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MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

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GEOLOGY OF THE NYERI AREA

(with colored geological map)

by

R.M. Shackleton, B.Sc. Ph.D., F.G.S. Geologist

First print 1945

Reprint 2007

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GEOLOGY OF THE NYERI AREA

I—INTRODUCTION

A rapid geological survey of the district around Nyeri was carried out early in 1945, partly in order to determine whether the geological structure between Mt. Kenya and the Aberdare Range was such that artesian water was likely to occur there. This report deals with the geology of the Nyeri quarter-degree sheet, which was surveyed in more detail than the surrounding areas. The limits of the sheet are the equator, 0° 30' S., 36° 30' E., and 37° 30' E.; it has an area of a little less than 1,200 square miles. Eleven weeks were spent in field work in this area; reconnaissance traverses were also made of surrounding areas to obtain a general idea of the structure of the areas where it had been hoped to find artesian water.

Maps.—The 1:125,000 Nyeri Sheet (Africa South A-37/A II), published in 1909 by the Geographical Section of the General Staff, was used as the topographic basis of the map of the Nyeri District. A large part of the area, covered by the Aberdare forests, is represented so inaccurately on the topographic map that no scruple was felt in altering lines to give a closer approximation to reality. No systematic topographic surveying was carried out, but a plane-table sketch map was made of the parts of the northern Aberdares above the forests. In the settled areas, geological data were usually plotted on the 1:62,500 cadastral sheets published by the Lands and Survey Department. A few heights have been re-determined by officers of the Survey Unit, East Africa Command; the new values have been incorporated in the map. The most important is Sattima, the elevation of which, at a point a few feet from the summit, was determined as 13,104 feet.

Acknowledgment is gratefully made for hospitality and assistance received from many people in the area. Particular thanks are due to Mr. Raymond Hook of Nanyuki, who organized mule transport on the Aberdare Range and Mt. Kenya, and gave me much useful information.

II—PREVIOUS GEOLOGICAL WORK

Gregory crossed southern Laikipia on his 1893 expedition. He was forced to hurry, but was able to see that the phonolites which he had traversed on his way from Lake Baringo passed beneath basalt sheets beyond the Ngobit River. He continued over these basalts to the foot of "a high down-like hill, Songari", which, he wrote "consists of a coarse phonolite with large crystals of anorthoclase and nepheline and rare olivine; this rock belongs to the Kapitian phonolites of the Kapiti Plains, but is a more basic variety". (Gregory, 1921, p. 136.)

Other rapid traverses were made by Gregory in 1919, from Naivasha to Songari Hill, and from Nyeri along the old Meru road. From the combined observations of these traverses the following Laikipian succession was deduced (*ibid.*, p. 143):—

Naivashan	..	Phonolitoid kenyte of Nyeri, etc.
Laikipian	..	Quartz trachyte and rhyolite. Phonolitic trachytes. Basalts and basanites and lower phonolitoid kenyte.
Nyasan	..	Unconformity.
Doinyan	..	Kenya type of phonolite and kenyte intrusions (Domo Arabel). Losaguta type of phonolite.
Kapitian	..	Coarse porphyritic phonolite.

Maufe also recorded details of a traverse across the area from Nyeri to Rumuruti. Besides basalts, the only rocks mentioned were a tuff quarried at Nyeri for building, and a coarse agglomerate in the bottom of the Amboni valley, beneath the basalts. (Maufe, 1908, p. 39.)

The rocks collected by Gregory were classified by Miss Neilson (Gregory, 1921, Appendix IV). The classification of these and some other rocks was revised, with the support of more analyses, by Campbell Smith (1931). A rock from the Amboni valley near Songari Hill was analysed and described as representing Neilson's "phonolite of

Kapitian type", but as it was recognized that this rock was petrographically identical with some of the rocks of Mount Kenya described as kenytes by Gregory, his distinction between kenytes and the phonolites of Kapiti type seemed to have no petrographic basis and to rest only on field evidence. A phonolite from a stream south of the Guaso Lashau (Suguroi River) was shown to be typical of the Mount Höhnel (or Kenya) type. The basaltic rocks were found to include fayalite-bearing phonolite (Nyeri Hill), fayalite-bearing alkali-trachyte (Guru Bridge on the Nyeri-Naivasha track), nepheline-basanite (south of the Ngobit River) and trachybasalts (Suta River south of Nyeri, and east of the Amboni River on the old Nyeri-Meru road).

III—SUMMARY OF THE GEOLOGICAL SUCCESSION

The principal groups of rocks distinguished in the area are:—

- (1) Simbara Series.
- (2) Sattima Series.
- (3) Thomson's Falls phonolites.
- (4) Kinangop trachytic tuffs and Nyeri tuff.
- (5) Laikipian basalts.
- (6) Rocks of the Laikipia vents.
- (7) Mt. Kenya Volcanic Suite.
- (8) Pleistocene and Recent superficial deposits.

A summary of their general features is given below. A more detailed description of their occurrence and character in different parts of the area is given in Section V and their age and correlation are discussed and tabulated in Section IV of the report.

(1) *The Simbara Series*

In the northern Aberdares, on Kipipiri and in valleys near the south-eastern edge of the area, the oldest exposed volcanic rocks are basaltic lavas and agglomerates of a distinctive type. They are here referred to as the Simbara Series after the area where they are best exposed. The principal centres of eruption of these basalts were near Sattima, and Kipipiri. Closely similar basalts were erupted, probably during the same volcanic phase, at Niandarawa and Kijabe Hill. Denudation has long ago removed any trace of the craters of these volcanoes and other lavas have been erupted on and around them.

Most of the lavas are of the Kijabe type basalt (*see p. 16*) with abundant parallel plagioclase phenocrysts. Some melanocratic basalts associated with the Kijabe type basalts have not been included in the Simbara Series on the map because their limits were not defined and similar lavas occur at other horizons. In Simbara, innumerable dykes of Kijabe type basalt, quartz trachyte and phonolite, cut the Simbara Series. Radial dykes converge towards a point a little south of Sattima and the lavas dip outwards from this focus.

Away from the eruptive centre, agglomerates predominate over lava flows. The blocks in these agglomerates are of Kijabe type basalt and melanocratic basalt with olivine and augite crystals, and scarcer basalts of other types. These agglomeratic rocks are exposed by the Amboni and Chania rivers, and have been seen also further south as far as Sabasaba and Makindi. (*See Fig. 1.*)

(2) *The Sattima Series*

The Simbara basalts are overlain, on and around Simbara, by fissile pale-weathering lavas, identified as phonolites, olivine alkali-trachytes, mugearites, and fissile basalts. A sheet of porphyritic quartz trachyte, the "Dragon's Teeth Trachyte", is closely associated with the lavas of the Sattima Series but it is at least partly intrusive.

There was probably an interval between the eruptions of the Simbara basalts and the lavas of the Sattima Series, as the contact between the two is everywhere sharp, and not one of the many dykes traversing the Simbara Series was seen to enter the Sattima Series. Nevertheless some of the dyke rocks closely resemble the Sattima Series lavas, and may represent their feeders.

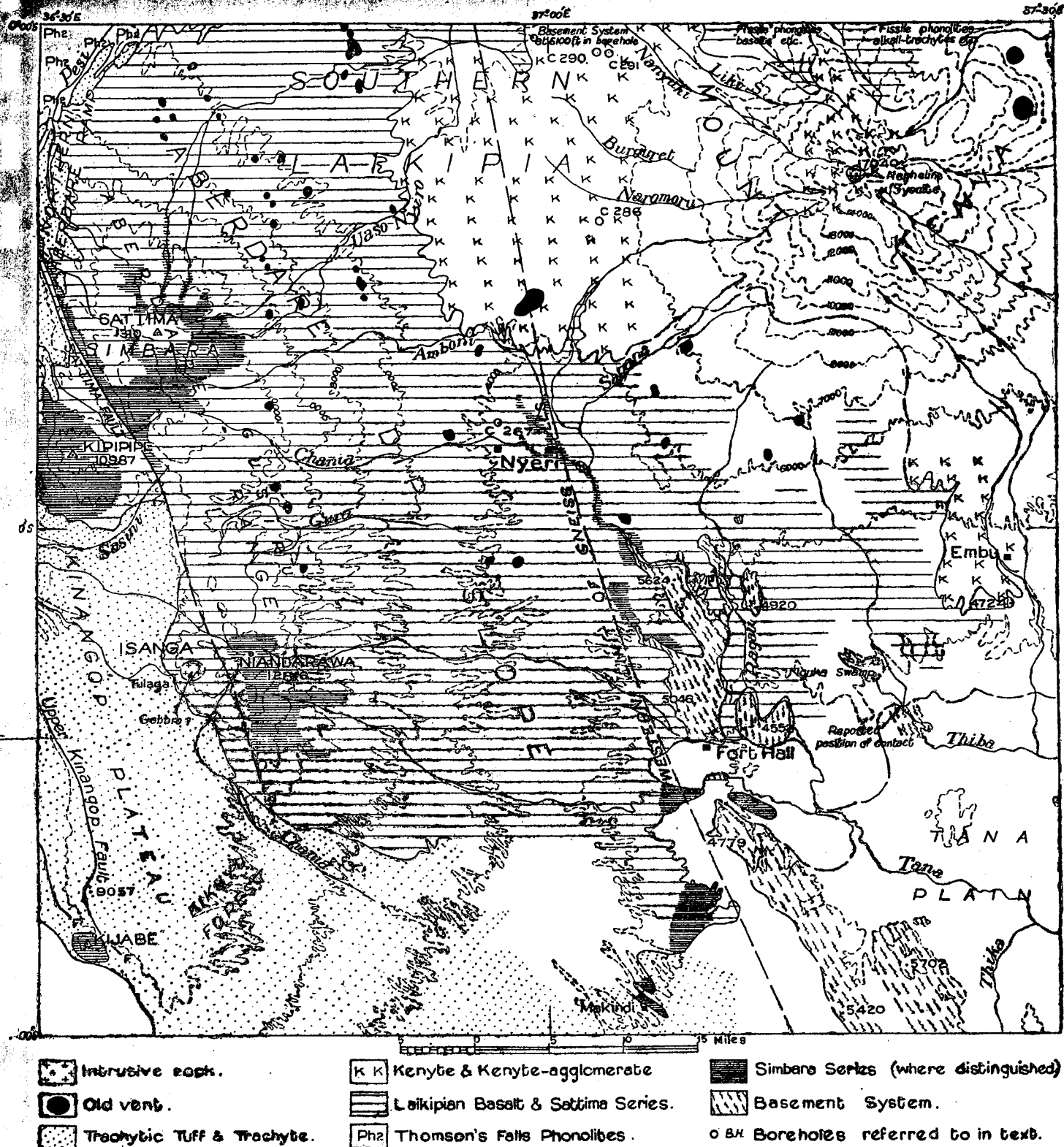


FIG. 1
Geological Sketch-map showing Mount Kenya and the Aberdare Range

The Sattima Series has not been recognized except in Simbara. Looking from above into the valleys that lead down through the Aberdare forests it appears as though the fissile lavas dip more steeply than the fall of the ground and therefore disappear beneath the Laikipian basalts of which most of the country below the forests is formed.

(3) *The Thomson's Falls Series*

In the north-western part of the area, a distinct and rather uniform series of phonolitic lavas overlies the Simbara basalts. These phonolites have a twisted flow-structure which gives their outcrops a distinctive irregular appearance. Closer examination shows small anorthoclase crystals, and often characteristic knobby inclusions of phonolite slightly different in texture and colour from the matrix. Where freshly broken the rocks are grey and glisten from minute parallel plates of felspar. Microscopically they are found to be phonolites of the Kenya type.

They appear to have been erupted from the Rift Valley region.

(4) *The Kinangop Tuff Series and the Nyeri Tuff*

These are light-coloured trachytic pumice tuffs. The main development of the Kinangop tuffs is outside the area. The sections on the Kinangop scarps east of Naivasha show hundreds of feet of trachytic tuffs, and water-lain stratified tuffs, as well as some trachytes. In the area of this report, no such thicknesses are exposed. Along the rivers flowing towards the Kinangop from the Sattima scarp and Kipipiri, rough grey-weathered unstratified tuffs are exposed. Fragments of obsidian, speckled trachyte resembling the Nairobi Trachyte, and other lavas, project on the weathered surfaces from the softer buff-coloured matrix of comminuted pumice. In the slides this pumice is seen to have a warm brown or purplish-brown tint. It is fibrous or minutely frothy. In the more crystalline trachytic fragments in the tuff, small poecilitic patches of quartz can be distinguished. The tuffs are probably pantelleritic.

The Kinangop tuffs underlie the Kinangop and Ol Bolossat plains and towards the north they are underlain by the Thomson's Falls phonolites. Precisely similar tuffs are again exposed at the top of the northern part of the Sattima fault scarp and on the northern Aberdare ramp, where again they rest on the Thomson's Falls phonolites. They appear to thin to a feather edge against the flank of the older volcanic pile composed of the Simbara basalts and the Sattima Series. Further north-east, by the Pesi River, the same series of trachytic tuffs, diminished to about 70 feet in thickness, underlies one of the Laikipian basalts; still further north-east, the tuff is exposed in the Suguroi valley, where it is quarried. There again it rests on the Thomson's Falls phonolites, and is overlain by Laikipian basalts. In the floor of the Ngobit valley similar trachytic tuff appears from beneath the Laikipian basalts for a short distance. There is then a twenty-five mile gap, without exposures of any such tuffs, until the Nyeri country is reached. There a trachytic tuff, petrographically similar to the Kinangop tuffs, is again found. It lies between the Simbara Series below and the Laikipian basalts above. It is correlated, with some hesitation, with the Kinangop tuff Series.

(5) *The Laikipian Basalts*

Gregory gave the name Laikipian to the Series of basalts which he observed overlying the phonolites in southern Laikipia. The term has been retained here (although it cannot at present be accurately defined), because the basalts which Gregory called Laikipian are mostly of one type and rocks of this type have a wide distribution in the area. It is clear that Gregory's term should not be used to include the Simbara Series, since it was intended for the basalts which overlie the phonolites, whereas the Simbara basalts underlie them. It is not so clear whether the Laikipian should include also the Sattima Series into which the typical Laikipian basalts seem to pass by alternation, but as the Sattima Series includes phonolites, and is probably itself mainly older than the Thomson's Falls Series, it seems that it should be excluded from the Laikipian. Thus restricted, the Laikipian includes in the type area a series of basalts, most of which are either non-porphyrific or contain very small specks of olivine. Many of them show a characteristic hackly fracture and in the majority of flows there is a widely spaced columnar jointing. Examination under the microscope shows that olivine alkali-basalts and analcite-basanites are the commonest types.

Most of the waterfalls in the district occur where columnar Laikipian basalts have been undercut. Examples are those on the Chania just above Nyeri, and others in the Aberdare Forest; the Amboni Falls just below the Nyeri-Nanyuki road; and several falls on the Zuka Zuka and Moyo rivers above their confluence.

The Laikipian basalts probably erupted from numerous small volcanoes, the stumps of which are a conspicuous feature of southern Laikipia. Similar basalts, referred to the same Series, occur high up on Simbara, especially on the western flank.

The Laikipian basalts are mainly developed east of the Sattima fault, but there is also a thick series of columnar non-porphyrific basalts of Laikipian type, exposed in the Wainjohi gorge north-east of Kipipiri, and similar basalts occur in the intermediate fault strip between the two branches of the Sattima fault.

Typical Laikipian basalts are seen to overlie the Kinangop tuff Series near the Pesi River, near the Mutara, and along the Suguroi. Their distribution suggests that they were there erupted on to a surface which was tilted towards the east with the result that they did not spread over the surface of the Kinangop tuffs of the Ol Bolossat plains.

The main mass of the Laikipian basalts is believed, for reasons stated below, to overlie the kenyte agglomerates of the Mount Kenya Suite, but the earliest of them are clearly seen to pass beneath the kenyte agglomerates in the Amboni valley. The kenytes were therefore erupted early in Gregory's Laikipian stage. As the Mount Kenya rocks were the chief representative of his Doinyan Series, supposed to be earlier than the Laikipian, it is obvious that this part of his classification is confused. Furthermore, the kenyte of the Amboni valley was identified by Gregory as Kapiti phonolite and so referred to his Kapitian stage.

(6) *Rocks of the Laikipian Vents*

Many small isolated hills rise abruptly from the otherwise smoothly undulating surface of southern Laikipia. These represent old volcanic vents. Few, if any, retain any trace of their original craters. Erosion acting on the scoriaceous lavas and pumiceous tuffs of which they are chiefly built has destroyed their original form and only the stumps remain.

The rocks of most of these vents are basaltic. Some are hackly basalts, either non-porphyrific or with small brown altered olivines. Others are highly porphyritic with abundant olivines and augites. Reddish basaltic tuffs usually occur on and around the vents.

Nyeri Hill and Songari consist of trachytic rocks. The Nyeri Hill rock was identified by Campbell Smith (1931) as a fayalite-bearing phonolite. On the northern slopes of Songari there are grey, fissile fine-grained trachytes, but near the triangulation point there is a very small outcrop of kenyte. The higher southern summit was not traversed during this survey, but Gregory who states that Songari Hill is kenyte, probably refers to the southern summit.

Rarely fragments of gneiss have been blown out of the vents, and a piece of Kijabe type basalt, indicating the presence of the Simbara Series below, was collected from a tuff at the side of Ol Doinyo Narasha.

The date of the last eruption of one of the Laikipian vents may be known when some fossils discovered in a basaltic tuff near the Moyo River have been identified (*see* p. 12). In the opinion of Dr. Leakey, they may be either Lower or Middle Pleistocene, but probably the former.

(7) *The Mount Kenya Suite*

The north-eastern part of the area is a gently rolling plain, traversed by shallow rather featureless valleys, along the sides of a few of which there are discontinuous exposures of agglomerates with blocks of kenyte and green fissile phonolite. Near the Amboni and one of its tributaries, kenyte lava is exposed. Fissile phonolites were seen by a stream about five miles north by west of Nyeri Station, and in a single outcrop on the slope north of the Naromoru river. From such scattered outcrops, the extent of the area underlain by these various rocks can be approximately determined. The only place where their contact with the Laikipian basalts was actually seen was on the north side of the Amboni valley, where kenyte agglomerates and lava overlie a basalt

of Laikipian type. The whole of the western boundary shown on the map is conjectural. It is drawn on the assumption that the Laikipian basalts which outcrop along a low scarp, overlie the kenyte agglomerates of the low ground east of it.

The kenyte agglomerates and lavas, and the phonolitic lavas mentioned, are part of a continuous field of such rocks which can be followed up the lower slopes of Mount Kenya, so that there is no doubt that they were erupted from the former Mount Kenya volcano. Pieces of nepheline syenite like that of the central plug of Mount Kenya are sometimes found in the agglomerate.

The kenyte agglomerates by the Amboni River near the Nyeri-Rumuruti road, rest directly on agglomerates of the Simbara Series. Further down the Amboni, on the other hand, there are a series of basalt flows of Laikipian type between the Nyeri tuff below and the kenyte agglomerates above.

(8) *Pleistocene and Recent Superficial Deposits*

These are thin unconsolidated or semi-consolidated deposits which have accumulated since the volcanic eruptions ceased. There is little evidence by which they can be dated. The deposits are classified into the following types:—

- (a) Naromoru ash.
- (b) Moraines.
- (c) Solifluxion deposits.
- (d) Red soils.
- (e) Red and pale lateritic earths.
- (f) Black soils.
- (g) Alluvium.

(a) *The Naromoru Ash*.—This is a thin deposit of greenish-grey tuffaceous material occurring in many parts of southern Laikipia, notably near Naromoru. Its most characteristic feature is the constant presence of small flakes of biotite. It is uncertain whether the deposit is pyroclastic.

In this area it is usually unstratified, but in the valleys, similar material (or the same, re-deposited), is distinctly stratified and contains small gritty fragments of kenyte and other rocks derived from Mount Kenya. These stratified deposits are termed the Uaso Nyiro Beds in the Nanyuki area (Shackleton: Maralal Report).

The Naromoru ash is younger than a Lower or Middle Pleistocene basaltic tuff (see p. 12) and older than the Late Middle Pleistocene Kenya Fauresmith horizon (see paragraph (e) below). It is exposed beneath black soil in many roadside pits. "Kunkar" concretions commonly occur both in the ash and in the lower part of the black soil.

(b) *Moraines*.—These are confined to the highest valleys on Simbara. They are believed to be of the same age as those on Mount Kenya referred to the Upper Pleistocene Gamblian Pluvial Period (see p. 11).

(c) *Solifluxion Deposits*.—Material believed to have accumulated as a result of solifluxion occurs on Simbara (see p. 10).

The fact that the Honi has cut a channel 20 feet deep through one of the deposits suggests that its age is Pleistocene and not Recent.

(d) *Red Soils*.—These are typically developed in the Nyeri area where they are often ten or twenty feet thick. They are unstratified and homogeneous, and appear to result from rock decomposition under forest cover during a long period of time. They have not yielded artefacts and it seems likely that the forests under which they formed were uninhabited by prehistoric man.

(e) *Red and Pale Lateritic Earths*.—At many places east of the limit of the area, erosion has exposed a series of red and pale lateritic earths. In the lowest of these, a rich red earth, artefacts of the Kenya Fauresmith (Nanyukian) culture have been found. At Leakey's type locality for this culture (Leakey, 1931) by the road to the Nanyuki Forest Station, red earths in which the artefacts occur, rest unconformably on the biotite-bearing Naromoru ash. Within the area of the map, artefacts of the Kenya Fauresmith culture have only been found at a few places near the Pesi River. These localities were discovered and shown to me by Mr. T. P. O'Brien. They are in eroded

patches and the sections show a foot or two of lateritic earths at or near the base, overlain by yellowish, brown to grey soils with "kunkar" concretions. There are artefacts, mostly unrolled, of Kenya Fauresmith, Levallois and other types. Some, with adhering laterite are obviously derived from the basal lateritic horizon, but none were seen *in situ*.

(f) *Black Soils*.—These cover most of the flatter ground. With them are included some brown soils into which they pass on slightly more sloping ground. Both the black and brown types have concretions of "kunkar lime" at their base.

The distribution of the red and black soils depends on slope, which controls drainage and consequently oxygenation, rather than on the nature of the bedrock. Both red soils and black soils are typically developed on basalts, phonolites and trachytic tuffs in this area.

(g) *Alluvium*.—Alluvium has been deposited during the silting up of some of the flatter valleys such as the Moyo. Gravels are surprisingly scarce and insignificant.

IV—CORRELATION WITH OTHER AREAS

A provisional correlation of the principal volcanic rocks and superficial deposits is given in the table. Some of the evidence on which the table is based is discussed below.

(1) *Correlation of the Older Basaltic Rocks*

The Samburu Series, the Simbara Series and the Ngong basalts are thought to be approximately of the same age, principally on account of their petrographic similarities. Basalts of Kijabe type are characteristic of the Samburu Series and the Simbara Series. Melanocratic basalts with olivine and augite phenocrysts occur in the Samburu Series east of Baringo, in the Simbara Series in Simbara, and in the Ngong basalts. Basaltic rocks are known to occur low in the volcanic succession in western Kenya (Kent, 1944, pp. 16–18), and in the Lake Rudolf Basin (Aranbourg, 1935; Fuchs, 1939, pp. 230–246); the description of the Miocene basalts and tuffs of the Losidok Hills west of Lake Rudolph (*ibid.*, p. 231) indicates that they are very similar to the Samburu Series of the north-western part of the Maralal area. In the Tambach–Kabarnet area at the western side of the Kenya Rift Valley, Mr. J. Scott of the Public Works Department determined (personal communication) the following succession:—

6. Kabarnet Trachytes.
5. Stratified tuffs, etc. (? Kamasian).
4. Uasin Gishu Phonolite.
3. Basalt.
2. Conglomerates, grits and green tuff (? Miocene).
1. Gneiss (Basement System).

Thus here also basalt occurs at the base of the volcanic series.

The presence of a flow of Kijabe type basalt between the Thomson's Falls Phonolites and the Rumuruti Phonolites, near the Pesi River (Shackleton, Maralal Report) suggests that the last of the basalts of the Simbara Series were erupted later than the Rumuruti Phonolites.

(2) *Correlation of the Kinangop Tuffs, Nyeri Tuff and Sattima Series*

The Nyeri tuff is correlated with the Kinangop tuff on account of its similar lithology, and because it lies in the same relation to the Laikipian basalts as the trachyte tuffs of Ngobit, Suguroi and Mutara, which undoubtedly belong to the Kinangop tuffs.

The Nyeri tuff contains cognate fragments of a quartz-trachyte which resembles the porphyritic quartz-trachyte of the Sattima Series, but their correlation is questionable.

(3) *Relative Age of the Trachytic Tuffs and the Mount Kenya Volcanic Suite*

In view of the occurrence of trachytic tuffs at many horizons in the Nairobi sequence, the suggested correlation of the Kerichwa valley tuff with the Nyeri and Kinangop tuffs is open to doubt. It is possible that the Kinangop tuffs and the Kerichwa valley tuffs are in part younger than the Mount Kenya Volcanic Suite.

V—PHYSICAL AND GENERAL GEOLOGY

The area is one where the form of the ground clearly reflects the main geological features. Most people familiar with the district are aware of differences in terrain, soil, rocks and drainage, between for example, the Kinangop plateau, the Aberdare farms, and the coffee growing areas around Nyeri. These depend on differences in the rocks and their structure.

The chief physiographic units (see Fig. 1) are:—

- (1) The Kinangop Plateau.
- (2) The Ol Bolossat Plain.
- (3) Kipipiri.
- (4) The Sattima Fault Scarp.
- (5) The Northern Aberdare Ramp (northern part of the Aberdare Range).
- (6) Simbara (the mountains) (northern part of the Aberdare Range).
- (7) Gusiru (the moorland) (northern part of the Aberdare Range).
- (8) The Aberdare Dip-slope.
- (9) Southern Laikipia.

(1) *The Kinangop Plateau*

This is a platform about ten miles wide, with an elevation of 8,000 to 9,000 feet. It extends westwards from the foot of the Aberdares to the upper Kinangop fault scarp. Only a small part of it, south and south-east of Kipipiri, is included in the area dealt with in this report.

The margin of the Kinangop plateau is a distinct topographic feature which corresponds, within perhaps half a mile, with the geological boundary between the trachytic tuffs of the plateau and the basalts of Kipipiri and the Aberdares. It follows an irregular course round Kipipiri and southwards along the foot of the Aberdares, marking the unconformable contact between the Kinangop tuffs and the underlying basalts.

The surface of the Kinangop is conspicuously smooth. It is the marginal strip of a plain of accumulation which formerly extended from the foot of the Aberdares and Kipipiri across the Rift Valley region, and probably also eastwards across the northern end of the Aberdares.

The trachytic tuffs of which the Kinangop is built are well exposed along the Sasin river.

(2) *Ol Bolossat Plain (Angata Pus)*

Geologically, this is a continuation of the Kinangop. It is formed of the same trachytic tuffs, built up to a similar even surface. The marsh of Ol Bolossat is the dwindling relic of a former lake. Its existence at the foot of the Sattima fault scarp indicates that when the faulting occurred, the rocks of the Ol Bolossat plain were tilted eastwards, and a lake thus formed by the water impounded against the scarp. Its disappearance is doubtless due to silting up, as well as to the progressive desiccation of the country since the Upper Pleistocene (Gamblian) Pluvial phase.

(3) *Kipipiri*

This enormous mound rises some 3,000 feet above the surrounding plains to 10,987 feet. Its sides are furrowed by radial valleys and covered with dense bush and forest. It stands apart from the main Aberdare Range, from which it is separated by a saddle deeply trenched by the streams draining either side.

