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GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
NORTH MACHAKOS-THIKA
AREA

DEGREE SHEET 52 N.W.
(with coloured geological map)

by

W. A. FAIRBURN, B.Sc.
Geologist

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FOREWORD

The field-work that lead to the account of the geology of the North Machakos-Thika area given in this report continued to the north the geological survey of the area around and south of Machakos township, which was published as Report No. 27 (1954). In passing from the southern area to the northern there is a notable change in geology, which is reflected in the topography. In the North Machakos-Thika area, in contrast to the area south of Machakos, there is less hill-country made up of ancient rocks and what there is is concentrated in the east side of the area. More than half the area has a rather monotonous topography underlain by volcanic rocks of relatively recent age. This distribution of rock types reduces the chance of the discovery of minerals such as mica, kyanite, vermiculite and garnet, which from time to time have provided production further south. The volcanic area is, however, of importance as the volcanic rocks yield constructional materials, notably building-stone in the Thika area.

The Thika area is also interesting as some thirty years ago diamonds were recovered from a boulder bed intercalated in the volcanic sequence at Thika. More detailed work in recent years failed to reveal diamonds, but many small rubies and sapphires of various colours were recovered from the same bed. Further work at the *outcrop* of the boulder bed and in the valley downstream from it might well reveal other diamonds. The source of the diamonds has not been found; it presumably lies on the eastern flanks of the Aberdare range, hidden by volcanic rocks.

The volcanic rocks are also important in so far as frequently water can be obtained from them at relatively shallow depths by drilling. An account of water-supply is given at the end of the report.

Nairobi,
24th October, 1960.

WILLIAM PULFREY,
Commissioner (Mines and Geology)

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MAP

Geological map of the North Machakos-Thika Area (Degree Sheet 52,
N.W. quarter). Scale 1:125,000 at end

ABSTRACT

The report describes an area of about 1,200 square miles of central Kenya in the Central and Southern Provinces, about thirty miles east of Nairobi. It is bounded by latitudes $1^{\circ}00'$ S. and $1^{\circ}30'$ S. and by longitudes $37^{\circ}00'$ E. and $37^{\circ}30'$ E. The area consists of flat volcanic plains in the west and generally hilly country to the east, formed by dissection of the sub-Miocene and end-Cretaceous peneplains. The north-western end of the lava-capped Yatta Plateau passes across the area east of Ol Doiyo Sapuk, and the surface on which the lava rests is believed to represent a remnant of the sub-Miocene bevel.

The rocks exposed consist of horizontal Tertiary lavas, pyroclastics and sediments in the west, and folded Basement System gneisses and schists to the east. The Basement System rocks are metamorphic, and have been in places granitized to a considerable degree, with the production of granitoid gneisses. Soil types in the area are dependent on drainage; black-cotton soils develop in poorly drained regions while sandy soils and murrums form in well drained regions.

An account of the petrography of the rocks and the nature of their structures, metamorphism and granitization is given. Associated mineral deposits are described in detail.

GEOLOGY OF THE NORTH MACHAKOS-THIKA AREA

I—INTRODUCTION

General Information.—The north Machakos-Thika area as defined for this report covers the quarter degree sheet 52 N.W. (Kenya) (Directorate of Overseas Surveys sheet No. 149), and is bounded by latitudes 1°00' and 1°30' S., and by longitudes 37°00' and 37°30' E. The area is approximately 1,200 square miles in extent and lies partly in the Southern Province of Kenya, administered from Machakos, and partly in the Central Province, administered from Thika. In general, the eastern half of the section of Southern Province in the area forms part of the Kamba Native Land Unit, while the remainder of the area mapped is occupied by European farms. A geological reconnaissance of the whole area was made between November, 1956 and April, 1957, to construct a geological map, and to evaluate any mineral deposits of economic importance.

Climate, Vegetation and Game.—The climate in the area is pleasant for most of the year and similar to that of the Nairobi district. Rainfall is moderate and fairly uniform throughout the area. The following table of rainfall figures illustrates the uniformity of conditions, except on the high plateau of Iveti which has a much higher than average rainfall.

RAINFALL IN THE NORTH MACHAKOS-THIKA AREA

(taken from records of the East African Meteorological Department)

Name of Station	Rainfall in 1956	Number of rainy days in 1956	Average yearly rainfall	Number of years recorded
	<i>inches</i>		<i>inches</i>	
Thika, Sassa Estate	23·98	56	31·84	40
Thika District Office	27·25	100	31·46	26
Doinyo Sapuk, Doinyo Sapuk Estate	33·11	93	32·59	35
Doinyo Sapuk, La Finca	38·91	64	37·94	37
Doinyo Sapuk, Kianzabe Estate	26·98	64	34·83	41
Mua Hills, Kamuthanga Estate ..	29·07	71	29·40	41
Mua Hills, Kithayoni	22·73	78	25·26	19
Kangundo	51·15	79	34·54	18
Matungulu	36·45	92	36·55	15
Iveti Forest Station	61·46	84	50·73	14
Athi Plains, Kamoru	15·65	44	24·65	6
Kithimani	28·32	63	23·73	4
Ndarugu	21·13	69	28·69	21

In the Kamba Native Land Unit the most extensively grown crop is maize, often with beans and millet. Other crops include sugar-cane and bananas, while small amounts of sisal, coffee and pineapples are also produced. On the European farms, sisal is the most common product, particularly on the flat volcanic plains near Thika. Coffee is also of some importance but is mainly restricted to the better drained areas at the edge of the volcanic regions. It is noticeable in the Kangundo region that an effort has been made to preserve the soil by extensive terracing.

A considerable part of the top of Ol Doinyo Sapuk, excepting the summit itself, is covered by forest consisting of tall trees, of which *Conopharyngia holstii* and *Croton megalocarpus* are the most important. Other trees present include *Cassipourea malosana*, *Cussonia holstii* and *Albizia schimperiana*. Plants of the forest floor include Cape peppers (*Piper capense*), stinging nettles (*Fleurya aestuans*), *Desmodium subrepandum*, and *Aneilema pedunculata*, a "Mickey Mouse flower".

Game is not abundant in the area, although buck are fairly common on the plains, while hippo and crocodile can be seen in the Athi and Nairobi rivers.

Drainage.—The most important rivers are the Nairobi, Athi and Thika, which receive water throughout the year from streams rising further west, on the high ground at the edge of the Rift Valley. All the other rivers are intermittent, flowing only during times of flood.

Communications.—The whole area is well supplied with roads and in only limited regions is access difficult. Parts of the tarmacadamized Nairobi-Thika and Nairobi-Mombasa roads cross the north-west and south-west corners, while rail communication is provided by the Nairobi-Nanyuki railway at Thika. Most of the murram roads are maintained in fairly good condition, though during heavy rains they are sometimes impassable. Roads built from materials lacking the binding power of good murram, often show rapid deterioration. This is illustrated by the Koma Rock road, which is built along part of its length from calcrete and crushed pyroclastic material.

An interesting feature of many of the roads is their parallelism with the strike of the Basement System rocks. This results from their being made along north-west-trending ridges of granitoid gneiss and biotite gneiss.

Maps and Methods of Mapping.—Geological field information was plotted on air photographs and subsequently transferred to preliminary plots South A37/HI N.W., S.W., N.E. and S.E. (scale 1:50,000). The topography for the geological map of the northern half of the area was based on the preliminary plots, while for the southern half form-lines were taken from the Army map Machakos, E.A.F. No. 1637, 1945 (scale 1:250,000). The air photographs proved to be of considerable value in demarcating the boundary of the volcanic rocks, but were of little use in detecting variations of rock type and structures in the Basement System.

The apparent lack of agreement of rock types mapped in the south-east corner of the area with those mapped earlier by other authors to the south and east is mainly due to differences in interpreting a series of Basement System rocks that lacks distinctive characteristics. The present interpretation is that the rocks there are mainly variable biotite gneisses with zones of migmatization which, owing to the poor nature of their exposure, the author considers it more satisfactory to describe as "Undifferentiated Basement System". Baker (1954)*, who mapped the area to the south, regarded most of these rocks as being biotite gneisses, whilst Schoeman (1948), mapping on the east, included them in a broad group of variable pelitic, semi-pelitic, and psammitic gneisses and schists.

The foliated southern margin of the Iveti granitoid gneiss was also mapped by Baker (1954), in the Southern Machakos District, as biotite gneiss. There is a close resemblance between the foliated granitoid gneisses and certain varieties of biotite gneiss.

Continuations of the basins of more recent sediments between Lukenya and the Mua hills, and between the Mua hills and Iveti, were not mapped by Baker (1954). The deposits thin rapidly southwards, and it is probable that their southern termination occurs just outside the southern boundary of the area. Some slight modification of the extent of the outcrop of the sediments previously mapped by Sikes (1939), was also made along the western edge of the area.

II—PREVIOUS GEOLOGICAL WORK

An early visitor to Machakos was Count Teleki, in 1888, on the return of his expedition from Lake Rudolf. Some rock specimens collected by the Teleki expedition near Machakos were later described by Toulia (1891, p. 552).

J. W. Gregory (1894, pp. 292–293) referring to his journey of 1893 to the Rift Valley, described passing through Machakos and across the Kapiti plains to Fort Smith. He (*op. cit.*, pp. 302–304) gave a full account of the nature of the Iveti hills, which he regarded as forming part of a primitive axis of Africa.

*References are quoted on pp. 42.

In a more detailed account of his journey Gregory (1896, pp. 88-89, 215) described the lava plain west of Machakos and the ridges of gneiss forming Lukenya and Koma Rock that stand above it. He had been led to believe by an old map that this plain was recent alluvium and not lava, though it is possible that the map intended to indicate the sedimentary basin between Lukenya and the Mua hills. On his return to Machakos, Gregory (1896, p. 200) followed the course of the river Thika southwards to Vroni (Mabaloni) and then westwards up the Thika gorge to the lava plain, before turning south towards Machakos round the southern end of Chanjari (Ol Doinyo Sapuk).

Later Gregory published an account of the extent of the Kapiti Phonolite (Gregory 1921, p. 195), the volcanic rocks seen on the Thika-Nairobi road (*op. cit.*, p. 161) and the nature of the Basement System rocks in the Thika valley (*op. cit.*, pp. 32, 33).

Several references have been made regarding the Yatta Plateau and its origin. E. E. Walker (1903, p. 4) described it as a great lava plateau capping, three to four miles wide and thirty to forty feet thick, stretching to the north-west from the Kitui region to join with the volcanics around Nairobi. Gregory (1921, pp. 184-189) ascribed its origin to a flow of lava poured down a river valley parallel to the present Athi river. The petrography of the Yatta Phonolite was described by Kunzli (1901, pp. 147, 148) from a specimen collected at the north end of the Yatta.

H. B. Maufe (Muff, 1908, p. 33) described the phonolites in the region of Athi river which form the Kapiti and Athi plains.

A report and geological map of the country surrounding Nairobi by H. L. Sikes was published in 1939. His mapping covered part of the present area along its western edge, extending to 37° 04' E. and being bounded on the north and south by latitudes 1° 12' S. and 1° 28' S. The map includes the Nairobi phonolite and the Kapiti Phonolite west of Lukenya and their petrography is described in the report (Sikes, 1939, pp. 15-17).

Recently a geological map covering the western half of the area has been completed by E. A. L. Gevaerts of the Ministry of Works.

Further information regarding the present area has been recorded by B. N. Temperley (1953, pp. 54-55), who made traverses across the crystalline limestone horizon east of Kyevaluki hill, and by J. J. Schoeman (1948, p. 28), who regarded the granite forming Mabaloni and Nzukini as similar to that forming Lion Rocks on the Thika-Garissa road.

III—PHYSIOGRAPHY

Two distinct units can be recognized in the area:—

1. Flat volcanic plains at an altitude of about 5,000 feet, stretching westwards from Ol Doinyo Sapuk and the Mua hills. The plains are cut by steep-sided well wooded valleys.
2. More hilly country formed by Basement System rocks varying in height from 4,000 feet to 7,000 feet.

Throughout Kenya erosion bevels have been recorded on the Basement System rocks at various altitudes. Dixey (1948, p. 6) recognized that the lavas of the Kenya Highlands rest in many places on a planed surface, the sub-Miocene peneplain. This surface emerges from beneath the lava ten miles east of Thika at about 4,600 feet and inclines east-south-eastwards beneath the phonolite of the Yatta Plateau. Dixey also recognized a higher bevel, the end-Cretaceous peneplain, in the Machakos hills at 6,400 feet. These two bevels have also been noted by Schoeman (1948, p. 3) east of the present area and by Baker (1954, p. 3) to the south. In the present area the sub-Miocene peneplain rises from 4,250 in the south-east to 4,850 feet in the north-west, while the end-Cretaceous peneplain rises from 5,800 to 6,200 feet. The erosion bevels are shown in Fig. 1.

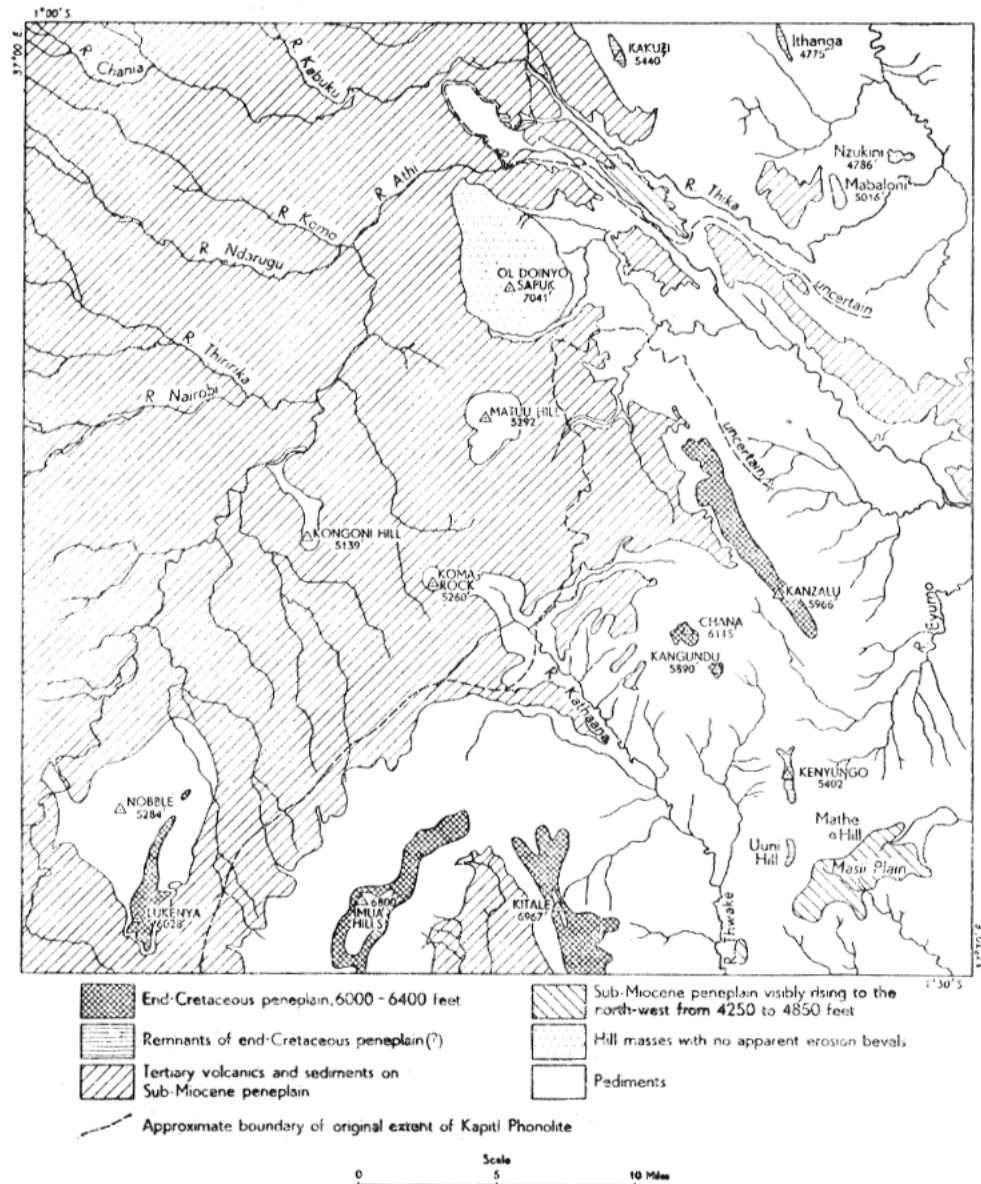


Fig. 1.—Erosion surfaces in the North Machakos-Thika Area.

It is assumed that the level of the sub-Miocene peneplain at any point is represented by the altitude of the base of the lowest volcanic rocks in that part of the area. If this is accepted the Yatta Plateau reveals the bevel for several miles, but the volcanic rocks of the plains south of Thika hide the peneplain. The altitude of the peneplain at the eastern end of the Yatta Plateau is 4,250 feet, south of Ol Doinyo Sapuk 4,600-4,800 feet, while under the volcanic rocks west of Thika it probably rises to a little over 5,000 feet. This slope of the peneplain is in agreement with the observations of Schoeman (1948) in the area farther east, who recorded it as standing generally at about 4,000 to 4,150 feet, though he did not recognize the easterly slope which, in the southern part of his area, takes the surface down to a level of about 3,900 feet.

As might be expected the sub-Miocene peneplain surrounding the Machakos hills was not perfect. Koma Rock, Kongoni hill and Lukenya rise above the general level of the volcanic plain and clearly were residual hills on the peneplain. Bore-holes put down through

the volcanic rocks confirm a pattern of buried ridges and valleys and prove that the pre-volcanic floor was far from being perfectly peneplained. When the first lava, the Kapiti Phonolite, was extruded, lower-lying parts filled with lava, sometimes to a depth of over three hundred feet, while the ridges were left bare and were only buried by later pyroclastics. Detailed work on the topography of the pre-volcanic surface has been carried out by Gevaerts, of the Hydraulic Branch of the Ministry of Works.

