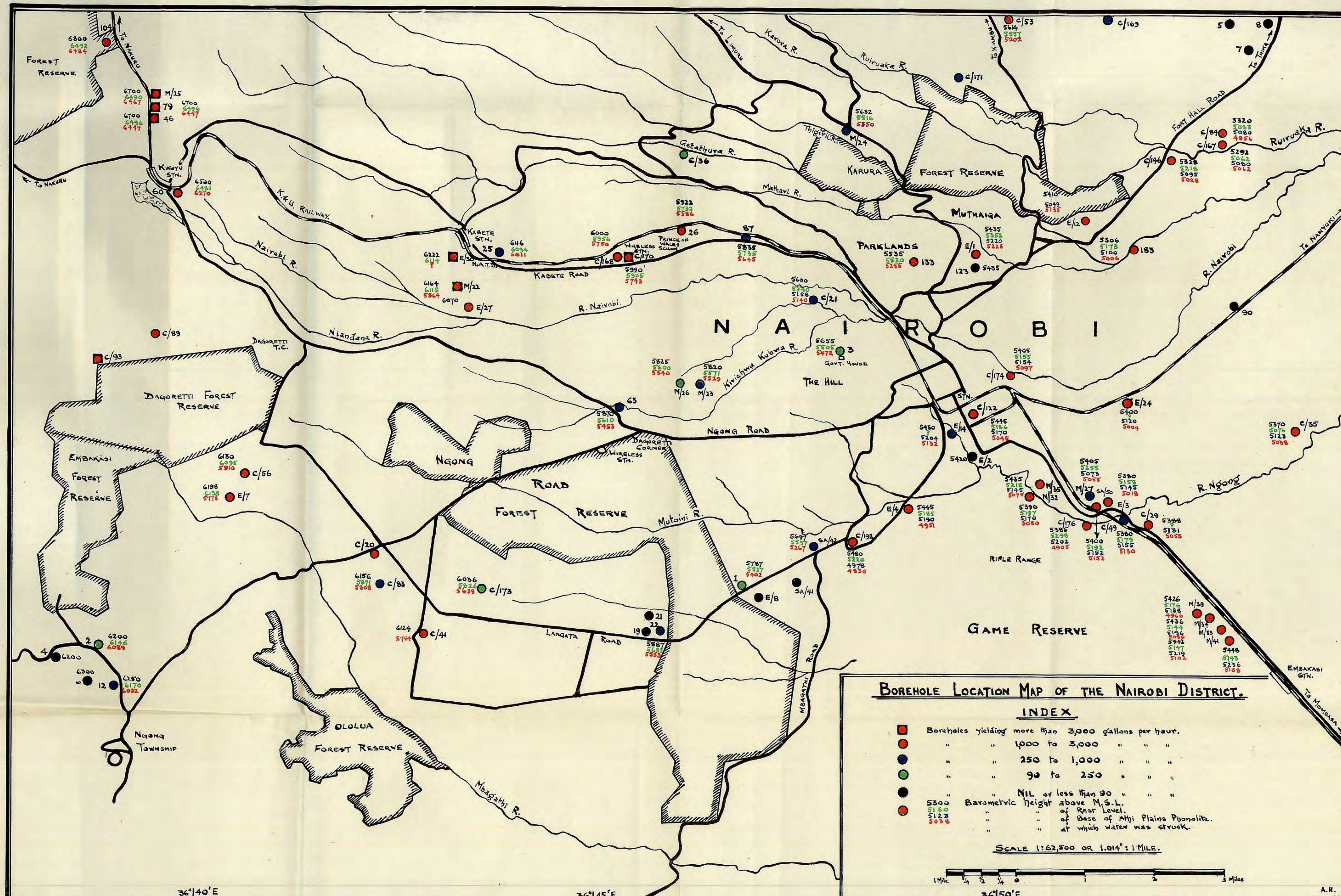
Dixey 1944.
Note:-
Reduced (& amended to 1944) from "Provisional Geological Map of Kenya" Scale 1:1,000,000, Compiled & Drawn by A. Huddleston, Attached 42nd. Geol. & Geophysical Sect. S.A.E.C., August 1941, Printed by E.A. Survey Group, November 1942.




500/8/45.

PLATE V.

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