The profile of Kipipiri is similar from each side and except for a spur extending northwards, it is nearly round in plan, with a diameter of about seven miles. Its symmetrical form suggests that it is an old volcano and outward dips in the lavas of which it is formed confirm this. From the 1:125,000 map one might indeed suppose that traces of the original crater perhaps still exist, but from the summit it is obvious that this is not the case. Several of the higher points are connected by a curved ridge, with a flat area between them, but there are others nowhere near this ridge, which has been formed by erosion. Moreover the profile of the mountain is no longer that of a simple cone. It is clear that it has been lowered by erosion hundreds of feet below its original height.

Three groups of rocks were seen on Kipipiri. There is a core of basalts of the Kijabe type; many thin flows are exposed in dark cliffs at the sides and head of the radial valleys, and similar rocks were seen in valleys along the western side of the mountain. This series of basalts is overlain by trachytes which form the pale slabby outcrops of most of the highest points, and extend down the north ridge and no doubt also down some of the other unexplored ridges. On the northern spur, and in the saddle between Kipipiri and the Aberdares, there are flows of columnar non-porphyrific basalt. A small hill near the end of the northern spur may mark one of the vents from which these basalts erupted.

The volcanic succession on Kipipiri is so similar to that of the Aberdares that their correlation is not in doubt. The Simbara Series is represented by the older basalts of Kipipiri, the Sattima Series by the trachytes, and the Laikipian Series by the columnar basalts of the saddle.

Kipipiri is thus as old as the Aberdares. It is not, as has generally been supposed, a younger volcano located on the Sattima fault.

(4) *The Sattima Fault Scarp*

The Sattima scarp is a long straight and steep rock face (see Pl. I (a)). It bounds the northern Aberdare ramp, and the high part of the range itself, from Thomson's Falls to north Kinangop, a distance of about 40 miles. The height of the scarp increases gradually from Thomson's Falls southwards, and then again declines still further south. Although the fault face is incised by some deep and precipitous-sided valleys, notably those of the several branches of the Melawa and the Wainjohi, the scarp between these incisions is little affected by erosion. It has the appearance of a geologically young feature.

Along one 7-mile stretch the fault is split, and as explained in more detail later, the geometry of the outcrops of the outer (eastern) branch suggests that it is inclined westwards. If so, the fault would be normal, that is tensional. As it is one of the principal boundary faults of the Rift Valley, proof that it is tensional would be hard to reconcile with any theory of the compressional origin of this Rift Valley.

Another point of interest is that the Sattima faulting appears to have taken place after the deposition of the Kinangop tuffs; the continuation of the tuffs of the Ol Bolossat plain is found at the top of the scarp.

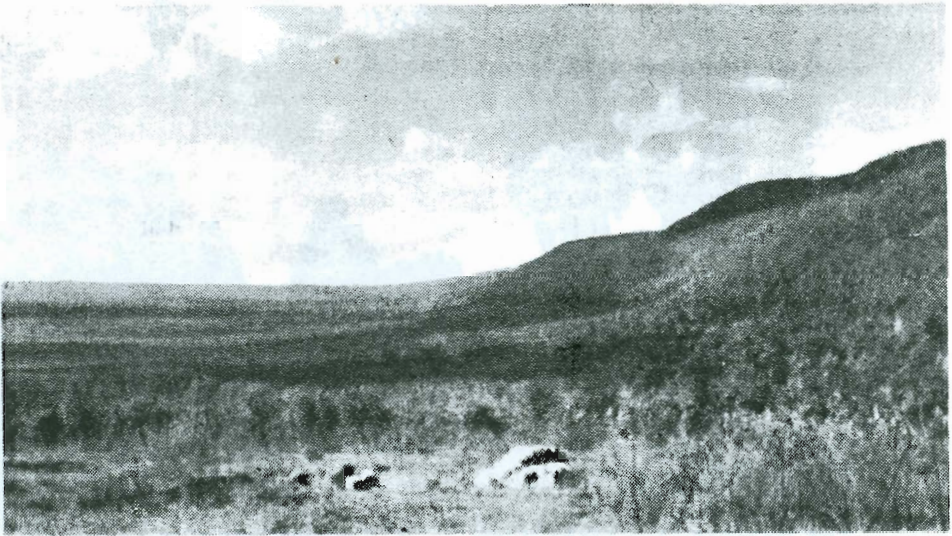
(5) *The Northern Aberdare Ramp*

In most parts of the Aberdare range the present slope of the ground has been determined both by the original slope of the volcanic rocks, away from their centre of eruption, and by subsequent tectonic tilt. There is, however, an area at the northern end of the range where the original volcanic surface was nearly flat, and the present slope is almost entirely the result of tilting. This area is described here as the northern Aberdare ramp. To the north and north-east it merges into the flatter plains and flatter structures of Laikipia.

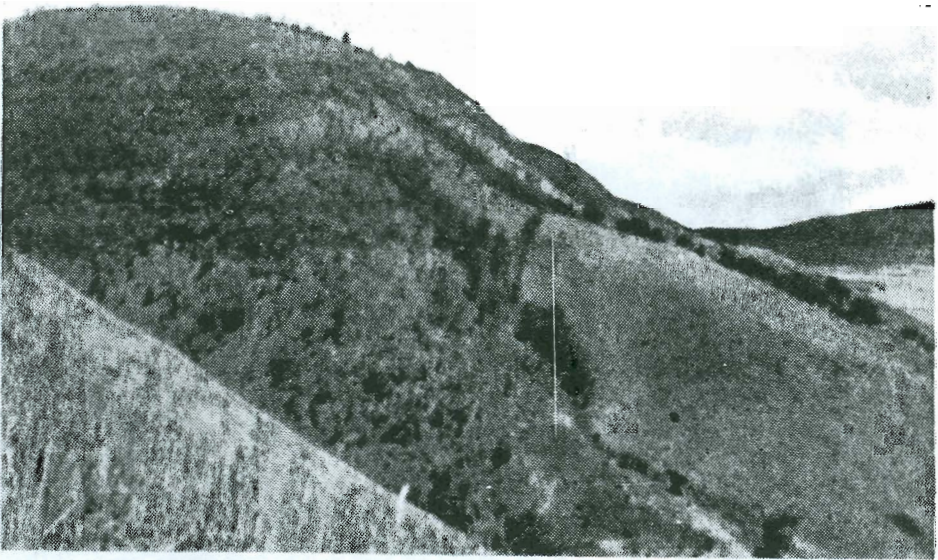
The rocks of the ramp are the Thomson's Falls Phonolites and the Kinangop trachytic tuffs. They are exposed in section on the Sattima fault face. There it is seen that the phonolites thin southwards to a feather edge on the Simbara basalts. Resting on the phonolites and extending to the very edge of the fault scarp are the Kinangop trachytic tuffs.

The river system of the ramp is interesting. The streams flow onto it from the old Simbara cone where they have a radial pattern, but as they run out over the ramp, instead of continuing in their previous courses, they swerve to the right, away from the edge of the Sattima scarp towards Laikipia, and the Sattima scarp drains only a small area of the edge of the ramp. The courses of these rivers across the ramp is proof that the Aberdare Block, as it was uplifted, was gently tilted towards the east. There is no sign of any pre-tilt drainage pattern, from which it appears that the faulting and movements followed very soon after the eruptions had ceased.

PLATE I



(a) View northwards along the Sattima Fault Scarp, from a point two miles N.E. of Kipipiri. This part of the scarp consists of basalts of the Simbara Series. The gentle slope in the middle is formed of talus. At the left is the Ol Bolossat Plain, formed of trachytic tuffs.



(b) Part of the Sattima scarp, showing the feature due to the eastern fault. The bush-covered slopes to the left of the fault feature are formed of nearly horizontal basalts of the Simbara Series. The smooth slopes below are formed by basalts of the Laikipian Series, covered with talus. The eastern edge of Kipipiri is seen across the end of the Ol Bolossat Plain, at the right. The view is taken looking south-eastwards.

PLATE II



(a) Crag of porphyritic quartz-trachyte ("Dragon's Teeth Trachyte") of the Sattima Series, two miles north of Sattima.



(b) View northwards up the Honi Valley to Sattima, showing supposed solifluxion deposit, ending in a rock-stream slope along the right bank of the Honi.

(6) *Simbara*

Simbara is the name applied by the Kikuyu to the high mountainous part of the northern Aberdares. The name Sattima, given to the highest point on the maps, is seldom familiar to them. Sattima is not an isolated peak, but the inconspicuous culmination of a considerable area of high ground. Simbara is uninhabited; most of the hills are unnamed and the streams have only the names of the rivers into which they flow. Existing maps are misleading and inaccurate. Simbara in the sense used by the natives corresponds roughly to the area occupied by the two older divisions of the local volcanic rocks. These are the Simbara Series below, and the Sattima Series above; together they form the old volcanic core of the northern Aberdares.

The rocks of the *Simbara Series*, as shown on the map, are exposed in the valleys of Simbara and on some of the ridges. Some deeply incised valleys show over a thousand feet of basaltic lavas and the base of the series is nowhere seen. The lava flows are thin, vesicular and mostly of porphyritic basalt of the Kijabe type. They are readily weathered and often underlie grassy slopes with few outcrops. Steeper and rockier slopes show dark parallel outcrops of a great number of thin flows.

The Simbara basalts dip outwards from the central part of Simbara. They are traversed by dozens of dykes, mostly of porphyritic basalt similar to the lavas. Some are of pale fissile trachyte and a few of phonolite and non-porphyritic basalt. As shown on the map, many of the dykes belong to a radial system evidently centred on the main eruptive focus, which is less closely defined by the dip of the lavas outwards from it. Besides the radial dykes, there is a linear swarm (inadequately shown on the map) along the axis of the range, parallel to the Sattima fault. Most of the dykes of this swarm, are nearly vertical.

Other dykes have no obvious regularity. Their direction often changes abruptly, and some are branched. Few of the dykes are more than ten feet thick and many are a foot or less. In the other areas where the Simbara Series is exposed, along the Sattima scarp, in the Amboni valley, by the Chania below Nyeri, and elsewhere, no dykes were seen and there certainly cannot be many, although an occasional one may have been overlooked. The dykes are apparently confined to the Simbara Series; none were seen in the overlying rocks.

Although it is evident that the Simbara basalts were erupted from a centre a mile or two south of Sattima, no plug or vent was discovered, nor any topographic feature to suggest one. Several small rock knobs were found to stand out where the basaltic lavas were reinforced by dykes. Nor were any blocks or boulders of plutonic rocks found anywhere in the northern Aberdares.*

It is presumed therefore that the dykes, of which there are many more than could be shown on the map, mark the fissures from which the lavas were erupted.

The dominant lavas of the Simbara Series are Kijabe type basalts crowded with porphyritic felspar crystals. On the northern and southern flanks of Simbara, however, the prevailing type is a basalt with many visible crystals of olivine and augite. In various places they can be seen to overlie the other type of basalts; they are themselves traversed by dykes, and overlain in at least one place by a trachyte of the Sattima Series. They form the subordinate upper division of the Simbara Series.

The *Sattima Series* includes pale-weathering slabby and fissile rocks which, on the summits of Simbara and on Kipipiri, overlie the Simbara basalts. They include porphyritic quartz-trachytes, fayalite alkali-trachytes, alkali-trachytes, and phonolites. Of these, the porphyritic quartz trachytes are at least partly intrusive, as dykes and a sheet, but the others appear to be lavas. They occur chiefly as isolated outliers.

The porphyritic quartz trachyte is the most striking and conspicuous rock in the whole district. (Plate II (a).) Down the western slope of Simbara it forms bizarre outcrops, comb-like outliers on the ridges, vertically fluted and serrated crags, and fields of pronged and knobby rocks. In the field the rock was named the Dragon's Teeth Trachyte.

* In the foothills and on Laikipia, stones of nepheline syenite the size of a tennis ball or less are sometimes found, but these are from Mount Kenya and were carried, and often shaped by prehistoric men for throwing-stones or bolas balls. The only plutonic rock yet known in the Aberdares is a gabbro (? essexitic), of which many blocks were found in the Turasha River near Tulaga, west of Niandarawa. (Spec. 43/65.)

At first this formation was taken for a lava sheet. In most of its exposures it directly overlies the Simbara basalts, but near the Melawa tributary four miles southwest of Sattima the sheet is overlain by other Simbara Series basalts, similar to those below it. In some of the valleys which cut into the Sattima scarp the same quartz trachyte sheet could be seen from below to cut transgressively through the great series of Simbara basalts. The sheet dips across the nearly flat lavas at angles up to 15° , and is here clearly intrusive. Near Sattima a similar rock which overlies a non-porphyrific alkali-trachyte of the Sattima Series may be a lava. Its connexion with the other fissile lavas is in any case certainly close. There are many dykes of similar rock.

The other rocks of the Sattima Series are apparently lavas.

In Simbara, which is probably the centre from which they were erupted, the Sattima Series is distinct, but on Gusiru, similar lavas are interdigitated with basalts of the Laikipian Series, and it has not been found possible to show the limit of the Sattima Series on the map. Low down on the western slope of Simbara, however, non-porphyrific basalts of Laikipian type were mapped, clearly overlying the porphyritic trachyte and the Simbara basalts.

Glaciation of Simbara.—It has been known for some time that there were at one time glaciers on the Aberdares (Nilsson, 1940, p. 4). The most convincing evidence of this glaciation is to be seen at the heads of the two main branches of the Melawa Ndogo River. In each of these, typical lateral moraines slant down the side of the valley to the lower end of an alluvial flat which evidently covers a small rock basin, now silted up. The heads of the valleys, above these old lake basins, have the scooped-out appearance and U-shaped cross-section typical of glaciated valleys, while immediately below the lips of the basins the valleys drop steeply and have the V-shaped cross-sections typical of river erosion. In the northern Melawa valley there is another small moraine above the old lake bed. The glaciers in these valleys reached down to about 12,000 feet.

At the head of the Wainjohi there is also an area whose form suggests glaciation. No moraines or old lake beds were seen there, but there is a distinct lip where the supposed glaciated part gives place to the V-shaped valley below, and this lip lies at about the same elevation as those in the Melawa valleys. In the Ngobit, moraine ridges converge towards the lower end of a flat-floored area that was evidently glaciated; below this the valley is deeply cut.

The small glaciers in these valleys lay round the western and northern side of the highest ridge of Simbara. The eastern side of this ridge drains into the Honi, around the head of which the highest summits are grouped. Yet no evidence of glaciation was seen at the head of the Honi streams, which run, on the contrary, in deep V-shaped valleys. Further down the narrow headstream valleys join and the valley becomes more open. There, for about a mile along the right bank of the Honi (Plate II, fig. 2, opp. p. 9) there is a deposit of large and small blocks of the rocks from the ridges above, in an earth matrix. The deposit ends in a steep slope along the right bank of the Honi. There is no corresponding slope on the other side of the stream. The slope must be an original feature and not the result of a stream erosion.

Away from the stream, the surface of the deposit slopes smoothly up and merges above into the stony earth which covers the hillside as far as the rock outcrops near the ridge. This cover, which is seen on most of the less steep hillsides of Simbara, is intricately and closely furrowed by a reticular pattern of alleys, some of them several feet deep, running transversely to the slope of the ground. The whole of this furrowed cover is believed to move by solifluxion, the embankment-like lower edge marking the limit of its flow. The downstream limit of this deposit is indefinite. Three successive smooth terraces which were at first interpreted as drift, were found to be lava scarps partly buried by detritus and soil.

Still further down, below these terraces, the stream, flowing east, plunges suddenly into a mass of loose rocks and earth, through which it has cut a narrow channel, about twenty feet deep. The deposit here is similar to the one upstream. It lies across the middle of the valley, merges imperceptibly into the slopes on either side, and no noticeable feature marks its lower limit, which is at an elevation of approximately 10,700 feet. A similar deposit was seen in the Chania valley at about the same elevation,

These deposits, and the glaciation of Simbara, deserve more study than was possible during hurried traverses. It is plausible to correlate the glaciation down to about 12,000 feet with the glaciation down to about the same level on Mount Kenya. This has been regarded (Nilsson, 1940, p. 70) as marking the maximum of the Gamblian Pluvial Period. It might be suggested that the deposits here attributed to solifluxion are denuded moraines of an earlier and greater glaciation, but the form of the deposits and of the valleys above them would then be difficult to understand.

(7) *Gusiru*

Quite distinct from Simbara is the plateau to the south, known to the Kikuyu as Gusiru, the moorland. A long but inconspicuous spur from Simbara extends along its western side; it drains eastwards. Its eastern edge, coincident with the upper limit of the bamboo forest, is sharply defined, the ground falling away there in a steep and sudden slope.

Some of the rocks of Gusiru are basalts, non-porphyrific dark blue-black rocks with columnar jointing. Others are fissile rocks, paler weathered, bluish-grey within and glistening on broken surfaces with minute felspar plates. These fissile rocks are provisionally identified as mugearites and fayalite alkali-trachytes. Some of them seem to be identical with some of the lavas of the Sattima Series both to the eye and microscopically, nor could any distinction be drawn in the field. It is quite clear in the stream sections on Gusiru, such as those along the Gura and Chania rivers, that the columnar basalts and the fissile lavas alternate and were being erupted at the same time. The northern part of Gusiru seemed, so far as could be seen from the few exposures noticed on two traverses, to consist entirely of the fissile lavas.

The flatness of the plateau is in striking contrast to the steep slope down through the forest. The gentle slope is little greater than the gentle eastward dip of the sheets of lava which build the plateau. Several low sinuously embayed lava scarps, facing east, mark the edges of successive sheets. Near the eastern margin, there are several isolated hills which are obviously old vents. The Nyeri-Naivasha track traverses the flank of one of these a mile east of the Gura bridge. Purplish basaltic tuffs, agglomerates, and rubbly lavas confirm the proximity to a vent. The arrangement of these vents near its edge may have protected the plateau from erosion while increasing the steepness of the slope to the east. The eastward dip of the lavas in the forest is probably steeper than it is on the plateau and this would favour faster and deeper erosion. Possibly too, the plateau was protected by the relatively hard sheets of the fissile lavas. There is nothing to suggest faulting at its edge.

The several ponds, meres and marshes on Gusiru are said to be shallow. They may be due to the unequal accumulation of silt trapped by rushes and other vegetation. Those seen were in flat peaty areas, on the broad shelves formed by the gently dipping lava sheets.

(8) *The Aberdare Dip-slope*

Between Gusiru, Simbara and the ramp to the west, and Laikipia to the north-east, is the Aberdare dip-slope. This, although deeply furrowed by valleys, slopes evenly with an average gradient of about 1 in 15. Most of it is covered by the Aberdare forests, through which few traverses were made. Photographs of some waterfalls on the Chania show columnar lavas, presumably basalts, and the pebbles in the streams are mostly of basalt and fissile lava. Below the forest boundary the deep valleys of the Gura and Chania expose both columnar and fissile lavas, dipping at about the same angle as the general slope of the surrounding country. It appears that the dip-slope is largely formed of lavas of the Laikipian Series, but whether some of the fissile lavas should be included in the Sattima Series is uncertain.

At the eastern foot of the dip-slope, around Nyeri, other rocks emerge in the valleys, from beneath the Laikipian basalts, as shown on the map. The oldest lavas and agglomerates of the Simbara Series, are well exposed in the cuttings along the Nyeri-Nairobi road on both sides of the Amboni valley. Agglomerates alternate with

lavas. Other good exposures of the Simbara Series can be seen on the steep slopes above the confluence of the Chania and Amboni. Flows of melanocratic basalt with augite and olivine phenocrysts occur here among agglomerates in which most of the blocks are of Kijabe type basalt.

The Simbara Series is overlain in this part of the area by the Nyeri tuff, a bed of columnar trachytic tuff usually about 30 feet thick. This tuff is used as a building stone and is well-exposed in numerous quarries and natural exposures. By the Chania east of Nyeri, feebly stratified tuffs were seen below the massive building stone. The contact of the Nyeri tuff with the underlying Simbara Series was nowhere seen.

The surface of the Aberdare dip-slope is in general deeply weathered to a rich red soil, and rock exposures are seldom seen except in the valleys with running streams.

(9) *Southern Laikipia*

The southern part of the extensive grass-covered plateau of Laikipia is included in the area dealt with in this report. Its limit is taken to be where the black soil of the plains gives way to the red soil of the Aberdare dip-slope. This corresponds to the former boundary between grassland and forest. The areas covered by black soil are distinguished by stippling on the map. The change in soil depends chiefly on drainage and slope, and is very little influenced by the nature of the underlying rock.

Much of southern Laikipia is formed of basaltic lavas of Gregory's Laikipian Series. These are well exposed in the Ngobit valley near the Nyeri-Rumuruti road, and in many other places.

Small hills rising above the plains are the stumps of the many small volcanoes from which the surrounding Laikipian basalts were erupted. Reddish basaltic tuffs are commonly found on and near the vents. Some of these tuffs have been used for building stone and in one of the trial holes on a farm north of the Moyo River some fossil bones were discovered by the owner, Colonel Elliot. The tuff in which they were found lies on a gently sloping ridge. Other exposures on the side of the same ridge show similar but less weathered tuffs, reddish in colour and typical of the lapilli tuffs discharged from many of the Laikipian vents. These tuffs overlie Laikipian basalts. The bones are unrolled and apparently articulated in their original position. It is supposed that they are the remains of animals buried in a sudden shower of "ash" and lapilli; if so, further finds are not very probable. The fossils have not been finally identified, but Dr. L. S. B. Leakey, to whom they were sent, informs me that the fauna includes a baboon not so far identified with any known species, but having affinities with a Lower Pleistocene form from South Africa. He is of the opinion that the fauna is not younger than Middle Pleistocene and is more probably Lower Pleistocene in age.

In the pit where the fossils were found, the basaltic tuff containing them is overlain by a layer, less than a foot thick, of pale brownish ash with biotite flakes. This is thought to represent the Naromoru Ash. The eastern part of southern Laikipia is underlain by the rocks of the Mount Kenya Volcanic Suite, but over most of this part of the area, black soil conceals the underlying rocks, which are seldom exposed except along the sides of the principal valleys.

In many parts of Laikipia the black soil of the plains is underlain by the Naromoru ash.

VI—PETROGRAPHY

A preliminary examination of about two hundred thin sections made from the rocks collected shows that similar types occur in various parts of the sequence, although some are locally restricted to a particular horizon or series. It appears from this first study of the slides that a continuous series can be traced from olivine basalts to phonolites and trachytes, and that any member of this series is liable to occur almost anywhere in the sequence. To avoid repetition, a sketch of the petrography of the chief types is given below without regard to their order or place of eruption. It should be realized that the classification is tentative since no analyses are available for most of the types, and hurried microscopic identification, especially of the potash-bearing plagioclase feldspars and the occult feldspathoids, is uncertain.

The principal rock types distinguished are:—

Olivine basalt	}	B ₃	2.84	(56)
Olivine alkali-basalt				
Analcite basanite				
Olivine trachybasalt				
Mugearitic basalt	}	fB	2.80	(9)
Mugearite			2.75	(9)
Olivine alkali-trachyte			2.70	(12)
Alkali-trachyte			2.74	(4)
Quartz trachyte	}	Tr	2.65	
Phonolite, non-prophyritic, fissile			fPh and kPh	2.67 (11)
Phonolite			Ph ₂	2.60 (4)
Kenyte			K	2.54 (2)
Basalt, Kijabe type		B ₁	2.83	(8)
Basalt with olivine and augite phenocrysts		B _p	3.08	(3)

The symbols are those used on the map. Figures on the right are mean specific gravities, the figures in brackets showing the number of specimens measured.

Other types of extrusive rocks noticed are picritic basalt and nepheline basanite (?); trachytic and basaltic tuffs occur; a few other rocks are found as ejected blocks in some of the tuffs.

Olivine Basalt

These rocks are generally non-porphyritic, and have basaltic texture. They are seldom vesicular. They consist essentially of olivine, augite, labradorite, and opaque ores. There is no obvious alkali tendency. Residual potash-felspar, analcite, and reaction-biotite are absent or insignificant. The pyroxene is augite, usually only faintly purplish, and non-pleochroic. Olivine is colourless in section, and optically positive. Apatite was very rarely noticed. Secondary minerals such as göthite, iddingsite (?) and serpentine, derived from olivine, are not uncommon.

Rocks of this type mostly with columnar jointing, were found south of Nyeri, on the Aberdares, near the Ngobit River, on Il Pejeta, north of Nyeri Station, west of Ndaragwa, by the Zuka Zuka River, and at many other places.

Olivine Alkali-basalt

The basaltic rocks classified under this head are those which contain sufficient biotite to indicate a definite alkali tendency, but which are without appreciable amounts of potash-felspar or analcite. The biotite is the variety usual in such rocks, pleochroic from pale golden brown to foxy brown. It forms ragged poecilitic plates, or small flecks. It has seldom grown on ore grains and seems to have crystallized directly from a potassic residuum rather than as a result of reaction between such a fluid and previously crystallized ores. Apart from the presence of biotite, these rocks are similar to the olivine basalts. Some contain small phenocrysts of olivine. No feature was noticed by which they could be recognized in the field.

Rocks of this type were collected from the Gura Falls, a little way north of the Nyeri-Naivasha track; from the west side of Simbara where they overlie the quartz-trachyte sheet; from the Sattima scarp, above Kijabe type basalts and from the upper Pesi, Suguroi, and Segara river valleys in each of which they overlie trachytic tuffs. One specimen (43/157) from a 6 ft. dyke in Simbara is of this type.

Analcite Basanite

In 19 of the slides of basaltic rocks, a colourless isotropic mineral with a low refractive index, was determined as analcite. It is interstitial and residual but apparently primary. The rocks are otherwise normal basalts with faintly purplish augite, colourless olivine in many cases partly or wholly altered to an iddingsite-like mineral, specks and minute crystals of ore (often identified by its form as magnetite), and plagioclase laths.

The plagioclase is generally labradorite, though occasionally it appears to be less basic. The texture is usually basaltic. In one thin section the pyroxene is sub-ophitic, and in another, the plates of labradorite are fluxionally arranged. Many of the rocks have phenocrysts or microphenocrysts of olivine.

About half of the specimens were of columnar basalts, all but one of which belong to the Laikipian Series. The exception (43/224), collected near the Uaso Nyiro close to the Aberdare forest boundary, is a basalt with phenocrysts of olivine and augite. It probably belongs to the upper division of the Simbara Series. Another rock with olivine and augite phenocrysts, also from the Simbara Series, has interstitial zeolitic material which may represent decomposed analcite.

Olivine Trachybasalt

Five rocks to which this name was doubtfully given have basic plagioclase as the chief felspar, but with it, a little alkali felspar which seems to be orthoclase. In other respects the five rocks differ; they are not a natural group. One (43/249) has trachytically arranged felspar plates, the larger of which (about 0.5 mm. in length) are labradorite, $Ab_{45} An_{55}$, and the smaller, oligoclase-andesine and orthoclase. There are granules of faintly yellowish ferri-ferous olivine, and pale greenish augite. Another rock (43/170) consists of fluxionally arranged labradorite laths, clear olivine grains, pale greenish pyroxene, serpentine, and alkali felspar. Specimen 43/269 is a fissile lava with labradorite, faintly purplish augite in poecilitic patches, and magnetite; some orthoclase forms fringes on the plagioclase and some is interstitial. These three rocks are fissile. A non-fissile basalt (43/289) which may belong here consists of labradorite ($Ab_{45} An_{55}$), olivine altering to iddingsite, greyish interstitial pyroxene, ore and scanty untwinned alkali felspar presumed to be orthoclase.

Mugearitic Basalt

These are fissile lavas which, like the mugearites and alkali trachytes, consist of trachytically arranged felspar plates, with ferri-ferous olivine grains, and subordinate greenish pyroxene, but with andesine instead of oligoclase or anorthoclase. The olivine, when fresh, is yellowish in section. In some of the rocks it is replaced by iddingsite (?).

In several of the sections, scraps of biotite were noticed and in a few small apatite prisms with minute inclusions. There are the usual ore specks.

Mugearite

About a dozen of the specimens are classified as mugearites. They are bluish-grey fissile non-porphyrific rocks, in which minute glistening felspars are visible. In slides the trachytically arranged felspars are seen to be mostly oligoclase but probably there is usually also some anorthoclase. The felspars have refractive indices below that of canada balsam, even those whose extinction angles would be taken to indicate andesine. Probably they all contain a notable proportion of potash. Zoning and lamellar twinning are generally faint but distinct.