At the present time the volcanic rocks are being eroded by a series of easterly-flowing rivers, which have developed gorge-like valleys with numerous waterfalls. Where not preserved by a volcanic cover the level of the sub-Miocene planed surface has been greatly lowered by erosion but can still be recognized as a fringe round the margins of larger hills and by the even elevation of divides and small hills in eroded country, as at Masii in the south-east corner of the area.

The second peneplain recognized by Dixey, which he described as standing at a height of 6,400 feet in the Machakos hills, has been tentatively dated as of end-Cretaceous age. This peneplain is conspicuous in the area mapped, being represented by the tops of most of the high hill masses at a height of 6,000 to 6,400 feet. The bevel is best seen on the Iveti and Mitaboni Hills, where it forms a conspicuous plateau-like region dissected on the east by a series of steep-sided valleys that isolate flat-topped spurs which are used for roads and tracks. On the Mua hills the bevel is also preserved but is less distinct, owing to considerable erosion and cutting back by streams draining to the west. Further to the north-east the bevel can again be detected at about 6,000 feet, as isolated patches on Kangundo hill, and on the flat-topped ridge of Kanzalu.

Lukenya also probably represents a remnant of the end-Cretaceous bevel, while smaller hills such as Koma Rock and Kongoni hill, may well be much eroded relics. Kenyungu, Ithanga and Kakuzi may also be denuded remnants of the surface. These hill ranges are small and composed of rock less hard and compact than the massive granitoid gneiss of the Machakos hills.

Ol Doiyo Sapuk, the highest hill in the area, forms a triangular isolated mass, elongated parallel to the foliation in the surrounding rocks. A possible erosion bevel can be observed on the north-west shoulder of the hill at about 6,400 feet, and may well represent the end-Cretaceous surface, which is seen more clearly on the Mua hills. The summit of Ol Doiyo Sapuk at 7,041 feet compares generally with the high points on the Machakos hills, Kitale 6,957 feet and the Mua hills 6,800 feet. These high points may represent residuals from a higher surface.

The belt of highlands formed by the Machakos hills, Kangundo, Kanzalu and Ol Doiyo Sapuk has been and is a major watershed, and in Tertiary times was an effective barrier against the eastward migration of the products of volcanic activity. Its deflecting action is illustrated by the Athi river, which flows east-south-east from its source to Athi River township, then north-east before turning to flow in a south-east direction round the northern end of Ol Doiyo Sapuk. The piling up of the volcanic rocks against the barrier is illustrated by the eroded remnant of a former band of tuff banked up against the western side of the Mua hills and by the overlapping of tuff over phonolite against Kanzalu.

The latest cycle of erosion is particularly active between the Kanzalu range and the Athi river. This region, at 4,000 feet, represents the lowest part of the area, river-courses are sand-filled with no distinct valleys, and rock exposure is meagre.

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL HISTORY OF THE AREA

The eastern half of the area is formed by rocks of the Basement System, while to the west lavas, pyroclastics and sediments of Tertiary age are exposed. In general, the rocks in the area can be divided into four main age groups—

- | | |
|----------------|-----------------------------|
| 4. Recent | soils and alluvial deposits |
| 3. Pleistocene | sediments |
| 2. Tertiary | volcanics and sediments |
| 1. Archæan | Basement System |

The Basement System is believed to represent an original sedimentary series of limestones, shales and sandstones, into which basic magma has been intruded. Intense compression with rising temperature has resulted in these rocks being transformed into a highly folded metamorphic series. The metamorphic rocks vary in grain size from fine-grained schists to coarse gneisses and in composition from pure quartzites and marbles to varieties rich in biotite, muscovite and hornblende, the intrusives being converted to plagioclase amphibolites. An attempt can be made to establish the grade of metamorphism, owing to the presence of kyanite, almandine and sillimanite, and of calc-silicate minerals developed near limestone horizons.

During compression and folding of the Basement System rocks much of the sedimentary series was affected to a greater or lesser degree by granitization. Over much of the area considerable alkali metasomatism took place, giving rise to microcline-rich rocks among biotite gneisses and migmatites. In other cases, the action of fluids must have been active enough to mobilize masses of rock, causing complete reconstitution and giving granitoid gneisses. A sequence of changes from biotite gneiss to granitoid gneiss can be recognized to a certain degree, mainly on mode of outcrop.

The lengthy period of time between the end of the Archaean and the Tertiary was probably one of repeated rejuvenation and erosion but the oldest clearly-recognizable erosion bevel is only end-Cretaceous in age. A younger peneplain matured in sub-Miocene times after renewed uplift.

After the formation of the sub-Miocene peneplain, disturbances along the Rift Valley resulted in the outpouring of the Kapiti Phonolite and the deposition of a considerable thickness of pyroclastics. In this period also, lake beds were deposited interbedded with the pyroclastics. It is believed that the volcanics and lake beds are of Tertiary age.

A small patch of younger lake beds on the western margin of the area are probably of Pleistocene age. Recent deposits in the area owe their origin to weathering and erosion and include soils, laterites and alluvial deposits.

The sequence of events occurring throughout the geological history of the area is shown in the following table:—

1. Deposition of sediments of the Basement System.
2. Basic intrusions.
3. Compression and folding of the Basement System coupled with metamorphism and granitization.
4. Injection of granite with pegmatites and quartz veins.
5. Periods of uplift and erosion.
6. Formation of the end-Cretaceous peneplain.
7. Uplift and rejuvenation.
8. Formation of the sub-Miocene peneplain.
9. Emplacement of Tertiary volcanics and deposition of lake beds.
10. Pleistocene deposits.
11. Formation of recent deposits.

V—DETAILS OF THE GEOLOGY

1. Basement System

Most writers in dealing with the Basement System of Kenya, for example Baker (1954, p. 5) and Joubert (1957, p. 8), express the view that the foliation of its members is parallel to the original bedding planes of the sedimentary rocks from which the system was derived. This seems to be true in the present area, and is best observed by mapping distinct lithological units such as limestones and quartzites. The mapping also indicates that distinctive groups of rocks can be traced parallel to the strike for several miles. This parallelism of foliation and bedding may not be true in the case of some granitized rocks, such as migmatites, and certainly not true in the massive granitoid gneisses which typically have quaquaversal dip at their margins.

The Basement System can be divided into two rock series:—

1. Rocks that have been granitized and tend to grade into types that approach granite
2. Rocks that have suffered metamorphism with little or no granitization and often more closely resemble sedimentary rocks.

A similar subdivision has been suggested by Goldschmidt (1922, p. 107) who believed that a distinction should be made between two kinds of metamorphic rock, viz.

1. Products of "normal" metamorphism where the chemical composition of the original rock has remained unaltered.
2. Products of metasomatic metamorphism, which owe their present composition essentially to the introduction of new substances.

In mapping the Basement System it is not possible to draw distinct boundaries between the two kinds as a steady gradation takes place between extremes.

The rocks of the Basement System are described on following pages under the headings:—

1. Meta-sediments
 - (a) Crystalline limestones
 - (b) Tremolite rocks
 - (c) Mica schists
 - (d) Graphite schists and gneisses
 - (e) Kyanite schists and sillimanite schists
 - (f) Hornblende-biotite gneisses and hornblende gneisses
 - (g) Biotite gneisses
 - (h) Quartzites
 - (i) Muscovite gneisses
 - (j) Muscovite-biotite gneisses.
2. Granitized sediments
 - (a) Migmatites
 - (b) Granitoid gneisses
 - (c) Augen gneisses.

For convenience intrusives into the Basement System are also described in this chapter under the following headings:—

1. Metamorphosed intrusives
 - (a) Plagioclase amphibolites and epidiorites
 - (b) Meta-dolerites.
2. Intrusives
 - (a) Granites
 - (b) Pegmatites
 - (c) Quartz veins.

Classification of the meta-sediments into pelitic, semi-pelitic or psammitic varieties is not always readily accomplished owing to uncertainty in deciding the nature of some of the original rock types. This applies to the graphite schists and gneisses, while some of the microcline-rich gneisses may represent either original psammitic biotite gneisses to which potash has been added, or completely altered and granitized original alumina-rich pelitic sediments. In the classification adopted it has been assumed that the biotite gneisses, whether altered by granitization or not, result from the metamorphism of psammitic sediments. The term "granitized sediments" is restricted to rocks that are believed to have been produced by the complete alteration of original sediments of unknown composition, but which were probably rich in alumina.

As most of the Basement System rocks of the Northern Machakos-Thika area have been formed by the alteration of original sedimentary rocks, an attempt can be made to deduce the stratigraphical sequence.

East of Iveti, a characteristic series of schists and crystalline limestones is exposed which, near the Thwake river, has the following succession:—

	Thickness (feet)
Pelitic and semi-pelitic schists and gneisses with muscovite- biotite gneisses and thin quartzites	6,500
Mica and hornblende schists	
Crystalline limestone	
Mica schists	
Crystalline limestone	

This sequence is also characterized by kyanite- and sillimanite-bearing rocks. It is thought possible that it represents part of the Turoka Series, as it closely agrees with a description of that series in the Namanga-Bissel area (Joubert, 1957, p. 9).

The Turoka Series is underlain on the east by variable biotite gneisses and migmatites with common thin bands of hornblende-biotite gneisses, plagioclase amphibolites and graphite gneisses and schists. Northwards, the outcrop of this sequence, which is exposed about as far east as the Athi river, thins out, probably along the axis of a northerly-plunging overturned anticline. These hornblende rocks are probably also represented by the biotite gneisses and plagioclase amphibolites exposed in the anticline north-east of Mabaloni.

A third distinctive set of rocks comprising uniform massive biotite gneisses, granitoid gneisses, migmatites and only rarely other rock types, forms Kangundo hill and the Kanzalu range, possibly the Kakuzi and Ithanga hills, and the granitoid gneisses at the edge of the Thatha syncline (Schoeman, 1948, p. 39) in the extreme north-east corner of the area. There appears to be a discontinuity at the contact of these rocks with the Turoka Series and the hornblende rocks underlying it.

The exact nature of the Mua hills-Iveti granitoid gneisses is not fully known, but as they appear to show some intrusive features, they must be younger than any of the above divisions.

A summary of the geological sequence in the Basement System rocks of the North Machakos-Thika area is tabulated below:—

	Thickness (feet)
3. Biotite gneisses and granitoid gneisses	12,000
2. Turoka Series	6,500
1. Biotite gneisses with hornblende rocks	>8,500

(1) META-SEDIMENTS

(a) Crystalline limestones

Crystalline limestones or marbles are found as thin bands in the Tulimani schist zone, a prominent band of schists passing north into the present area from the southern Machakos district (Baker, 1954, map). Two limestone bands were mapped in the southern part of the schist zone in the present area; one soon dies out, but the other continues northwards to disappear at a point east of Kyevaluki hill. Lenses of limestone are also present in the schist zone south of Kangundo hill.

The limestones vary from pure white to blue-grey and are coarsely crystalline. It is unlikely that the bands are ever more than fifty feet thick and this fact, coupled with their fairly steep westerly dips, greatly limits any economic value.

The limestones are dolomitic in composition, consisting of compact mosaics of dolomitic calcite crystals. Inclusions of calc-silicate minerals are rare, although specimen 52/536* from south of Kangundo hill contain small crystals of tremolite. Graphite, as small flakes, can also be detected in some of the limestones (specimen 52/476, from the Thwake river).

*Numbers 52/536 etc., refer to specimens in the regional collections of the Geological Survey of Kenya.

(b) *Tremolite rocks*

Tremolite rocks are invariably associated with the crystalline limestones, usually forming a zone at their margins. The felted aggregates of tremolite usually include no other mineral, although small amounts of talc can sometimes be detected.

Where best developed in the Thwake river, tremolite rock forms a thin band a few inches thick on top of the limestone. The tremolite, usually grey or white in colour, is in slender needle-like crystals or in radiating aggregates or rosettes, as in specimen 52/479. East of Kyevaluki hill, the appearance of the tremolite has changed and a fairly thick band of pale green tremolite is exposed (specimen 52/475). To the north of this locality the limestone thins and disappears, but when it reappears under Kangundo hill tremolite is again abundant, in some places almost wholly replacing the limestone.

(c) *Mica Schists*

Most of the schistose rocks in the area are confined to the Tulimani schist zone, which passes north along the line of the Thwake river, before swinging north-west, round the flanks of Kangundo hill. The outcrop of the zone is largely controlled by the granitoid gneisses for, south of the present area, it turns to the east round the granitoid mass of Mbooni.

The schists in the zone mainly vary from muscovite-rich varieties to biotite-rich varieties, while quartzose schists and tremolite schists are not uncommon. Specimen 52/483, from near the Thwake river bridge, is a typical biotite schist with biotite abundantly developed on the planes of schistosity. Quartz is abundant associated with orthoclase and perthite, and accessories include common sphene and apatite and rare zircon. An example of a quartzose schist is provided by specimen 52/482, again from near the Thwake river bridge, which consists almost entirely of fine quartz particles with small anhedral to euhedral, partly oxidized almandine garnets, small biotite crystals and a little feldspar (albite-oligoclase and microcline). In general, apart from the larger mica flakes and garnets, the grain size of the schists varies from about 0.25 mm. to 0.5 mm. A notable character of these rocks as compared with many others in the area, is the abundance of quartz and the lack of microcline, a feature indicating their largely ungranitized state.

The only other large schist zone in the area occurs north-east of the Yatta Plateau. As with the Tulimani schist zone the outcrop is controlled by the shape of a granitoid gneiss mass. Schists in this zone are variable along the strike and rather coarse-grained, being interbedded in places with gneissose rocks.

(d) *Graphite schists and gneisses*

Graphite schists and gneisses are fairly common in the area, but are unlikely to be of economic interest. Most of the occurrences take the form of narrow highly weathered bands of restricted extent with only a small percentage of graphite. One fairly large deposit forms a distinctive horizon round the southern end of Kanzalu near Kibani, and has been investigated as a source of graphite.

Specimens 52/485 and 52/552 from Kibani are coarse-grained quartz-feldspathic schists with graphite flakes giving a rather crude schistosity. Biotite is rare. Another type of graphite schist is illustrated by specimen 52/502 from the Kithima river, an extremely fine-grained rock consisting of a powdery mixture of graphite, feldspar and quartz.

(e) *Kyanite schists and sillimanite schists*

Kyanite schists and gneisses are poorly exposed and only four isolated outcrops were recorded. Three of these are weathered kyanite schists, while the fourth is a kyanite-quartz segregation probably of pegmatitic origin. In the schists the kyanite is associated with almandine and mica, with staurolite absent.

Specimen 52/529 collected four miles south-west of Kangundo is a kyanite-biotite-almandine schist with quartz and graphite. The kyanite occurs in long bladed crystals and includes numerous chadocrysts of quartz, as well as inclusions of biotite and graphite. Biotite is abundant and is partly intergrown with the kyanite, while the almandine present occurs as slightly irregular crystals with numerous small inclusions.

In contrast to the above kyanite-biotite schist, specimen 52/512 from a small exposure six miles west-south-west of Mitaboni, has muscovite as its dominant mica. The kyanite forms idioblastic crystals with few inclusions and large grains of magnetite are common.

Specimen 52/493 is a highly aluminous schist, appearing in hand specimen to consist almost entirely of muscovite and kyanite, showing slight iron staining. In thin section biotite is seen to be fairly common while flakes of graphite are abundant as inclusions in the other minerals. Important accessory minerals are garnet and pink and green tourmaline which shows strong absorption. This specimen comes from schists occurring beneath the limestone of the area east of Kyevaluki hill. The schists are the continuation of the main limestone-kyanite horizon of the Tulimani schist zone.

The remaining kyanite-bearing rock obtained from the area, specimen 52/534 from near Kibani, is probably of pegmatitic origin and consists of large radiating clusters of kyanite with quartz in a fine-grained groundmass of kyanite.

Only one instance of the occurrence of sillimanite is known in the area and that is from a narrow band just to the north of where the limestone horizon disappears east of Kyevaluki hill. The rock (specimen 52/496) is essentially a muscovite-biotite schist with large almandine garnets and lenses of quartz. In a section through one of the quartz lenses, the sillimanite can be seen to consist of felted masses of needle-like crystals. Also present are large grains of iron ore. The sillimanite seems to be restricted on the whole to the quartz and to be absent from the mica-rich layers, except near the quartz lenses.

(f) *Hornblende-biotite gneisses and hornblende gneisses*

Hornblende-biotite gneisses and hornblende gneisses are fairly common in the area, particularly between Kanzalu and the Athi river and also in a zone east of the Kakuzi hills and extending south-east across the valley of the Thika to Kithimani. Smaller lenses of hornblende-biotite gneiss were also noted in the granitoid gneisses of Kanzalu. Apart from the Kakuzi-Kithimani band, the hornblende gneisses have little lateral extent. Along the Eyumo river south-east of Kanzalu, for example, there is considerable thickness of hornblende gneisses, but in valleys further north within a mile their place is taken by biotite gneisses and migmatites.

One of the hornblende-biotite gneisses from Kanzalu (52/528) is a crudely foliated rock, with the light and dark minerals concentrated into lenses. Biotite and hornblende appear in equal amounts, in a groundmass largely composed of twinned and untwinned plagioclase. Quartz is also present with apatite and sphene. Specimen 52/489 from near Mwala is a biotite-free granular rock with about 40 per cent of hornblende. The light minerals are mainly untwinned plagioclase and quartz, with sphene and iron ore as accessories.