Olivine is plentiful, occurring in minute granules, which are identified by their yellowish colour and optically negative character as fayalite. Pyroxene, subordinate to olivine, is greenish diopside or aegirine-augite. Small prisms of apatite, dusted with inclusions, were seen in several slides. Ore specks are scattered much less thickly than in the basalts. Late primary biotite is rare. Secondary iddingsite and serpentine are common.

Olivine Alkali-Trachyte

In texture and general appearance both to the eye and microscopically, these rocks are very much like the mugearites, but their felspar is mostly anorthoclase. Olivine, as in the mugearites, is a yellowish, optically negative fayalite. Pyroxene, of which there is normally less than olivine, is often an aegirine-augite with distinct pleochroism. It sometimes forms small pleochroic patches. Apatite with minute inclusions was noticed not infrequently and kataphorite is an occasional minor constituent. Magnetite, as minute specks and crystals, is thinly scattered in all the rocks.

The principal rock types distinguished are:—

Olivine basalt	}	B ₃	2.84	(56)
Olivine alkali-basalt				
Analcite basanite				
Olivine trachybasalt				
Mugearitic basalt	}	fB	2.80	(9)
Mugearite				
Olivine alkali-trachyte				
Alkali-trachyte				
Quartz trachyte	}	fTr	2.70	(12)
Phonolite, non-prophyritic, fissile				
Phonolite				
Kenyte				
Basalt, Kijabe type	}	Tr	2.74	(4)
Basalt with olivine and augite phenocrysts				
		Ph ₁ and kPh	2.65	
		Ph ₂	2.67	(11)
		K	2.60	(4)
		B ₁	2.54	(2)
		B _p	2.83	(8)
			3.08	(3)

The symbols are those used on the map. Figures on the right are mean specific gravities, the figures in brackets showing the number of specimens measured.

Other types of extrusive rocks noticed are picritic basalt and nepheline basanite (?); trachytic and basaltic tuffs occur; a few other rocks are found as ejected blocks in some of the tuffs.

Olivine Basalt

These rocks are generally non-porphyritic, and have basaltic texture. They are seldom vesicular. They consist essentially of olivine, augite, labradorite, and opaque ores. There is no obvious alkali tendency. Residual potash-felspar, analcite, and reaction-biotite are absent or insignificant. The pyroxene is augite, usually only faintly purplish, and non-pleochroic. Olivine is colourless in section, and optically positive. Apatite was very rarely noticed. Secondary minerals such as goëthite, iddingsite (?) and serpentine, derived from olivine, are not uncommon.

Rocks of this type mostly with columnar jointing, were found south of Nyeri, on the Aberdares, near the Ngobit River, on Il Pejeta, north of Nyeri Station, west of Ndaragwa, by the Zuka Zuka River, and at many other places.

Olivine Alkali-basalt

The basaltic rocks classified under this head are those which contain sufficient biotite to indicate a definite alkali tendency, but which are without appreciable amounts of potash-felspar or analcite. The biotite is the variety usual in such rocks, pleochroic from pale golden brown to foxy brown. It forms ragged poecilitic plates, or small flecks. It has seldom grown on ore grains and seems to have crystallized directly from a potassic residuum rather than as a result of reaction between such a fluid and previously crystallized ores. Apart from the presence of biotite, these rocks are similar to the olivine basalts. Some contain small phenocrysts of olivine. No feature was noticed by which they could be recognized in the field.

Rocks of this type were collected from the Gura Falls, a little way north of the Nyeri-Naivasha track; from the west side of Simbara where they overlie the quartz-trachyte sheet; from the Sattima scarp, above Kijabe type basalts and from the upper Pesi, Suguroi, and Segara river valleys in each of which they overlie trachytic tuffs. One specimen (43/157) from a 6 ft. dyke in Simbara is of this type.

Analcite Basanite

In 19 of the slides of basaltic rocks, a colourless isotropic mineral with a low refractive index, was determined as analcite. It is interstitial and residual but apparently primary. The rocks are otherwise normal basalts with faintly purplish augite, colourless olivine in many cases partly or wholly altered to an iddingsite-like mineral, specks and minute crystals of ore (often identified by its form as magnetite), and plagioclase laths.

Alkali-Trachyte

A few slides are of trachytic rocks, consisting chiefly of anorthoclase plates and sodic pyroxene, with, so far as could be seen, neither olivine, feldspathoid nor quartz. Re-examination has shown that some rocks had been misplaced here, as they contain olivine or feldspathoid or both of these minerals. Closer scrutiny or microchemical tests might show their presence in other rocks still retained in the group.

A rock from Sattima summit (43/179) has phenocrysts of a felspar that is thought to be potash-oligoclase and a few smaller phenocrysts of greenish pyroxene. The matrix, which varies in coarseness, consists of laths of anorthoclase and interstitial yellowish-green material.

Another rock (43/208) from the north summit of Songari Hill, is a fine-grained grey fissile lava. The slide shows thin flow-aligned plates of anorthoclase, small grains and microphenocrysts of ore (magnetite?), apatite crystals full of black dust, and yellowish ferruginous alteration products which have perhaps formed from interstitial sodic pyroxene.

Phonolite (fissile, non-porphyrific type)

Phonolites closely related to the olivine-alkali trachytes occur in the Sattima Series. They are fissile greenish-grey rocks, pale and slabby in outcrops. In slides, the minerals usually seen are anorthoclase, aegirine-augite, fayalite, magnetite and nepheline or analcite or both. Anorthoclase occurs in trachytically arranged plates, which in some rocks range in seriate gradation from 1 mm. in diameter down to very small ones. In others, they are thin and minute, and form a feathery mesh. Aegirine-augite forms prismatic tufts or irregular interstitial specks. In some specimens there is perhaps a little aegirine. The fayalite has a distinct yellowish-brown colour. It forms either subhedral minute grains, or poecilitic patches enclosing anorthoclase. Magnetite specks are evenly scattered in all the slides.

The feldspathoids are generally inconspicuous. Euhedral crystals of nepheline, about 0.2 mm. in diameter, and outlined by aegirine-augite growths, are evident in 43/192 and interstitial clear analcite is plentiful in 43/151. In several of the other rocks close search is needed to see either of these minerals.

Ore-saturated green "ghosts" in two slides are relics of resorbed phenocrysts. Anorthoclase phenocrysts were seen in one rock (43/182) which was regarded as a phonolite only on account of its similarity to another (43/183) in which analcite was doubtfully identified. Cossyrite and kataphorite (?) were noticed in 43/192. One of the fissile phonolites (43/166) is a dyke rock from Simbara. It contains small euhedral nephelines surrounded by mossy aegirine, with cossyrite, pale kataphorite, and slender felted alkali-felspar plates.

Other fissile non-porphyrific phonolites, petrographically like those of the Sattima Series, occur in the Mount Kenya Volcanic Suite. They are greener in colour than the Sattima rocks. A flow of this kind is exposed along the side of a ravine about a mile west of the railway, and five miles north of Nyeri station. Large blocks of similar lava are common in the agglomerates, where they seem to be indiscriminately mixed with blocks of kenyte. Microscope study shows that the fissile phonolites of the Mount Kenya Suite vary in texture and mineral composition. The lava mentioned above has microphenocrysts of anorthoclase in a dark base of mossy aegirine and cossyrite, clearer areas of alkali felspar, minute nephelines, and analcite. A block (43/207) from an agglomerate has ragged patches and subhedral granules of fayalite as well as the usual aegirine, cossyrite, anorthoclase, and nepheline. Another block (43/210) contains trachytic anorthoclase, flecks of arfvedsonite, some kataphorite and probably fayalite, aegirine, aegirine-augite and cossyrite. Some vaguely defined shapes seem to represent altered nephelines.

One fissile lava belonging to the Mount Kenya Suite is similar in appearance to the phonolites but seems to be a fayalite alkali-trachyte or possibly a mugearite. It outcrops on the north slope of the Naromoru valley about two and a half miles east of the Uaso Nyiro. It contains phenocrysts probably potash-oligoclase and microphenocrysts of fayalite in a trachytic base with interstitial aegirine.

Phonolite (Kenya type)

The phonolites of the Thomson's Falls Series are petrographically uniform and agree with Campbell Smith's description of the Kenya type of phonolite (Smith, 1931, pp. 229-236). They are fissile dark grey lavas, almost always with small phenocrysts of anorthoclase.

Thin sections show anorthoclase phenocrysts with marginal inclusions in a base of anorthoclase, aegirine and aegirine-augite, cossyrite, usually a little kataphorite, a little bluish arfvedsonite-like amphibole, and specks of magnetite.

Nepheline, usually cloudily altered, is conspicuous, as small euhedra about 0.1 mm. in diameter. Olivine is seen in some slides, but is never plentiful.

"Kenyte"

Gregory (1900, page 209), gave the name kenyte to the rocks which surround the nepheline syenite in the plug of Mount Kenya. Unfortunately, as Campbell Smith (1935, pp. 242-250) found when he re-examined the type rocks, Gregory did not notice the nepheline crystals in his kenytes, and so his definition of them does not apply to the rocks for which it was intended. Further confusion has arisen because Gregory also mistook some rocks near Songari Hill for the Kapiti phonolite and Campbell Smith described one of them as an example of the Kapiti type of phonolite. As he found it to be essentially identical with Gregory's kenyte, he doubted whether there was any significant difference between the kenytes and the Kapiti type of phonolite. Actually, this supposed Kapiti phonolite is a kenyte of the Mount Kenya Suite and has no connexion with the Kapiti phonolites which are stratigraphically and petrographically distinct from the kenytes.

The term kenyte is here used for rocks corresponding to Smith's re-description of Gregory's types. The similarity between these and the kenytes of the present area is so close that further re-description is superfluous.

The kenytes are distinguished in the field by their very abundant large anorthoclase crystals, usually of the rhombic habit, and fewer greenish nephelines, in a dark grey non-fissile base. Weathering to very large rough masses, round rather than angular, is highly characteristic (and entirely different from the slabby outcrops of the fissile Kapiti phonolite, or any other of the plateau phonolites). There are often small irregularly shaped vesicles lined with zeolites.

Olivine Basalt, Kijabe type

The characteristic basalts of the Simbara Series are similar to the Kijabe basalts described by Shand (1937, pp. 265-267). His lucid description of the Kijabe rock applies equally well to most of the rocks of Simbara, except that in the very much greater mass of lavas exposed there, there is naturally a greater range of variation, which is, however, only in non-essential particulars. As the type is now known to have a wide distribution in Kenya, it is convenient to have a local name for it, and the name Kijabe type is proposed. The type rock is the one from Kijabe Hill described and analysed by Shand. The type should include similar olivine basalts characterized by abundant plagioclase phenocrysts—the limiting proportion cannot be decided without quantitative analysis of the rocks to be included—and an alkali residuum of either zeolite, analcite or orthoclase.

The plagioclase phenocrysts in most of the slides examined, are labradorite, though in two they are bytownite. There are usually some smaller phenocrysts of olivine, and sometimes augite also.

The groundmass consists of granular purplish augite, small laths of labradorite, olivine granules, and ore, together with prisms of apatite, and various interstitial minerals. The ore is in rough plates and skeletal crystals, or parallel rods with knobby growths and pagoda-like forms. These forms suggest ilmenite. Interstitial zeolite, analcite, orthoclase and dirty serpentinous material were seen. No nepheline was identified in any slide; a little biotite was seen in a few.

A number of the specimens sliced were from dykes. Both microscopically and megascopically they are essentially the same as the lavas. The thickest dyke seen, about 30 feet, is more coarsely crystallized than the other rocks.

The Kijabe type basalts are generally more vesicular than other basic lavas of the area, although some thick flows are non-vesicular. No correlation was found between the proportion of plagioclase phenocrysts and the vesicularity (cf. Shand, *ibid.*, pp. 269 and 270). In two dykes the phenocrysts were seen to be much smaller at the chilled margins than in the middle. These phenocrysts must have crystallized in the rocks where they now are: they were not concentrated there by gas-flotation. Moreover, they lie parallel to the walls of the dykes, without any bubbles underneath them. If the concentration of plagioclase crystals is attributed to gas flotation, then it must be supposed that in this case the crystals first collected were dissolved in the magma, and that others later crystallized from it.

It is, moreover, clear that in this area the crystals were not concentrated in the lavas after eruption. As the pressure would inhibit the separation of a gas phase in depth, the gas flotation mechanism suggested by Shand could only happen in a body of magma relatively near the surface. Such conditions are hardly likely to have been fulfilled persistently enough to produce the enormous volume of these lavas seen in the northern and southern Aberdares, and further north. As a general explanation of the abundance of plagioclase phenocrysts in the Kijabe type basalts, the gas flotation theory is perhaps inadequate. That it must have happened in some places is, however, shown by a specimen from Kijabe. In this, crowds of small bubbles are collected under each of the thin plagioclase plates, which must obviously have been buoyed up.

Basalt with olivine and augite phenocrysts

Heavy melanocratic basalts, studded with many olivine and augite crystals are a distinct type, easily recognized in the field. Of the eight such collected and sliced, five were classified as melanocratic basalts, two as picritic basalts, and one as picrite.

The *melanocratic basalts* have phenocrysts of augite and olivine in a base of pyroxene, basic plagioclase, olivine and ore, with either flecks of biotite, or interstitial analcite, or zeolite. The large augite crystals are very pale or colourless in section; the augite granules and prisms in the base are usually purplish. Olivine is mostly fresh, but sometimes altered peripherally or wholly to an iddingsite-like mineral. The ore has the octahedral form of magnetite. Felspar, often subordinate, is a basic plagioclase determined in several of the rocks as labradorite.

The pyroxene phenocrysts in one slide (43/217) enclose small irregular patches of plagioclase, ore and biotite, resembling the same minerals in the groundmass. It is unlikely that the magma from which these inclusions crystallized, was enclosed in the crystals at depth, and it is, therefore, supposed that phenocrysts crystallized from the magma during its eruption.

The two *picritic basalts* (43/238 and 43/293) are closely allied to the rocks described above, but plagioclase is scarcer. The large augite crystals in slide 43/293 are weakly pleochroic from very pale dirty green to a faintly purplish green. They are zoned, and contain inclusions of felspar, serpentine and ore similar to the groundmass minerals. In the other rock (43/238), instead of augite phenocrysts, there are large ragged poecilitic crystals of an amphibole of the kataphorite series, with pleochroism.

X—very pale brown.

Y—purplish.

Z—raw-sienna brown.

There is possibly some interstitial analcite.

The picrite (43/240) has many large and small euhedral phenocrysts of olivine and augite in a dense black base. The olivine is colourless in section, and the pyroxene faintly green with a narrow feebly pleochroic titaniferous rim. The base consists of closely packed granules and prisms of purplish augite, grains of ore, altered granules of olivine and a small proportion of basic plagioclase. Small irregular clear pools are apparently of zeolite.

No distinction was made in the field between the above three types. All are included on the map under the symbol B_p. The picrite was collected from the bed of the Nairutia River west of Tanyai Hill: one of the picritic basalts (43/238) is from a hill south of Il Pejeta and the other from the Sattima scarp east of Kipipiri. Rocks of these three types occur at various horizons from the Simbara Series upwards. Some of the lavas erupted from the Laikipian vents were of this type.

Other Rocks

A few rocks collected fall within none of the above groups. Those of interest are—

Tephrite? (43/168) specific gravity 2.87.

Nepheline basanite (43/237) specific gravity 2.97.

Tinguaite? (43/227, 43/295) specific gravity of 43/227, 2.75.

Nepheline Syenite (43/214).

Tephrite? (43/168).—The slide shows microphenocrysts of ore (magnetite?), and greenish-purple titaniferous augite. The dark base has a slaggy appearance owing to the segregation in streaks and lenticles of colourless minerals, apparently both feldspar and nepheline. The dark part of the base consists of yellowish-green pyroxene, ore, and an undetermined brown pleochroic mineral. There are some apatite prisms full of black dust.

Nepheline Basanite (43/237).—This was collected on a spur of Il Pejeta. The slides show a few small and corroded microphenocrysts of greenish-brown barkevikitic amphibole, and many small crystals of olivine, ore, and pyroxene in a dense blackish base. The olivine has been replaced by a brown iddingsite-like mineral. The pyroxenes are pale dirty greenish within, and purplish at the edges. There is a little biotite.

Felsic constituents are scanty. They are in small clear pockets, sharply defined from the rest of the rock. Both plagioclase and nepheline were doubtfully identified.

The above two rocks are interesting as the only basaltic lavas in the area in which nepheline was found.

Tinguaite? (43/227, 43/295).—The first of these rocks was collected near the south bank of the Ngobit River, east-south-east of Il Pejeta. It was taken for a basaltic lava. In the slide, there are microphenocrysts of a sodic titanaugite with peculiar pleochroism in purplish and brownish greens, and a high extinction angle. There are also some small microphenocrysts of ore. The base consists of matted prisms of dirty green pyroxene, small plates and larger poecilitic patches of anorthoclase (?), grains of ore, and decomposed nepheline crystals. A few apatite prisms full of inclusions, and a little zeolite, were also seen. The texture is coarser than the lavas of the district and it is quite likely the rock is intrusive. It differs from the ordinary Laikipian basalts, though it has affinities with the previously described rock (43/237) from the same area.

The other rock, 43/295, is part of a boulder from a stream at the foot of the Sattima scarp east of Kipipiri. There were many more boulders of the same type there. It is a striking rock, with black crystals of hornblende and pyroxene, and crystals of nepheline, in a grey base. The slide shows that the amphibole is barkevikite, in crystals prominently edged with black dust. The augite of the phenocrysts is a pleochroic titaniferous and slightly sodic variety. There are also some sharply euhedral microphenocrysts of grey sphene. The nepheline crystals in the slide are microphenocrysts, but others in the rocks can be seen by eye. The groundmass is fine-grained, and consists of simply twinned "orthoclase", pale greenish augite, and ore specks. Apatite is accessory.

This rock is unlike any of the lavas of the district and is probably intrusive, although its base is fine-grained.

Nepheline Syenite (43/214).—A piece of nepheline syenite of the Mount Kenya type was collected from the kenyte agglomerate near the Amboni River. The slide shows anorthoclase, nepheline, kataphorite, diopside, aegirine, cossyrite, apatite and ore. Nepheline and anorthoclase are the major constituents and both crystallized early.

VII—STRUCTURE

(1) *The Sattima fault and related displacements*

The Sattima fault is the most important structural feature of the area. It is one of the main eastern boundary faults of the Kenya Rift Valley. Near Thomson's Falls, north-west of the limit of the map, it forms an inconspicuous wooded scarp with a north-west to south-east trend. Traced southwards, the fault scarp curves slightly and continues, in a south-south-easterly direction, as a long, straight and steep scarp, increasing gradually in height, until opposite Kipipiri its face is over 2,000 feet in height. (See Pl. I (a).) Still further south it declines and seems to disappear as a topographic feature, short of the North Kinangop Forest Station. Some features suggest that it may continue, across the western side of the peak of Niandarawa, and along the western side of the southern spur of the Aberdare range, almost as far as the Chania River. (See Fig. 1.) This possible southern extension of the fault has not, however, been proved. The known length of the fault from Thomson's Falls, to a little north of the Kinangop Forest Station, is about 45 miles.

The increase in height of the fault face southwards from Thomson's Falls is due to the increasing displacement towards the south. At Thomson's Falls, the ground on both sides of the fault is underlain by phonolites of the Thomson's Falls Series. Southwards, on the downthrown side these phonolites soon pitch below the surface and are overlain by trachytic tufts of the Kinangop Series, which underlie the plain below the scarp probably as far as the Wainjohi valley. While the rocks on the downthrown side pitch gently towards the south, those on the upthrown pitch in the opposite direction. Consequently the Thomson's Falls Phonolite Series is seen gradually rising southwards up the face of the scarp. About 15 miles south of Thomson's Falls, the underlying basalts appear at the foot of the scarp and four miles further, the phonolites wedge out near the top of the scarp, about a thousand feet above the surface of the plains below. Beyond this, the lines of the basaltic lava flows can be followed by eye, still rising gradually southwards. The culmination of pitch on the upthrown block seems to be about opposite Kipipiri, but the dips and structure south of this are obscured by forest. The greatest displacement on the Sattima fault may exceed 3,000 feet.

Only the middle section of the Sattima fault is included in the map (though more was examined). In the section included, for about seven miles, there are two parallel faults, about half a mile apart. The eastern is the main fault. It has produced a sharply defined rock face, cleanly cut through the series of basalt flows. Against this rocky fault face lies the intermediate strip, in which the outcropping rocks are another series of basalts, correlated with those at the top of the main scarp. These basalts weather much more smoothly than those on the adjacent fault face. (See Pl. I (b).) To some extent the smoother surface of the fault strip is due to a cover of talus fallen from above, and actual rock outcrops were not seen on the fault strip very close to the main fault. None the less, the difference in the form of the ground on the two sides of the line is so distinct, and so regular, that a line can be drawn which, it is believed, accurately marks the position of the fault.

The fault scarp is furrowed by deep valleys. The line of outcrop of the fault plunges up and down across these valleys. Just above it, for several miles, runs a surveyed and cut line marking the forest reserve boundary. This line, straight in plan, runs across the valleys in the same way as the outcrop of a vertical plane of the same strike. The outcrop of the fault, just above this line, swings alternately towards it and away, as it plunges into the deep valleys and climbs the intervening ridges. Therefore, the fault must be a surface dipping westwards, and since the downthrow is to the west, a normal fault. The inclination was judged, at a point north of the Melawa Ndogo, to be slightly over 80° . Further south it appears to be less.

Along the seven-mile stretch where there are two fault scarps the upper one is straight and continuous. The western one is also straight, but weaker and less continuously exposed than the one above. It is impossible to regard either fault as due to a landslide or to secondary superficial faulting developed on an earlier fault scarp. At the base of the lower fault is a flat plain, continuous from near Thomson's Falls to the Kinangop. Nothing that could be attributed to local landsliding breaks its surface. The intermediate fault strip shows basalts which are correlated with others

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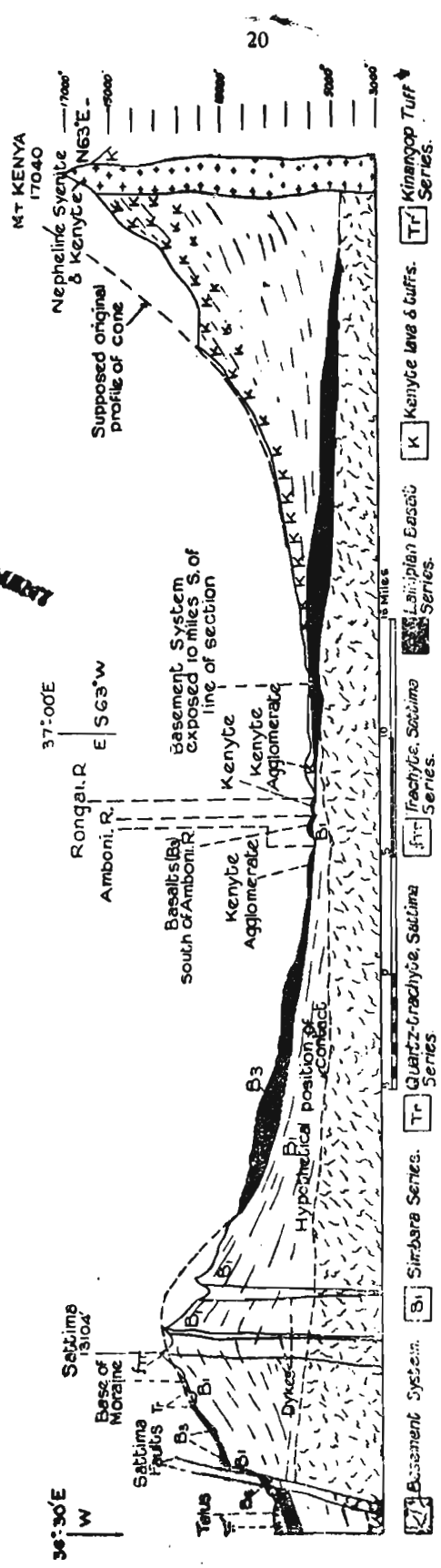


FIG. 2
Geological Section from Sattima to Mount Kenya

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at the top of the main scarp. It is clear that the base of this intermediate slice, were it a landslide, could not be less than a thousand feet or so *below* the level of the adjacent plain. It could only have reached such a position before the rocks forming the plain were in existence. But further north, above the main fault, the rocks capping the scarp are the same series of trachytic tuffs which underlie the Kinangop platform. They outcrop along the top of the fault face, and again at its foot. No lithological change is noticed as they are traced westwards across the plateau towards the scarp edge, nor could any difference be seen between the tuffs at the top and those at the foot of the scarp. Those at the base are free from admixed talus. It cannot be doubted, therefore, that, like the rest of the rocks exposed on the fault face, these tuffs were actually displaced by the fault. Their situation cannot be explained by supposing that they were erupted on to a pre-existing fault scarp. These trachytic tuffs were, however, almost the last beds to be deposited before the Kinangop faulting. It is clear, therefore, that the common belief that the Sattima fault belongs to an earlier phase than the Kinangop faults is untenable. Nor does the form of the Sattima scarp suggest any greater age; it is still very steep, clean and straight. The western margin of the Aberdare range, further south beyond the limit of the map, is indeed an irregular line, but this is in my opinion due, not to prolonged erosion of an earlier fault scarp, but to the absence there of any faulting whatever. Along the margin of the southern Aberdares the trachytic tuffs can be proved, at various exposures from Tulaga in the north to the Chania in the south, to rest directly and unconformably on the Aberdare basalts. Whether the regular westwards slope of the basalt ridges there corresponds to the original dip of the lava flows, or whether it indicates the presence of a monoclinial flexure, is uncertain.

The dislocation and movement of which the Sattima fault is the most obvious effect in the area, also resulted in tilting and warping of the crustal blocks on either side of the fault. The western block was tilted south-eastwards. Its southward pitch is shown by the disappearance of the Thomson's Falls Phonolites beneath the Kinangop tuffs south of Thomson's Falls, and its easterly tilt by the presence of the Ol Bolossat and other marshes at the foot of the scarp.

The vertical movements in the block east of the Sattima fault—that is in most of the area—must have been differential. Superimposed on the general eastwards slope towards the Indian Ocean, which affects all the country east of the Rift Valley, there are local tilts correlated with the movements at the Sattima fault. They can be regarded as due to differential upward displacements of the Aberdare-Nyeri block. The amount of this displacement increases westwards to a maximum against the fault, while at the same time it increased along the fault from zero north of Thomson's Falls to a maximum, opposite Kipipiri or thereabouts, of about 3,000 feet.

The tilt of the crustal block east of the Sattima fault is difficult to evaluate. If the correlation of the Nyeri tuff with the Kinangop tuffs is correct, and if the surface of these tuffs was originally nearly level from the Ol Bolossat area and the Aberdare ramp to Nyeri, it can be used as a datum. Its present elevation north-east of Sattima is nearly 10,000 feet and at Nyeri about 5,700 feet, giving a difference of over 4,000 feet between points about 30 miles apart. This would imply a tilt of about 1 in 30 at right angles to the fault. Consideration of the probable form and elevation of the surface of the Basement System suggests, however, that such a tilt would bring the Basement System surface to a minimum elevation of about 7,000 feet under the Sattima Scarp. This allows for an original drop of 2,000 feet from the old gneiss hill now exposed at 5,700 feet, six and a half miles east of Nyeri, to the base-level elsewhere known as the Sub-Miocene Peneplain (Shackleton, Maralal Report). As it seems doubtful whether the Basement System is actually so close beneath the surface under the Sattima scarp, it is thought that the estimated value of the tilt may be slightly too high.

(2) *The Simbara Dykes*

The majority of dykes mapped on Simbara fall into a radial pattern, but there are also many others, under-emphasized on the map, which together form a swarm parallel to the Sattima fault. These are evidently injected along fractures of tectonic origin. The quartz-trachytes north of Sattima are traversed by a close system of shear-joints in the same direction. So far as could be seen, most of the linear dykes, and the shearing, are very nearly vertical, though two persistent dykes were seen to be inclined steeply westwards.

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(3) *Laikipian Vents*

The arrangement of the vents of southern Laikipia appears from the map to be haphazard. Certain features suggest, however, that north-north-west to south-south-east fractures parallel to the Sattima fault, may, to some extent have controlled the position of the vents. Dykes on Il Pejeta and on a hill ten miles north of Sattima trend between north-west to south-east and north to south. A north-north-west to south-south-east alignment of adjacent vents of similar character, at Ol Doinyo Narasha, is apparent in the field where the form of the individual hills can be appreciated, and a similar alignment can be seen in the Il Pejeta group.

(4) *Relation between the trend of the Rift Valley faults and strikes in the Basement System*

Along the eastern side of the Rift Valley, both in this area (see Fig. 1) and further north (Shackleton, Maralal Report), the trend of the Rift Valley faults corresponds to the strike in the Basement System.

VIII—ECONOMIC GEOLOGY

(1) *Building Stone*

The most useful building stone in the area is the Nyeri tuff. The main quarries now being worked are those near Nyeri Station, but local demand at Nyeri would probably justify working the outcrops nearer the township. Some of the houses in Nyeri that are built of the Nyeri tuff are cracked, but this is the result of poor foundations, and not faulty stone. It is possible that this is a rock which would be better laid with the original bedding flat. Some reaction between alkalies extracted from the rock by rain water, and cement used in pointing, would be expected, but it is unlikely to be appreciably harmful in practice.

Trachytic tuff was formerly quarried in the Ngobit valley. The rock exposed there is soft and crumbly but apparently the stone was not unsatisfactory for building. Harder trachytic tuff, with columnar jointing, is quarried near the Suguroi, and is a good building stone. Trachytic tuffs also outcrop on the northern Aberdare ramp. Their quality varies from one bed to another, but good stone should be obtainable over most of the mapped outcrop, except in the flatter areas.

On the slopes of many of the Laikipian vents, there are reddish basaltic lapilli tuffs, and in various places attempts have been made to quarry them. Although they are much more intractable than the trachytic tuffs, they yield a durable building stone and the difficulty of quarrying and dressing is probably worth meeting, if competent stone-masons can be found.

(2) *Road Metal*

Plenty of rocks suitable for road metal are available in most parts of the area, except on the Naromoru plains. The basalts are usually easiest to work as under red soils weathering often penetrates to a depth of ten feet and the weathered rock can easily be quarried. The Thomson's Falls phonolites are seldom weathered so deeply and when fresh are tough and difficult to work. They should be avoided where possible. Most of the tuffs are too soft to be of use. The kenyte agglomerate is worked in a large quarry by the railway, some distance north of Nyeri Station.

(3) *Diatomite*

A thin deposit of diatomite occurs near a tributary watercourse of the Ngobit, three miles west-north-west of Tanyai Hill. Although apparently of good quality, the deposit is too small to be of any commercial value. The thickness at the place where the bed is exposed is less than ten feet. No other outcrops are known, and it is unlikely that a thicker deposit could be found in the vicinity, and in any case transport costs would be prohibitive, except in the unlikely event of a local demand arising.

(4) *Brick Earths*

Bricks have been made on several farms in the district, with various results, but there is no doubt that suitable subsoils or alluvial silts exist in many places. There has perhaps been a tendency to use earths that are too plastic.

IX—WATER SUPPLY GEOLOGY OF THE AREA BETWEEN MT. KENYA AND THE ABERDARE RANGE

It has been suggested that there might be a possibility of artesian conditions in the area between Mount Kenya and the Aberdares. The argument, briefly, is that both Mount Kenya and the Aberdares were built up by volcanic eruptions and consist of lavas and tuffs which dip outwards from the volcanic centres. It is assumed that some of the lavas are impermeable while others, and probably most of the tuffs, are permeable. Water entering the permeable beds might be confined between impermeable ones, under a considerable head owing to the great height at which it enters the rocks. If not completely confined, it might still be under pressure if the resistance to its passage through the rocks were sufficient. It is further argued that the underlying floor of relatively impermeable gneisses of the Basement System, sloping southwards from about 6,000 feet near Nanyuki to under 4,000 feet at the margin of the Tana plains, would prevent the subsurface water from escaping northwards to the Uaso Nyiro catchment, and thus increase the resistance to be overcome before the water escaped at the surface.

The geological aspect of this problem is discussed below and illustrated in Fig. 1 and Fig. 2.

(1) *The Basement System Floor*

The sub-volcanic floor, formed of gneisses of the Basement System, is a highly irregular surface. This irregularity is the result of erosion acting on a diversity of rocks, and not to the faulting or folding of a previously peneplained surface. The elevation of the surface is difficult to predict, as no peneplains have been recognized in this area, although the surface beneath the Kapiti phonolite of the Tana plain may be part of the sub-Miocene Peneplain. West of the Tana there is an almost continuous barrier of gneiss hills, which disappears under the volcanic rocks near Tumu-tumu, reappears as an inlier in the Chania east of Nyeri, and is doubtless represented by the gneiss penetrated by a borehole near Nanyuki (Sikes, 1934, Pl. X, Fig. 4). Still further north, this zone of gneiss hills merges into an elevated region which extends from the Loldaikas to the Karissia Hills. It is evident that on the pre-volcanic land surface, no rivers flowed eastwards from the Rift Valley region across this barrier to the Indian Ocean anywhere between 1° S. and 1° 30' N. The drainage west of the barrier may have been towards a depression in the area of the present Rift Valley. It is in any case clear that so far as the Basement System floor influences the subsurface flow, its effect would be to turn the water in the rocks beneath Mount Kenya towards the south or south-east, and that beneath Laikipia, the Nyeri area, and the Aberdares, towards the west or south-west. The Basement System floor appears from beneath the volcanic rocks south of Mount Kenya and water diverted in that direction should emerge there as springs. Springs are in fact reported at this surface, near the Nguka swamp, and others were noticed during this survey south of Karatina on the side of the Sagana valley. West of the zone of gneiss hills the Basement System is not again exposed east of the Rift Valley.

It should perhaps be emphasized that subsurface water flows in the direction of the slope of its surface (the water-table), which may have no relation to the slope of any subsurface floor.

(2) *The Aberdare Range*

The structure and rock succession of the northern part of the Aberdare range have been discussed in the report above. The southern part of the range is known to be formed of similar rocks, and the structure is doubtless also similar. A concentration of dykes near Niandarawa shows that this mountain is near to a main focus of eruption comparable to the one near Sattima. As regards artesian water, the significant features of the Aberdare structure are—

- (a) the oldest rocks are exposed around Sattima and Niandarawa in the highest parts of the range;
- (b) the same series of rocks emerge, much thinner and in an agglomeratic facies, at the eastern edge of the basalt field, as near Nyeri in the Sagana and Maragua valleys, and near Saba-saba and Makindi;

- (c) the eastern slope is essentially a dissected dip slope;
- (d) all the rocks are basaltic;
- (e) the Laikipian basalts which cover the middle and lower slopes are trenched, in places to their base, by deep valleys.

As the oldest rocks emerge again at the foot of the dip slope, water permeating through them can escape freely. Furthermore, the cover of Laikipian basalts, in which columnar jointing is a conspicuous feature, are likely to behave as aquifers. It is believed, therefore, that the subsurface water of the Aberdare dip-slopes will in general be found to behave as a single system, the hydrostatic pressure at any point depending on its depth below the water table. The slope of the water table will tend to reflect the general slope of the ground and will determine the flow of the subsurface water.

(3) Mount Kenya

Only the north-western sector of Mount Kenya between Nanyuki and the peak, and its periphery from Nanyuki to Embu, were hurriedly examined during this survey. Gregory recorded details of his route up the south-western side of the mountain, (Gregory, 1900, pp. 215 and 216).

In the deep valleys radiating from the central peak, the rocks exposed are kenyte lavas and tuffs. Two thousand feet of these rocks are seen on Sendeyo, and their full thickness must be very great. They dip outwards at angles diminishing from 20° near the plug to less than 10° five miles away, and still less further down the slope. In profile, the lower slopes show the upward steepening curve characteristic of a volcano such as Fujiyama, but the upper slopes lie below the imaginary continuation of this line. It is evident that the upper part of the volcano has been lowered by erosion at least 3,000 feet below its original height, while the lower slopes still reflect its original form. It follows from this interpretation that the lavas and tuffs exposed around the core plunge beneath those of the lower slopes, and water can readily enter the permeable strata, through which it will sink beneath the intermediate slopes of the mountain.

At the periphery of the Mount Kenya volcanic area, however, the base of the kenyte series is exposed. The Series rests, around the western and southern sides of the mountain, on basaltic lavas. Therefore the immense thickness of kenyte lavas and tuffs of the main cone diminishes to a feather edge, which is freely exposed at the periphery of the mountain. The water which enters the permeable parts of the Series high on the mountain must either escape at the surface, or sink downwards through the underlying rocks to the water table and thereafter flow, according to the pressure gradient, within the ground-water system of the region.

Borehole Data

Few boreholes have been drilled in the area that is being considered. Some in the Nanyuki area were discussed by Sikes (1934, pp. 30-32).

Samples from other more recent ones have been examined in connexion with the present work. The localities are shown on Fig. 2. Material from the samples was merely mounted in oil and inspected under the microscope, and the logs are to be regarded as provisional. Those of interest are given:—

(a) Borehole C. 267 (Muringato Estate, Nyeri).—

Depth		
From	To	
ft.	ft.	
0	30	Red soil.
30	55	Gritty clay.
55	186	Olivine basalts (Laikipian Series).
186	306(?)	Gravel and trachytic tuff (Nyeri tuff).
306	345	Gravel; stones are Kijabe type basalt (Simbara Series).
345	440	Kijabe type basalt (Simbara Series).

Main water from the lowest basalts, below 386 ft. (37,032 gal./24 hrs). Rest level 347 ft. Perched water table at about 148 ft.

(b) *Borehole C. 286 (Farm 5175, Naromoru).—*

Depth

<i>From</i>	<i>To</i>	
<i>ft.</i>	<i>ft.</i>	
0 ..	19	Grey soil, etc.
19 ..	244	Kenyte lavas; tuff or weathered kenyte at two horizons?

Main water at 225 ft. (20,400 gal./24 hrs.). Rest level 173 ft.

(c) *Borehole C 290 (Farm L.R. 2830/4, Nanyuki).—*

Depth

<i>From</i>	<i>To</i>	
<i>ft.</i>	<i>ft.</i>	
0 ..	28	Soil, etc.
28 ..	80	(Gravel and boulders, according to drillers log.) Fragments of phonolite.
80 ..	100	Tuffaceous earth?
100 ..	110	Gravel (phonolite fragments).
110 ..	125	Light-brownish clay.
125 ..	150	Polygenetic gravel. A fragment of nepheline-syenite.
150 ..	275	Kenyte?
275 ..	419	Kenyte.

Water at 148 ft., 200 ft., 293 ft., 415 ft. (21,600 gal./24 hrs.). Rest level 123 ft.

(d) *Borehole C 291 (Farm 1232, Nanyuki).—*

Depth

<i>From</i>	<i>To</i>	
<i>ft.</i>	<i>ft.</i>	
0 ..	44	Black soil, murrum, etc.
44 ..	110	Gravel (fragments of kenyte, nepheline syenite, etc.).
110 ..	195	Kenyte.
195 ..	208	Clay (bentonitic?).
208 ..	320	(?)Kenyte.
320 ..	354	Gravel and clay.
354 ..	365	Kenyte.

Water at 105 ft., 180 ft., and 290 ft. downwards (17,280 gal./24 hrs.). Rest level 78 ft.

The first of these boreholes (C 267) penetrated about 100 feet into the Simbara Series, from which a good supply was obtained, but there is no indication of artesian conditions.

The other three (C 286, C 290, C 291) all enter the Mount Kenya Volcanic Series. In these too, good supplies were obtained, but the water does not rise above the expected level of the water table.

Conclusions

In view of the evidence outlined above the chance of striking artesian water is thought to be poor. Both the Simbara Basalt Series and the Kenyte Series of Mount Kenya outcrop so extensively at the periphery of their respective volcanic fields that the water which enters them on the higher areas can easily escape at their base. Boreholes into both series have failed to show any artesian pressure and there appears to be no reason why conditions deeper below the surface should in this respect differ from conditions in similar lavas and tuffs of the same series at less depth. Over much of the area, deep boreholes—1,000 feet has been mentioned—would in fact pass through these series either into the Basement System, or into other volcanic rocks unlikely to yield artesian water. It is possible that artesian conditions may prevail over small areas, but it is doubtful whether, if so, they could be discovered by intensive geological or geophysical surveys.

Although the chance of artesian water is thus thought to be poor, the district appears to be a favourable one for boreholes to normal depths. In particular, on the plains west of Naromoru, underlain by rocks of the Mount Kenya Volcanic Suite, the chances of getting water appear to be good. The water table in this area is unlikely to be far below the level of the principal watercourses, and as the relief is low, depth to water should not be excessive in boreholes on the ridges. On the slopes formed by the Laikipian basalts the water table may be slightly deeper, since these rocks are open-jointed, and the gradient of the water table from the plains mentioned above, towards the Aberdares, is thus likely to be low. In the Ngobit gorge, which is cut deeply into the Laikipian Basalt Series there are apparently no springs whatever. The water table must therefore be at or below the level of the Ngobit river, and boreholes in that area which stop short of this level can only obtain water from perched water tables.

X—REFERENCES

- Arambourg, C. (1935).—"Esquisse géologique de la bordure occidentale du lac Rodolphe, Mission scientifique de l'Omo, 1932-33". *Bull. Mus. Hist. nat.* Paris, I, fasc. 1.
- Fuchs, V. E. (1939).—"The Geological History of the Lake Rudolf Basin, Kenya Colony". *Phil. Trans. Roy. Soc. London*, Ser. B, No. 560, Vol. 229, pp. 219-274.
- Gregory, J. W. (1896).—*The Great Rift Valley*, London.
- Gregory, J. W. (1900).—"Contributions to the Geology of British East Africa—Pt. II. The Geology of Mount Kenya". *Quart. Journ. Geol. Soc.* London, LXXXVIII, pp. 212-258.
- Gregory, J. W. (1921).—*The Rift Valleys and Geology of East Africa*. London.
- Kent, P. E. (1944).—"The Age and Tectonic Relationships of the East African Volcanic Rocks". *Geol. Mag.* LXXXI, No. 1, pp. 15-27.
- Leakey, L. S. B. (1931).—*The Stone Age Cultures of Kenya Colony*. Cambridge.
- Maufe (Muff), H. B. (1908).—Report relating to the Geology of the East Africa Protectorate. *Col. Rep. Misc.* No. 45 (cd. 3828), London.
- Nilsson, E. (1940).—"Ancient changes of Climate in British East Africa and Abyssinia". *Geol. Ann. Arg.*, XXII, Haft 1-2, 1-79, Stockholm.
- Shackleton, R. M.—"The Geology of the Country between Nanyuki and Maralal". Report No. 11, Mining and Geol. Dept., Nairobi. (Awaiting publication.)
- Shand, S. J. (1937).—"The Rocks of the Kedong Scarp, Kenya Rift Valley". *Geol. Mag.* XXIV, pp. 262-271.
- Sikes, H. L. (1934).—*The Underground Water Resources of Kenya Colony*. Crown Agents, London.
- Sikes, H. L. (1939).—"Notes on the Geology of the Country surrounding Nairobi". Mining and Geol. Dept., Nairobi.
- Smith, W. C. (1931).—"A classification of some Rhyolites Trachytes, and Phonolites from part of Kenya Colony, with a note on some of the associated Basaltic Rocks". *Quart. Journ. Geol. Soc.*, London, LXXXVII, pp. 212-258 and Plates XVIII and XIX.
- Willis, B. (1936).—*East African Plateaus and Rift Valleys*. Carnegie Inst. of Washington.

REPORT No. 23



COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

**A GEOLOGICAL RECONNAISSANCE
OF THE
AREA SOUTH-EAST OF EMBU
(WITH COLOURED GEOLOGICAL MAP)**

EXPLANATION OF DEGREE SHEET 44, SE. QUADRANT

By

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1952

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MAP

Geological map of the area to the south-east of Embu. Scale 1:125,000 ..	At end
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PROVINCIAL WATER OFFICER
 EASTERN PROVINCE
 P. O. Box 410
 EMBU

FOREWORD

The report and map of the area south-east of Embu completes the first geological survey of a strip of country, composed mainly of ancient rocks, extending between Meru, north-east of Mount Kenya, and Kitui. The quarter-degree areas on either side of the present area were described in Reports Nos. 14 and 17. Unexpectedly the area south-east of Embu has closer affinities with that west of Kitui, and lacks the large masses of basic and ultrabasic intrusives that are so prominent in the Embu-Meru area, and which it was anticipated would continue farther south. The area is, however, distinguished by the occurrence of a group of ancient rocks that appear to be younger than those of the Basement System, which are the oldest rocks known in Kenya. Apparently at present no economic significance attaches to the discovery, but the finding of outliers of pre-Cambrian rocks that may be correlated with the Nyanzian or Kavirondian systems of Western Kenya, which have been valuable for the gold and silver they have yielded, may ultimately be of great importance.

The area has at various times in the past been prospected for mica, but with disappointing results. It is, however, remarkable in containing some unusually large pegmatites, and it is perhaps possible that more intensive prospecting backed by adequate capital would lead to the discovery of workable mica deposits. During the present survey various other mineral occurrences were noted, but usually they appear to be present in too small quantities for them to be of economic value. The occurrences of graphite and magnesite that were discovered may, however, warrant more detailed examination with a view to exploitation.

NAIROBI,
6th February, 1952.

WILLIAM PULFREY,
Chief Geologist.

ABSTRACT

The report describes an area of approximately 1,250 square miles in the Embu, and Kitui districts, enclosed by latitudes $0^{\circ} 30' S.$ and $1^{\circ} 00' S.$ and by longitudes $37^{\circ} 30' E.$ and $38^{\circ} 00' E.$ Physiographically the area may be divided into the following units: (1) the Mumoni mountains and (2) the Tana valley in the east, (3) the Central Kiangombe mountains and Kanjiro hills, (4) the gently undulating country in the south and west forming the dissected remains of the sub-Miocene peneplain.

The rocks of the area fall into three groups: (1) the Basement System which includes calcareous, psephitic, pelitic and psammitic types with subordinate gabbroic intrusives; (2) the Embu Series, a group of ungranitized rocks of low-grade metamorphic state consisting essentially of banded gneisses, knotenschiefer, and hornfelses, with subordinate conglomerates and limestones, which are tentatively considered to be post-Basement System in age, and (3) the Tertiary volcanics of the Mt. Kenya suite, represented by kenytes, agglomerates, tuffs, phonolites and olivine basalts. The petrography of the rocks is briefly described and the metamorphism, granitization and structure of the Basement System are discussed.

Occurrences of mica, graphite and magnesite were noted and their economic possibilities are assessed. Certain areas are suggested as being more favourable for further prospecting.

I—INTRODUCTION AND GENERAL INFORMATION

A geological reconnaissance was made of the area south-east of Embu between July, 1950, and March, 1951. Six months were spent in the field investigating the possibility of the existence of mineral deposits of economic value and delineating, where possible, favourable geological formations which warrant closer investigation. The area is the south-eastern quadrant of degree sheet 44 (Kenya) and is bounded by latitudes $0^{\circ} 30' S.$ and $1^{\circ} 00' S.$ and by longitudes $37^{\circ} 30' E.$ and $38^{\circ} 00' E.$ It includes portions of the Embu and Kitui districts. Except for the south-western corner, which is held under leasehold title, the entire area is African reserve and includes parts of the North Yatta Native Reserve and the Kamba Native Land Unit.

The topography has been compiled from aerial photographs and locality names taken from the military map "Mt. Kenya", E.A.F. No. 1577 (1944), and Cadastral South A37.

Sheet ——— Local native names have been used for previously unnamed features.

B

COMMUNICATIONS

As indicated by the map, roads are comparatively scarce and much of the country is accessible only on foot. The Embu-Kitui road with the two branches leading to Kiambere and Siakago can be considered as the only reasonably good roads traversing the area. Many of the others shown on the map are simply cattle tracks or hunting tracks running down the watersheds to the Tana. The three most inaccessible areas are between the Thiba and Tana Rivers, between Kiangombe and the Tana, and between Mumoni and the Tana. The first of these areas can be reached from the road running SE. of Kagio to the Tana, and the northern portion of the second may be approached from Ishiara. A track branching from the Mwingi-Grand Falls road goes to the eastern foothills of Mumoni.

Sagana is the nearest railway siding to the area north and west of the Tana and is 60 miles by road from the suspension bridge where the Embu-Kitui road crosses the Tana. The area to the south and east of the Tana is best served from Thika which, via the Garissa road, is 75 miles from the suspension bridge.

The formerly proposed Thika-Garissa railway, surveyed and partly constructed during the early years of the 1939-1945 war, and since abandoned, cuts diagonally across the south-eastern corner of the area, north of Lutuni.

NATURE OF THE COUNTRY

Only a small portion of the north-western corner of the area lies on the outermost southern slopes of Mt. Kenya. Southwards and eastwards there is a marked decrease in rainfall, soil fertility and density of population, accompanied by an increase in pastoral herding at the expense of cultivation. The following figures indicate the decrease in rainfall that takes place both eastwards and southwards:—

STATION	Elevation (feet)	Total Rainfall for 1950	No. of Rainy days	Yearly Average	No. of Years Recorded
Embu D.C.	4,500	47.32	—	40.72	42
Rhombia Catholic Mission . .	4,830	34.26	54	—	—
Kabondori	3,750	24.70	60	29.06	11
Katze Dispensary*	2,500	13.18	41	20.66	8
Mwingi Mission*	3,400	15.80	41	—	—

* Katze and Mwingi are in the adjoining quarter-degree sheet on the east. The former is at the north-eastern foot of Mumoni and the latter is a few miles outside the south-eastern corner.

South of the Tana, soil erosion of both sheet and gully type continues to advance unabated and presents the same problems as in most parts of Africa south of the Sahara. Sheet erosion forms the greater menace because its effects are less spectacular and consequently it escapes detection for a longer period. North of the Tana, however, there is a tradition of soil conservation. In the Mbere country, long before the advent of Europeans, the inhabitants built stone terraces as a soil protection measure and the remains of these can still be seen. According to the *East African Standard* of 21st September, 1951, about 100 miles of new stone terracing were built during the last year (1950)—a resuscitation of a custom, as well as part of modern policy. Another African area in which such use was made of stone is the Pare Mountains of the Moshi district. In the north-east of the present area the cultivation and grazing of hillsides—a policy much favoured by Africans—has been prohibited on the Mumoni Mountains.

EXPOSURES

Exposures on the whole are adequate for broadly determining the geological boundaries, although in certain areas, e.g. between the Thiba and Tana, and south of the Tanz., there are extensive areas covered by thick layers of residual soil where no outcrops and little float are found. In such areas boundaries shown on the map are largely conjectural.

The resistance to weathering of the various rock types is fairly consistent and affords considerable assistance in mapping. The rocks named below are arranged in order of decreasing resistance to weathering, a sequence that is comparable with one established in Tanganyika (Temperley, 1938, p. 15):—

1. Meta-dolerite (resistance to weathering decreasing with increase of amphibolitization).
2. Quartzo-felspathic para-granulites and gneisses.
3. Quartz muscovite schists.
4. Plagioclase amphibolites, amphibolites and hornblendites.
5. Marbles.
6. Calc-silicate rocks associated with marbles.
7. Banded migmatitic gneisses.

Of the pre-Cambrian rocks of Mozambique, Holmes (1919, p. 55) has reported "... the glomeroplasmatic gneisses have been found only on the slopes of hills and inselberge peaks. Towards the adjoining valleys or plains they merge outwards into banded gneisses that usually are comparatively richer in biotite; while in the hills themselves, especially in the case of the large mountain groups, they pass inwards into granites much poorer in biotite". This relationship between relief and geology is applicable to much of the Basement terrain of the present area, particularly west and north of the Tana.

Other features of assistance in the mapping are:—

- (1) The weathering of plagioclase amphibolites and basic intrusives to a distinctive reddish-brown soil, e.g. the dyke east of Manutha.
- (2) The characteristic sandy soil derived from weathered psammites, e.g. along the main road south of the Tana.
- (3) The distinctive vegetation covering the limestone bands.
- (4) The exfoliation weathering of the granitoid gneisses giving rise to massive crags, tors and monoliths, whereas the basic rocks form hills with steep grassy slopes and few outcrops.

Areas of black cotton soil as well as all the above features are easily recognizable on the aerial photographs of the area.

PREVIOUS GEOLOGICAL WORK AND PROSPECTING

The pegmatites of the Embu district have attracted the attention of prospectors since 1913, but although they have been pegged many times, there is no record of mica having been shipped. In June, 1942, 500 square miles of the Embu-Meru area

were closed to prospecting by Government in order to invite applications for exclusive prospecting licences, but only a very small portion, north of the Ena River, fell into the present quarter-degree sheet. In July, 1942, B. A. Brannstrom, a Government prospector, prospected the area shown in figure 1 but apparently found nothing of economic interest. In September, 1942, Dr. W. Pulfrey examined the Thura River mica occurrences and neighbouring rock types and his findings are embodied in an unpublished departmental report. No records exist of any other previous geological work in the area.

II—PHYSIOGRAPHY

The area can be divided into four physiographical units:—

- (1) The Mumoni Mountains.
- (2) The Kiangombe Mountains and Kanjiro Hills.
- (3) The Tana valley.
- (4) The western and southern lowlands.

The most prominent features in the area are the blocks of resistant granitoid gneiss forming the central Kiangombe Mountains and Kanjiro Hills, and the banded gneisses of which Mumoni is composed. They form the chief mountainous regions and are confined to the northern half of the area. Separating these mountain ranges is a broad valley formed of less resistant migmatitic gneisses, through which the Tana River has cut its course. The floor of the valley has been moderately dissected by the Thura, Ruanjoga and Ena Rivers, flowing eastwards, and by the Thura and Ukoni Rivers which rise in the Mumoni Mountains. The topography of the floor, particularly nearer the Tana, is fairly rugged. Remnants of the sub-Miocene peneplain are preserved in the north-western, south-western and south-eastern portions of the area south-south-east of Embu; the surface has been considerably reduced by erosion and forms lowlands that stretch southwards to the Tana, swinging eastwards to include the bulk of the southern half of the area. South of the Thiba and Tana Rivers the plain is gently undulating with rolling grassland and open bush, studded with inselbergs of plagioclase amphibolite and metadolerite in the west, and monadnocks of granitoid gneiss in the east. In the north-west of the area the outermost lava flows of Mt. Kenya form a plane surface sloping gently southwards at 55 feet per mile. The boundary of the lavas does not form a prominent escarpment, the surface of the lavas merging into that of the Basement System. Immediately outside the northern boundary a few inliers of Basement System protruding through the lavas form conspicuous hills.

DRAINAGE

The two main rivers of the area—the Tana and the Thiba—are perennial, while two others, the Ena and the Itabua, have a limited flow in their upper reaches even during the dry season. Except in the north-west, the drainage pattern over the whole area has been determined by variations in the Basement System. Features such as faulting, the relative hardness of rock types, intrusives, and ubiquitously developed dip jointing have had a marked effect on the stream fabric. This is particularly noticeable along the Tana, the recipient of all the drainage in the area, which for the greater part of its course flows across the strike of the formations and is characterized by a number of right-angled bends. The drainage is emerging from late youth and approaching early maturity with the establishment of grade throughout a considerable portion of its course. Very little alluvium has been deposited, no large river terraces cut, and degradation predominates. Rapids and small waterfalls are not uncommon and deep steep-sided gorges have been cut north-east of Kagumo and east of the suspension bridge. The Lutuni-Muguthu area in the south-east exhibits a typical example of dendritic drainage developed by numerous insequent streams on relatively homogeneous rock types.