(g) *Biotite gneisses*

Biotite gneisses are the most abundant ancient rocks in the area. They vary from well foliated non-granitized varieties, to highly granitized types approaching granitoid gneiss. Most of the area shown on the map as undifferentiated Basement System is formed by biotite gneisses, of very variable nature with associated migmatites while zones of biotite gneisses of a more uniform nature have been indicated. These differentiated zones of biotite gneisses consist of rocks foliated in hand-specimen as well as in outcrop, composed of orthoclase, quartz, biotite and microcline, which strike in a direction dictated by the trend of the granitoid gneisses.

Three types of biotite gneiss were recognized, mainly classified on their field appearance and the nature of granitization they have suffered.

(i) *Non-granitized biotite gneisses.*—Biotite gneisses of this group usually occur in schistose zones and are pelitic or semi-pelitic in nature. Petrologically they are usually poor in microcline. Specimen 52/546 from the Ndalani river is a pelitic biotite gneiss consisting largely of quartz, biotite and plagioclase with minor amounts of apatite, garnet and muscovite. Occasionally such gneisses are banded by felsic material which differs from the host-rock in being rich in microcline.

(ii) *Granitized biotite gneisses*.—The granitized biotite gneisses, in both hand-specimen and in thin section, closely resemble the granitoid gneisses. They differ however, in exposures as they have a distinct foliation. Specimen 52/551 from just west of Mabaloni is a typical example, and is a buff-coloured rock composed of orthoclase, microcline, quartz, sodic plagioclase and biotite. Replacement textures are characteristic. The rock has a uniform appearance with no signs of granite injection, and evidently alkali metasomatism must have taken place evenly throughout it. Such biotite gneisses can be regarded as permeation gneisses.

(iii) *Pegmatitized biotite gneisses*.—Biotite gneisses of this group can be seen in the Kakuzi hills and elsewhere in the area. They are unlike the granitized biotite gneisses in the fact that granitization by uniform alkali permeation has not taken place, but instead they appear to have soaked up granite pegmatite fluid into pore spaces and cracks. The resulting rock contains patches and lenses of coarsely crystalline microcline, masking the original texture, and giving in places a pegmatitic appearance.

To compare the granitized and non-granitized biotite gneisses the approximate modes of specimens 52/484 and 52/551 are set out below along with the mode of the non-granitized gneiss, 52/546:—

	52/484	52/551	52/546
	%	%	%
Quartz	42	20	54
Orthoclase	40	29	+
Microcline	+	35	—
Plagioclase	5	10	15
Biotite	12	5	30
Muscovite	1	1	—
Accessories	+	+	1

52/484—Valley south-east of Masii

52/551—One mile north-west of Mabaloni

52/546—Five miles east of Mabaloni Rock

(h) *Quartzites*

Quartzites are not important rocks in the area and only occur in thin bands, mainly associated with the muscovite-biotite gneisses round the eastern edge of the Iveti-Mitaboni hills.

(i) *Muscovite gneisses*

Muscovite gneisses are not abundant and except for isolated occurrences are confined to a zone running southwards from a point north-east of Uuni hill. In this zone, there is a north-south variation from biotite-free muscovite gneiss to muscovite-biotite gneiss. The muscovite gneisses are leucocratic rocks with either colourless or green muscovite. Foliation is sometimes pronounced, as in specimen 52/488 from near Kenyungu, which has developed a schistose structure by the accumulation of muscovite in conspicuous planes. The muscovite layers are separated by lenses of granular quartz, with minor orthoclase and microcline. Mineralogically specimen 52/495 from east of Kyevaluki is similar but the muscovite is in smaller flakes and more evenly distributed throughout the rock. Bending of the muscovite flakes has produced a rather wavy foliation. In contrast to the quartzose muscovite gneisses, specimen 52/499 from south of Uuni hill is a feldspathic muscovite gneiss with garnets. Microcline showing replacive textures is present, but quartz is still dominant. The quartz in this slide shows conspicuous strain shadows.

(j) *Muscovite-biotite gneisses*

The term muscovite-biotite gneisses is here restricted to gneisses with visible muscovite and biotite in the hand-specimen or outcrop. Associations of biotite and muscovite are common in the Basement System rocks of the present area, and are usually found in most of the schists, while muscovite is very common as an accessory mineral in the biotite gneisses and in the granitoid gneisses, where it is usually intergrown with the biotite. To the east of Kyevaluki hill, localized bands of muscovite-biotite gneiss occur, formed by metasomatic enrichment in muscovite.

Specimen 52/474 from the eastern side of Kenyungo is essentially a biotite gneiss but with muscovite conspicuously developed on foliation surfaces. Microcline is abundant, showing replacement textures and commonly enclosing quartz grains. The biotite and muscovite are closely associated, usually by intergrowth. The biotite is more abundant but the muscovite is present in larger flakes. In this specimen and also in other highly granitized gneisses, such as specimen 52/541 from Lukenya, muscovite is probably of late origin and formed like the microcline during alkali metasomatism. In the non-granitized meta-sediments, however, such as the mica schists, the muscovite would seem to be original i.e. of metamorphic and not metasomatic origin.

(2) GRANITIZED SEDIMENTS

Granitization has been defined by Read (1944, pp. 46–47) as a process whereby solid rocks are converted to rocks of a granitic character without passing through a magmatic stage. It is generally conceded that granitization implies a process of alkali metasomatism. Metasomatism was defined by Goldschmidt (1922, p. 106) as “a process of alteration which involves enrichment of the rocks by new substances brought in from outside. Such enrichment of the rocks takes place by definite chemical reactions between the original minerals and the enriching substances”. Goldschmidt defined the various metasomatic processes including the alkali metasomatism of silicate rocks, dividing the latter according to the manner in which the alkalis are bound during the process. Perhaps the most important division, with reference to the present area, is his second group in which alkali is bound by excess alumina in the precipitating mineral. Examples of this process are the formation of albite or potash feldspar.

Eskola (1939, pp. 375–392) adopted a simplified version of Goldschmidt's classification and was followed by Turner and Verhoogen (1951, pp. 485–487), who state that the most important instances of alkali metasomatism in metamorphic rocks are those that involve fixation of alkali by excess alumina in pelitic types. It is imagined that alkali solutions penetrate the pelitic rocks and react with alumina-rich minerals, such as micas and chlorites, producing enrichment in potash feldspar or albite. Turner and Verhoogen (1951, p. 487) suggest that the assemblage muscovite-microcline can be formed in the amphibolite facies by alkali metasomatism.

In the present area the Basement System rocks can be divided into two groups depending on the presence or absence of microcline. The microcline-free rocks are practically confined to the micaceous schists and gneisses of the Tulimani schist zone. Most of the remaining rocks in the area contain microcline to a variable extent and in some cases, where it is limited, its place is taken by an abundance of orthoclase, as in specimen 52/484, a biotite gneiss occurring south-east of Masii. Of the microcline-rich rocks, the most prominent are the granitoid gneisses, which consist dominantly of microcline, orthoclase and albite-oligoclase. The granitoid gneisses are believed to represent the end-product of alkali metasomatism of pre-existing rocks by the fixation of alkalis (potassium and sodium) by alumina, yielding the present observed feldspathic assemblage. It is probable that during the formation of the granitoid gneisses, they became mobile enough to deform the surrounding plastic metamorphosed sediments.

The migmatites give a clue that the first stage of granitization is the formation of banded gneisses, consisting of alternating layers of non-granitized rock and bands rich in alkali feldspar. Such a stage is represented by parts of the granitoid gneisses of Kanzalu, which do not everywhere have the uniform texture of typical granitoid gneisses, but show in parts a coarse banding of felsic material in the normal gneissose structure of the rock. Although the gneisses of Kanzalu have been mapped as granitoid gneisses, they are in fact partly migmatites.

In general, it can be said that a granitization sequence can be recognized between unaltered metamorphic rocks and granitoid gneisses, as follows:—

Meta-sediments—banded gneisses—migmatites—granitoid gneisses.

A similar sequence has been recognized by Baker (1954, p. 9) and Dodson (1953, p. 9). The final product of this sequence in the area mapped is granitoid gneiss, but there is no reason to doubt that the ultimate end-product could well be a mobile granite.

(a) Migmatites

Migmatites have been defined by Turner and Verhoogen (1951, p. 294) 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 recognizable". Rocks that fulfil these requirements form a large part of the present area, and give rise to part of the hill masses of Kangundo and Kanzalu, and a belt of country stretching north-west from Kanzalu. On the map these rocks have for convenience been included with the granitoid gneisses.

The main difference in outcrop between the migmatites and the granitoid gneisses is the development of a foliation in the migmatites which where well developed, gives large dipping smoothly polished rock surfaces. Tracing the migmatites along the strike, all variations from foliated migmatites to massive migmatites can be observed. Another conspicuous feature of the migmatites is their essential granitic veins which are usually parallel to the foliation and in fact tend to make the foliation more conspicuous.

In hand-specimen the migmatites and granitoid gneisses again show important differences and similarities. The migmatites as in specimens 52/535 from Matungulu and 52/538 from Kanzalu are conspicuously banded rocks, cut by narrow felspathic veins that are more coarsely crystalline and with a greater percentage of pink felspar than the remainder of the rock and do not have sharp contacts, as intrusive bodies would. The granitoid gneisses are much more uniform rocks, but transitional types between the two extremes have been recorded. Specimen 52/500 from the northern foliated margin of the Machakos hills granitoid gneiss is of this type and shows a rather restricted banding.

The similarity between the host-rock of the migmatites and the granitoid gneisses is illustrated in thin section. Mineral content as is illustrated by the estimated modes given on p. 13 and p. 14 and textures are very similar and no important differences can be observed.

Specimen 52/535 is a typical migmatite, with granitoid host-rock containing a conspicuous felspathic band. The dominant minerals are quartz, microcline and orthoclase forming an irregular aggregate of grains in which replacement textures can be seen. Albitic plagioclase is present in small amounts while biotite is poorly developed. Accessory minerals include iron ore, apatite, sphene and zircon. The main difference between this specimen and 52/538 from Matungulu is that the coarse felsic banding is quartzo-felspathic instead of felspathic. In the felsic bands felspar is subordinate to quartz and muscovite is as abundant as biotite.

The estimated volumetric modes are set out below:—

	52/535	52/538A	52/538
	%	%	%
Orthoclase	28	15	28
Albite-oligoclase	5	13	8
Microcline	26	28	8
Quartz	32	34	48
Biotite	8	8	5
Muscovite	—	+	5
Accessories (zircon, apatite, sphene, iron ore and garnet)	1	2	—

52/535 Host-rock of migmatite. Eastern side of Kanzalu range, four miles north-east of Kangundo.

52/538A Host rock of migmatite. Western side of Kanzalu range, Matungulu.

52/538 Felsic band in migmatite. Western side of Kanzalu range, Matungulu.

Striped pelitic biotite gneisses forming a contact zone round the Mabaloni granite are migmatites with pelitic host-rock. The pelitic biotite gneisses in this part of the area have been deformed by the granitic intrusion, layered with granitic material (*lit-par-lit* layering) and cut by intrusive tongues of granite, while earlier basic intrusions have been broken up and deformed leaving isolated lenses of amphibolite. The banded gneisses so formed have

already been described on p. 11. It is probable that they are younger than the main period of metamorphism and of the same age as the Mabaloni granite, which is regarded as contemporaneous with the Lion Rocks granite of the area west of Kitui township, which was provisionally considered as Upper Archaean in age by Schoeman (1948, p. 29).

(b) *Granitoid gneisses*

The granitoid gneisses are usually homogeneous, unbedded rocks forming large masses, whose outline controls the directional trend of the surrounding metamorphic rocks. Typically they form large exfoliation surfaces or outcrop as large slabs or blocks of dimensions great enough for their presence to be detected on air photographs. Granitoid gneisses are very abundant in the area forming the horse-shoe shaped mass of the Machakos hills, the ridges of Kanzulu and Kangundo (of which the rocks have already been described with section on migmatites) the smaller inliers of Matuu Hill, Koma Rock and Kongoni hill, as well as four occurrences in the region of the Thika river. In all these instances there is a tendency for the strike of the surrounding rocks to conform to the outline of the granitoid gneisses (*see* Fig. 2). The origin of the granitoid gneisses in the present area is attributed to the alteration of pre-existing rocks by alkali metasomatism producing rocks of granitic character. It is probable that during the process the granitic material became plastic.

The most typical of the granitoid gneisses in the area are those that form the large horseshoe-shaped ridge of hills north of Machakos, comprising the Mua hills to the west and the high plateau of Iveti and Mitaboni to the east and north. This structure has been referred to by Pulfrey (1954, p. 205) as possibly the fourth concentric structure of the Machakos area, the remaining three being at Mbooni, Opete and Kemozo in the Machakos-Sultan Hamud region. The contacts of the Iveti granitoid gneiss are usually fairly well defined and conformable with the strike of surrounding rocks, as is well demonstrated around Mitaboni. Occasionally, minor intrusive features were noted where the contact is sharp. The only deformation that can be seen round the margin is a belt of vertical rocks marking a line of overturning, which follows the eastern margin before swinging to the north-west (Fig. 2). Minor deformations include the bending of incompetent beds round sheets of granitoid gneiss, isolated from the main outcrop.

The granitoid gneisses are most distinctive in outcrop owing to their massive unfoliated condition. A foliation is usually present, however, round their margins, giving a dome-like structure with quaquaversal dip. Such a doming can be demonstrated across Iveti. As a rule, pegmatites and quartz veins are rare or absent in the granitoid gneisses, and if present, only occur near their margins.

In hand-specimen the granitoid gneisses resemble the granitized biotite gneisses and the massive migmatites but generally show a much more uniform texture. Specimen 52/508 from the Mua Hills is a buff-coloured rock with a homogeneous texture and a fine gneissose foliation caused by small streaks of parallel biotite flakes. This fine gneissose banding is typical in the granitoid gneisses, but is sometimes lost when the grain is coarser, or as a result of cataclasis (specimen 52/510).

Petrographically the granitoid gneisses are much alike and consist of orthoclase, microcline, albite, quartz and biotite. Muscovite is sometimes present in small amounts, while common accessories include iron ore, sphene and apatite. The similarity is illustrated by the following estimated modes:—

				52/500	52/501	52/508
				%	%	%
Orthoclase	..	..	..	20	37	25
Albite	..	..	..	10	10	12
Microcline	..	..	..	30	15	20
Quartz	..	..	..	35	25	40
Biotite	..	..	..	5	10	2
Muscovite	..	..	..	+	2	+
Accessories	..	..	..	+	1	1

52/500 Foliated margin of granitoid gneiss, east of Mitaboni.

52/501 Granitoid gneiss, two miles north-east of Mitaboni.

52/508 Massive granitoid gneiss, Mua hills.

Microcline is prominent showing replacement textures with the other minerals. Orthoclase is usually abundant, partly altered to sericite, while albite although common is always in smaller quantities than the other feldspars. Biotite, sometimes intergrown with muscovite, is almost invariably the only dark mineral, although in specimen 52/509 it is associated with hornblende.

Examination of the above modes reveals that the granitoid gneisses consist essentially of about 60 per cent alkali feldspar and 40 per cent quartz. Other constituents including biotite are present only in minor amounts. This is in marked contrast to the non-granitized metamorphic rocks which have feldspar as a minor constituent and are dominantly quartz-biotite rocks. It is largely on this evidence that the granitoid gneisses are considered to represent an end product of the alkali metasomatism of pre-existing alumina-rich rocks.

(c) *Augen gneisses*

Augen gneisses or granitoid gneisses with porphyroblastic eye texture are confined to the Lukenya hills. In many ways they resemble the ordinary granitoid gneisses, particularly in mode of outcrop. The Lukenya hills trend in a north-east direction (a direction contrary to the normal regional north-westerly trend) and their trend is paralleled by the foliation direction and the lineation of the rocks that compose them. Foliation surfaces are not commonly seen, exfoliation surfaces being more typical, as in the granitoid gneisses. A general westerly dip can be observed, however, in the massive outcrops, and there are scarps on the eastern side of the hills.

The distinctive feature of the augen gneisses is the presence of large eyes of pink microcline in gneissose groundmasses of orthoclase, albite, quartz and biotite similar to the granitoid gneisses. In some localities on the Lukenya hills the place of the common augen gneiss is taken by granitoid gneiss. Unlike the granitoid gneisses, however, certain outcrops of the augen gneisses have muscovite as an important mineral and it is sometimes as abundant as the biotite.

The exact position of the augen gneisses in the granitization sequence is not clear, although they may represent a variety of granitoid gneiss. Some varieties that have a marked porphyroblastic habit resemble gneissose granites, and it is possible that some of the augen gneisses are granite ortho-gneisses and not altered sediments.

(3) METAMORPHOSED INTRUSIVES INTO THE BASEMENT SYSTEM

The metamorphosed intrusives include two distinct rock types:—

(a) Plagioclase amphibolites

(b) Meta-dolerites.

Both are believed to represent metamorphosed basic intrusions. The plagioclase amphibolites occur as thin sill-like bodies and are typical metamorphic rocks, having lost their igneous textures. In contrast the meta-dolerites occur in much larger bodies and have both igneous and metamorphic characteristics.

(a) *Plagioclase amphibolites and Epidiorites*

Plagioclase amphibolites and epidiorites are fairly common in the area in bands striking parallel to the foliation of the surrounding rocks. It is probable that they represent basic intrusions that were introduced among the Basement System sediments before the main phase of metamorphism. They do not give large continuous bands and are only well demonstrated across an anticlinal fold east of the Thika river in the north-east corner of the area.

Most of the plagioclase amphibolites and epidiorites have marked foliation, caused by the parallel banding of light and dark minerals, and often well lineated surfaces due to the orientation of hornblende. They consist almost entirely of hornblende and plagioclase, sometimes with diopside and quartz, and generally with sphene as an accessory. The modes of a range of plagioclase amphibolites and epidiorites are shown below:—

	52/490	52/494	52/516	52/539	52/549
	%	%	%	%	%
Plagioclase	38	30	50	55	65
Hornblende	55	65	50	40	20
Diopside	—	5	—	—	15
Sphene	1	—	—	5	+
Quartz	5	—	—	—	—
Accessories	1	+	+	+	+

52/490 Epidiorite. One mile east of Mwala.

52/494 Plagioclase amphibolite. East of Kyevaluki.

52/516 Plagioclase amphibolite. West of Thwake river bridge.

52/539 Epidiorite. North-west of junction between Eyumo and Athi river.

52/549 Epidiorite. Three miles north-east of Nzukini.

It can be seen that hornblende and plagioclase occur in almost equal amounts and make up over 90 per cent of the rocks. The hornblende is green, or green-blue, occurring either in subhedral prisms or irregular crystals, while the plagioclase (oligoclase-andesine) varies from large twinned crystals (52/549) to small granular untwinned crystals (52/516). Diopside is not abundant and is only present in quantity in specimen 52/549, where it is light green in colour and intergrown with the hornblende. Quartz although not abundant was only noted in specimen 52/490. The most abundant accessory mineral is sphene, occurring in nearly all the specimens examined. In specimen 52/539, pink pleochroic sphene has inclusions of small yellow granules. Other accessory minerals include iron ore and apatite.

(b) *Meta-dolerites*

Meta-dolerite is probably the best displayed rock in the area, apart from granitoid gneiss, as it forms the impressive hill of Ol Doinyo Sapuk which rises to a height of over 7,000 feet, about 2,000 feet above the general level of the surrounding plain. The hill is triangular-shaped with its longest edge trending north-west, parallel to the foliation direction of adjacent Basement System rocks. The boundary of the meta-dolerite is sharp and is often at an angle to the strike of the surrounding rocks, and not parallel to it as is the case with the margins of the granitoid gneisses. It is probable that Ol Doinyo Sapuk is the relic of a transgressive doleritic (or primary gabbroic) intrusion.

In outcrop the meta-dolerite is massive with no visible foliation and can thus be compared with the granitoid gneisses. A foliation can, however, be observed in some hand-specimens (52/531 from the north-east side of the hill) caused by coarse banding of light and dark minerals. In specimen 52/532 from the southern margin of the hill only a vague foliation is present, and foliation is completely absent from very coarse examples. Most of the unfoliated types have a dominance of plagioclase, in which dark minerals form rounded crystals giving a troctolitic appearance. The texture is emphasised on exposed surfaces owing to the more easy removal of plagioclase by weathering.

Specimen 52/532 from the southern side of Ol Doinyo Sapuk is typical for much of the hill, showing a slight foliation in the dark minerals, which are about equal in volume to the felspar. An approximate mode is shown below:—

	52/532A
	%
Pyroxene altered to hornblende	40
Twinned plagioclase	20
Untwinned plagioclase	30
Epidote	10
Accessories (pyrite and calcite)	+

It would appear that originally the rock consisted of large porphyritic pyroxenes in a groundmass of coarsely crystalline plagioclase. Remnants of the original structure are now represented by large altered crystals of hornblende, or hornblende enclosing pyroxene, and occasional feldspars in a finer-grained groundmass of metamorphic origin. The primary pyroxene, probably augite, has been largely replaced by the pale green faintly pleochroic hornblende. The untwinned plagioclase of the granular groundmass has a composition in the region of andesine. Epidote giving anomalous low order interference colours is fairly abundant, either as needles and prisms in the feldspar crystals or as irregular aggregates of obvious secondary origin. Accessories, mainly pyrite and calcite, are not common.

(4) INTRUSIVES

In this group are included rocks "intrusive" into the Basement System that are either not metamorphosed or are only slightly metamorphosed. The group includes granites and, for convenience, pegmatites and quartz veins.

(a) *Granites*

Only one large body of granite is present in the area and it forms a near-circular mass in the north-east, where it gives rise to the rugged hill of Mabaloni and the smooth near vertical faces of Nzukini (Sokeni). Smaller associated granites in this part of the area form conspicuous smooth rocky ridges and resistant bars across rivers. Gregory (1921, p. 33) described Mabaloni and Nzukini (or Voroni as he called it) as being composed of granite and his views have been upheld by Schoeman (1948, p. 28). The Mabaloni granite resembles the granitoid gneisses in its massive unfoliated granitic mode of outcrop, but is dissimilar in that hand-specimens are unfoliated or only weakly foliated, while its contact is often not concordant with the surrounding rocks.

The main granite mass has its long axis parallel to the regional fold axes. On its east and west sides the surrounding rocks are generally concordant with its margin, and are near vertical and associated with minor folds. To the north and south, however, the concordance ends, and the strike in the metamorphic rocks is perpendicular to the granite margin. The general structure suggests that the granite is an intrusive body whose bulk has been partly compensated by folding on the east and west.

The age of the granite is probably later than the main phase of metamorphism and metasomatism.

The granite outcrops on low ground as smooth exfoliation surfaces and on higher ground as rugged tors and impressive rock faces, often wind pitted. Foliated outcrops are absent even at the margins, a situation where foliations are common in the granitoid gneisses, and the granite appears to rise vertically from the surrounding rocks. Steeply dipping migmatites with granite injection veins and occasional large masses of granite surround the main granite mass. These migmatites are not truly conformable with the edge of the granite as might be the case with a granitoid gneiss, and this might indicate a slightly discordant intrusive habit, which is also contrary to the nature of the granitoid gneisses.

Specimen 52/550 from Mabaloni is a hornblende biotite granite with black biotite and phenocrysts of alkaline feldspar. The phenocrysts of microcline and microcline-microperthite are up to three centimetres long and lie in parallel arrangement with the long axes of the dark minerals, giving the rock a crude foliation. Specimen 52/548 one of the small subsidiary granites from two miles north-east of Nzukini is rather different, having a rather equigranular granitic texture with few phenocrysts and no hornblende. The principal feldspars of the granites are microcline and microcline microperthite, and as in the granitoid gneisses, they show replacement relationships with quartz and orthoclase. Orthoclase and albite-oligoclase are present in a slightly altered state; being partly replaced by sericite and clay minerals. Accessory minerals are rare in the granites, but magnetite, apatite, sphene and zircon are present. Mineral concentrates in rain wash from the granite outcrops particularly at Nzukini consist mainly of hornblende.

(b) *Pegmatites*

Pegmatites in the area are variably intrusive or segregational. In all cases they consist essentially of microcline and quartz, sometimes with biotite and muscovite but with no indications of any other mineralization.

The intrusive pegmatites are mainly confined to small areas of more intense granitization, although they are rare or absent in the granitoid gneisses. They are not restricted to any major direction and are sometimes parallel to both foliation and dip directions. Their intrusive nature is indicated by sharp contacts, the tendency for younger pegmatites to displace older ones and the bending up of foliation surfaces at the margins of some pegmatites. Some of the pegmatites, however, in zones where intrusive pegmatites are common show little indication of intrusive nature.

The non-intrusive pegmatites, seldom greater than a few inches thick, occur as *lit-par-lit* veins in the banded gneisses and as segregations in the migmatites.

(c) Quartz veins

The quartz veins like the pegmatites are seldom, if ever, found in the granitoid gneisses and are mainly confined to rocks showing an intermediate degree of granitization. Mineralization is absent and although the quartz is often clear, large crystals were not observed.

2. Tertiary—Volcanics and Sediments

An extensive development of volcanics and sediments occurs in the western half of the area, forming the plains south of Thika and the Lukenya-Mua hills basin, and being flanked to the east by the Mua hills, Kangundo hill, Kanzalu, Ol Doinyo Sapuk and the Kakuzi hills. The only large occurrence of volcanic rocks to the east of this barrier is the Kapiti Phonolite forming the Yatta Plateau, which was probably caused by a stream of lava passing through gaps north and south of Ol Doinyo Sapuk.

The oldest volcanic rock in the area is the Kapiti Phonolite which is believed to be of Miocene age. The overlying volcanics and sediments are probably all of Tertiary age but, as no fossils are available and no age determinations have been made, it is not known whether they range into the Pliocene. Mainly following on the work of Shackleton (1945) around Nyeri a correlation of the volcanics in the Nairobi and the Nyeri areas has been drawn up. (Table I). It will be seen from the table that the volcanic rocks above the base of the Limuru quartz trachyte are included in the Pleistocene but that no attempt has been made to subdivide the Tertiary volcanics. The correlation is largely based on the belief that the Kerichwa Valley tuffs are of the same age as the upper tuffs with thin basalts at Thika and with the Nyeri tuff.

Two distinct volcanic associations are present in the area—that in the region of Thika, which is related to volcanicity in the region of the Aberdare Mountains and that in the region of Lukenya which forms part of the Nairobi sequence. These two sequences are tabulated below:—

	LUKENYA		THIKA	
Nairobi Phonolite	Nairobi Phonolite	100 ft.	Trachytic tuffs with thin basalt flows	50 ft.
			Absent	
Athi Tuffs and Lake Beds	Agglomerates tuffs and Lake Beds	200 ft.	{ Welded tuffs	15 ft.
			{ Upper Thika building stone	15 ft.
Simbara Series			{ Lake beds	0-50 ft.
			{ Coarse agglomerates	50-100 ft.
			{ Lower Thika building stone	30 ft.
			Basalts and agglomerates	50 ft.
Kapitian	Kapiti Phonolite	50 ft.	Kapiti Phonolite	0-200 ft.

TABLE I
CORRELATION OF TERTIARY AND PLEISTOCENE VOLCANIC ROCKS BETWEEN NAIROBI AND NYERI

	Lukenya-Nairobi Area (Gevaerts—Ministry of Works, verbal communication)	Thika Area (Present Report)	Kijabe Area (Thompson—Report at the Press)	Fort Hall Area (Fairburn—Report at the Press)	Nyeri Area (Modified from Shackleton, 1945)
Pleistocene	Limuru Quartz Trachyte		Laikipian Vents	Thiba Basalts Mount Kenya Phonolite and Agglomerate	Upper Laikipian Basalts Mount Kenya Volcanics
Tertiary	Kerichwa Valley Tuff and Nairobi Claystone Nairobi Trachyte Nairobi Phonolite Athi Tuffs and Lake Beds Kapiti Phonolite	Tuffs with thin Basalts Athi Tuffs and Lake Beds Simbara Series Kapiti Phonolite	Pyroclastics with Basalt and Trachyte Sattima Series Simbara Series (Kapiti Phonolite)	Basalts Tuffs and Claystones Simbara Series Kapiti Phonolite	Lower Laikipian Basalts Nyeri Tuff Sattima Series Simbara Series Not present
Precambrian	Basement System	Basement System	Not seen	Basement System	Not seen

In the Thika area, the Kapiti Phonolite is followed by basaltic agglomerates and then by about 200 feet of pyroclastic rocks and lake sediments, which form a uniform series of horizontal beds showing little variation over an area of about 250 square miles. Sections through the pyroclastics are well displayed in the gorges cut by the Thika, Athi, Ndarugu, Komo and Nairobi rivers. Most of the tuffs contain fragments of devitrified glass containing spherulites or microlites. It is probable that they represent varieties of welded tuffs. There are no ignimbrites (cf. Temperley, 1957, p. 7). Where some of the tuff bands thicken, a certain degree of fritting has sometimes taken place at the base, as is typical of ignimbrites. The tuffs on the flanks of the Mua hills show this feature in places, as do some of the tuffs south of Tala.

South of the Nairobi river in the region north and east of Lukenya, the volcanic sequence is different and much less uniform. As near Thika, the basal member is the Kapiti Phonolite, but is overlain by sandstone and then by a variable sequence of tuffs and agglomerates some of which may be water deposited. The highest volcanic bed is the Nairobi Phonolite, which is not seen near Thika in the area mapped. Important absences from this southern sequence are the basalts of the Simbara and the upper tuffs. The exact relationship between the two sequences is not clear, although a fairly accurate correlation table can be tabulated (see above p. 19).

The main problem concerning many of the tuffs is to account for their agglutination if they originated by the deposition of air borne material from a distant source and not from *nuées ardentes*. Welding in the tuffs is commonly associated with streaks of obsidian or devitrified glass flattened parallel to the bedding. One of the most distinctive horizons showing this feature has been mapped as a welded tuff.

(1) KAPITI PHONOLITE

The Kapiti Phonolite forms the plains south of Ol Doiyo Sapuk, where it surrounds Koma Rock and Matuu hill; part of the plains west of Lukenya, and capping the Yatta Plateau. It is also present under the pyroclastics in the Athi and Thika valleys, and under the Thika plains where it has been proved in bore-holes. The evidence shows that the phonolite is present over an area of 450 square miles. An eastern limit to its extent can be suggested, as shown in Fig. 1. West of Kanzalu the pyroclastics of the Athi tuffs have overstepped the edge of the phonolite and come to rest on Basement System gneisses while north of Fourteen Falls an original lava-flow edge can be mapped. Other evidence for the extent of the phonolite is provided by the tuffs and agglomerates south and west of Kakuzi, which rest directly on the Basement with no underlying phonolite. The line marking the limit of the phonolite is parallel to the edge of the end-Cretaceous surface, as seen on the Mua hills, Kanzalu and Kakuzi and is only broken by the tongue of lava forming the Yatta Plateau. Originally the main part of the phonolite must have been joined to the phonolite east of Ol Doiyo Sapuk and also probably extended southwards past the northern end of Kanzalu. In the deductions on the original extent of the lava it is presumed that erosion of the Kapiti Phonolite before the deposition of the pyroclastics was slight.

A striking feature of the Kapiti Phonolite is that where an edge can be observed, it is seen that the phonolite varies from about 50 to 100 feet in thickness and appears to be resting on an even surface. This is noticeable along the Yatta Plateau and at the phonolite edge near Ol Doiyo Sapuk. It is largely on this evidence that it has been concluded that the Kapiti Phonolite rests on an erosion bevel, the sub-Miocene peneplain. In contrast to this rather uniform picture, bore-hole evidence shows that under the Thika plains the Kapiti Phonolite is sometimes absent or varies up to over 300 feet. This is caused by relief in the Basement System old land surface over which the lava flowed, accumulating in hollows and leaving the higher points to be covered by later pyroclastics. The greatest thickness of phonolite recorded in bore-holes was on the Yatta Plateau near Kithimani market, where 500 feet of phonolite were penetrated without finding a base. Some of the bore-hole work indicates that more than one lava flow is present in the Kapiti Phonolite.

The phonolite is a hard, black, fine-grained rock with conspicuous phenocrysts of orthoclase and nepheline. The phenocrysts of orthoclase are commonly 2 to 3 cm. long and occasionally up to 5 cm. and sometimes form cruciform twins. Orientation of the phenocrysts is common, but no exact information as regards flow was determined in the area mapped. Near Lukenya the phenocrysts are aligned north-south, but on the Yatta

Plateau two alignments were noted, one being nearly north-south and the other being parallel to the sides of the plateau. This alignment parallel to the sides of the plateau is more common further south-east, outside the present area. Amygdales filled with zeolites and calcite are fairly common.

Microscopically specimens 52/473 and 52/533 from near Koma Rock and east of Ol Doinyo Sapuk agree with that described by Campbell Smith (1931, p. 238) and Schoeman (1948, p. 36). The groundmass consists of prisms of anorthoclase about 0.3 mm. in length with an abundance of the soda pyroxenes aegirine and aegirine-augite and the soda amphiboles, cossyrite and kataphorite. Euhedral nephelines are also present, with iron ore and analcite.

Yatta Plateau.—The Yatta Plateau is a narrow flat-topped ridge, between the Athi river on the west and the Tiva river on the east, over much of its length, stretching 180 miles in a south-easterly direction from Ol Doinyo Sapuk to the Galana valley east of Tsavo. Preservation of the plateau is due to a capping of Kapiti Phonolite, which at its edge is about 50 to 75 feet thick. Along its length there is a gentle slope to the south-east of the phonolite-Basement contact.

In the present area, the plateau extends from near Fourteen Falls to south-east of Kithimani, forming the divide between the Athi and Thika rivers. Phonolite caps the plateau only as far north as a point south-east of Kathini, where the plateau is formed by biotite gneisses. Further to the north-west, the biotite gneisses are covered by tuffs with no underlying phonolite until the northern edge of the area is reached. The northern end of the phonolite on the Yatta Plateau must have been joined to the main phonolite sheet at the edges of Ol Doinyo Sapuk, before being isolated by erosion by the Athi river. Evidence for this is provided by an isolated patch of phonolite on the western side of the Athi river, between the Yatta Plateau and Ol Doinyo Sapuk.

The problem set by the Yatta phonolite is to account for an outcrop of lava 180 miles long and on an average only 2 to 3 miles wide. Gregory (1921, p. 186) suggested that the present observed lava of the Yatta Plateau "is a remnant of a wider sheet or it must have been confined like a stream between the banks of a valley". Walsh (1963, p. 9) supports the view that the phonolite flowed down an old valley and suggests that spurs of phonolite extending laterally from the main mass mark the course of tributary valleys. As the phonolite outcrop is not continuous near Ol Doinyo Sapuk it might be possible at this point to trace the original valley. So far no evidence for a former valley has been found, and no old river deposits have been recorded, although sub-phonolite deposits of doubtful origin have been found east of Ol Doinyo Sapuk.

A third theory to account for the Yatta Plateau was put forward by Dodson (1953, p. 5) who regarded it as improbable that a single lava flow could continue for 180 miles. He found brecciated zones in biotite gneisses adjacent to the plateau and parallel to its sides and suggested that they represent belts along which phonolite was extruded by a series of feeding fissures. Lateral flow from the main line of extrusion would give spurs of phonolite, such as the spur in the Keite-Thwake valley where valleys were dominated and the lava flowed up or down them. Up to the present, however, no phonolite feeder dykes have been located and the only trace of an intrusive cutting the phonolite sheet in the present area is some dolerite float near Fourteen Falls.