The drainage in the north-west, affecting particularly the Ena and Itabua Rivers, has been influenced by the slope of the Mt. Kenya volcanics,

EROSION HISTORY

The highest peaks of the Kiangombe Range (5,920 feet) and the Mumoni Mountains (5,588 feet) are considered to be relics of the 6,000-foot high-level peneplain of supposed end-Cretaceous age (Shackleton, 1946, p. 2)*. The peneplain may at one time have extended from the Machakos Hills and the Kitui Range in the south to the Matthews Range and Karissia Hills in the Maralal area, north of Mt. Kenya. This high-level peneplain has, in fact, been traced over a large part of Africa (Dixey, 1946, p. 243).

A lower peneplain, approximately 3,800 feet above sea-level, is clearly recognizable in the north-west where a portion of it has been preserved under a thin capping of Mt. Kenya volcanics. Contacts of the lavas and the Basement System are not exposed, and no interposed sediments that might have assisted in determining the age of the erosion surface were found. It is, however, considered to be part of the sub-Miocene peneplain (Shackleton, 1946, p. 2). Remnants of this dissected peneplain are found in the area bounded by the Thiba and Tana Rivers. Here the comparatively flat floor is broken by inselbergs of basic plutonics such as Nduni, Muthuru and Twooini which have resisted erosion. South of the Tana the Basement terrain has for the greater part been lowered well below the level of the sub-Miocene peneplain and it is only around Lutuni and Muguthu in the south-east and Kauthi and Masinga in the south-west that remnants are recognizable.

III—SUMMARY OF GEOLOGY

The rocks of the area fall into four groups, the Archaean rocks of the Basement System, the Embu Series, the Tertiary volcanics, and superficial deposits of Pleistocene and Recent age.

1. The Basement System

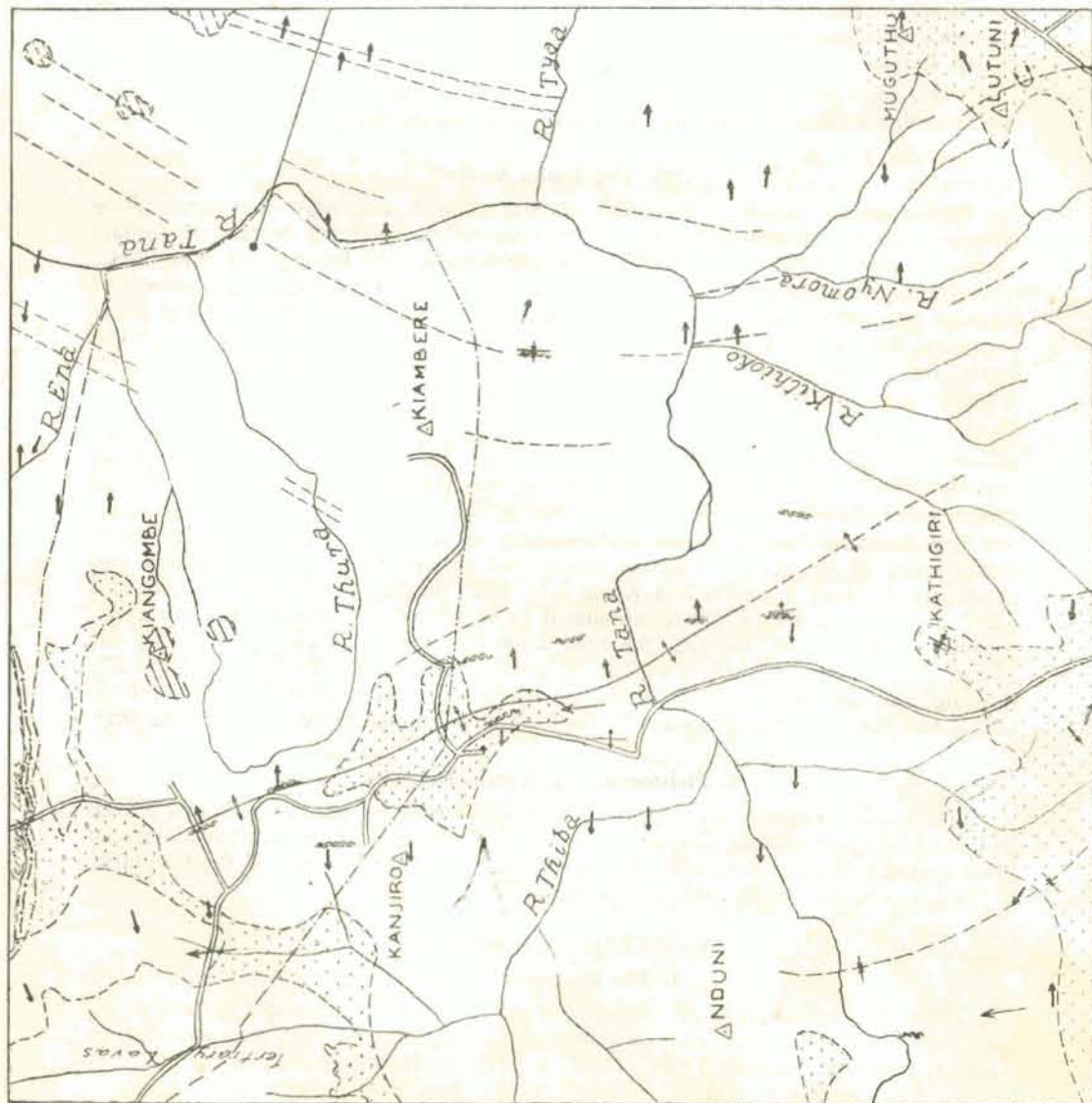
The Basement System in this area consists of a wide variety of calcareous rocks, gneisses and schists. Other rocks have been formed from them by granitization and pneumatolysis, which have been responsible for the formation of granites and migmatites, and the sporadic development of such minerals as tourmaline, phlogopite, scapolite and beryl.

The effects of granitization have been variable and generally increase in intensity towards the east. Index minerals, indicative of the higher degrees of metamorphism, are also more common in the east, suggesting that the degree of metamorphism and granitization are systematically linked (cf. Misch, 1947, pp. 241-245). Calcareous bands and basic rocks have essentially escaped granitization.

Plagioclase amphibolites and hornblende gneisses are widespread, the largest concentrations occurring south of the Thiba, and between Karie and Kiangombe. In the latter zone, however, there are no gabbroic or meta-dolerite cores, and many of the rocks are tentatively considered to be ortho-gneisses with appinitic characteristics and of approximately dioritic composition. Smaller lenses of gabbroic rocks occur between the Ruanjoga River and Thambu. No hypersthene-bearing acid or intermediate rocks are associated with any of the basic intrusives, nor were any found bordering the Embu-Meru quarter-degree sheet in the north.

The broader zones of granitoid gneiss, stretching for considerable distances across the area, are confined to that portion of the Basement System dominantly composed of alternating originally argillaceous and arenaceous sediments. The layers often retain their identity as melanocratic micaceous and leucocratic quartzo-felspathic bands respectively. The widespread irregularly banded migmatitic gneisses, which form the bulk of the Basement rocks, have been formed by intense granitization along favourable zones within biotite gneiss host rocks. Bedding is often preserved, particularly in thinly

* References are listed on p. 39.



- '8000' Surface'—sub-Miocene
- ▨ '6000' Surface'—end-Cretaceous?
- ▩ Denuded Remnants of '6000' Surface'
- Geological structure-lines
- Direction of pitch of lineation
- Anticline
- Syncline
- Overturned anticline
- Foliation dip
- Boundary of area closed to prospecting in 1942
- Boundary of area prospected by Bramstrom in 1942
- Shear-zones
- Hinge-fault

Fig. 1—Erosion surfaces and chief structural elements of the area south-east of Embu.

laminated biotite gneisses, but is almost completely obliterated in many instances by metamorphic differentiation and intense granitization. In the eastern half of the area a marked change in the lithology is apparent, the rock types being derived from predominantly calcareo-argillaceous sediments with only subordinate horizons of psammitic composition. In this zone dips are generally to the east at high angles. The banded gneisses are somewhat more regular, though not of so simple a composition as those in the west. Diopside-bearing gneisses are common, particularly between Mumoni and the Tana, and biotite gneisses grade into them through intermediate stages of hornblende-biotite and hornblende-diopside-bearing types. Coarse-grained garnetiferous rocks, not including those associated with the metacalcareous rocks, and sillimanite gneisses, are confined to the area between Mwangi and Chanzuko.

Limestones are concentrated in the south-eastern corner of the area where they form numerous parallel lenses, though smaller discontinuous lenses have been traced as far north as Memende and east of Kiambere. Two smaller occurrences of limestones were noted in the zone of hornblende gneisses south of Kanjiro. One of these carries a considerable amount of siderite and both are coarser grained than the limestones around Lutuni.

A few miles north of Masinga locally ferruginous sediments have been transformed into staurolite-sillimanite granulites. This is the only occurrence of staurolite in the area.

2. The Embu Series

Non-granitized pelitic rocks south of Siakago are tentatively considered to be younger than the Basement System. They have suffered varying degrees of contact metamorphism and the rocks grade from knotenschiefer into fine-grained granoblastic types (hornfels). Transitional types include those in which granulose, gneissose and schistose structures have developed. In some horizons bedding has survived the metamorphism and is represented by alternating thin micaceous and quartzo-felspathic layers. An intraformational conglomerate and a friable saccharoidal limestone form subordinate members of this suite.

3. The Tertiary Volcanics

The period between the Archaean and Tertiary was one of uplift and erosion, and is devoid of any signs of sedimentation or vulcanicity.

The Basement System in the north-western corner of the area is overlain by a thin capping of Mt. Kenya volcanics represented by kenytes, agglomerates, tuffs, and phonolites. Between Kiambiti and Karie four small patches of olivine basalt, one of which is associated with tuff, are considered to be related to the same volcanic cycle. Another olivine basalt, entering the area from the west, and closely following the course of the Thiba, is a narrow band of poorly exposed vesicular rock occasionally showing rude columnar jointing. A few isolated small patches of tuff, some overlying kenyte and the others the Basement System, are large enough to be shown on the map.

4. Pleistocene and Recent Deposits

Post-Tertiary deposits are superficial and represented by semi-consolidated gravels and sands, impure surface limestones, lateritic ironstones and by extensive areas of black cotton soil and sandy soils. Travertine float was found in one of the tributaries of the Thura River near its confluence with the Tana.

IV—DETAILS OF GEOLOGY

1. The Basement System

There is a great variety of non-migmatized rocks in the Basement System of the area, and their differences and relationships can perhaps be best demonstrated by Table 1, which is based on Tyrell's (1941, p. 279) "crystalloblastic series".

TABLE 1—ROCK TYPES FOUND IN THE BASEMENT SYSTEM OF THE AREA SOUTH-EAST OF EMBU

COMPOSITION	STRUCTURE			
	Maculose	Schistose	Gneissose	Granulose
Rudaceous	—	—	—	Pebbly Grit
Argillaceous	Hornfelsic types	Muscovite Schist Quartz-muscovite schist	Pelitic Gneiss Sillimanite gneiss	Staurolite-sillimanite granulite
		Garnet-mica schist *Muscovite-tourmaline schist	Biotite gneiss Hornblende gneiss Biotite-garnet gneiss Plagioclase amphibolites *Felspar porphyroblast gneiss	Kinzigit
Arenaceous	—	Quartz schist	Psammitic gneiss *Granitoid gneiss *Augen gneiss *Felspar porphyroblast gneiss	Quartzites Quartzofelspathic granulites
Calcareous and Dolomitic	Forsterite marbles	Calc-schists	Ophicalcite	Crystalline limestone
	Calc-silicate rock		Crystalline limestone	Calc-silicate granulite Calc-magnesian silicate rocks Calc-microcline pyroxene rocks
Igneous rocks (mainly Basic)	Spotted anorthositic types	Chlorite and Tremolite schists Hornblende schists Amphibolites	Hornblende gneiss	Meta-dolerites
	Hornblende-biotite types		Plagioclase amphibolites	Uralite gabbros
				Appinitic types

*Rocks due to recrystallization and additive processes.

For the purpose of description the rocks may be classified into the following groups:

(1) SEDIMENTS

(a) *Calcareous*

- (i) Crystalline limestones.
- (ii) Calc-silicate and calc-magnesian silicate rocks.
- (iii) Semi-calcareous gneisses.

(b) *Pelitic and Semi-Pelitic*

- (i) Biotite gneisses.
- (ii) Hornblende gneisses.
- (iii) Hornblende-biotite gneisses.
- (iv) Sillimanite gneisses.
- (v) Muscovite schists.
- (vi) Micaceous hornfelsic types.

(c) *Psammitic*

- (i) Biotitic quartzo-felspathic gneisses.
- (ii) Quartzo-felspathic granulites.
- (iii) Quartzites.

(d) *Psephitic*

- (i) Pebbly grit.

(2) VOLCANIC ROCKS

(3) MIGMATITES

(4) MAJOR INTRUSIVES

(a) *Granites*

(b) *Pegmatites and aplites*

(c) *Basic igneous types*

- (i) Olivine-pleonaste norites.
- (ii) Hornblende gabbros.
- (iii) Anorthosites.
- (iv) Meta-dolerites and plagioclase amphibolites.
- (v) Ortho-amphibolites.
- (vi) Chlorite and actinolite schists.

(5) MINOR INTRUSIVES

(a) *Dolerites*

(1) SEDIMENTARY ROCKS OF THE BASEMENT SYSTEM

(a) *Metamorphosed Calcareous Sediments*

(i) *Crystalline Limestones*

These have been found in many places, the greatest concentration, however, being in the south-east corner, around Lutuni. They are more resistant to weathering than the associated country rock and form low-lying ridges and isolated hills with characteristic vegetation. Most of the bands are narrow and steeply inclined to the east. Although field evidence is lacking, because of poor exposures, it appears likely that strike faulting and/or folding has caused duplication of many of the bands. The colour usually varies from white to dark grey, a notable exception being the pale pink marble band south-west of Memende. Taken as a whole they are medium to coarse grained, and banding is distinct only in some where graphitic horizons are present. Dedolomitization has been facilitated by the presence of siliceous and argillaceous impurities, the silica, as is usual, showing a preference for magnesium rather than calcium and forming the various magnesium meta- and orthosilicates. Some contain rounded and oval grains of forsterite which have been serpentinized with the concomitant liberation of magnetite. With the development of complete pseudomorphs, often rimmed with iddingsite, the rocks containing them grade into ophicalcites. Flaky graphite occurs in irregular bands or as disseminated particles, and has an erratic distribution. It is invariably accompanied by phlogopite which has been derived by reaction of the limestone with either muscovite or potash felspar. In the more highly serpentinized limestones these minerals are either subordinate or absent.

In the limestone band south of the Kithioko-Tana confluence euhedral crystals of purple fluorite and reddish-brown rutile are locally abundant. Partly serpentinized diopside, fine platy talc and tabular bent crystals of chlorite are subordinate. Specimen 44/832, the pink marble south-west of Memende, carries small quantities of ferri-ferous tremolite, and the dark grey foliated limestone from south-east of Siakago is highly dusted with opaque ore, the only other impurity being quartz.

Locally magnesite has formed in and on the marbles through hydrothermal or groundwater alteration. At Lutuni, five miles west of Lutuni, and south of Kaumothoi, small irregular veins of magnesite traverse a surface crust of impure breunneritic material. The veins are rarely more than a few inches thick and are not persistent as regards length or orientation. The magnesite is usually porcellaneous and amorphous, but rarely breaks with a conchoidal fracture. Quartz-lined cavities and dendrites of iron ore are not uncommon. The fact that some of the specimens react with cold hydrochloric acid indicates a high lime content. Some of the impurer varieties are veined with blackish serpentinous material.

(ii) *Calc-silicate and Calc-magnesian Silicate Rocks*

These rocks have been formed by the regional metamorphism of impure limestones, calcareous shales, marls and other partly calcareous types. They have a wide distribution in the eastern half of the area and are found not only associated with the crystalline limestones, but also in areas far removed from them. The lenses south and south-west of Kaumothoi also suffered thermal metamorphism during the intrusion of gabbroic dykes near them, prior to the regional metamorphism, and some unusual and more comprehensive mineral assemblages have been formed.

The calc-silicate and calc-magnesian silicate rocks are composed of varying amounts of the following minerals: pyroxene, hornblende, epidote, garnet, scapolite, plagioclase and opaque minerals.

The most common pyroxene is xenoblastic diopside. It often shows various stages of alteration to amphiboles, either as marginal encroachments or multiple-centre growths. Not infrequently the pale green or colourless diopside exhibits slight dispersion and fleeting pale green to pinkish pleochroism. Other pyroxenes observed were mauvish titan-augite, pigeonite, diallage and in specimen 44/867 the diopside is enriched in the hedenbergite molecule. A deep green variety, possibly chrome-bearing, occurs as cores in epidote, in slide 44/710. Unusual mineral associations were observed in thin sections 44/756 and 44/739. The former shows titan-augite as cores in isotropic orthite, and in the latter vermicular titan-augite, in optical continuity, lies in a base of granoblastic plagioclase.

Most of the hornblende is derived from the pyroxenes and complete pseudomorphs are not uncommon. It includes both green and brown varieties. Extinction angles vary according to the colour, the brownish hornblende invariably extinguishing at smaller angles than the greener varieties.

Epidote is widespread and abundant. It occurs variably as xenoblastic grains, skeletal crystals or subhedral stumpy prisms, and is occasionally accompanied by optically positive zoisite. Other minerals of the epidote family include the pale pink feebly pleochroic manganiferous variety, thulite, altered isotropic orthite and possibly magnesium orthite.

The garnets vary from pale pink to deep reddish brown. They exhibit a variety of irregular forms including ring- and atoll-shaped grains. They are frequently corroded and exhibit sieve structures and imperfect porphyroblastic growth, the chadacrysts consisting of epidote, quartz, plagioclase and sphene. Rarely anisotropic garnets, with a uniaxial positive figure, were observed, e.g. in specimen 44/709. Some thin slices show vermicular intergrowths of garnet and epidote, and garnet and plagioclase (cf. Schoeman, 1948, p. 32).

Scapolite occurs as either large replacive plates or as smaller irregular skeletal grains. It replaces both feldspar and quartz and rarely the ferromagnesian minerals. The unusually high birefringence and relief suggests that it is rich in the meionite molecule.

Except in the microcline-pyroxene rocks, the feldspars are plagioclase of the more calcic varieties. The crystals are usually large and fresh, and only occasionally sericitized. Strain polarization is unusual but is sometimes present. Thin sections show vermicular and graphic intergrowths of twinned or untwinned plagioclase with each of the following minerals: titan-augite, epidote, garnet, thulite or magnesium orthite (?) and orthite. In the thin section of specimen 44/709 the feldspars exhibit typical diablastic texture, the inclusions consisting of subangular quartz, irregular garnets, skeletal epidote and granular sphene. Although quartz is sometimes locally abundant, it is generally subordinate and frequently absent. It is commonly interstitial and secondary.

The opaque minerals can only be classed as accessories. They are erratically disseminated throughout the rocks and show no concentrations into bands or irregular lenses, a feature common to pyrometamorphic deposits. Graphite is the most abundant, and occurs only in those calc-silicate granulites intimately associated with the crystalline limestones. The oxides, ilmenite and magnetite, were not observed in any appreciable quantities *in situ*, but concentrations were found in the dry river courses intersecting the limestones and calc-silicates. Occasional grains of pyrite, pyrrhotite, chalcopyrite and bornite are visible in the more pyroxene-rich types, and are considered to be original constituents of these rocks.

The thermal metamorphism of a dolomite with abundant siliceous and micaceous impurities has formed an unusual rock type, which occurs in the band of calc-silicate rocks east of Kiambere. It is composed almost entirely of microcline, microcline-perthite and partly altered diopside. Similar types have been described from South Australia (Tilley, 1920, p. 493). In a thin section of specimen 44/712 two generations of alkali feldspar are apparent and they show a mutual replacive relationship. The colourless diopside in the slide does not show the degree of alteration that is so obvious in many grains of the mineral in the hand-specimen. Prismatic pale greenish tremolite is the only other ferromagnesian mineral present in fair quantities. Other minerals occurring in variable, but generally, small amounts include: reniform-granular vesuvianite, patchily pleochroic from colourless to reddish brown, myrmekite, chlorite, subhedral allothigenic monazite (?) and zircon, euhedral apatites, and small granular aggregates of colourless sphene often surrounding cores of ilmenite.

The large calc-silicate lens, south-east of the Tana-Kithioko confluence is characterized by the presence of wollastonite. The rocks weather with a pronounced knobby surface. They are essentially green, but are mottled with granular brown garnets and satiny white wollastonite. In a thin section of specimen 44/749 the texture is found to be coarse-grained xenoblastic granular. The bulk of the slide consists of large cracked straw-yellow oikocrysts of garnet poikilitically enclosing grains of wollastonite, diopside, calcite, epidote and sphene. The colourless wollastonite is tabular, and has well-developed cleavages and moderate birefringence. Many grains show optical strain, others lamellar twinning. Secondary quartz forms borders around interstitial and vein calcite, and was introduced before the calcite, but subsequent to the metamorphism.

Other thin sections, 44/778B and 44/788, show vermicular epidote, with a parallel overgrowth of a brownish isotropic mineral considered to be altered orthite, graphically intergrown with plagioclase. As the isotropic cores of orthite merge into the epidote so they become anisotropic with increasing, though never strong, birefringence. A similar phenomenon is illustrated by larger isotropic garnet-like grains of orthite, the dactylitic projections of which, on penetrating plagioclase laths, become anisotropic. The deep green pyroxene is also present and often shows peripheral alteration to epidote but is rarely intimately associated with the orthite.

Specimen 44/783 was taken from the limestones north of the junction of the Kitui-Garissa and Garissa-Thika roads. Phlogopite is abundant and occurs in small veinlets and as disseminated flakes. The bulk of the slide consists of pale partly amphibolized diopside and large twinned crystals of plagioclase, skeletal epidote, pellucid rounded quartz, fibrous scapolite, interstitial calcite and wedge-shaped pleochroic sphenes. Tremolite, bastite and graphite occur in subordinate quantities.

The low-lying range of hills east of Karie are composed of calc-magnesian silicate rocks derived from the metamorphism of impure magnesian limestones. Two distinct rock types are recognizable; they are essentially composed of the same minerals, although in different proportions. Specimens 44/720 and 44/691 illustrate the medium-grained, equigranular and moderately schistose characteristics of the one type; whereas the other is coarse-grained and porphyroblastic. The exposed surfaces of the latter often weather to a soft pale-yellowish or brownish encrustation as much as half an inch thick. The rocks are comparatively homogeneous and the approximate volumetric modes* of some representative specimens are given below:—

							44/693	44/720
							%	%
Quartz	..	..	..	..	..	..	—	+
Microcline	..	..	..	..	..	..	+	+
Plagioclase	..	..	..	..	..	..	10	10
Hornblende	..	..	..	..	..	..	32	70
Pyroxene	..	..	..	..	..	..	35	6
Scapolite	..	..	..	..	..	..	—	5
Tremolite	..	..	..	..	..	..	2	+
Epidote-zoisite	..	..	..	..	..	..	18	5
Calcite	..	..	..	..	..	..	+	—
Accessories	..	..	..	..	..	..	3	4

44/720—Hornblende pyroxene schist.

44/693—Hornblende porphyroblast gneiss.

Much of the hornblende has formed at the expense of the pyroxene, as is revealed in thin section 44/725. The plagioclase is usually sodic labradorite.

In the Mumoni Mountains and south of Muguthu narrow discontinuous lenses of a heavy friable pyroxene-hornblende rock were observed. They are medium-grained and schistose and in thin section are seen to consist of 95 per cent of interpenetrating prisms of hornblende and diopside, and 5 per cent plagioclase and accessories. In thin section 44/781 numerous prisms of fresh dark-green primary hornblende are poikiloblastically enclosed in large pale-green crystals of diopside, whereas in specimen 44/791 the hornblende has partly replaced diopside, the minerals having the same optical orientation.

(iii) *Semi-calcareous Gneisses*

According to Harker (1950, p. 260) "... with a sufficient original admixture of siliceous and aluminous material a limestone or dolomite will suffer complete decarbonation, and we find accordingly silicate rocks, not merely as nodules or inconstant bands, but occurring in mass". In the body of calc-magnesian silicates east of Karie, there was sufficient silica to allow maximum silication, so that olivine and forsterite are absent. Between the Tana and the Mumoni Mountains, however, the excess of silica in some of the calcareo-arenaceous sediments was sufficient to allow the formation of numerous diopside-quartz and diopside-felspar gneisses. These rocks are medium-grained, equigranular, and well-banded types, the individual bands being thin and parallel. The leucocratic layers consist of interlocking mosaics of quartz,

* All modes quoted were estimated.

plagioclase and myrmekite. Only rarely do they show signs of partial recrystallization. The mafic minerals consist of poorly formed porphyroblastic dark-green hornblende, often clearly derived from lighter-green diopside, and skeletal and vermicular epidote. Large replacive crystals of scapolite, not infrequently of fibrous habit, are also present. The accessories include calcite, granular sphene, subrounded zircons and apatite.

Other semi-calcareous gneisses have been formed from originally marly sediments. The best exposures of these rocks are found south-west of Gakuyu, where gradations exist from hornblende biotite gneisses to hornblende diopside gneiss. They are discussed in greater detail in the section dealing with semi-pelitic rocks.

(b) *Metamorphosed Pelitic and Semi-pelitic Sediments*

(i) *Biotite Gneisses*

Biotite gneisses are far more extensively developed than is indicated on the map but, being neither large nor continuous masses, and having a tendency to grade into granitoid gneisses over comparatively short distances, they are included in the undifferentiated Basement System, where they for the greater part form the melanocratic component of the migmatitic banded gneisses. They vary from leucocratic, foliated, relatively biotite-poor types, of semi-pelitic origin, to melanocratic fine- to medium-grained flaggy gneisses. The following volumetric compositions indicate their approximate mineral composition:—

		44/474	44/602	44/546
		%	%	%
Quartz	.. .. .	27	40	37
Microcline	.. .. .	—	20	20
Plagioclase	.. .. .	35	15 (An ₂₀)	20
Myrmekite	.. .. .	—	3	3
Biotite	.. .. .	25	20	15
Epidote	.. .. .	10	—	—
Accessories	.. .. .	3	2	5

With increase of feldspathization they develop heteroblastic textures and grade into feldspar porphyroblast gneisses and augen gneisses, eventually losing their gneissosity and assuming a granitic texture. The biotite varies from deep brown to dirty green and is variably of flaky, tabular or ragged habit. The colour is often so intense that grains appear to be isotropic. Thin section 44/474 shows the effects of the redistribution of lime in that granular epidote has formed at the expense of biotite. The quartz often occurs in small mosaics of subangular grains with faint rims of brownish material. The original feldspars are somewhat turbid, twinned, soda plagioclase usually with well-developed cleavages. Replacive microcline, and subordinate microcline-perthite and myrmekite have been formed in those rocks affected by granitization. Muscovite often replaces biotite, but is never abundant. It sometimes shows a fleeting pinkish pleochroism, but is generally colourless. The usual accessory minerals include rod-like zircons, granular sphene, subhedral small garnets, apatite and opaque iron ores. Minute stumpy prisms of buff tourmaline and chlorite, rutile and granular calcite were observed in thin sections of thinly laminated biotite gneisses from north of Kiarawara. This band also reveals weird contortions where quartz segregations have been promoted by metamorphic differentiation.

It is interesting to note that hornblende is invariably absent from these biotite gneisses and their granitoid derivatives.