There is some evidence to confirm the suggestion that the Yatta Phonolite represents the remains of a larger sheet. Schoeman (1948, p. 6) for example, located alluvial phonolite fragments 15 to 20 miles east of Ol Doinyo Sapuk some distance from the Yatta Plateau and in drainage channels not rising on the plateau, suggesting a much wider extent for the phonolite originally. The destructive erosion of most of an extensive sheet could well have been carried out by the Athi and Tiva rivers. The origin of the plateau lava as the remains of an original extensive lava sheet has also been suggested by Sanders (1963, p. 8-9) from evidence in the Voi-South Yatta area.

(2) SIMBARA SERIES

Overlying the Kapiti Phonolite in the Thika valley is a variable sequence of basaltic agglomerates, which correspond to the basaltic agglomerates of the Simbara Series described by Shackleton (1945, p. 2) in the Chania valley at Nyeri and as far south as Makindi. The

basaltic agglomerates are best displayed in the Thika valley, but also occur in the Komo and Ndarugu valleys. There is no indication of basaltic agglomerates in the Athi valley or near Lukenya, overlying the Kapiti Phonolite. The surface of the basalt agglomerates is extremely uneven, a feature well demonstrated in the Ndarugu valley.

The blocks of basalt with agglomerates are characterized by their highly vesicular nature, many samples having a honeycombed appearance. The blocks do not show great variation, but there is a gradation from varieties with olivine phenocrysts to varieties with felspar phenocrysts. Specimen 52/543 from the Komo valley is a fine-grained dark grey rock, with small phenocrysts and clusters of calcic plagioclase felspar and small inlets of iddingsite and iron oxide, probably representing altered olivine phenocrysts. In thin section in addition to the phenocrysts tabular prisms of labradorite can also be seen in a fine-grained groundmass consisting of small felspar prisms, granular magnetite and pyroxene, and small specks of iddingsite.

(3) ATHI TUFFS AND LAKE BEDS AND TUFFS OF THE THIKA AREA

The pyroclastics are the most abundant of the volcanic rocks, forming a thick widespread series of variable deposits in both the Thika and Lukenya regions. They cover the Kapiti Phonolite over much of the area and apart from the lava on the Yatta Plateau, are found further east than the phonolite.

In the region of Thika and Lukenya they can be divided into two parts. The Athi tuffs include all the pyroclastics up to and including the welded tuff which forms such a well marked horizon in the valleys south of Thika. Overlying the welded tuff and forming the surface of the plains west of Ol Doi Ny Sapuk are grey trachytic tuffs with thin basaltic lava flows of Laikipian type, and are here considered as the upper tuffs of the Thika area.

The Athi tuffs form a uniform sequence of rock types between the Thika and the Nairobi rivers. South of the Nairobi river however, the sequence is rather changed, although the Athi tuffs can still be recognized underlying the Nairobi Phonolite west of Lukenya. From the western edge of the area the Athi tuffs extend as far east as Ol Doi Ny Sapuk, but are only rarely found to the east of Ol Doi Ny Sapuk.

The youngest pyroclastics do not underlie the Nairobi Phonolite and for this reason are regarded as being of similar age to the Kerichwa Valley tuffs (*see* Table I). They obviously mark a stage of extensive pyroclastic extrusion as they are much further widespread than the underlying Athi tuffs and overstep older volcanic rocks. Near Thika, they rest on the Athi tuffs, south of Ol Doi Ny Sapuk on the Kapiti Phonolite, while west of Kanzalu they rest directly on the Basement System. They also form the isolated band of tuff fairly high on the west flank of the Mua hills, the small finger of tuff between Kangundo hill and the Mua hills and form the capping on a small hill just west of Mabaloni.

Most of the pyroclastics are probably of trachytic nature, commonly containing crystals of orthoclase and anorthoclase and rarely crystals of aegirine, in a groundmass made up largely of glass shards. The pyroclastics in the Thika region are well displayed in all the valleys and tend to give a uniform sequence over a wide area. In contrast, the tuffs and agglomerates under the Nairobi Phonolite are much more variable, they are usually of an earthy appearance, sometimes with blobs of obsidian and unlike the Thika pyroclastics, may be partly water-deposited.

The lowest pyroclastic horizon in the Thika region above the lower building-stone (to be described later) is a coarse soft pale agglomerate, which, where the building-stone and Simbara basalts are absent, lies directly on the Kapiti Phonolite. The agglomeratic horizon is unbedded and about 50 feet thick, consisting mainly of coarse pumice and glass in a finer groundmass of glass. Obsidian and lava fragments are rarely present.

In the Nairobi valley, the lowest agglomerate is overlain by lake beds, but further north, the upper building-stone can be seen resting on the agglomerates. Where the Upper building-stone is absent, its place is taken by a fairly thick tuff with crystal inlets or an agglomeratic tuff. This tuff with crystals is an extremely hard band and forms the lip of the Thika and Chania falls. The agglomeratic tuff is softer and is used in places as a building-stone.

The bed mapped as a welded tuff is a widespread deposit, although not very thick, forming the edges of most of the river gorges and underlying the youngest tuff. It is distinctive owing to the presence of large fragments of obsidian flattened parallel to the bedding, giving the rock the appearance of an obsidian agglomerate. Many of the welded tuffs in the Lukenya region are similar but with a lesser development of obsidian. The welded tuff can be mapped as a distinctive horizon over the Thika plains but, south of the Nairobi river, it appears to thicken and pass into the tuffs around Lukenya.

The youngest pyroclastic bed in the Thika region is a grey pumiceous tuff underlying the thin Laikipian type basalts, which are exposed between the Ndarugu and Komo rivers. It forms the surface of the plains south of Thika for an area of about 250 square miles and is represented by the tuffs west of Kanzalu. The pumiceous tuff, like the underlying welded tuffs forms a prominent bed among the pyroclastics but, unlike the welded tuffs, does not appear south of the Nairobi river. Locally the tuff is used as a building stone and is proving of importance in the Tala-Matungulu region.

The most impressive feature of the pyroclastics (including the building-stones) is the tendency for a given bed to cover a wide area, without any great variation in thickness or composition.

(4) THIKA BUILDING STONES

The term Building Stone is used to describe a series of massively bedded, fine-grained tuffs or claystones occurring in the Thika valley. Generally they are pale bluish in colour and resemble mudstones or fine-grained limestones more than volcanic rocks. In the Thika valley two building-stone horizons are present, a lower building-stone up to 30 feet thick and an upper building-stone about 15 feet thick. The extent of the lower building-stone is considerable, it occurs in the Thika valley from the Chania falls to the junction with the Samuru, and also in the Komo and Ndarugu valleys as small inliers in the valley bottom. The writer believes that, in all, the lower building-stone must occupy an area at least 50 square miles in the Thika region. The upper building-stone is not so extensive, however, forming discontinuous exposures in the Thika and Komo valleys, though it seems to be more continuous in the steep-sided valleys north-west of Thika. An important economic factor of the building-stones is their importance as high-grade building material and extensive quarrying of the building-stones has taken place in the Thika valley.

The distinctive feature of the building-stones is their fine-grained character and their uniform pale colouring, which varies in tints of blue, purple, green and brown. The lower claystone is usually capped by about six inches of brown flinty claystone (specimen 52/526). As with most of the tuffs and agglomerates in this region, the building-stones consist mainly of glass fragments with occasional crystals of orthoclase.

(5) TERTIARY SEDIMENTS

As with the volcanic rocks, two distinct sets of lake-beds can be recognized in the area. One was laid down in a Lukenya-Mua hills lake and the other set in a Juja lake, the two lake areas being separated by the Kongoni hill ridge of granitoid gneiss extending across the Athi river. The Lukenya deposits rest on the Kapiti Phonolite and are probably slightly older than the Juja deposits, which rest on the coarse agglomerates of the Simbara Series overlying the Kapiti Phonolite. Accurate dating of the lake-beds would be valuable as a guide to the age of the volcanics, but has not been possible owing to the absence of fossils.

The southern lake-beds are mainly confined to the Lukenya-Mua hills basin, but can also be seen north of Lukenya in the Athi valley and below the scarp of the Nairobi Phonolite. The exact sequence of lake-beds and pyroclastics is not clear due to local minor variations, but in general, the lake-beds rest on the Kapiti Phonolite and are overlain by the pyroclastics. This sequence can be recognized west of Lukenya and also in a deep pit sunk to the Kapiti Phonolite just south of Koma Rock. The lake beds are mainly sandstones and conglomerates derived by erosion from the surrounding hills of granitoid gneiss. Some of the pyroclastics overlying the sandstone may also have been deposited in water and in some instances are intermingled with the sandstones.

The Juja lake has been so called, because at Juja in the Nairobi valley, the lake-beds are at their thickest and show more variation in rock type than elsewhere in the region of Thika. Lake-beds assigned to this lake are mainly confined to an area bounded by the Athi and Thika rivers and the Thika-Nairobi road. Near Juja the lake-beds are about 50 feet thick and show a great variation from finely banded clays resembling varved clays to coarse conglomerates. The most typical deposits here are soft clays, but sandstones and grits are also present along with calcareous bands and bands of chalcedonic silica. Chalcedony from these bands may be the source of artifacts found near Koma Rock. Fossils are not present in the sediments, which in the case of the coarser deposits, were definitely derived from volcanic rocks. Specimen 52/523 is a conglomerate consisting of rounded pebbles of volcanic rocks in a fairly coarse groundmass, consisting mainly of rounded grains derived from volcanic rocks and including magnetite. Elsewhere in the Thika region, particularly in the Komo and Ndarugu valleys, the lake-beds show much less variation and mainly consist of coarse felspathic grits with small fragments of obsidian.

No direct observation of the relationship between the two sets of lake-beds can be made, as the Juja beds, although exposed in the Nairobi valley thin against the Kongoni basement ridge and are not present in the Athi valley to the south-east. South of the Kongoni ridge, the Lukenya lake-beds are also thin, as can be seen near Koma Rock where only a few feet of sandstone overlie the phonolite. The Kongoni ridge seems to be present from Koma Rock to just south of Juja where it has been proved by a bore-hole (C 1925) and is apparently one of several ridges existing in this area on the sub-volcanic floor.

Tertiary sediments of another type have been located in a pit sunk to below the base of the Kapiti Phonolite, east of Ol Doinyo Sapuk. They consist of coarse conglomerates and arkose-like grits with fragments of fossil wood. The age of the deposits must be pre-Kapiti Phonolite and is probably Miocene. They probably formed on the sub-Miocene surface as torrential deposits from Kanzalu, or other nearby hills, being later cemented by deposition of secondary silica.

The coarse conglomerates are made up of large angular fragments of Basement System biotite gneiss, with smaller sub-angular grains of orthoclase, quartz, microcline and hornblende, cemented together by clay and secondary silica. The presence of secondary silica in the groundmass gives the rock a glassy appearance, with a resemblance to a fused product. Finer-grained examples of the sediments include grits of composition similar to the conglomerates. Specimen 52/560 from the pit is an example of arkosic grit containing a silicified fragment of fossil wood.

(6) NAIROBI PHONOLITE

The Nairobi Phonolite forms the Athi Plains between Athi River and Nairobi. In the present area, the eastern edge of the phonolite forms a scarp over soft underlying agglomerates west of the Lukenya hills.

Megascopically the Nairobi Phonolite is dissimilar from the Kapiti Phonolite, though in thin section it resembles it to some extent. The Nairobi Phonolite, unlike the Kapiti Phonolite, has a rather platy structure caused by small flat plate-like phenocrysts of anorthoclase. The large phenocrysts of anorthoclase so typical of the Kapiti Phonolite are missing, as are large phenocrysts of nepheline. Also characteristic of the Nairobi Phonolite are small flakes of biotite visible in the hand-specimen. Small amygdales are fairly numerous and are filled by zeolites.

Microscopically the Nairobi Phonolite (specimen 52/520 from the Athi Plains) is seen to be composed of anorthoclase, aegirine, aegirine-augite, augite, cossyrite, kataphorite, nepheline, zeolites and iron ore, as is the Kapiti Phonolite, but it can be distinguished from the Kapiti Phonolite by important textural differences. Characteristically the Nairobi Phonolite contains rounded patches of isotropic material surrounded by ragged fringes of aegirine. Larger swirl structures are formed by prisms of feldspar. The texture of the phonolite agrees with the description of the Kenya-type phonolite given by Campbell Smith (1931, p. 230).

(7) BASALTS IN THE UPPER TUFFS OF THE THIKA AREA

The youngest volcanic rocks in the Thika area are olivine basalts, which form two fairly conspicuous ridges between the Komo river and the Ndarugu river. These basalts are probably of the same age as the thin basalts mapped at Githuya by Thompson, in the southern

part of the Kijabe area, overlying the oldest pyroclastics and as the basalts recorded from bore-holes in the upper tuffs west of the present area. They are regarded as being an early development of the Laikipian Basalts which are more extensive further north. Their occurrence in the Nyeri areas was described by Shackleton (1945, p. 2). As with the Simbara Series, these basalts are not found in the Lukenya region, making correlation with the Nairobi volcanic sequence difficult.

Specimen 52/525 from the easterly outcrop of basalt south of the Komo river is a fine-grained, apparently non-porphyrific platy rock with numerous amygdalae of calcite. Iddingsite is fairly abundant giving the rock a speckled appearance. Microscopically the basalt is seen to contain abundant small porphyritic, euhedral olivine crystals up to 0.5 mm. in length, showing complete or part alteration to iddingsite, and rarer small weakly purple pyroxene phenocrysts. The fine-grained groundmass consists of laths of labradorite, pale purple augite, euhedral magnetite and secondary calcite. Interstitial material is mainly feldspar, and analcite.

(8) INTRUSIVES OF PRESUMED TERTIARY AGE

In the soil mantle, on Kapiti Phonolite, about one mile north-west from Fourteen Falls, some pebbles of dolerite were recorded. It is presumed that the pebbles originated from a dyke, of doleritic composition, cutting the Kapiti Phonolite.

3. Pleistocene

A thin set of fluvial deposits is exposed on the western edge of the area in the low ground occupied by the fork of the Nairobi and Kamiti rivers. These sediments, mainly fairly coarse poorly cemented sandstones, cannot be definitely dated, but as they lie on the highest pyroclastics in the area they must be late Tertiary or Pleistocene in age.

4. Recent Deposits

Recent deposits in the area include soils and alluvial sand deposits. The soils are normally residual weathering deposits, whose composition is controlled more by the physical conditions of formation than by the type of rock from which they were derived. The alluvial sands include river deposits and outwash fans from the hills.

In general, the well-drained soils are sandy, and the badly drained soils black-cotton soils, there being well defined soil catenarities from the tops of hills which are well drained to the badly drained surrounding plains. Because of the distribution of the rock types the plains being underlain by volcanic rocks and the hilly country by Basement System rocks, the black-cotton soils are mostly confined to the volcanic areas, while red soils are confined to the Basement areas.

On the Basement System red lateritic soils are the most common, but in places they give way to more sandy soils and even black-cotton soils. The variation of soils on the volcanic rocks is not so great, the principal soils being black and grey. On the edge of the volcanic field, however, principally on the Kapiti Phonolite near Ol Doinyo Sapuk a chocolate-brown soil has developed which contains material derived from Basement System rocks. This change in soil type on the volcanic rocks is mirrored to a certain degree by the type of agriculture. On the typical black soils sisal is the principal crop, but on the chocolate soils coffee is more common. It is a noticeable feature of the area that sisal is grown on the pyroclastics and coffee on the lavas, principally as a result of the soil change caused by drainage. Gracie (1930, pp. 32-38) after testing the soils in the Mua hills area recorded that the red soils show an increase of acidity with depth while the black soils become more alkaline.

Another important feature of the soils on the plains south of Thika is the development of mound topography. The low mounds on the plains are extremely abundant near Juja and are well seen on air photographs. They are usually about 20 to 50 yards in diameter, at 50- to 100-yard intervals, and develop a stronger growth of vegetation than the surrounding depressions. Similar mound topography has been recorded from Australia and America. In the Juja region the mounds occur in crude radiating patterns and are not haphazard in their arrangement. On top of the mounds, the underlying rock surface, usually composed of cemented brecciated material is exposed or is covered by only a few inches of soil. In between the mounds the soil is much deeper.

A report of the Rothamstead experimental station (Muir and Stephen, 1956, p. 55) attributes the mound topography to the production and swelling of montmorillonite by weathering in the underlying rock. During the investigation for the report the uneven growth of crops on the Athi plains over the mound topography was examined. Several suggestions to account for mound topography have been put forward in America; it was thought by Krechtl (1952, pp. 689-700) that mounds in Oklahoma are due to the development of fissure polygon networks caused by soil desiccation and shrinkage, causing increased erosional activity along the fissures. In the present area, the mounds and depressions probably owe their shape to the action of drainage along the channels, which may have originated as suggested by Krechtl or may be due to subsidence along polygonal joint systems in the underlying rocks.

VI—METAMORPHISM AND GRANITIZATION

The Basement System rocks are believed to have been formed by the metamorphism and intense granitization of an original sedimentary series. An indication of the grade of metamorphism is provided by certain index minerals, as in the Barrovian metamorphic zones of the Scottish Highlands. Mineral assemblages in characteristic rocks also allow allocation of the rocks to metamorphic facies. Granitization of an intense nature is indicated by the formation of granitoid gneisses and migmatites as a result of alkali metasomatism.