Locally developed coarse-grained garnetiferous biotite gneisses are found associated with the calc-silicate granulites and sillimanite-bearing rocks in the eastern half of the area. They conform closely with those described by Shackleton (1946, p. 10) from the country between Nanyuki and Maralal. The essential minerals consist of sieved and corroded garnets, quartz, reddish-brown biotite, plagioclase and microcline. Calcite,

small grains of myrmekite, perthite and relics of highly corroded muscovite are subordinate. The leucocratic varieties of these rocks are rich in replacive microcline and many small flakes of biotite are altered to greenish chlorite with the release of magnetite. Those richer in garnets generally exhibit the effects of granulation and recrystallization.

(ii) Hornblende Gneisses

A distinct class of hornblende-bearing biotite-free paragneisses occurs as minor intercalations in both limbs of the Thatha syncline, at the foot of Kibara and north and east of Karie. They are relatively free from the effects of granitizing fluids and are fine-grained and mesotype, often developing a rudely banded aspect. No linear fabric has been developed. At Kibara and east of Karie they are generally pink with scattered greenish epidotic layers.

Thin sections show these rocks to consist mainly of equidimensional interlocking grains of quartz and plagioclase, varying amounts of granular epidote, and porphyroblastic brownish-green to bluish-green sieved hornblende. Of 15 thin-sections examined, only two carried small amounts of biotite. Microcline and myrmekite where present are subordinate and appear to be primary. The microcline in thin section 44/489 is cluttered with small inclusions of epidote.

With increase in the hornblende content these rocks grade into plagioclase amphibolites, the simplest and most characteristic of which consist of green hornblende and feldspar. The well-defined epidotic bands, so frequently observed in these rocks and to a lesser extent in the gneisses, owe their origin to calcareous impurities in the original sedimentary rocks, to calcification of the rocks prior to metamorphism or to hydrothermal agencies.

The approximate modes of some hornblende gneisses are given below:—

	44/591	44/590	44/605	44/608	44/489
	%	%	%	%	%
Quartz	30	62	18	60	15
Plagioclase	30	62	45 Ab ₇₅	10	39 Ab ₆₅
Myrmekite	—	—	—	—	12
Hornblende	25	18	35	15	17
Biotite	—	—	—	—	5
Epidote	40	20	—	15	10
Accessories	5	—	2	—	2

Garnets were observed only in the gneisses east of Karie and calcite in those at Kibara. The accessories consist of rounded zircons, skeletal and granular sphene, apatites and ore.

(iii) Hornblende-Biotite Gneisses

Biotite-bearing hornblende gneisses are closely associated with the biotite-free hornblende gneisses, and the best exposures are found where the Tana cuts across the Thatha syncline. Minor occurrences were noted west of Kanjiro and around Thambu. They correspond closely to the plagioclase hornblende gneisses described by Schoeman (1951, p. 10) in the Embu-Meru area. He considered them to be partly derived from soda- and lime-bearing sediments but suggested the possibility that some of them might be meta-intrusives. It is also not unlikely that some of them are derivatives of basic rocks that have been subjected to soda metasomatism. For the purposes of the present survey they have provisionally been placed with the metamorphosed pelitic and semi-pelitic rocks, but the facts listed below may be of assistance in elucidating their origin at some later date:—

(a) Mineralogically they correspond closely to descriptions of appinites from Sutherland, which Read (1931, p. 172) regards as being formed by the mixing of acidic felspathic magma with solid ultrabasic olivine-bearing rocks.

(b) They differ from the appinites of Tanganyika (Wade and Oates, 1938, pp. 38-41) in that diopside is absent and biotite is present in subordinate amount. According to Wade and Oates (op. cit., p. 39) "The characters displayed strongly suggest that appinite is a hybrid rock resulting from a two-phase reaction between a late granitic differentiate charged with reactive liquids and solid rock rich in mafic material".

(c) Reynolds (1936) claims that in the Hebrides they have formed through reaction of a hornblende magma with quartzite.

(d) Their limited development in the area south-east of Embu is, with one exception, confined to areas of basic intrusion.

(e) Palimpsest structures as observed in thin sections, suggest a derivation, in part at least, from sediments.

The hornblende-biotite gneisses are mesotype rocks with granitoid to mildly gneissose structure and dioritic composition. They weather easily, so that outcrops are found only in stream courses. The exposed contacts show no chilled borders and reveal a reticulate veining, that sometimes gives rise to local irregular banding. The gneisses are of simple and remarkably uniform composition, the essential minerals showing little variation in optical and physical properties over the wide area in which they occur. In thin section they are medium-grained xenoblastic granular and only occasionally exhibit a mild gneissosity. Mineralogically they are the same as the plagioclase hornblende gneisses in the adjoining Embu-Meru area, and consist of poikiloblastic hornblende, large crystals of plagioclase, small flaky biotite that not infrequently is partly altered to chlorite, quartz, and subordinate epidote, which often occurs as chadacrysts in plagioclase. Although much of the irregular quartz is secondary, it also occurs as isolated sutured mosaics suggestive of original sand grains. The composition of the plagioclase varies from An_{40} to An_{25} . The accessories include apatite, zircon, calcite, sphene and iron ore.

The mineral composition of some representative specimens is given below:—

	44/500	44/486	44/573	44/629
	%	%	%	%
Quartz	3	25	20	8
Plagioclase	30	35	35	42
Hornblende	60	25	35	35
Biotite	2	10	7	12
Epidote	2	4	+	3
Chlorite	3	—	—	—
Accessories	—	1	3	—

Specimen 44/666, from a thin faulted band immediately east of Thambu, is considered to fall into this class, although it is not at all representative of it. It is moderately gneissose and of glomero-porphyroblastic texture. The gregaritic clusters of hornblende project prominently from weathered surfaces giving the rock a distinctly spotted appearance. In thin section it is seen that the plagioclase grains are equidimensional and fresh, with sutured outlines indicating partial recrystallization, and exhibit polysynthetic and pericline twinning. Small biotite flakes are subordinate and opaque ore makes up 10 per cent of the slide.

The hornblende-biotite gneisses, like the hornblende gneisses, grade into plagioclase amphibolites and amphibolites, when recrystallization under pressure has imparted a mild schistosity or gneissosity on those rich in hornblende.

East of the Tana, between Memende and Mumoni, the hornblende-biotite gneisses occur as narrow disconnected lenses and differ markedly from those already described. They are melanocratic, rudely fissile types of medium grain and moderate gneissosity but devoid of any linear fabric. They exhibit typical crystallization foliation. North-

wards, they grade into hornblende-diopside gneisses corresponding with an increase of calcareous impurities in the original sediments. Green hornblende is invariably the most abundant mineral and is variably accompanied by either diopside or biotite, but never both. Quartz, myrmekite, and calcite are subordinate. The feldspar in some slides was determined as An_{20} and, although usually fresh and twinned, highly sericitized and untwinned plates were also observed. Granular sphene, often faintly pleochroic, is the commonest accessory and in some slides may account for as much as 4 to 8 per cent of the total composition. Epidote, zircon and apatite are also present. The variable composition of these rocks is indicated below:—

			44/822	44/848	44/819	44/802
			%	%	%	%
Quartz	..	..	—	—	—	4
Plagioclase	..	..	62	40	39	54
Hornblende	..	..	36	43	38	30
Biotite	..	..	—	—	—	10
Diopside	..	..	—	14	20	—
Epidote	..	..	—	2	3	—
Accessories	..	..	2	1	—	2

(iv) *Sillimanite Gneisses*

Except for one small occurrence north-west of Masinga, it is only between the Mumoni Mountains and Mwango that the sediments were sufficiently aluminous to yield the distinctive index mineral sillimanite. The gneisses are neither extensively developed nor conspicuous in the field. They are coarse-grained types but, unlike comparable rocks in the Nanyuki-Maralal area (Shackleton, 1946, p. 9) are interbedded with rocks of semi-calcareous origin, and are themselves considered to be derived from semi-pelitic sediments. The plagioclase feldspar shows no evidence of having been metasomatically introduced and is a sodic variety (about An_{20}). Only the very limited replacement of some of the sillimanite by muscovite could be interpreted as being due to the effects of granitization. The chief sillimanite-bearing rocks are:—

- (a) Sillimanite-quartz gneisses.
- (b) Sillimanite-biotite-garnet gneiss.
- (c) Sillimanite-staurolite granulite.

Outcrops of sillimanite-quartz gneiss were found on Mtui and between Mtui and Mumoni. They are well-foliated leucocratic rocks, which in places show local patches of reddish-brown colour produced by weathering of the iron-bearing minerals they contain. The colourless sillimanite occurs both as slender prismatic crystals and as fibrous sheafs which show a definite parallelism. The feldspar is untwinned and fresh but often cracked, and like the quartz grains, frequently shows optical strain. The accessories are rounded zircons and magnetite.

The sillimanite-biotite-garnet rocks are melanocratic coarse-grained types with a foliation which, although well developed in some, is barely discernible in others. Thin sections often show an intimate association of sillimanite, biotite and subordinate muscovite. The sillimanite occurs as a generally unorientated felted mass of fibres with quasi-fluxional arrangement in places. Swarms of needles are embedded in quartz or wind streamlike around the larger grains, particularly the garnets. The pink garnets are cracked and poikilitically enclose chadacrysts of quartz, feldspar, biotite, chlorite and rutile. In thin section 44/875 some of the garnets contain numerous minute prisms of sillimanite arranged with parallel orientation and parallel to the schistosity of the rock. The untwinned soda plagioclase and quartz grains which have, in some instances, partly recrystallized to form a sutured mosaic, invariably show signs of strain, and cracks can be seen to run across numerous grains. Pseudomorphs of chlorite after biotite are common and the two minerals are frequently interleaved. Partial replacement of sillimanite by biotite is not uncommon, and suggests the possibility that, at one time sillimanite was far more widespread and abundant, but with subsequent granitization and retrogressive metamorphism (?) it is now represented by the micas.

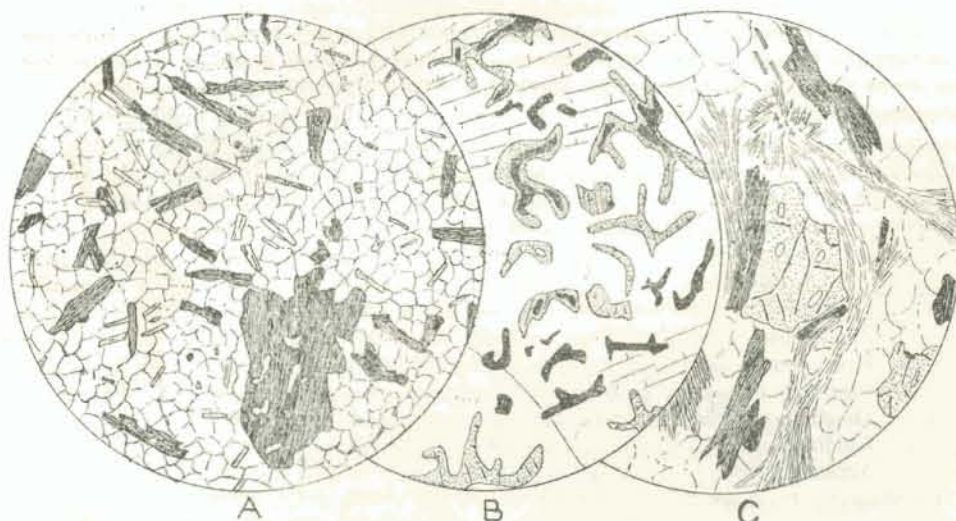


Fig. 2—A. Knotenschiefer. Specimen 44/835, three miles south of Siakago. Ordinary light x 17. The large biotite porphyroblast encloses small chadacrysts of quartz and is embedded in a granoblastic quartz matrix. The small flakes of muscovite show no orientation.

B. Plagioclase-epidote-orthite granulite. Specimen 44/778, South-west Memende. Ordinary light x 17. The epidote and orthite are graphically intergrown with both twinned and untwinned plagioclase. The orthite also forms a parallel overgrowth on the epidote and often merges almost imperceptibly into it.

C. Sillimanite-biotite-garnet gneiss. Specimen 44/792, Mumoni. Ordinary light x 17. The drawing shows the intimate association of biotite and sillimanite and the manner in which the sillimanite fibres wind around the sieved garnet porphyroblasts.

The sillimanite-staurolite granulites are associated with epidote-garnet-magnetite rocks north-west of Masinga. They are fine- to medium-grained melanocratic types. The only specimen sliced, 44/857, consists of fibrous sillimanite, golden-yellow subhedral staurolite of short prismatic habit, abundant magnetite, subordinate muscovite, greenish chlorite, and interstitial plagioclase. The rocks were presumably derived from sediments which were more aluminous and feriferous than usual.

The volumetric modes of some sillimanite gneisses are given below:—

	44/780	44/818	44/792	44/804	44/820	44/812	44/857A
	%	%	%	%	%	%	%
Quartz.. ..	38	64	26	48	62	35	—
Plagioclase	12	8	15	18	15	25	3
Biotite	—	1	10	4	12	15	—
Muscovite	—	+	—	—	+	+	+
Sillimanite	46	25	36	22	10	+	57
Staurolite	—	—	—	—	—	—	22
Garnet	—	—	10	6	—	20	—
Chlorite	—	—	—	—	—	4	+
Accessories	4	2	3	2	1	1	18

44/780 and 44/818—Sillimanite-quartz gneisses.

44/792, 44/804, 44/820 and 44/812—Sillimanite-biotite-garnet gneisses.

44/857A—Sillimanite-staurolite granulite.

(v) *Muscovite Schists*

The best exposures of muscovite schists are found south of Siakago, at Kathigiri and south of Kanjiro. They are of medium to coarse grain, invariably biotite-free, and the more highly quartzo-felspathic types are sufficiently resistant to weathering to give rise to low-lying hillocks.

Specimen 44/594 is a pinkish friable schist with large corroded plates of feebly pleochroic muscovite, in a base of granoblastic quartz. Specimens 44/831 and 44/850 have silvery lustre and are highly sheared rocks composed of muscovite of sericitic habit, granulated quartz and angular pink garnets. At the foot of Kathigiri the rocks are moderately foliated felspathic types with erratically disseminated small garnets. Microcline replaces quartz, and myrmekite is subordinate. The hill itself is composed of tourmaline-bearing muscovite schist, in which the euhedral black tourmaline crystals, a result of pneumatolysis, sometimes attain a length of two and a half inches. A thin section of the schist (44/595B) consists of decussately arranged interpenetrating laths of muscovite, small scattered clusters of anhedral quartz, and large brownish tourmalines, enclosing numerous unreplaced relics of quartz, muscovite and iron ore.

(vi) *Micaceous Hornfelsic Types*

These poorly exposed and highly weathered rocks were observed only in the south-western corner of the area. They are rudely foliated and have a speckled appearance due to small unorientated and partly altered laths of brownish biotite and silvery muscovite. In thin-section the rocks have a typical sedimentary texture and consist of subangular grains of quartz separated by brownish interstitial material, flakes of muscovite and biotite, a mamillated yellow-green mineral that is possibly a member of the epidote family, and abundant subangular fragments of rutile. The yellow-green mineral is partly limonitized, shows aggregate polarization, and appears to have formed by alteration of biotite.

The only thin section examined, 44/637, has the following mineral composition:—

Quartz	Felspar	Epidote (?)	Muscovite	Altered Biotite	Rutile	Ore
60	10	10	15	3	1	1

(c) *Metamorphosed Psammitic Sediments*

The psammitic gneisses are generally fine- to medium-grained rocks in which the ferromagnesian minerals are always subordinate. Their resistance to erosion is far greater than that of the pelitic rocks and they consequently form the bulk of the hills, the Mumoni Mountains, however, being a notable exception. They are considered to have been derived from sandstones, quartzites, felspathic quartzites and arkoses. Except for the quartzites they have all suffered granitization to a greater or lesser extent. Exfoliation is the characteristic method of weathering and this has given rise to massive crags, such as are seen on Kanjiro. Less frequently they are well jointed, the joints being parallel to the dip and strike of the strata, as at Kiarawara. Quartz and thin aplitic veins, usually in joint planes, commonly traverse these rocks.

(i) *Biotitic Quartz-felspathic Gneisses*

These are medium grained, equigranular, and usually either brown or grey in colour. The gneissosity is commonly accentuated by flakes of biotite segregated into bands or aligned along foliation or bedding planes. Although in most cases all microscopic evidence of sedimentary textures has been obliterated by the effects of both regional metamorphism and granitization, occasional small palimpsest structures suggestive of original sand grains were observed. The essential minerals are quartz and felspar with

subordinate biotite, not infrequently intimately associated with chlorite and epidote. Some of the rocks have a small percentage of highly corroded dirty-green hornblende. The feldspars are of two generations: original grains of oligoclase-andesine are replaced by later microcline, microcline-perthite and myrmekite. The latter frequently encroaches on the earlier feldspars as small bays. Myrmekite and microcline tend to be more abundant in those rocks which are sheared and foliated. Accessories observed in one or another of the slides include subrounded zircons, granular sphene, apatite, epidote and small pale-pink garnets.

The estimated volumetric modes of some representative specimens are given below:—

	44/626	44/551	44/655	44/518	44/759
	%	%	%	%	%
Quartz ..	45	40	43	50	25
Microcline ..	—	18	+	5	22
Plagioclase ..	37	35	50	32	39
Myrmekite ..	—	2	+	—	—
Biotite ..	8	4	6	5	10
Muscovite ..	+	—	+	—	2
Hornblende ..	2	—	—	5	—
Epidote ..	4	—	+	+	—
Chlorite ..	4	—	—	—	—
Accessories ..	—	1	1	3	2

(ii) *Quartzo-feldspathic Para-granulites*

The variation in colour of these types is essentially the same as in the gneisses. They are fine-grained, sometimes show poorly developed foliation, and characteristically weather to smooth rounded surfaces. Where adequately exposed in dry stream courses, e.g. north of Kibara and in the Thura north-east of Karie, they show sedimentary disposition. South of Thambu they occur as numerous concordant sheets not unlike aplitic dykes. They are considered to be derived from fine-grained impure sandstones much of which may have been of silt grade.

Specimen 44/614 is fissile along well-defined parallel partings which, accentuated by iron staining, are suggestive of bedding planes. It is the only specimen in which microcline is completely subordinate, the bulk of the feldspars being composed of twinned and untwinned albite and orthoclase. The only mafic minerals present are isotropic greenish chlorite and minute flakes of muscovite. Skeletal and angular grains or opaque iron ore make up 3 per cent of the rock, and aggregates of a brownish mineral considered to be either rutile or orthite are accessory.

Thin sections of specimens typical of these granulites show intense replacement of original quartz and feldspar by microcline and subordinate myrmekite. Biotite, muscovite and chlorite are present in varying but generally small amounts. Pale-pink garnets are the commonest accessory, but may be accompanied by epidote, zircons and apatite. In biotite-free types, banding caused by variable colouring of the predominantly quartzo-feldspathic material is sometimes conspicuous. The only specimen sliced, 44/757, consists of strained and crushed quartz, perthite, microcline-perthite, microcline, cracked pink garnets and subordinate muscovite and myrmekite. Zircon and ore are the only accessories. A distinct class of the granulite is formed by the medium-grained garnetiferous types exposed in the Thura River north-east of Karie. The garnets are small and, although usually erratically disseminated throughout the rocks, are occasionally segregated into irregular bands.

(iii) *Quartzites*

No true quartzites were observed *in situ*. Float was picked up near the Ena River north-east of Kiarawa, north of the Thiba-Tana confluence, and near the Tana south of Karie. Agreeing with Shackleton's (1946, p. 12) observations in the Nanyuki-Maralal

area, the most striking feature of these rocks is their comparative scarcity in this part of Kenya. Schoeman found only one small mappable body of quartzite in Embu-Meru area and none in the area west of Kitui.

On freshly fractured surfaces the quartzites are seen to be fine-grained and grey in colour. Specimen 44/527 is a homogeneous quartzose rock composed of mutually interferent quartz grains in which no distinction between the original detrital grains and cementing material exists. Most of the quartz shows optical strain. About 10 per cent of the rock consists of opaque minerals, predominantly magnetite with subordinate flakes of graphite. Occasional flakes of muscovite occur and these were presumably derived from argillaceous impurities. The accessory minerals are zircon and rutile.

Thin section 44/550A shows no signs of recrystallization or polarization strain of the subangular quartz grains, which are surrounded by interstitial brownish material. Approximately 30 per cent of the rock consists of magnetite concentrated into thin closely spaced layers, giving the rock a banded appearance. Chlorite is subordinate and the accessories include zircon, rutile and apatite.

(d) Metamorphosed Psephitic Sediments

(i) Pebbly Grits

Only one isolated exposure of a rock that is tentatively considered as derived from a pebbly grit was observed, beside the Ena River north-east of Siakago. The specimen (44/525) is leucocratic and unfoliated. Pebble-like grains of vitreous quartz are embedded in a predominantly quartzo-felspathic matrix imparting a blastopsephitic texture to the rocks. The feldspars are mainly calcic oligoclase and highly sericitized. Small plates of muscovite are subordinate.

(2) METAMORPHOSED VOLCANIC ROCKS OF THE BASEMENT SYSTEM

No metamorphosed rocks of volcanic origin were observed *in situ*. Float of tuffaceous breccias tentatively ascribed to the Basement System was found on the western slopes of Kiangombe and in the headstreams of the Thura River. The rock has blastopsephitic texture, and consists of subangular fragments of quartz, and quartzo-felspathic material, subhedral plates of biotite and augite, and melanocratic lapilli, embedded in a predominantly tuffaceous (?) matrix, which contains granular iron ore and small crystals of augite. An intricate network of veins composed of calcite, quartz and a greenish chloritic product traverse the rocks.

(3) MIGMATITES

For the purpose of this report migmatites are defined as rocks in which a granitic component and a metamorphic host-rock are intimately admixed on a scale sufficiently coarse for the mixed condition of the rock to be *megascopically* visible (Turner and Verhoogen, 1951, p. 294). The veins and laminae of granitic material variably show either a rude parallelism or pygmatic folding. The migmatites owe their origin to ionic exchange of material between the host-rock and penetrating fluids, or to the production of a low-melting granitic liquid by differential fusion of the host-rocks (op. cit. 297). The wavy foliation suggests plastic flow and the pygmatic folding is considered to have arisen as a result of deformation prior to solidification.

Specimen 44/765 is a fine example of a lit-par-lit replacement gneiss (cf. Misch, 1947, p. 231) in which well-preserved parallel banding has been only occasionally disrupted by the growth of large ovoid feldspar porphyroblasts. The mafic bands are composed of flaky biotite and hornblende and have relatively sharp contacts. Lenticular folia of coarse-grained sutured quartz grains are aligned approximately parallel to the banding. A finer-grained leucocratic pinkish fraction, forming thin bands, consists of metasomatically introduced felspathic material. Microcline replaces the original quartz grains, in which polarization strain is present but never intense. The accessories consist of zircons, apatite, opaque iron ore and hematite. No muscovite was observed in this thin section.

The early macroscopically visible signs of granitization are represented by the scattered and unorientated development of feldspar porphyroblasts. These consist of either oligoclase or microcline and, although in most cases they are comprised of individual grains, it was noted that in some instances they are formed of numerous small crystals, each with independent orientation, lying adjacent to one another. Specimen 44/506, a typical feldspar porphyroblast gneiss, is a leucocratic fine-grained rock, from the weathered surface of which the pale flesh-coloured feldspar porphyroblasts project prominently. In thin section the texture is seen to be heteroblastic and the microcline porphyroblasts usually consist of a mosaic of numerous grains. Myrmekite encroaches marginally on quartz grains. Other minerals include twinned oligoclase, orientated plates of biotite and muscovite, and granular epidote. As the number and size of the porphyroblasts increase and with subsequent deformation, the feldspar porphyroblast gneisses grade into augen gneisses of granitic appearance. The leucocratic component of some of the banded gneisses has resulted where certain planes afforded easy passage to the infiltration of granitizing fluids, thus promoting the increased growth and coalescence of the porphyroblast feldspars (Misch, 1947, p. 225).

Augen gneisses with mortar texture have been formed locally where porphyroblasts of oligoclase or microcline with granulated edges have resisted crushing and brecciation. Strained quartz grains are often segregated into lenticular folia. Some crystals of oligoclase contain replacement blebs of microcline and the micas often tend to wrap themselves around the larger porphyroblasts.

Thin sections of other migmatites reveal inequigranular xenomorphic textures, in which the phenomena characteristic of metamorphism and granitization, such as crystalloblastic and replacement structures, show various stages of development. Myrmekite is usually the last to form. It replaces the earlier introduced feldspars, often encroaching on them as fungoid growths. Sheared rocks have often an unusually high microcline content and in many instances the amounts of microcline and myrmekite vary proportionally. Biotite is the commonest ferromagnesian mineral and is sometimes accompanied by, or interleaved with hornblende. Muscovite is invariably subordinate, and no empirical relationship could be established between potash metasomatism, soda metasomatism and muscovitization.

(4) MAJOR INTRUSIVES

(a) *Granites*

Field criteria and microscopic evidence confirm that the granites have been formed by granitization *in situ* of pre-existing sedimentary rocks and by rheomorphism and subsequent intrusion. Specimens 44/674, 44/682 and 44/687 were taken at different intervals along the strike of the numerous closely spaced concordant granite sheets extending from Kamukanya in the north to Matta, where they merge into the massive homogeneous granitic rocks of Kiambere. They are medium-grained, non-foliated, pinkish rocks that have been selected for description because of their close similarity to rocks which are considered to be true magmatic granites.

In thin-section these rocks have an allotriomorphic granular texture showing no marked directional arrangement of either the felsic or mafic components. They consist of large replacive crystals of microcline and microcline-perthite, somewhat turbid soda plagioclase, quartz, often as lobed grains or blebs in the feldspar, irregular grains of myrmekite and subordinate biotite, in some instances altered to chlorite and in others interleaved with muscovite. Optical strain is often present in the quartz and may be fairly intense. The accessory minerals consist of small subhedral cracked zircons, wedge-shaped and granular sphene, apatites and opaque iron ore. The granites differ from the granitoid gneisses formed *in situ*, in that the gneissosity of the latter is often accentuated by sub-parallel streaks and wisps of biotite. The mineral composition of the granites is essentially the same as that of the gneisses except that in the latter the muscovite and biotite content is higher, and in addition they contain small subhedral

garnets and granular epidote, and the zircons are subrounded. Melanocratic lenticular schlieren are commonly enclosed in the granites particularly nearer the contacts. They are usually aligned parallel to the strike of the country-rock and their appearance suggests that they were semi-plastic while enclosed in the mobilized host-rock. Specimen 44/675 is a fine-grained, mildly foliated inclusion in a granitic host-rock. It has crystalloblastic texture and is composed essentially of a recrystallized and intensely strained quartzo-felspathic matrix, enclosing numerous microlites of apatite, fibrous pyroxene, and tabular biotite. Perthite, myrmekite and granular sphene are subordinate.

The estimated modes of some granites are given below:—

	44/682	44/687	44/674
	%	%	%
Quartz	38	31	20
Microcline	24	38	40
Myrmekite	—	3	3
Soda plagioclase	26	22	23
Biotite	3	6	10
Muscovite	8	+	1
Chlorite	—	+	+
Sphene	—	+	1
Accessories	1	+	2

(b) *Pegmatites and Aplites*

As in other Basement areas two classes of *pegmatites* were recognized, viz. auto-segregations and intrusive pegmatites. The former generally occur in rocks of fairly advanced granitization and are small, irregular bodies with gradational contacts, that are often surrounded by a narrow fine-grained biotitic aureole. They are generally mica-poor rocks consisting of coarse-grained perthitic feldspars, strained quartz and subordinate myrmekite. They attain their best development in the Rutea-Kabe area.