The most valuable rocks in the present area for the determination of metamorphic grade are the non-granitized rocks of the Tulimani schist zone. In the schists, the most common zone mineral is almandine, which is abundant along certain horizons. Kyanite is not uncommon, usually occurring with muscovite, biotite and almandine, but with no staurolite or sillimanite. Sillimanite was recorded from only one exposure where it was associated with quartz, biotite, muscovite and almandine. These associations tend to show that the schists are mainly confined to the kyanite zone. Outside the schist zones, most of the other metamorphic rocks are highly granitized and rarely contain any of the zonal minerals.

The majority of the metamorphic rocks can be classified in the almandine-amphibolite facies of metamorphism, which is characterized by the stable assemblage hornblende—calcium-bearing plagioclase. This is typified by the following mineral assemblages of the plagioclase amphibolites which consist dominantly of hornblende and andesine—

Hornblende-plagioclase	} -quartz-sphene
Hornblende-diopside-plagioclase	
Hornblende-clinozoisite-plagioclase	

The kyanite and sillimanite-bearing rocks have the following assemblages—

Kyanite-muscovite-almandine	} -quartz-iron ore
Kyanite-muscovite-biotite-almandine	
Kyanite-biotite-almandine	
Sillimanite-biotite-muscovite	

The kyanite assemblages are characteristic of the kyanite-muscovite-quartz sub-facies, and the sillimanite assemblage of the sillimanite-almandine sub-facies. The absence of staurolite can probably be attributed to unsatisfactory $\text{Fe}_2\text{O}_3/\text{Al}_2\text{O}_3$ ratios.

Baker (1954, p. 17) regarded the majority of the metamorphic rocks in the southern Machakos area as falling into the cordierite-anthophyllite sub-facies of the (then) amphibolite facies, but also with assemblages in the staurolite-kyanite sub-facies, the garnet-diopside-hornblende sub-facies and the albite-epidote-amphibolite facies.

Apart from the schistose rocks, many of the metamorphic rocks in the area probably owe their mineral assemblages to metasomatism and consist largely of microcline, quartz and orthoclase, with plagioclase, biotite and muscovite. The highly altered rocks, such as the granitoid gneisses, show no indication of earlier metamorphic structures or minerals that might be present.

The crystalline limestones with their associated suite of calc-silicate minerals can also be used as a guide to grade of metamorphism. Analysis has shown that all the limestones are dolomitic. They are nearly always associated with a prominent development of tremolite, and talc is sometimes also present in minor amounts. High-grade metamorphic minerals such as diopside, forsterite and wollastonite were not recorded. This assemblage of dolomite-tremolite-talc is probably representative of the quartz-albite-epidote-almandine sub-facies of the green schist facies. The apparent low grade of metamorphism in the calcareous rocks may be indicative that temperatures were not very high during metamorphism and that pressures were the dominant factor.

The most important features of the Basement System rocks are their degree of metamorphism, their alteration by granitization, and their deformation as a result of strong compression. It would appear that there must be a link between orogenesis, metamorphism and granitization. Read (1948, p. 2) has suggested that the making of granite, migmatization and regional metamorphism are all part of one process.

The original sediments of the Basement System were probably deposited in a basin of geosynclinal nature, which developed a deep sialic root. Gradual uplift in the geosyncline, causing thrusting and folding at the margins, probably coincided with melting in the sialic root. This melting of the sialic root would cause the migration of granitic magma and alkaline fluids and the general warming up of the geosynclinal sediments, which could be reduced to a plastic condition. To this uprising granitic material Kennedy (1948, p. 233) ascribed the widespread injection and migmatization of the folded rocks belonging to the deeper zones of mountain chains, regional metamorphism at higher levels and the ultimate emplacement of batholithic granites.

The Basement System rocks exposed in Kenya probably represent a fairly deep zone of the original geosyncline and must correspond with the migmatized and folded rocks of Kennedy. The dominant rocks in the present area are granitoid gneisses and migmatites, around which are wrapped the more normal metamorphic rocks in almost perfect concordance. The granitoid gneisses are believed to have been formed from pre-existing rocks by alkali metasomatism as a result of the action of uprising alkaline solutions. Though probably becoming somewhat mobile they were held in a plastic environment which allowed deformation without discordant intrusion. Ramberg (1952, p. 248) alternatively explained the origin of such conformable bodies as due to the migration of potassium, silicon and sodium ions through the solid rock. On the hypothesis adopted by the writer, granites of a more fluid nature than the granitoid gneisses, caused by melting of the sialic root, could be expected to be mainly emplaced at higher levels in metamorphic rocks showing little signs of granitization, and to have produced clearly defined metamorphic aureoles.

VII—STRUCTURE

The main structural features in the area, the extent of the granitoid gneisses and the volcanics-Basement System boundary are shown on Fig. 2. Structures in the Basement System rocks are fairly complicated while those in the volcanics are simple. The general strike direction in the Basement System rocks, as in much of Kenya, is between north and north-west except for important variations in strike round the outcrops of granitoid gneiss, as can be demonstrated north of Mitaboni. Dips are dominantly to the west generally at moderate angles of about 20° to 40°. Lineation directions are mostly approximately parallel to the normal regional trend, plunging to the north or north-west and rarely to the south-east at low angles. Statistical analysis tends to show that the lineations are *b*-lineations parallel to the fold axes. The volcanic rocks are horizontal or near horizontal with no folding and only minor faults.

Foliations are most pronounced in the schistose rocks and to a lesser extent in the other rocks with the exception of the granitoid gneisses, which commonly show no foliation. The foliation is paralleled by the boundaries between distinct rock types, by mineralogical banding and by preferred orientation of flaky minerals. When the poles to foliation are plotted on a stereographic projection (Fig. 3 (a)) it can be seen that the foliations exhibit imperfect monoclinic symmetry with a fairly high degree of homogeneity for a fold-axis plunging at 17°, in a direction of 326°. The plot illustrates cylindroidal folding with a predominance of westerly dips, which could indicate either folds overturned to the east or folds with more prominent westerly limbs.

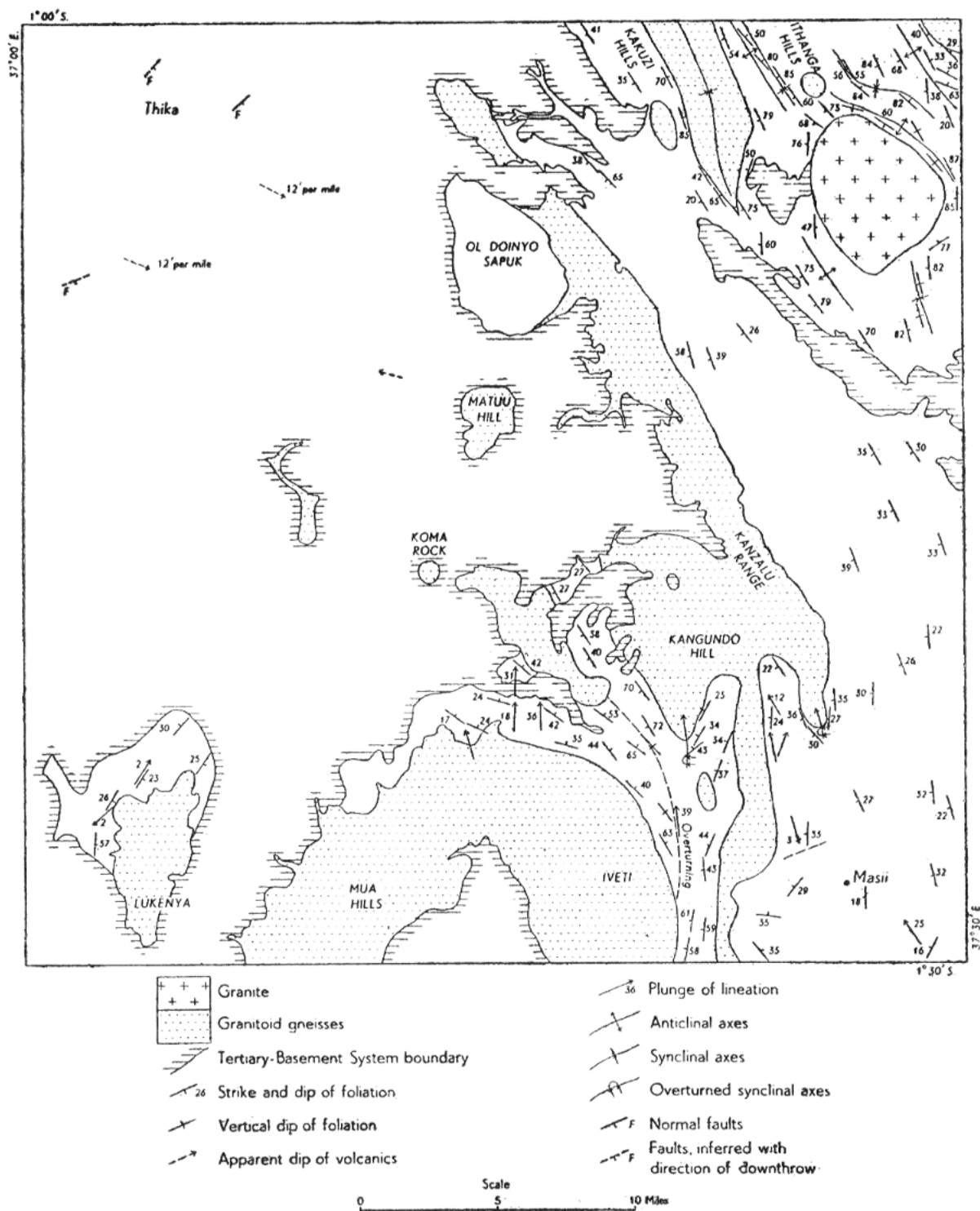


Fig. 2.—Structural map of the North Machakos-Thika Area.

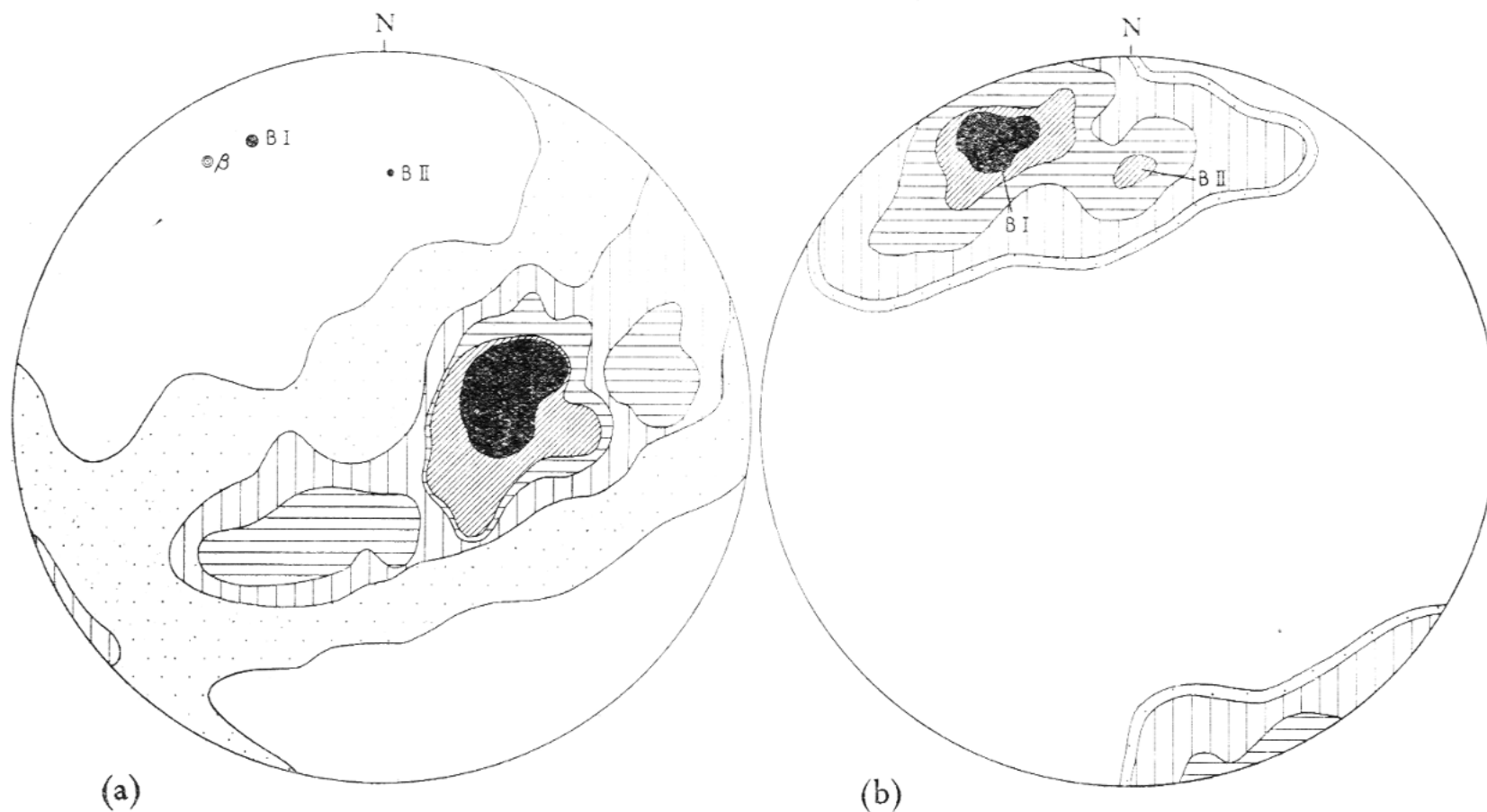


Fig. 3 (a).—Orientation diagram of foliation poles in the North Machakos-Thika area (700 readings). β is the statistical fold-axis. BI and BII are lineation maxima.

Fig. 3 (b).—Orientation diagram of lineations (100 readings). Maxima at BI and BII. Contours at 1, 2, 4, 5-10 and >10 per cent per one per cent area in each diagram.

Lineations are fairly distinct, usually being manifested in the elongation or streaking of minerals on the foliation surfaces. A stereographic plot of the lineations (Fig. 3 (b)) reveals a certain degree of homogeneity, with a statistical maximum BI plunging at 18° in a direction of 336° . The secondary maximum BII, plunging at 34° in a direction of 2° , is caused by a large number of lineation readings being taken in the region of Mitaboni, where the lineations trend in a more northerly direction. Only one locality shows a notable deviation from the statistical fold axes direction, and that is near Lukenya, where the foliations and lineations trend north-easterly. A lineation plot omitting recordings from the Lukenya and Mitaboni areas would reveal a high degree of homogeneity.

Verification of the statistical fold axis is provided by measurements on individual folds that can be identified in a single exposure. The minor folds have concordant axes and are overturned to the east, which suggests that overturned folding is prevalent in the area.

Support for overturned folding is provided by the structures south of Kangundo and Kanzalu (see Fig. 4). Flow folds in the north-east corner of the area, however, are not overturned (see map section). The nature of the folding thus seems fairly consistent on all scales.

The most unusual structure in the area is that provided by the migmatitic granitoid gneisses of Kanzalu and Kangundo. South of Kyevaluki hill the Tulimani schist zone is striking to the north and dipping steeply to the west and it would appear that it would pass to the east of Kangundo hill. Just to the west of Kibani, however, the schist zone is sharply overturned and it swings round the southern end of Kangundo hill before being lost to the north-west under the volcanics. A similar structure was mapped south of Kanzalu where the nose of granitoid gneiss is sheathed by a U-shaped band of graphite schists and gneisses. These two schistose bands which bound the southern margins of Kangundo and Kanzalu indicate overturned structures, which are illustrated by the transverse profile (Fig. 4) drawn normal to the fold-axes across Kangundo and Kanzalu. The profile also shows that south of the granitoid gneiss the folds are not clearly recognizable and that the foliation directions seem to bear no relationship to the large fold structures, which must be pinching out rapidly. The most striking structural feature is the high degree of conformity of strike of the surrounding gneisses and schists with the boundaries of the granitoid gneiss. This is clearly illustrated in Fig. 2 and most clearly demonstrated round the northern end of the Iveti-Mua hills granitoid gneiss, which is the most typical of the granitoid gneisses in the area. A similar degree of conformity was recognized by Baker (1954, p. 21) round the granitoid gneisses in the southern Machakos area, and by Searle (1954, p. 24) round the Kemioso granite near Sultan Hamud. The Opete mass south of Machakos and the Kemioso structure not only have concordance of strike, but are surrounded by series of concentric folds. Folding of this nature has been attributed to rotational movement round plastic plugs of granitoid gneiss at the height of metamorphism. North of Mitaboni, folding of this type has not been observed and the lineations trend northwards and not parallel to the sides of the granitoid gneiss. It would seem probable that the Iveti-Mua hills granitoid gneiss originated by simple doming without any secondary folding or rotation yielding a mass horse-shoe-shaped in plan. Another structural feature that can be attributed to this mass is the belt of vertical beds near the eastern boundary, which marks a line of overturning, transgressing across different horizons in a manner contrary to a fold structure (Fig. 4).

The small mass of granitoid gneiss exposed in the northern part of the area, between the Kakuzi hills and the Ithanga hills also exhibits some unusual structural features. To the north of the Thika river the granitoid gneiss separates a schistose horizon and a band of hornblende-biotite gneiss. At its contact with the granitoid gneiss the hornblende-biotite gneiss has a north-easterly dip, contrary to the prevailing dip of the other rocks in that part of the area (see Fig. 2 and map section).

Folding at and near the margin of the Mabaloni granite and north-west of it was probably caused during its intrusion.

Faulting in the Basement System rocks does not seem to be common and only minor faults were observed.

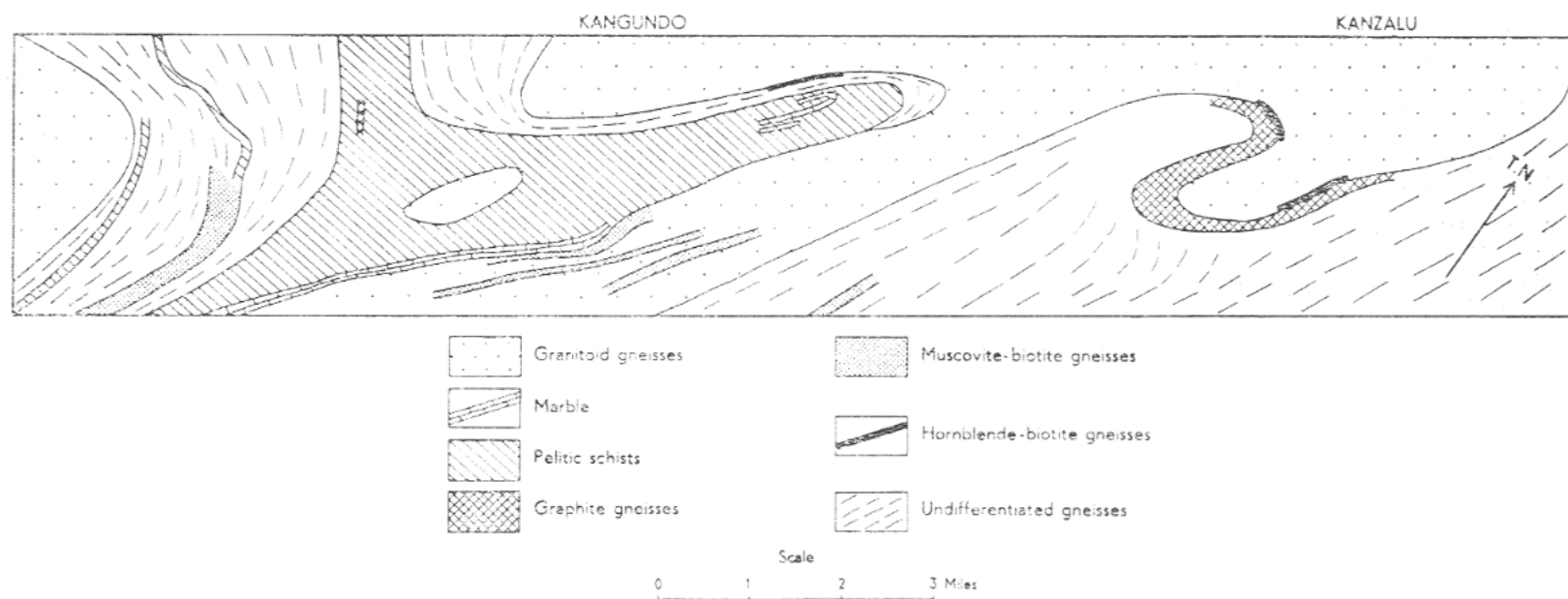


Fig. 4.—Transverse profile across the granitoid gneisses of Kangundo and Kanzalu.

The volcanic rocks in the Thika region are consistently horizontal or near horizontal over a wide area. Mapping has revealed, however, that there is in fact a gentle dip to the east of about 12 feet per mile, the volcanic beds rising towards the Rift Valley. East of the Athi river the dip is to the west and this is probably due to piling up of the volcanics on a basement floor rising rapidly towards Ol Doinyo Sapuk and Matuu hill. Two small faults throwing east were recorded in the volcanics, one in the Thika valley and the other in the Thiririka valley. A third fault is also likely in the Thika valley near the Thika Falls.

VIII—MINERAL DEPOSITS

1. History of Prospecting

Compared with the southern Machakos area, little prospecting appears to have been carried out in the Basement System rocks north of Machakos. This difference is largely due to the thinning of the Tulimani schist zone with the loss of marble, kyanite and talc and to the abundance of granitoid gneisses, migmatites and biotite gneisses, which show no trace of mineralization. Much of the prospecting in the area has centred round the marble-kyanite-corundum occurrences on a small hill east of Kyevaluki, the graphite schists forming Kabalya Hill near Kibani and non-existent precious stone deposits along the Athi river. Mineral occurrences in the area are small but include a wide range of non-metallic minerals and some metallic minerals. The mineral localities shown in Fig. 5 are of little apparent value and it is unlikely that the area will ever produce an important economic mineral deposit.

The earliest mineral claims that were pegged were for diamonds in gravel deposits near Ol Doinyo Sapuk, but so far as is known, nothing of value was found. Since 1936 most of the mineral claims pegged have been on the Kabalya hill graphite schist deposits as is shown in the following table:—

Date	Name	Minerals	Locality
1941	F. H. Jordan ..	Non-precious minerals	Yatta No. 1
1944	C. R. Stokes-Fair ..	Graphite	Kibani
1950	T. Blevins	Kyanite	Hill east of Kyevaluki
1950	T. Blevins	Non-precious minerals	Ituni Hill
1950	G. S. Katumbi ..	Graphite	Kabalya Hill
1951	G. S. Katumbi ..	Graphite	Kabalya Hill
1951	O. C. McMahon ..	Graphite	Kitui, north of Kibani
1951	O. C. McMahon ..	Graphite	Kabalya Hill

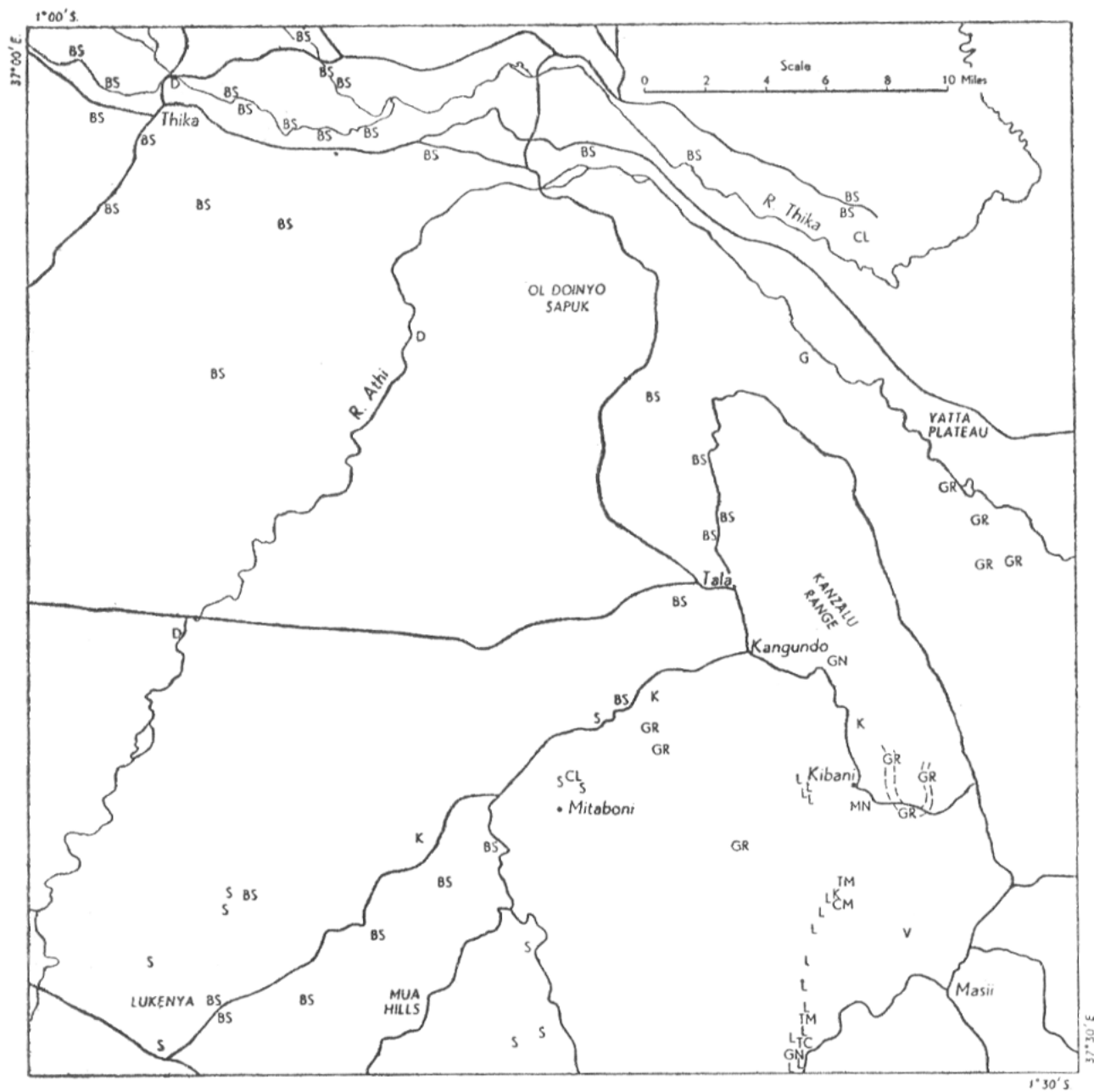
The kyanite outcrops and the Kabalya graphite deposits have been examined by Government prospectors and it seems unlikely that kyanite or graphite could be worked on an economic basis.

The only deposits of economic value in the area are the pyroclastic beds in the region of Thika which yield high-quality building-stones. Many of the more important beds, such as those near Thika itself, have been extensively quarried for a number of years. At the present day, there is a great need for the quarries to be worked on an organized basis to reduce inefficiency and wastage. In the Wakamba reserve also, much work could be done to increase the output of building-stone, so as to allow the Africans to build more permanent houses and to improve their living conditions.

2. More Important Minerals

(1) COAL

At Mitaboni, before the area was settled by the Wakamba, a sample of coal was found in a gully by a European prospector. The locality was pegged and the sample taken to England. Some years later when the prospector returned to Mitaboni he could not find his location pegs, as erosion had altered the appearance of the ground. He engaged several Africans to aid him in a search for more coal and provided them with coal specimens obtained from Nairobi. The search was continued for some time but no coal was found.



- | | |
|------------------------|---------------|
| BS Building-stone | GR Graphite |
| S Sand | K Kyanite |
| CM Corundum | L Limestone |
| CL Coal (fragments) | TC Talc |
| D Diamond (not proved) | TM Tremolite |
| GN Garnet | V Vermiculite |
| G Gold | MN Manganize |

Fig. 5.—Mineral occurrences in the North Machakos-Thika area. Localities where building-stone or sand are worked are indicated.

A Mr. Anderssen of Nairobi also found coal at Mitaboni and there seems little doubt that his specimens were of genuine coal. It is not known, however, whether these samples form part of the coal brought from Nairobi, which was probably widely scattered by the Africans, or whether they were from some other source. There still remains the problem, however, for the source of the original coal found at Mitaboni.

It is impossible that coal could occur in the gneisses and schists of the Mitaboni area, as carbonaceous material, if present, would be in the form of graphite. There is also no evidence for the presence of coal-bearing beds in strata younger than the Archaean gneisses. North of Mitaboni, however, there is a flat plain of tuff overlying Basement System rocks and it is possible that the tuffs could cover an occurrence of lignite or brown coal formed in Mesozoic or early Tertiary lake-beds. The original sample of coal found at Mitaboni could have been derived from such a source, although at the present time there is no evidence to indicate lake-beds. If lignites do occur, they can be only of small extent and the area is not worth prospecting. The possibility that the coal was carried from the railway cannot be discounted.

During the present survey no coal was found at Mitaboni but a small fragment of lignite was found in murram just below the exposure of tuff west of Mabaloni. This lignite, like the original Mitaboni coal, may have been derived from underneath the tuff as no other source is known, unless it was brought into the area from Nairobi, or from the nearest railway.

(2) GRAPHITE

Graphite schists and gneisses are fairly common in the area and include narrow bands near the Athi river east of Kanzalu and in tributaries to the Kathaana south-west of Kangundo, and a broad band south of Kanzalu, near Kibani. The most important of these occurrences is that near Kibani. In general there is little chance of any of these deposits being of economic value owing to the low content of graphite.

The Kathaana graphite was examined by W. Pulfrey (unpublished departmental report), in 1938 and it was decided that although parts of the deposit appeared to be rich in graphite, it would be uneconomical to work in view of the cost of crushing and washing.

The Kibani graphite occurs in a horse-shoe-shaped outcrop at the southern end of the Kanzalu range. Along the outcrop the graphite schists and gneisses are often banded with barren biotite gneisses and pegmatites, the whole sequence being seldom more than 300 feet thick. Exposures, apart from those in valleys are poor, but just east of Kibani the graphite schists swell to form Kabalya Hill. It is on Kabalya Hill, where the graphite schists are soft and weathered, that it has been hoped to work graphite. Claims on Kabalya hill were pegged by C. R. Stokes-Fair in 1944, G. S. Katumbi in 1950 and O. C. McMahon in 1951, but as yet no graphite has been produced.

In 1950 the graphite deposits were examined by A. L. Stewart, Government Metallurgist (unpublished departmental report) on behalf of G. S. Katumbi acting as agent for the African Mining Company and some samples were graded with the following results:—

<i>Graphite</i>				<i>% of rock</i>
+18 mesh (B.S.S.)	..	..	..	0.03
—20+25 mesh (B.S.S.)	..	..	..	0.4
—25+60 mesh (B.S.S.)	..	..	..	5.6
—60 mesh (B.S.S.)	..	..	..	3.2
Total graphite				9.23

These results, coupled with the cost of dressing the graphite ore (particularly the cost of pumping water from the Athi river) made it doubtful whether the selling price of the graphite would cover costs and it was thought unwise to continue prospecting the deposit.

In 1956 further interest in the graphite was shown by the African Mining Company and the Kibani deposits were re-examined by the Mines and Geological Department, as it had by then developed dry winnowing methods for the pre-concentration of graphite in dry areas and as there was a possibility of selling the product to another graphite producer in the Kitui district. Determinations of the graphite content of a number of samples were not, however, encouraging, the maximum obtained being 7.5 per cent, with only two out of nine samples containing crucible grade graphite. Estimates of working costs, on the expectancy of a recovery of 3 per cent, gave a possible profit of three shillings per ton, which showed that workings would have to be highly organized, no complicated machinery could be bought during initial working, and that a deciding factor would be labour. Further determinations of recoverable graphite gave only 1.28 per cent and, because of this, the African Mining Company was advised not to spend money on the project unless richer ore was discovered or higher prices were offered for graphite.

(3) LIMESTONE

Limestone is present in the area as marble in the Basement System and as a product of weathering of the Kapiti Phonolite.

The main marble band in the area follows the course of the Thwake river as far north as Kyevaluki hill. Other marble outcrops occur south of Kangundo hill. These marbles are at a maximum only 50 feet thick, are usually steeply dipping and always associated with calc-magnesium-silicate minerals. Magnesia determinations on two marble samples gave the following results:—

<i>Specimen No.</i>	<i>% of MgO</i>
52/476	18.93
52/536	20.54
52/476 One and a half miles east-south-east of Kyevaluki hill.	
52/536 Three miles north of Kyevaluki hill.	

Analyst: Mrs. R. A. Inamder.

The high magnesium content of the marbles and the difficulty of working such thin steeply dipping beds would prevent them being considered for use in the manufacture of Portland cement.

Calcrete, an impure superficial limestone in the form of small white nodules, is derived as a weathering product from the Kapiti Phonolite and occurs on the plains. The visible thickness of the nodular deposit at the surface is never great, but south of Koma Rock, a pit sunk to the Kapiti Phonolite through overlying sediments and pyroclastics proved a 6 foot band of compact, white limestone containing small fragments of phonolite.

Calcrete is used as a secondary source of limestone in the cement factory at Athi River.

(4) DIAMONDS AND OTHER PRECIOUS STONES

Diamonds and other precious stones have been reported from three localities in the area but, in all cases, diamonds were not proved and in only one locality were gemstones identified.

The earliest report of precious stones was in 1920 in connexion with alleged deposits on the east bank of the Athi river, west of Ol Doinyo Sapuk, near the junction with the Ndarugu river. In that year, about 71 claims were pegged for precious stones in the names of seventeen prospectors. Despite the activity no precious stones appear to have been found in this region.

A. N. Smit, in 1938, prospected for diamonds in gravel deposits on his farm near the banks of the Athi river about 15 miles south-south-west of Juja. The workings yielded clear and coloured quartz, felspar, agate, chalcedony and fragments of Tertiary lavas, but no diamonds.

The most interesting diamond locality is that near the confluence of the Chania and Thika rivers just east of the Blue Posts Hotel at Thika, where diamonds are stated to have been found some 30 years ago in a boulder bed interstratified with the volcanic tuffs and agglomerates. Examination of the deposit in 1937 and again in 1951-52 did not reveal any diamonds but small gemstones including rubies, blue sapphires, white sapphires and chrysoberyls were found, which were, however, of no commercial value.

The Thika gemstones must have originated from outcrops of Basement System rocks to the west of Thika, which are now covered by volcanic rocks younger than the Thika boulder bed. Gemstones could also be present in the Athi river alluvial deposits and the coarse sedimentary conglomerates at Juja, but is unlikely, as all these deposits seem to have been derived from volcanic rocks and not Basement System rocks.

(5) KYANITE

Kyanite was recorded at only four localities, three of which are extremely small exposures. The fourth occurrence, a muscovite-kyanite schist, beneath the main marble band east of Kyevaluki is much bigger, but not extensive enough to prove of any economic importance. The kyanite horizon seems to be limited to the small hill between Kyevaluki and Kenyungo and was not found beneath the marble further south. Where exposed, the kyanite is seen to be evenly distributed throughout the rock with no segregations, iron-stained, and of poor quality.

3. Other Minerals

(1) GOLD

Prospectors have detected gold east of Ol Doinyo Sapuk in the Athi and Kalala rivers by panning. Claims for gold have also been pegged in the region of Ol Doinyo Sapuk but no gold is known to have been found. The idea that gold is present on Ol Doinyo Sapuk may be due to the presence of pyrite as an accessory mineral in the rock forming the hill.