The intrusive pegmatites are characterized by their sharp contacts and the presence of numerous garnets and much magnetite. It is in these pegmatites that mineral deposits are more likely to be found. The felspar crystals, which are frequently visibly intergrown with quartz, are either colourless or green (amazonite) and only rarely flesh-coloured. The micas often have an erratic distribution as unorientated books and nests of various dimensions, but on the whole are more frequently developed in the more quartzose portions of the dykes. Garnets are usually present and are locally abundant. They are not uniformly distributed throughout the pegmatites and are frequently concentrated into elongated zones. Although some crystals of garnet attain a diameter of two inches, the majority are small with cross-sections varying between an eighth and a tenth of an inch. Xenoliths of country rock are not uncommon in the pegmatites and the garnets presumably have been derived by the absorption and interaction of such material with the volatile-rich pegmatitic magma. Individual bodies frequently attain thicknesses of 30 to 40 feet, and can be followed for considerable distances along the strike. Except for the development of tourmaline crystals in the muscovite schists at Kathigiri, and the identification of grains of beryl, assumed to be of pegmatitic origin, in the sands of the Thura River, the pegmatites and adjacent country rock are apparently devoid of any traces of mineralizing volatiles.

The intrusive pegmatites are most numerous and best exposed along and in the neighbourhood of the Thura River, between Matta and a point north of Karie. Other concentrations of pegmatites are found in the area between Thambu and Kamukanya and farther south.

The fine-grained *aplites* are most common as anastomosing narrow veinlets. They consist essentially of a quartzo-felspathic intergrowth with subordinate amounts of small pale-pinkish garnets and flaky micas. They correspond closely to the garnetiferous orthogranulites described by Shackleton (1946, p. 18) in the Nanyuki-Maralal area.

(c) Basic Igneous Types

(i) Olivine-pleonaste Norites

Olivine and spinel-bearing gabbroic rocks are confined to the low range of hills extending between Rongori and Nduni. The rocks are medium-grained with only locally developed coarser-grained patches, in which the increase in grain size is usually accompanied by a decrease in the plagioclase content. Decomposition of the olivine, under atmospheric weathering, imparts to those with a high olivine content a characteristic pitted surface. The best exposure of the more olivine-rich varieties are found at the north-eastern foot of Twooini.

The norites are composed essentially of varying amounts of olivine, ortho-pyroxene, augite, basic plagioclase, pleonaste and hornblende. Gradations from one type to another are caused by changes in the relative proportions of the chief minerals. Magmatic differentiation of the fluid that gave rise to them has also yielded anorthositic as one end-stage rock and pyroxenites and olivine-rich types as the other. The majority of the pyroxenites have, as a result of subsequent metamorphism, suffered alteration to amphibolites. Other pyroxenites and the olivine-rich fractions have been altered by meteoric waters, charged with carbon dioxide and circulating within the zone of weathering, to magnesite and serpentine rocks. The metadolerites are considered to be genetically related to the gabbroic rocks.

The *olivine* is colourless and usually occurs in large, fresh, cracked plates, frequently showing undulatory extinction and ill-defined twinning. Serpentinization on a large scale is absent, and is only incipiently developed along some of the cracks, with concomitant release of magnetite. Thin veinlets of yellowish bowlingite are common. Optic angle estimations indicate that the olivine has a composition lying between Fa_{26} and Fa_{46} . Coronal rims of hypersthene invariably separate the olivine grains from the plagioclase, and in some cases double reaction rims have formed, the inner hypersthene being surrounded by an outer, usually discontinuous, rim of hornblende. In thin section 44/650 irregular grains of magnetite have reaction rims of hypersthene and cores of olivine.

The orthopyroxenes include both hypersthene and enstatite, but the former predominates. The *hypersthene* is feebly to moderately pleochroic. Zoned crystals were observed, and the core of one of them was determined as being of pigeonitic composition, grading imperceptibly to a hypersthene mantle. In thin-section 44/654A alteration of the hypersthene to tremolite has proceeded both marginally and along cleavage planes. Alteration to bastite is also common. Rarely corroded plates of hypersthene have an ophitic relationship to the plagioclase. Other thin-sections show schillerization produced by closely spaced, minute, rod-like inclusions aligned parallel to cleavages or normal to cracks. Occasional crystals of enstatite are also present.

The *augite* is usually colourless or pale green. The crystals are frequently twinned and crowded with minute particles of iron ore and calcite. Some grains closely approximate pigeonite in optical properties. Replacement of the augite by hornblende is proceeding by a method known in polished section microscopy as multiple-centre growth, and some of the larger enclosed hornblende laths are a result of continued growth and coalescence of innumerable centres of replacement.

The green *spinel* pleonaste is usually intimately intergrown with hornblende, but occasionally intergrowths of spinel and hypersthene were observed, which in some cases form cores surrounded by mantles of hypersthene. These intergrowths, often of petaloid structure, are sometimes separated from plagioclase grains by a fine, coil-like peripheral intergrowth of two unidentifiable minerals. Larger irregular grains of spinel devoid of intergrowth structures, usually occur adjacent to hornblende or iron ore. It is interesting to note that when in contact with the former, the hornblende appears to assume a deeper green colour.

The pale-greenish *hornblende* is usually in ill-formed grains, often occurring as irregular inclusions in the pyroxenes as well as forming reaction rims around them. Some colourless grains, with well-developed cleavage, rather larger extinction angle and moderately high birefringence may be enriched in the cummingtonite molecule (Stewart, 1946, p. 478).

The *plagioclase* is usually fresh and occurs as large twinned crystals with smooth, rounded and embayed outlines. Rarely are they in contact with the ferromagnesian minerals without the development of reaction rims or secondary tremolite. The composition of the plagioclase lies approximately in the range labradorite-bytownite.

The subordinate minerals include fibrous tremolite, calcite and scattered small amounts of epidote.

The estimated modes of some representative specimens of the noritic rocks are as follows:—

	44/653	44/654A	44/654D	44/650
	%	%	%	%
Plagioclase	25	65	5	42
Olivine	18	+	20	8
Ortho-pyroxene	15	22	18	6
Augite	18	+	27	8
Hornblende	16	6	24	15
Pleonaste	8	—	3	7
Tremolite	—	6	—	11
Accessories	+	1	3	3

(ii) *Hornblende Gabbros*

The hornblende gabbros, like all the basic intrusives, are poorly exposed and contacts, which would elucidate their relation to, and effects upon the country rock, were not observed.

The textures of the hornblende gabbros have been modified to a greater or lesser extent by the effects of metamorphism. Depending on whether the hornblende is primary or secondary the rocks may be classed as uralite gabbros or bojites. The majority, however, are intermediate in that they contain both uralite and common green hornblende.

The uralitic gabbros are genetically related to the anorthosites and all gradations exist between them, the uralite being derived by paramorphic replacement of the original augite. The hornblende of thin section 44/651B is secondary and surrounds cores of augite into which occasional veinlets penetrate in irregular fashion. In specimen 44/651A complete uralitization of the pyroxene has taken place. The plagioclase is strained and partly recrystallized with the production of irregular sutured aggregates, and encloses numerous microlites of epidote and needles of hornblende.

The majority of the bojites are pyroxene-free. A typical specimen, 44/669, from the Ruanjoga River, south-east of Thambu, has subordinate flakes of biotite in larger plates of pale-green hornblende. This structure may be interpreted as due to the influence of potash metasomatism tending to convert hornblende into biotite, with the release of lime, which has been fixed as scattered grains and columns of epidote. Fresh, well-twinned plagioclase makes up the rest of the rock. In thin section 44/683 the hornblende has a rudely decussate structure. The accessory minerals include rutile, sphene, tremolite, pyrite and in one instance calcite.

Types containing both primary and secondary hornblende were found as scattered boulders between the Ruanjoga River and Thambu. They are medium-grained and the exposed surfaces carry an encrustation of soft brownish material. Specimens 44/670 and 44/703 are representative. The plagioclase is of labradorite-bytownite composition, the pale-green hornblende is often sieved, and the subordinate minerals include epidote, fibrous tremolite, calcite, chlorite, and rarely scapolite.

Specimen 44/680 from Thambu is foliated and it is with some uncertainty that it is included in this class as it may well be of sedimentary origin. Except for the presence of pyroxene and abundant sphene the mineral composition is the same as the gabbros. The texture, however, is simple granular.

The approximate modes of the gabbros are:—

	44/671	44/669	44/651	44/680
	%	%	%	%
Plagioclase	30	51	60	6
Hornblende	50	45	37	45
Pyroxene	—	—	+	15
Biotite	—	+	—	—
Epidote	18	3	3	30
Accessories	2	1	+	4

(iii) *Anorthosites*

Only a few narrow anorthositic dykes were observed. These are mostly associated with the basic intrusives in the Twooinini-Nduni area and south-east of Thambu. The majority are greyish with a spotted or mottled appearance, the exposed surfaces weathering to a reddish-brown colour. All gradations exist between these epidotic spotted anorthosites and ortho-amphibolites. The subordinate ferromagnesian minerals show no preferred orientation and are only rarely concentrated into bands. They occur as decussately arranged prisms or as indefinite greenish smudges.

The complex texture of these rocks, as revealed in thin section, is due to the instability of the calcic molecule of the plagioclase under dynamic metamorphism when it breaks up to give epidote-zoisite, calcite and a more sodic variety of feldspar. This leads to irregular replacive intergrowth of twinned and untwinned plagioclase. Granular epidote-zoisite is far more abundant in the anorthosites than field inspection indicates. The original pyroxene has been completely altered to almost colourless, corroded hornblende aggregates. Specimen 44/648 has, in addition to hornblende and plagioclase, small amounts of interstitial calcite, fibrous scapolite, and flakes of tremolite. Granular sphene is the commonest accessory.

The two specimens sliced have the following estimated modal compositions:—

	44/648	44/472
	%	%
Plagioclase	75 (An ₆₂)	72 (An ₅₀)
Hornblende	8	6
Epidote	16	22
Scapolite	+	—
Accessories	1	+

(iv) *Meta-dolerites and Plagioclase Amphibolites*

The metamorphism of the basic intrusives commenced on the outside and gradually penetrated inwards, in many instances leaving relatively unmodified cores of meta-dolerite, the medium-grained granular texture of which is still recognizable as that of a consolidated magma. The cores have resisted erosion and now stand out prominently as inselbergs. They grade outwards into plagioclase amphibolites and amphibolites, which are sometimes well foliated but only rarely develop linear orientation of the prismatic minerals.

The meta-dolerites are generally medium-grained melanocratic, granular rocks occasionally exhibiting mild foliation. They contain colourless augite dusted with minute inclusions of iron ore, which are in places sufficiently concentrated and orientated to impart schiller structure. Some patches rich in ore are of a darker green colour and more pleochroic than the remainder of the crystals. In thin section 44/647 alteration to amphibole has rarely proceeded beyond the stage of marginal encroach-

ment or small patchy internal replacements. In thin section 44/652, however, the original pyroxene now consists of an interlacing network of fibrous tremolite. Bastite is also common as a decomposition product of the pyroxenes. The feldspars (about An_{50}) are usually fresh and twinned, but in some slices are partly recrystallized. Occasionally they enclose numerous rod-like grains of epidote and scattered veinlets of calcite. Chlorite and granular epidote are present in subordinate amounts in some of the rocks.

From the above description it will be seen that the phenomena of uralitization, saussuritization, and to a lesser extent chloritization, have all effected the dolerites at some stage.

The associated plagioclase amphibolites are fine-grained, generally foliated, and consist essentially of flaky hornblende, andesine feldspar, and accessory sphene. In one specimen dull brown flakes of biotite were observed on the fractured surface, but not in the slide. Garnets, which have been reported as a constituent of many of the plagioclase amphibolites from other parts of Kenya, are not present.

(iv) *Ortho-amphibolites*

Amphibolitization of pyroxenite has led to the production of ortho-amphibolites, which are invariably closely associated with the hornblende gneisses and basic intrusives. They are generally massive hard rocks only rarely exhibiting weak schistosity. Interlocking stout prisms of hornblende form the bulk of such rocks. Thin sections reveal that the cores of the blue-green hornblende crystals are often crowded with minute inclusions producing a crude schiller structure. Sieved structures are not uncommon. The finer-grained matrix is composed of varying but small amounts of plagioclase, epidote, scapolite, calcite and sphene. The genetic relationship between the amphibolites and the spotted anorthosites is suggested by thin section 44/656 in which the plagioclase and hornblende have habits similar to the same minerals in the anorthosites, though their amounts are in inverse ratios. There is, however, a noticeable decrease in the epidote content and occasional intergrowths of hornblende and plagioclase were observed.

The estimated modes of two typical ortho-amphibolites are given below:—

		44/886	44/656
		%	%
Plagioclase	.. .. .	7	7
Hornblende	.. .. .	80	93
Epidote	.. .. .	5	—
Scapolite	.. .. .	6	—
Accessories	.. .. .	2	+

Some small irregular lenses of coarse-grained *hornblende* are so closely associated with the basic intrusives, particularly at Muthuru and south of Rongori, that they are considered to be genetically related. They probably represent the complete amphibolitization of originally coarse-grained pyroxenites. A lack of any directional textures is attributed to the protection from metamorphism afforded them by the surrounding basic intrusives. The fresh unaltered types are black, the more weathered varieties a dull green. Specimen 44/658, from Muthuru, has a hypidiomorphic granular texture and consists of brownish subhedral hornblende and fresh twinned plagioclase (about An_{30}). Iron ore and apatite are the only accessories. The hand-specimen contains over 90 per cent of hornblende.

(vi) *Chlorite and Tremolite-actinolite Schists*

These are the metamorphic representatives of the ultrabasic igneous rocks. As the grade of metamorphism decreases, the place of amphibolites of the epidote-amphibolite facies is taken by actinolite schists, and chlorite becomes increasingly abundant (Turner and Verhoogen, 1951, p. 465). Chloritization also arises under intensive weathering conditions or as a result of shearing. The schists occur as small

discontinuous lenses associated with the cores of the basic intrusives in the Muthuru-Rongori area and between the Thiba and Tana. Smaller isolated occurrences, e.g. north-west of Kiambere and east of Thambu, may have been derived from sediments, although determination of the alumina content by chemical analyses would be necessary to confirm this. They are medium- to fine-grained, generally fairly soft and friable, and their colours vary from shades of grey to green with occasional brownish iron-stained varieties. They consist essentially of members of the chlorite family, tremolite-actinolite, talc and magnetite. The chlorite is pale-greenish and is sometimes moderately pleochroic. It occurs as minute interlaced flakes, as aggregates of fibro-lamellar structure, or as larger grains that tend to form rosette- and fan-shaped clusters. In those rocks with a high tremolite-actinolite content the chlorite is segregated into clusters. Specimen 44/873 consists of large interpenetrating plates of talc and chlorite. Numerous veinlets of a brownish unidentified decomposition product, not unlike iddingsite, occur both interstitially and along cleavage traces. Thin section 44/864 shows bastite that has formed patchily in the larger, somewhat fibrous, tremolite-actinolite plates. Specimen 44/865 consists of approximately 70 to 80 per cent (by volume) of magnetite separated by veinlets of colourless fibro-lamellar chlorite.

(5) MINOR INTRUSIVES

(a) *Dolerite*

Small discontinuous lenses of rock thought to be derived from dolerites occur among the calc-silicate granulites in the eastern half of the area. They are melanocratic granular rocks, the exposed surfaces of which weather to a thin brownish encrustation out of which the ferromagnesian minerals project haphazardly.

In thin sections (44/813 and 44/742) it is seen that the rocks are composed of crystals of plagioclase (about An_{60}) associated with hornblende and less commonly pyroxenes. Some plagioclase grains show isolated patches of sericitization. Epidote occurs as chadacrysts in the plagioclase and in the larger hornblende grains. The pyroxenes include a green variety and occasional much-larger poikiloblastic crystals of a colourless type. Where brownish orthite (?) is present (44/762) it is usually intimately associated with the pyroxenes, and there is a noticeable decrease in the amount of epidote. The accessory minerals include calcite, ilmenite, sphene, apatite and pyrite.

2. The Embu Series

Distinctive predominantly pelitic rocks comprising the Embu series are confined to the area south of Siakago and are not extensively developed. They differ from all the Basement System rocks described in East Africa and are tentatively considered to be of later age. The various rocks exhibit no signs of granitization and are characterized by low-metamorphic-grade mineral assemblages and by the presence of tourmaline as an accessory mineral. The small stumpy prisms of tourmaline appear to have developed from the boron content of the original sediments rather than by pneumatolysis.

For the purpose of description the rocks of the Embu series are classified into the following groups:—

- (1) *Calcareous*
Friable saccharoidal limestone.
- (2) *Pelitic and Semi-pelitic*
 - (a) Knotenschiefer.
 - (b) Granulose types.
 - (c) Schistose types.
 - (d) Gneissose types.
 - (e) Semi-hornfelsic types.
- (3) *Psephitic*
Meta-conglomerate.

(1) METAMORPHOSED CALCAREOUS SEDIMENTS

The limestones are poorly exposed and occur on the west of the Thura River. They are friable fine-grained types with saccharoidal texture and are traversed by irregular veins of calcite. A thin section of specimen 44/839 shows that it is composed of a mosaic of subrounded carbonate grains with rims of brownish cementing material. The sedimentary fabric of these limestones has to a great extent survived the metamorphism, but there has been some recrystallization as well as orientation of the axes of the grains. Flakes of talc and fibrous chlorite are subordinate.

(2) METAMORPHOSED PELITIC AND SEMI-PELITIC TYPES

Rocks of this type form the bulk of the Embu series. In some horizons bedding has been preserved by regular parallel banding of leucocratic quartzo-felspathic and melanocratic micaceous layers. Other types have maculose structure such as is typically developed in argillaceous rocks under thermal or contact metamorphism in which spotting appears as a result of the incipient crystallization of biotite or other minerals. According to Tyrell (1941, p. 272), "The porphyroblasts form by metamorphic reconstitution from the original mixture of decomposition products and rock flour, which is retained under a low-grade metamorphism as the groundmass in which the porphyroblasts are embedded". With increased metamorphism such knotenschiefer in the present area grade into fine-grained granoblastic types often showing an incipient banding. Transitions exist from this stage, in which the spotting sometimes persists, to gneissose, schistose and granulose types. Under more intense metamorphism semi-hornfelsic types have been formed. The grade of metamorphism increases from west to east, the semi-hornfelsic rocks out-cropping adjacent to the small band of crystalline limestone and associated calc-silicate rocks.

Knotenschiefer

The most characteristic of the knotenschiefer are leucocratic rocks with numerous black unorientated spots of biotite. The spots, which are roughly equidimensional and average about three millimetres diameter, project prominently from weathered surfaces.

The biotite porphyroblasts exhibit poikiloblastic structure and are usually pleochroic from yellowish-brown to almost black and rarely to reddish-brown. The matrix consists essentially of subangular quartz grains and numerous unorientated small flakes of muscovite. Not infrequently larger corroded muscovite plates appear to have been derived from biotite. A rise in the colour index of the rocks is accompanied by an increase in the feldspar content at the expense of quartz, by coarser-grained muscovite, and the presence of replacive scapolite, and by irregular grains of calcite and granular to rudely columnar epidote. The accessory minerals include subrounded zircons, minute stumpy prisms of buff feebly pleochroic tourmaline, granular sphene and rare apatites.

Typical knotenschiefer were estimated to have the following composition:—

	44/835	44/826	44/838
	%	%	%
Quartz	62	35	50
Plagioclase	—	10	10
Biotite	22	25	20
Muscovite	15	4	12
Scapolite	—	8	+
Epidote	—	6	+
Calcite	—	11	7
Accessories	1	1	1

Granulose Types

The granulose types are fine grained, equigranular and rudely fissile. In thin-section it is seen that ragged and flaky biotite is sometimes partly altered to chlorite with the

simultaneous release of granular magnetite. Muscovite and somewhat turbid feldspars are subordinate, and calcite and quartz is of the same habit as in the spotted rocks.

The composition of specimen 44/833, a typical example of these rocks, was estimated as:—

Quartz	Biotite	Muscovite	Chlorite	Plagioclase	Calcite	Accessories
38	30	5	3	8	15	1

Schistose Types

The schistose pelitic rocks are melanocratic and fine-grained, and in appearance not dissimilar to graphitic schists. Relic bedding, barely discernible in most exposures, is locally accentuated by quartz veining. The rocks consist essentially of a quartz-feldspathic matrix with innumerable small laths of biotite and muscovite. The biotite is sometimes partly altered to a brownish unidentifiable decomposition product, and usually contains zircons with pleochroic haloes. The other accessory minerals consist of apatite, epidote and tourmaline.

Specimen 44/512B has the following composition:—

Quartz and feldspar	Biotite	Muscovite	Tourmaline	Accessories
52	40	6	$\frac{1}{2}$	$1\frac{1}{2}$

Gneissose Types

The gneissose types sometimes show perfect, though gradational, banding of micaceous and quartzose layers. The individual bands are thin and parallel, and in one case 12 melanocratic layers were counted in a thickness of two inches of rock. The minerals are essentially the same as those described in the associated types above—the modal composition of specimen 44/513 is:—

Quartz	Feldspar	Biotite	Muscovite	Chlorite	Calcite	Accessories
48	8	26	6	2	8	2

The pseudo-isotropic chlorite is greenish and slender needles of rutile are an abundant accessory mineral. Other accessories include tourmaline, rod-like zircons, epidote and apatite.

Semi-hornfelsic Types

The semi-hornfelsic rocks are hard, sporadically spotted, and melanocratic. They represent the highest grade of metamorphism of these pelitic sediments. They contain porphyroblasts of intensely sieved green hornblende and pale-pinkish garnets. Specimen 44/838 has the following composition:—

Quartz	Plagioclase	Hornblende	Calcite	Garnet	Sphene	Ore
38	6	32	12	2	4	6

The larger quartz grains have the smooth, though irregular, outlines indicative of recrystallization, but still exhibit optical strain. Twinned plagioclase, irregular sphene with cores of ilmenite and granular calcite are subordinate. The whole rock is highly dusted with fine particles of black opaque ore, probably magnetite and ilmenite.

(3) METAMORPHOSED PSEPHITIC SEDIMENTS

A metamorphosed conglomerate forms a part of the pelitic sediments in the Thura River south of Siakago. It is an intraformational conglomerate which was formed by penecontemporaneous erosion of the strata in which it occurs, and it is evident that the material of which it is composed has not suffered much transport. The period of erosion and decomposition represents a minor interval in the deposition of the whole pelitic formation. The conglomerate weathers with a rugged, pitted, dark-greyish surface from which leucocratic pebbles project prominently. Freshly fractured surfaces show that the spotted aspect of the associated pelitic types persists in the dark-coloured predominantly argillaceous matrix, and that the pebbles have ill-defined outlines.

The pebbles attain a length of between one and a half and two inches although the average size is between a half and a quarter of an inch. Some of the larger ones are ellipsoidal and well worn, others are of subangular oblate habit, though the majority are subrounded. The pebbles account for only 15 to 20 per cent of the total rock. Although they show no obvious directional alignment in outcrops, the long axes of the pebbles do, on closer inspection, appear to have an approximate north to south orientation. Poor exposures did not allow the dip of the conglomerates to be measured, but that of the associated pelitic rocks is 75° to the east.

Three types of pebbles are recognizable—quartz, quartzite and those derived from para-gneisses and granulites. Some patches in the matrix, rich in epidote and quartz, and with sharp boundaries and subangular outlines, may represent pebbles of epidiosites. The quartz pebbles are generally small, rounded, and with vitreous lustre. In thin-section they are seen to have irregular outlines, and have evidently suffered varying degrees of crushing and recrystallization. Not infrequently they show signs of replacement by muscovite. The quartzite pebbles, also small, are mostly either whitish or tinged with green. In thin-section it can be seen that the individual grains are separated by interstitial brownish material, and are occasionally surrounded by curved flakes of biotite. The majority of the pebbles have been derived from predominantly quartzofelspathic para-gneisses and granulites. The former are medium-grained and rich in quartz, much of which is cracked or strained, accompanied by feldspars, which are usually turbid. Corroded muscovite is the most abundant mafic mineral. Greenish chlorite and pseudo-isotropic biotite are subordinate, and the accessories observed include zircon, garnet and opaque iron ore. In the pebbles of granulitic texture mafic minerals are subordinate and consist of muscovite and biotite in a fine-grained quartzofelspathic groundmass.

The texture of these conglomerates is typically blastopsephitic, and the matrix is of essentially the same composition as the associated pelitic rocks. In a thin section of the matrix of specimen 44/537 a mild gneissosity is discernible. Some flakes of biotite are partly replaced by muscovite. Fine-grained quartz and feldspar are abundant, and varying, though usually subordinate, amounts of calcite and epidote are present in these rocks. The accessories consist of apatite, zircon, tourmaline and granular aggregates of an unidentifiable reddish-brown mineral.

3. The Tertiary Volcanics

Only the southern fringe of the volcanic rocks of Mt. Kenya is included in the area and is composed of the following types:—

- (1) Kenytes with agglomerates and tuffs.
- (2) Finely porphyritic and dense phonolites.
- (3) Olivine basalts.

Both the field occurrence and petrological characteristics of these rocks have been described by Campbell Smith (1931, p. 242), Shackleton (1946, pp. 35, 36), and Schoeman (1951, pp. 46-49). The rocks of the present area are so similar to those described by Schoeman in the adjoining Embu-Meru district that detailed redescription is superfluous. Boulders of monchiquitic rocks were found in the north-eastern corner of the area and small outcrops of basaltic rocks were mapped in the Ruanjoga Valley and near Mugutha in the south-east corner of the area. They are probably of Tertiary age.

(1) KENYTES AND ASSOCIATED PYROCLASTIC ROCKS

Locally the kenytes are markedly vesicular but with only partial infilling of the vesicles with zeolitic material and carbonates. The phenocrysts of the coarsely porphyritic types show no pronounced flow orientation. They consist of waxy nepheline, and anorthoclase of rhombic habit. Micro-phenocrysts of olivine are common. According to Schoeman (op. cit., p. 47, 48) the aphanitic groundmass consists of anorthoclase, nepheline, ægerine-augite, cossyrite, kataphorite, olivine, analcite and iron ore.

The intercalated agglomerates vary in colour from chocolate brown to grey and the inclusions, of all sizes, consist essentially of lava fragments, pumiceous material, feldspar, calcite, zeolites, basaltic glass, and iddingsite pseudomorphs. The groundmass consists of a glassy base dusted with volcanic ash and iron hydrates.

Seven patches of tuff are large enough to be shown separately on the map. Two distinct types were recognized, one melanocratic gritty tuff and the second pale-grey homogeneous tuff. The former, which occurs north of Siakago on either side of the road, is a brittle rock of dull-black colour showing rude stratification. The inclusions consist of clastic grains of quartz and feldspar, small rock fragments and basaltic glass. The homogeneous tuffs, which are more suitable for building purposes, have a few inclusions of foreign material embedded in an irregularly stained groundmass carrying numerous colourless and weakly birefringent microlites and brownish aggregates of an unidentifiable isotropic mineral of fibrous and spherulitic habit.

(2) PHONOLITES

The dense and finely porphyritic phonolites occur as small isolated intercalated lenses within the kenytes. They are sometimes rudely fissile. Mineralogically they are essentially the same as the kenytes but differ in the following respects. They are decidedly less coarsely porphyritic, the needle-like plagioclase is arranged in a trachytic texture, microphenocrysts of pyroxene have mossy habit and are more abundant than olivine, and fine cross-hatched twinning is frequently developed in the anorthoclase phenocrysts.

(3) OLIVINE BASALTS

The largest occurrence of olivine basalts forms a narrow band running approximately east-west and following the low-lying ground immediately south of the Thiba River. Exposures in some of the dry river-courses reveal rude prismatic or columnar jointing. They are fine-grained, non-porphyritic rocks with only a few scattered megascopically visible olivine phenocrysts. The majority are finely vesicular with the vesicles generally empty or only partly lined with carbonates. The vesicles are mostly ovoid in outline although in some rocks they are extremely irregular. Specimens 44/664 and 44/665 are typical representatives of these rocks. Lathy twinned plagioclase with criss-cross orientation is usually the predominant mineral. Violet-brown titanite occurs in poorly formed grains often of skeletal habit, and not infrequently with a sub-ophitic relationship to the plagioclase. Anhedral colourless olivine is also present and shows centrifugal alteration, in various stages, to brownish iddingsite. In some slices isotropic and feebly anisotropic pools of yellow-brown glass with numerous microlites, generally concentrated nearer their edges, occur interstitially between the plagioclase laths. Calcite, granular and microlitic iron ore, and a green alteration product (chlorite?) were also observed.