(2) CORUNDUM

Corundum is known to occur in association with the tremolitic amphibolite overlying the marble in the same locality as the principal kyanite schist horizon. The corundum is not abundant being found mainly as crystals on the surface near the marble-amphibolite contact. A conspicuous green quartzite with corundum and hornblende has been reported from the vicinity of Ol Doinyo Sapuk by prospectors, but an exposure was not seen during the present survey.

(3) VERMICULITE

Vermiculite is probably not an uncommon mineral in the more highly weathered gneisses, but was only recognized in quantity in a small epidote-rich band bordering the muscovite gneiss south-west of Mathe Hill. The vermiculite occurs as small flakes, almost certainly derived by the weathering of original biotite. The poor quality of the vermiculite and the limited extent of the occurrence prevent the deposit being of any economic value.

(4) TALC

Talc is developed as one of the magnesium minerals bordering the main marble horizon in the Thwake valley. It is usually present in only small amounts and is closely associated with the more abundant tremolite.

(5) TREMOLITE

Rocks rich in tremolite are fairly abundant, forming zones of variable thickness on the surfaces of most of the marbles in the area. In some places the marble has been completely altered to a calcareous tremolite rock. The tremolite usually occurs as slender needle-like crystals, but no asbestiform varieties were recorded. Anthophyllite has also been found associated with the tremolite east of Kyevaluki, but is of no economic value.

(6) KAOLIN

Only one occurrence of kaolin is known in the area, a kaolinized pegmatite, about 2 to 3 feet thick, near the western margin of the Kibani graphite schist where it crosses the Mwala river. The kaolin probably owes its origin to hydrothermal action.

(7) GARNETS

Garnets are common in the area as euhedral crystals in the mica schists and occasionally as segregations in more gneissose rocks. The deposits most likely to be workable for garnet for abrasive purposes are the garnet segregations, as the schists, although often containing an abundance of garnet crystals, could never be worked profitably owing to the thinness of the garnet-rich horizons and the often considerable development of quartz.

A segregation of massive garnet was examined some years ago by an official geologist in granite gneiss near Kangundo at the head of one of the branches of the River Miu, and it was thought that the garnet when crushed and freed from quartz could be sold as an abrasive. Smaller garnet segregations of no economic value are also present elsewhere in the region.

(8) MANGANESE

Manganese oxides, forming a gossan in garnet granulites at the head of the Mwala river, were investigated by a Government Senior Geologist in 1942. The deposit was found to contain 19 per cent of MnO_2 but the occurrence was regarded as being too limited in extent to be of economic value.

4. Building-stones

All the building-stone in the area is derived from horizontally-bedded pyroclastic beds in the volcanic series. The hard fine-grained Thika building-stones and the trachytic tuffs provide the best building stones but, for limited purposes where a high quality stone is not required, coarse agglomerates have been used. In the north-west quarter of the area there are three major beds of building-stone:—

- (c) Trachytic tuffs
- (b) Upper Thika building-stone or agglomeratic tuff
- (a) Lower Thika building-stone.

The building-stones are the most important near Thika, while the trachyte tuffs are of value near Tala and Matungulu. More localized tuffs have also been quarried for building-stone on the flanks of the Mua hills and near Lukenya.

(1) LOWER THIKA BUILDING-STONE

The lower Thika building-stone is a hard fine-grained blue massive tuff breaking with conchoidal fracture, fairly easily worked and providing a high quality building-stone. It is exposed in most of the valleys east and south of Thika, particularly the Thika valley, but also in the Kabuku, Samuru, Ngenia, Komo and Ndarugu valleys (*see* Fig. 6). At its maximum the bed is about 30 feet thick. It has been worked for building-stone in the Thika valley from the Falls to the junction with the Kabuku, and in the Kabuku valley, the Komo valley (where it overlies the Simbara basalts) and the Ndarugu valley near the Thika-Nairobi road. The most extensive workings are in the Thika valley where the stone has been cut for a number of years and the total length of the outcrop has been quarried.

The volume of available stone in the Thika valley has never been great, owing to the thinness of the stone band and the steepness of the valley sides, which results in overburden increasing rapidly as the band is worked back. Quarrying of the stone has also been wasteful and inefficient, largely due to a desire to extract the stone cheaply and quickly with a minimum of supervision. In most places long quarry faces working the full thickness of the stone bed have not been achieved and generally the stone is quarried from the top of the outcrop with quarry waste obscuring the lower workable stone. Some of the quarries have had to close owing to excessive accumulation of rock waste. At the present time, stone is still being worked and reopening of old quarries could take place provided the price for high quality building-stone was attractive enough, and there was a desire for efficient working.

The Thika building-stone is also still being worked in the Ndurugu valley but reserves are not great owing to steep valley sides and the limited extent of the outcrop. Rock waste from the quarries is fairly abundant and to allow for adequate quarrying should be removed. It is possible that the waste could be used in and around Thika for road making.

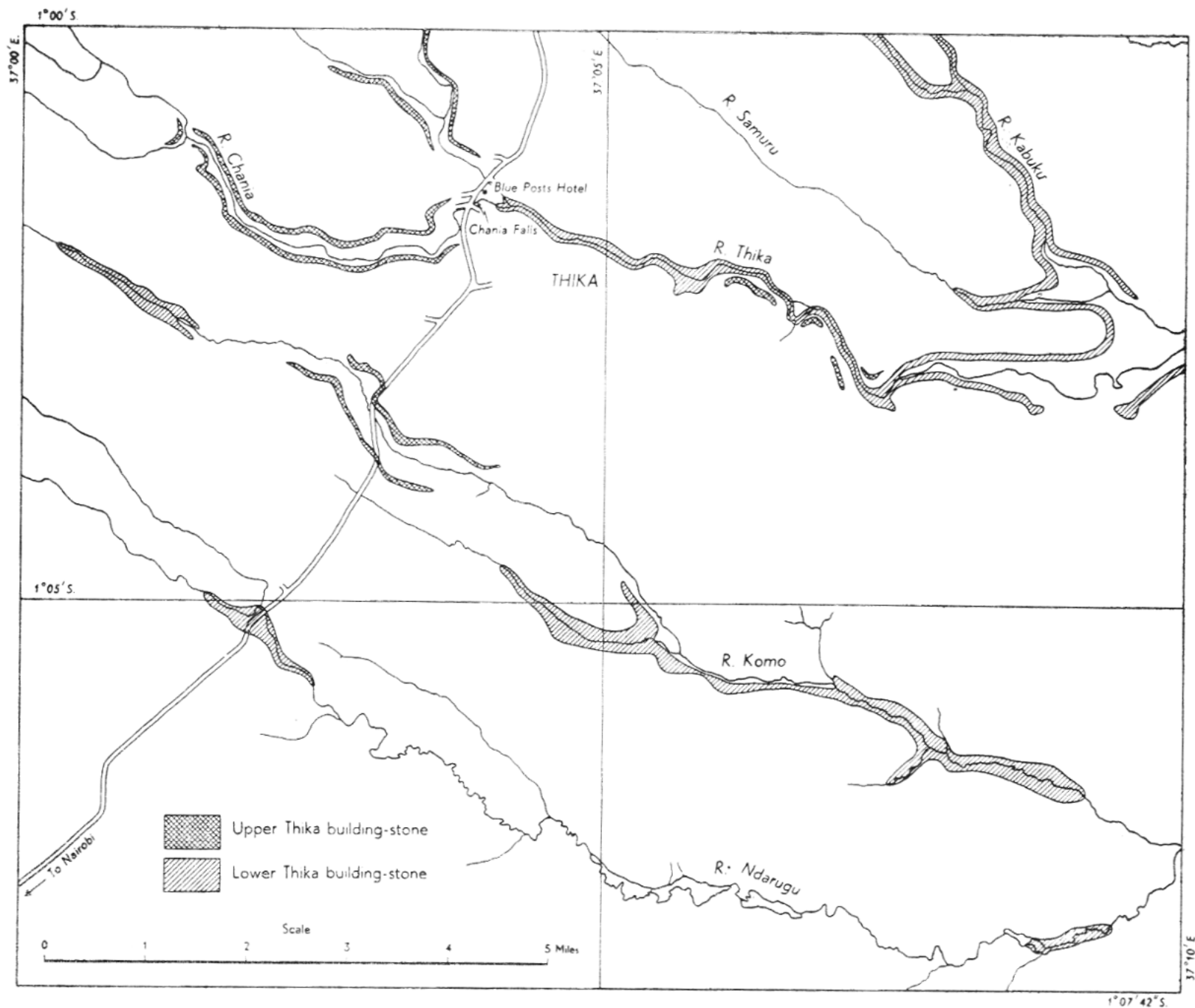


Fig. 6.—Sketch map showing extent of the building-stones in the Thika region.

(2) UPPER THIKA BUILDING-STONE AND AGGLOMERATIC TUFF

The upper Thika building-stone is very similar in appearance to the lower bed although rather bluer and more fine-grained. It is however much less continuous and widespread (Fig. 6) and tends to be more closely jointed. It is probably suitable for small-sized high-quality building-stone. When the upper Thika building-stone is absent, its place is taken either by a hard tuff with crystals, of no value as a building-stone, or a soft agglomeratic tuff which has a limited value in providing low-grade building-stone.

The upper Thika building-stone is exposed as isolated lenses in the Thika valley east of Thika, and as a thin continuous bed west of Thika in the Thika and Chania valleys. Further outcrops occur in the Komo valley near the Thika-Nairobi road. In all these localities quarrying has taken place on a limited scale. Reserves of stone at this horizon are small, largely owing to the discontinuous nature of the outcrop and the presence of steep-sided valleys. The best sites for quarrying are in the Thika valley east of Thika and in the Komo valley. West of Thika where the band is fairly continuous the valleys are gorge-like and only very small quarries could be attempted.

Along much of the Thika valley the upper Thika building-stone is absent and its place is taken by a hard tuff, which forms the lips of the Thika and Chania Falls. The hard tuff is of no value as a building-stone, but in places such as north-west of Ol Doinyo Sapuk it passes into an agglomeratic tuff which can be used as a building stone.

(3) TRACHYTIC TUFFS

The tuffs are the youngest pyroclastic member in the area and form the plains south of Thika, covering an extensive area. They are probably also represented by the tuffs flanking the Kanzalu range in the region of Tala and Matungulu, by the tuffs west of Kangundo hill and by a tuff band on the flanks of the Mua hills. At all these places the tuff has been quarried to a varying degree.

At Thika and over much of the area to the south, the tuffs have only rarely been extracted for building-stone, as they are inferior to the high quality Thika building-stones. The main difficulty in using these tuffs as building-stone is the presence in them of pumice which when abundant, makes uniform cutting difficult, blocks with uneven edges and sides being usually obtained. That the stone can be used, however, has been proved in several places, particularly where it has been obtained from small privately owned quarries. Reserves of stone at this horizon are considerable.

To the west of Kanzalu in the Tala-Kangundo region the tuff forms a fairly thick band overlying the Basement System gneisses, but here it contains much less pumice. The abundance of cheap building-stone hereabouts is indicated by the stone buildings at Tala, which contrast with the more usual burnt-earth brick buildings of the area. Numerous small quarries have been opened and quarrying, as in the region of Thika, is very inefficient, and is particularly noticeable at the quarries near Tala, which consist of small holes in the ground abandoned as soon as they become blocked with rock waste. Reserves of building-stone in this part of the area are notable and there could be considerable expansion in quarrying to provide building-stone for African housing.

The extent of building-stone on the flanks of the Mua hills is not great and it is mainly worked in the valleys, where the tuff band is broader and thicker.

(4) LUKENYA REGION

Tuff beds suitable for building-stone are present east of Lukenya, although a well-defined building-stone bed is not present. Quarries have been opened wherever the rock is suitable.

5. Bricks

In the Masii and Mwala locations in the south-eastern part of the area where building-stone is not available soil is moulded into blocks and fired in earth-covered stacks to produce bricks. The general quality of the bricks is poor, owing to the low temperatures of the kilns and to the abundance of quartz sand in the raw material. Often a brick made from such materials and baked in the sun is less fragile than one fired in a kiln.

Where the soil is more clayey and contains less sand good bricks have been obtained, and it is suggested that suitable areas of good brick-earths should be reserved for the sole purpose of making bricks.

6. Building Sand

There are two main sources of sand in the area; the sand outwash round the edges of hills and the sand accumulations in sand-rivers. Sand outwash is most abundant near the Lukenya hills, particularly to the south and east, where thick deposits have been formed and must be of some economic value due to the nearness of Nairobi. North of Machakos, sand derived from the Mua hills and Mitaboni hills is also worked in several small streams. Sand-rivers are fairly abundant and sand is worked in many of them, particularly tributaries of the Kithima near Mitaboni and the Kathaana south-west of Kangundo.

7. Road-metal

The majority of roads in the area apart from the tarmac roads have unmetalled surfaces which are graded at suitable intervals. Where prepared surfaces are made, such as on the Tala-Koma Rock-Nairobi road, murram for the purpose is usually worked in nearby pits. The coarse lateritic deposits resting on the phonolite have proved valuable for this purpose at the eastern end of the Koma Rock road and have provided material superior to that worked on the pyroclastics further west. Good murram has also been worked on the Thika-Garissa road. If road development takes place in the area to the extent of providing tarmac roads, suitable road metal can be obtained from the lava horizons, particularly from the Kapiti Phonolite which is extensive. As already suggested, quarry waste near Thika could be used for making road foundations.

8. Water-supply

Surface water-supply in the area is strictly related to the geology and rivers in the eastern part of the area that do not receive a supply of water from the volcanic areas soon dry up after the completion of the rains. The only permanent rivers are the Thika, Nairobi and Athi, although the small Komo and Ndurugu rivers may also be permanent or nearly permanent. Rivers deriving their supply of water from Basement System rocks show intermittent flow, periods of flood being separated by periods of dryness. It is noticeable that rivers such as the Kalala, south-south-east of Ol Doinyo Sapuk, which have a few small tributaries from the edge of the volcanic area, flow for a longer period after the rains than rivers which do not have tributaries on the volcanics.

Most of the land in the Wakamba reserve is on Basement System rocks, so that for much of the year when the rivers are dry there is an acute shortage of water and water-supply, as in much of the drier parts of Kenya, constitutes a major problem. The only effective solution to the water problem is the construction of dams, capable of holding enough water to supply the local population during the dry periods. The dams at Masii and in Matungulu location east of Koma Rock are of this type and more like them should be built wherever possible.

Numerous bore-holes have been sunk in the area, particularly through the volcanic rocks on European farmland. In general, it may be said that bore-holes sited on the volcanic areas are more successful than those sited in Basement System rocks. The nature and locality of the bore-holes in the western half of the area are fully dealt with by Gevaerts in a Ministry of Works report and only the bore-holes in the eastern half of the area are listed below, although the positions of all bore-holes in the area are indicated on the map.

RECORD OF BORE-HOLES

Supplied by the Hydraulic Branch, Ministry of Works

No.	Location	Bed-rock	Depth	Struck water	Rest-level	Yield
			<i>Feet</i>	<i>Feet</i>	<i>Feet</i>	<i>Gal. per hour</i>
C1769	Ol Doinyo Sapuk	Phonolite ..	178	100 158	100 155	100 600
93	Kakuzi ..	Gneiss ..	87	—	—	167
106	Kakuzi ..	Gneiss ..	58½	—	—	Dry
C401	Kangundo ..	Surface deposits ..	0- 30			
		Tuff ..	30- 57			
		Gneiss ..	57-111	95	0	3,750
C2132	Kianzabe ..	Phonolite ..	344	226	98	280
C2266	Masii ..	Gneiss ..	357	90	33	
				295		1,250
C2407	Mbiuni ..	Gneiss ..	340	95	67	80
				290		180
C1864	Muisuni ..	Tuff ..	320	180	85	840
C1949	Muisuni ..	Murram ..	0- 37	90-100	67	75
		Lava ..	37- 73	250	72	120
		Gneiss ..	73-390	380	153	900
128	Ndalani ..	Gneiss ..	73	52- 60	42	200
C2167	Ndalani ..	Lava ..	92	—	—	Dry
C2168	Ndalani ..	Lava ..	287	—	—	Dry
C2169	Ndalani ..	Lava ..	125	120	78	150
C2406	Siathani ..	Gneiss ..	304	90	61	50
				295		1,000
C436	Tala ..	Tuff ..	0- 53			
		Schists ..	53-400	75	22	2,310
C1133	Yatta Ranch ..	Phonolite ..	500	394	74	3,200
C1493	Yatta Ranch ..	Phonolite ..	0-150	100	80	1,000
		Gneiss ..	150-210			

In the volcanic areas, particularly around Thika, where the volcanic rocks rest on an old bevelled land surface, an aquifer is probably provided by the weathered gneiss of that surface. Gevaerts, however, has demonstrated that there is a series of buried ridges and valleys on the sub-volcanic floor in this part of the area, and it is usually found that when a bore-hole passes through the volcanic rocks into a buried valley, the yield of water is greater than that of a bore-hole sunk onto a ridge. The shortage of water near Basement System ridges is also illustrated by bore-holes sunk too near Kongoni hill. There is also a water-table where the surface of the Kapiti Phonolite is impervious and drilling started at a higher level in the volcanic sequence could be stopped at this level, if the water yield was adequate.

Bore-holes in the Basement System rocks have not been very successful owing to the abundance of impervious granitoid gneisses and massive biotite gneisses in the area. Two bore-holes put down at the edge of the Mabaloni granite were dry and a third yielded only 150 gallons per hour. As can be seen from the table given above, the highest water yields from bore-holes sunk into the Basement System rocks were obtained at localities where the old rocks have a capping of tuff. Bore-holes in the Basement System terrain will probably be more successful if drilled in low-lying schistose areas or in areas where there is a capping of tuff or agglomerate, and not on the granitoid gneisses.

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