Between Kiambiti and Karie there are four irregular bodies of olivine basalts. They occupy the higher ground and may represent infillings of pipe-like channels up which the lava welled without any extensive surface flows. Alternatively they may have formed in spaces produced by horizontal movement along an irregular fault-line. Exposures were too poor to afford any direct evidence of the origin.

They are dense, non-vesicular, and only sparingly porphyritic, the phenocrysts consisting of small scattered grains of glassy olivine. Thin section 44/492 from Kiambiti consists of rectangular laths of twinned plagioclase (labradorite) embedded in a hypocrystalline groundmass composed of microlites of plagioclase, augite, granular ore, and cryptocrystalline material. The squat, colourless olivine of subhedral habit shows only incipient alteration along cracks. The pyroxene occurs in two generations of which the microphenocrysts were determined as pigeonite. The crystal outlines of the pyroxenes, olivines and many of the feldspars have been modified to a greater or lesser extent by magmatic corrosion, so that edges are rounded and sides embayed. Specimen 44/688 from east of Kanjiro is of slightly coarser grain size. Pyroxene occurs only in the groundmass which is relatively free of cryptocrystalline material. Scales and small flakes of reddish-brown biotite and greenish chlorite are scattered throughout the rock, but usually closely associated with the iron ore.

Monchiquitic Rocks

Several loose boulders of amygdaloidal rocks were picked up where the Tana leaves the area in the north. They are of basic composition and crowded with numerous amygdales and phenocrysts. The amygdales are white and composed almost entirely of calcite, occasionally of calcite and secondary quartz, or calcite and chlorite and rarely of quartz alone. Thin sections 44/843, 44/844, 44/846 reveal that the matrix is composed largely of fibrous zeolite in which are embedded prismatic colourless augite, pseudomorphs of olivine, euhedral brown amphibole and long apatite needles and occasionally biotite. The hornblende crystals usually have dark reaction rims and small specks of pyrite are accessory; occasionally veinlets of quartz and calcite traverse the rock. A few large, rounded quartz inclusions are also present. The boulders probably represent undiscovered dykes of Tertiary age.

West of Muguthu a narrow dyke-like body of poorly exposed basalt occurs in the crystalline limestones and calc-silicate granulites. Numerous rounded knots project prominently from its weathered surface, but are less discernible when the rock is freshly fractured. A thin section of specimen 44/767 consists of small prisms of basaltic hornblende, augite, a small amount of a green pyroxene, and subordinate chlorite, embedded in variably brown or colourless glass containing numerous crystallites. Plagioclase was not observed and the only leucocratic minerals are corroded microphenocrysts of apatite. Granular iron ore is abundant. The rounded knots, which may represent original vesicles or amygdales, consist of cryptocrystalline or isotropic material, associated with zeolite in some cases.

Another small exposure of basalt was found south of the Ruanjoga River, about six miles west of its confluence with the Ena. It outcrops for only a few yards and its exact relationship to the Basement System rocks is obscured by the soil-capping. Basaltic hornblende, not infrequently forming discontinuous mantles around the pyroxene, pyroxene, irregular grains of calcite with cores of serpentine, twinned plagioclase and granular iron ore make up the bulk of thin section 44/668. Zeolites are present in interstitial patches which are commonly arranged in a coarse sheaf-like manner and associated with calcite.

4. Pleistocene and Recent Deposits

These deposits are of superficial type and except for the areas of black cotton soil, are not extensively developed.

The bulk of the black cotton soil is confined to the south-eastern sector of the area where it has developed irrespective of the nature of the underlying rock on the interfluvies, and effectively conceals all rock exposures. Smaller patches have formed in the marshy areas overlying the kenytes north-west of Kiambiti and the olivine basalts south of the Thiba. Transpiration of lime-bearing groundwaters through the soil and subsoil has resulted in the accumulation of numerous nodules of kunkar limestone. Continued growth of these, presumably by capillary attraction, has in some localities given rise to the formation of impure sheet limestones a few feet below the surface.

Lateritization has been active but not intense and no extensive or thick deposits of consolidated lateritic ironstone were observed.

Long-continued weathering of the ultrabasic intrusives and some of the limestone bands has resulted in the formation of irregular veins of magnesite and a hard surface encrustation of magnesian calcareous laterite.

Loosely consolidated conglomerates, gravels and sands are exposed in many stream-courses. Recent alluvial gravels are, however, scarce. A small patch was seen on the Tana south-east of Kindaruma and some thinly scattered layers are found along the Thua River. An alluvial fan with relatively flat slopes has been formed where the headstreams of the southern tributaries of the Thua emerge from the Gakuyu Foothills.

Travertine float was found in a tributary of the Thura River near its confluence with the Tana. It is solid, and not cellular as much travertine is, irregularly banded, and possibly capable of taking a good polish. Small drusy cavities lined with secondary calcite are not uncommon.

V—GRANITIZATION

Some aspects of granitization have already been discussed, particularly in the section dealing with migmatites. The majority of the rocks of originally arenaceous and argillaceous composition have been affected to some extent by granitizing fluids. Granitization has been most intense in the east with the production of migmatites around Muguthu and homogeneous granitic rocks north-east of Memende. This agrees with Schoeman's (1948, p. 9) observations in the area to the west of Kitui. The grade of metamorphism also increases eastwards so that degree of granitization and metamorphism appear to be intimately linked. The absence of granitization in some of the lower-grade argillites and hornfelsic types, e.g. north-west of Siakago and south of Rongori, suggests that granitization does not begin before regional metamorphism has attained a grade approaching the epidote-amphibolite facies.

Microscope investigation indicates that granitization has taken place chiefly by alkali metasomatism. The basic rocks appear, except for the occasional conversion of hornblende to biotite, to have escaped granitization. It is possible, however—though this would need confirmation by more detailed microscope work and by chemical investigation—that some of the hornblende-biotite gneisses are derivatives of basic rocks that have been subjected to a predominantly soda metasomatism. Misch (1947, pp. 238–240) considers that in the north-west Himalayas the basic rocks tend to be granitized preferentially if the permeating fluids have a high sodium content as well as large amounts of silica.

The reasons why calcareous bands have not been affected by granitizing fluids are that limestones are chemically less susceptible to transformation than pelitic and semi-pelitic rocks, that they are relatively feebly permeable to percolating solutions, and that whereas psammitic rocks and to a less extent pelitic rocks fracture and shear under pressure, thus affording easy passages for the granitizing fluids, the limestones tend to flow plastically. (Misch, 1947, p. 237.) The unfavourability of calcareous bands to chemical migration is illustrated by the presence of relatively pure marbles next to the intensely migmatized rocks between Lutuni and Muguthu.

Quartzites, too, have escaped granitization. Their escape is attributed more to their degree of compaction, with consequent low porosity, rather than to any inherent resistance to replacement of the quartz grains of which they are composed.

In the area west of Kitui, Schoeman (1948, p. 19) traces the progress of granitization in migmatitic melanocratic schists, through the following stages: schist—felspathized schist—felspathized gneiss—biotite-rich granitoid gneiss. Further south Dodson has suggested the following rock grouping: Banded gneiss—biotite gneiss—granitoid gneiss—non-intrusive granite. In the area south-east of Embu, where the original rock was in most cases a biotite gneiss, advancing granitization can be traced through the following stages: Biotite gneiss—felspar porphyroblast gneiss—augen gneiss—migmatitic banded gneiss (including lit-par-lit replacement gneisses)—granitoid gneiss—granite (non-intrusive)—granite (intrusive). These variously granitized rocks are intimately inter-fingered and interlayered with the host-rock.

The elongation and alignment of the porphyroblasts, acquired by crystalloblastic growth, and their cataclastic deformation where movement outlasted growth (e.g. specimen 44/616), indicates that the augen gneisses are synkinematic. The postkinematic phase of granitization is indicated by the abundance of microcline in shear zones and the directionless fabric of many of the granitoid gneisses.

The intrusive granitic bodies and pegmatites are interpreted as the final stage of granitization during which the metasomatized material became mobilized and was injected into slightly cross-cutting tension fractures striking, for the most part, a few degrees east of north. Such an origin for the pegmatites would account for their deficiency in volatile mineralizers, such as are so often characteristic of pegmatites which have formed by crystallization of the residual volatile-rich fractions of deep-seated magmas.

VI—METAMORPHISM

The variability in composition of the sediments of the Basement System both along the dip and the strike, the absence of distinctive marker horizons, the possibly anomalous effects of intense granitization, and local peculiarities in chemical composition, make any attempt at metamorphic zoning by means of isograds, extremely difficult, if not impracticable on a quarter-degree sheet scale.

The highest grade of metamorphism in the area is indicated by the following ideal mineral assemblages, towards which, in spite of the presence of unstable relics, the rocks are progressing. The assemblages fall within the pyroxene-hornfels facies and are:—

1. Derivatives of the basic rocks north-east of Twinojini:—
Spinel-anorthite-hypersthene-olivine.
2. Impure calcareous, dolomitic or marly sediments, south-west of the Tana-Kithioko confluence:—
Calcite-diopside-grossularite-wollastonite.

Although no stable assemblage could be recognized in the sillimanite gneisses of the Mumoni Mountains, the equilibrium assemblage towards which chemical reconstitution is trending, falls into the high-grade sillimanite-almandine subfacies of the amphibolite facies. This grade is quite closely matched by that of the neighbouring calc-silicate rocks where stable epidote-diopside-hornblende assemblages reflect the almandine-diopside-hornblende subfacies which also falls within the amphibolite facies.

The chlorite and tremolite-actinolite schists are the results of the metamorphism of ultrabasic igneous rocks.

The biotite gneisses east of Kiarawara with assemblages approaching those of the biotite-chlorite subfacies, represent the lowest grade of metamorphism in the area. The texture of these rocks confirms that retrogressive metamorphism could not have been responsible for the low-grade mineral assemblages.

Instances of mineralogical changes responsible for reversion to lower-grade mineral assemblages, are indicated by the following reactions (Turner, 1948, p. 300):—

1. Forsterite $\longrightarrow$ Serpentine
2. Sillimanite $\longrightarrow$ muscovite
3. Hornblende $\longrightarrow$ chlorite + epidote
4. Serpentine $\longrightarrow$ magnesite + quartz

The minerals shown on the left remain as relics.

Although most of the dolerites in the south-western sector of the area are now represented by plagioclase amphibolites, they often have a less modified core in which the original texture is recognizable. The chemical changes that proceeded in them *pari passu* with metamorphism (but which may be attributable to granitization) are, an increase in the soda content, reflected in the acidification of the plagioclase, and the limited influx of potash responsible for the formation of rare flakes of biotite. It should be possible at some later date to trace in more detail the progress of the metamorphism of these dolerites along the same lines as has been done by Sutton and Watson (1951, pp. 252, 253 and 275) in the Loch Torridon and Scourie areas of Scotland.

The Embu Series

The pelitic rocks of the Embu series have been modified by contact metamorphism. The degree of metamorphism increases from west to east and has been responsible for the formation of biotite porphyroblasts in the knotenschiefer and hornblende and garnet porphyroblasts in the hornfelsic rocks. The origin of this local contact metamorphism could not be ascertained.

VII—STRUCTURES

The three major factors responsible for the structural features in the area are: (a) the migration of the migmatitic front, (b) the operation of stresses producing structures with predominant north-east-south-west and north-west-south-east trends, and (c) the different physical properties of the rock types comprising the Basement System.

Regional stresses produced different results according to the plasticity of the rocks involved. This is particularly well illustrated by the irregular structure formed north-east of Kaumothoi which is the result of plastic deformation. Similarly the lenticularity of some of the limestone bands is attributed to plastic flow under pressure. In certain areas where the rocks were more rigid, they yielded to pressure by shearing, producing marked shear zones. These zones, which are often roughly parallel to the strike, are commonly developed at the junctions of narrow bands of hornblende gneiss and granitoid gneiss, particularly south of the Tana.

The continuation of the Thatha syncline north-west of Kitui (Schoeman, 1948, pp. 39, 40) was traced well into the present area. Very little evidence was observed that can positively establish its relation to the surrounding formations. No signs of thrust faulting, or that the syncline is part of an overlying unconformable series, were observed. Of the three possibilities as to its origin suggested by Schoeman (*op. cit.*, p. 39) the slender evidence available supports the second, i.e. that the rocks are an inter-banded portion of the general succession. Exposures of the granitoid gneisses forming the eastern limb, are comparatively good and dip westwards. Lack of exposures in the other limb and also north of the Tana in the adjoining area, contribute to the difficulty of elucidating the structure. Immediately outside the area, however, south of the Tana, the granitoid gneisses of Ekarakara can be matched with those in the east running from the Thatha Hills to Kanjiro. Pending further detailed investigation theories on the origin of the syncline are best left in abeyance. Minor structures within the trough are indicated by the anomalous dips and discordant dykes,

East of Kiambere a marked change in the lithology and structure is apparent, and the gradual curving of the strata to the north-east in the north, and south-east in the south, points to the application of pressure from directions from north or south. The nose of this broad synclinal flexure has been fractured and sheared and reversals of dip are not uncommon.

A poorly exposed but intricate structure is formed by the discontinuous limestone bands in the south-eastern sector of the area and is interpreted as an overturned plunging anticline. Dips, where measurable, are either vertical or steeply inclined to the east, and the nose of the structure has been distorted by fracturing and flowage.

A general change of dip interpreted as a steep anticlinal structure, but with no obvious duplication of the strata, occurs along a line (see Fig. 1) from west of Siakago, through Kiangoya, to east of Manutha. Beyond this point its exact position cannot be followed due to poor exposures, but it is considered to link up with the anticlinal axis mapped by Schoeman (op. cit., p. 24) in the north-east corner of the area west of Kitui.

Faulting

No major faulting could be positively identified owing essentially to the absence of well-exposed and persistent marker horizons. North of Mwango a small displacement in the strata, gradually decreasing westwards to the Tana, indicates a hinge fault. Smaller faults were noted in the limestone bands, in the muscovite schists south of Kanjiro, and in the hornblende gneisses east of Thambu. In other areas abrupt discontinuity of structures suggests faulting, but faults have not been shown on the map because of insufficient evidence, mainly the inability to match displaced segments. It is possible that the isolated, sheared inselberg of Thambu is a displaced portion of a large band of gabbroic rocks occurring in the adjoining Embu-Meru area (Schoeman, 1951, p. 26).

Lineation

Although lineation, expressed by the orientation of mica flakes on foliation surfaces, is common in the biotite gneisses, it is rarely pronounced and, unless searched for, may easily be overlooked. The hornblende gneisses and diopside gneisses, on the other hand, rarely exhibit a linear fabric, but are often characterized by crystallization foliation. A rough lineation is also apparent due to the drawing out of semi-plastic schlieren during the flow of mobilized sediments. The linear orientation of the elongated pebbles of the conglomerate south-east south of Siakago is approximately north-south, but the amount of pitch could not be measured accurately nor could any relationship be established between amount of elongation and extent of deformation. South-east of Kanjiro some of the sheared biotite gneisses have lineation marked by the parallel arrangement of small corrugations. Insufficient measurements were made to evolve any detailed tectonic pattern, but the puckers indicate that the regional folding has a northward plunge at angles varying from 5° to 25° . This agrees with the observations made in the Nanyuki-Maralal area (Shackleton, 1946, pp. 25, 26), in the Embu-Meru area (Schoeman, 1951, p. 52) and west of Kitui (Schoeman, 1948, p. 40).

Jointing

The last effects of pressure were to produce relatively steeply inclined joints. The two most prominent sets are dip and strike joints, and these are particularly well developed along certain sections of the Tana, where they have markedly influenced its course. As in other parts of the Basement System closely spaced jointing has imparted a flaggy and slabby aspect to the gneisses. This is well illustrated along the Tana, a few miles east of the suspension bridge, and north-west of Kiarawara. Other exposures often reveal a third set of oblique joints moderately inclined to the strike joints. Many of the joints are filled with aplitic and quartz veins from half an inch to nine inches in width.

VIII—ECONOMIC GEOLOGY

The part of the area in which geological conditions favour prospecting, because of the abundance of pegmatites, is bounded by the Tana in the east, the Kiangombe Mountains in the west, the northern boundary of the area, and Kiambere in the south. Parts of it were examined superficially by a Government prospector in 1942. During the present survey an African produced some specimens of high-grade copper ore, which he claimed to have picked up three miles north of Masinga. A visit to that area, however, revealed neither veins *in situ* nor float, nor were copper sulphide or carbonate grains found in the neighbouring dry river-courses.

Asbestos

Some of the magnesian calcareous laterites associated with the limestone bands west of Lutuni carry thin isolated discontinuous seams of white asbestos. The quality is reasonably good, but in quantity it can be considered of no more than scientific interest.

Beryl

Grains of beryl were identified in the sands of the Thura River, but no crystals were observed *in situ*. They are presumed to have been derived from the pegmatites. The beryl in pegmatites is often not dissimilar in appearance to coloured quartz, and may be overlooked during prospecting, as has been recorded from Southern Rhodesia in recent years. Its hardness, poor cleavages, and usually green or blue-green colour are the most reliable field criteria.

Building Stone

Although the Tertiary tuffs vary, there is sufficient of suitable quality that can be easily quarried and dressed, to meet all immediate local demands. The patch of tuff on the road north of the suspension bridge is the nearest to the site of the projected Seven Forks power scheme—but its suitability has still to be ascertained.

Copper

Traces of copper mineralization in the form of green malachite staining, were found in the granitoid gneisses south-east of Memende and immediately outside the area, west of Twoinoini. They have no economic significance.

Fluorite

The limestone band south of the Tana-Kithioko confluence carries scattered grains of grey fluorite, but nowhere were concentrations observed that might arouse more than scientific interest.

Garnets

Garnets are developed in the pegmatites and associated rocks along the Thura River, north-west of Kiambere, and in the sillimanite and biotite gneisses between Mwango and Mumoni. None of the occurrences can be considered of economic value for the following reasons:—

- (a) The garnets have erratic distribution, and in the best exposures do not exceed 5 per cent of the total rock. At least 10 per cent is required for economic exploitation provided transport costs are not excessive.
- (b) The majority of the garnets are of small size. Manufacturers often demand garnets the size of peas, and in the Thura River area they are generally little bigger than pinheads.
- (c) The demand for garnets is subject to considerable fluctuation owing to competition from artificial abrasives.
- (d) No clear, flawless garnets of ornamental quality were observed.

Graphite

Occurrences of graphite were observed in the following localities:—

1. In many of the limestones in the south-eastern corner of the area.
2. East of Kambere.
3. South-east and south-west of Thambu.

Flaky graphite is erratically disseminated throughout many of the limestone bands particularly south and west of Lutuni and south-south-west of Kaumothoi. Although the overall percentage of graphite in the limestones is low, it is not impossible that systematic prospecting might reveal concentrations, the grade of which is sufficiently high to warrant exploitation, provided that a beneficiation process that requires only small quantities of water is employed.

Float of quartz veins, carrying a high percentage of flake graphite, was picked up among the calc-silicate rocks east of Kambere. Exposures are poor in this area and trenching would be required to reveal the ore body. Some of the diopside-rich calc-silicate rocks also carry small amounts of graphite.

To the south of Thambu the small occurrences of graphite are of the amorphous variety and occur in joint planes in the granitoid gneisses. Although the graphite content is high, the quantity is limited and the occurrences are not of economic significance.

Limestone

Although certain quantities of crystalline limestone are available at most of the places indicated on the map, many of the bands may be eliminated as a big source of lime because their narrow widths and steep dips would necessitate underground mining. The marble bands south and west of Lutuni are more favourable for quarrying, but although situated close to the Thika-Garissa road, they are still 75 miles from rail. The amount of magnesia permissible in commercial limestones varies according to the use for which it is intended. A maximum of 4 per cent magnesia is allowed in British Standard Portland Cement, so that a limestone required for cement manufacture should preferably contain less than 2 per cent of magnesia. The limestones from the following localities were assayed for their magnesia content:—

(1) Graphitic limestones south of Lutuni	2.93 % MgO
(2) Grey crystalline limestone four miles south-east of Siakago	0.73 % MgO
(3) Limestone three miles south of Siakago	16.58 % MgO

Magnesite

Occurrences of magnesite were observed in the following localities:—

- (1) One mile south of Twoinoini.
- (2) Mutheru, half a mile outside the area south of the Thiba River.
- (3) Three miles north-west of the Tana-Thiba confluence.
- (4) Lutuni.
- (5) In some of the limestone bands between the Kithioko and Ngomora Rivers, the largest of which is east of spot-height 3550.

The magnesite of the first three occurrences is a secondary mineral, formed in the zone of weathering by meteoric waters rich in carbon dioxide. It is thus essentially a superficial deposit that will not persist to depths much below the water-table. Of these occurrences, the deposit south of Twoinoini is the largest. The magnesite occurs in narrow, discontinuous veins varying in thickness from mere films to about 12 inches, and can rarely be followed for more than 20 feet. It is usually partly obscured by a brownish surface encrustation of magnesian calcareous laterite. These surface indications do not furnish reliable evidence as to the nature of the magnesite underground, and without pitting or trenching the percentage of recoverable magnesite or its purity cannot be ascertained. The exposed magnesite is hard and compact and where silicified tends to be brittle. Glistening crystalline silica has not only formed in vugs but also

in shrinkage cracks. Blackish alteration products, derived from the host-rock, form coatings, veins and inclusions. The presence of iron is indicated by brownish stains, and the abundance of lime is revealed by the positive reaction on applying cold dilute hydrochloric acid. This deposit is 40 miles from rail and under present conditions cannot be considered of economic significance.

Local replacement of the limestones by magnesite has been effected by hydrothermal or groundwater alteration. The nature of the occurrence and the impurities in these minor deposits, is essentially the same as those derived from the basic rocks. The surface encrustation, which conceals the exposures, has less admixed impurities, but would still fall short of the rigid specifications for breunnerite fixed by manufacturers.

Mica

The most promising mica-bearing pegmatites are found along the Thura River north-west of Kiambere, and south of Thambu. The former were investigated by Dr. W. Pulfrey in 1942 and much of the following account is based on his findings, which are embodied in an unpublished departmental report.

The majority of the pegmatites strike towards the north-west. They attain a maximum width of 30 to 40 feet and some can be traced for many hundreds of yards. Where the pegmatites have been opened up, the display of high-quality mica is not impressive. The mica is erratically distributed in books and nests and rarely attains a diameter of 12 inches. Some of the books are soft and more or less vermiculitized, others have innumerable physical imperfections and only a small percentage (mostly of No. 5 size—i.e. about three square inches) of that recovered could meet the strict specifications of mica brokers. The mica has a preference for developing in the quartz-rich fractions of the pegmatite. Garnets are often abundant but bear no relation to either the quality or quantity of mica. That the quality of the mica will improve with depth is possible, but it is impossible to predict whether the quantity will increase.

Sillimanite

Sillimanite is found in the gneisses between Mwango and Mumoni. Owing to prohibitive transport charges and the low and erratic percentage of sillimanite in the rocks, these occurrences have no commercial value at present.

Water

The Tana and Thiba Rivers are perennial and the Ena and Itabua carry water in their upper reaches for many months after the rains. In areas far removed from these rivers, the shallow depth of the water-table enables sufficient water to be obtained for domestic needs and the watering of stock, by sinking holes and wells a few feet deep in the beds of the sandy stream-courses. The water problem becomes more acute in areas, usually of higher ground, and some distance from such sandy river-beds. In such localities the siting of boreholes is best accomplished by combining the results of geophysical tests and geological information. Assistance is afforded by the relation of relief to geology. The relatively impermeable granitoid gneisses resist weathering and form hills, whereas the intervening valleys are composed of less resistant and more permeable biotite gneiss and banded gneisses. Features such as faulting, folds, dykes, nature and distribution of vegetation, and direction of movement of underground water (i.e. recharge capacity) are aids to the siting of good boreholes.

In the north-west the water-supply problem is not so acute. Here, should the sinking of boreholes be necessary, the most favourable sites are those that would allow intersection of the contact of the lavas and weathered Basement System at depths of 100 to 120 feet.

The only borehole that has been sunk in the area lies one and a half miles south of Masinga. It has only recently been completed and was drilled to a depth of 110 feet. Water was struck at 95 feet, the yield being 1,000 gallons per hour. Another borehole has been sited west of Kiambere and if this is successful an attempt will be made to locate water at Kiritiri.

Small springs are not uncommon and many of those noted are found well up the sides of steep hills and mountains and have been marked on the map.

The desirability of conserving water by means of the construction of numerous small dams, particularly where high evaporation losses could be offset by the accumulation of thick deposits of sand, has already been stressed in previous reports.

IX—REFERENCES

- Dixey, F., 1946.—"The Relation of the Main Peneplain of Central Africa to Sediments of Lower Miocene Age." *Quart. Journ. Geol. Soc.*, London, CI, pp. 243-253.
- Dodson, R. G.—"The Geology of the South-east Machakos Area" (in preparation).
- Harker, A., 1939.—"Metamorphism". London.
- Holmes, A., 1919.—"The Pre-Cambrian and Associated Rocks of the District of Mozambique." *Quart. Journ. Geol. Soc.*, London, LXXIV, pp. 31-96.
- Misch, P., 1949.—"Metasomatic Granitization of Batholithic Dimensions." *American Journal of Science*, New Haven, Vol. 247, pp. 209-245, pp. 372-406, pp. 673-705.
- Read, H. H., 1931.—"The Geology of Central Sutherland." Mem. Geol. Surv. Scotland.
- Reynolds, D. L., 1936.—"Demonstrations in Petrogenesis from Kiloran Bay, Colonsay: (1) The Transfusion of Quartzite." *Mineral. Mag.*, London, XXIV, pp. 367-407.
- Schoeman, J. J., 1948.—"A Geological Reconnaissance of the Area West of Kitui Township." Report No. 14, Geological Survey of Kenya.
- Schoeman, J. J., 1951.—"A Geological Reconnaissance of the Country Between Embu and Meru." Report No. 17, Geological Survey of Kenya.
- Shackleton, R. M., 1946.—"Geology of the Country Between Nanyuki and Maralal." Report No. 11, Geological Survey of Kenya.
- Smith, W. Campbell, 1931.—"A Classification of Some Rhyolites, Trachytes, and Phonolites from Part of Kenya Colony, with a Note on Some Associated Basaltic Rocks." *Quart. Journ. Geol. Soc.*, London, LXXXVII, pp. 212-258.
- Stewart, F. H., 1946.—"The Gabbroic Complex of Belhelvie in Aberdeenshire." *Quart. Journ. Geol. Soc.*, London, CII, pp. 465-498.
- Sutton, J., and Watson, J., 1951.—"The Pre-Torridonian History of the Loch Torridon and Scourie areas of the North-west Highlands and its Bearing on the Chronological Classification of the Lewisian." *Quart. Journ. Geol. Soc.*, London, CVI, pp. 241-295.
- Temperley, B. N., 1938.—"The Geology of the Country Around Mpwapwa." Short Paper No. 19, Department of Lands and Mines, Geological Division, Tanganyika Territory.
- Tilley, C. E., 1920.—"Metamorphism of Dolomites in South Australia." *Geol. Mag.*, London, LVII, pp. 492-500.
- Turner, F. J., 1948.—"Mineralogical and Structural Evolution of the Metamorphic Rocks." Memoir No. 30, Geological Society of America.
- Turner, F. J., and Verhoogen, J., 1951.—"Igneous and Metamorphic Petrology." New York.
- Tyrell, G. W., 1941.—"The Principles of Petrology." London.
- Wade, F. B., and Oates, F., 1938.—"An Explanation of Degree-sheet No. 52 (Dodoma)." Short Paper No. 17, Department of Lands and Mines, Geological Division, Tanganyika Territory.