REPORT No. 25

COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE SOUTH-EAST MACHAKOS AREA

DEGREE SHEET 52, S.E. QUADRANT
(with coloured map)

by

R. G. DODSON, M.Sc.
Geologist

1953

PRINTED BY THE GOVERNMENT PRINTER, NAIROBI

Price: *Sh.* 6/50

CONTENTS

		PAGE
I.	Introduction ..	1
II.	Previous Geological Work ..	1
III.	Physical Features ..	2
IV.	Summary of Geology and Geological History of the Area ..	5
V.	Details of Geology ..	7
	1. Basement System ..	7
	(1) Meta-sediments ..	8
	(2) Migmatites ..	9
	(3) Intrusives ..	13
	(4) Mineral belts ..	14
	(5) Metamorphism ..	15
	(6) Structures ..	16
	2. Tertiary—Yatta Plateau phonolite ..	17
	3. Pleistocene deposits ..	17
	(1) Sediments ..	17
	(2) Lavas ..	18
	4. Superficial deposits ..	18
VI.	Economic Geology ..	19
	1. Minerals ..	19
	2. Water ..	19
VII.	References ..	20

LIST OF ILLUSTRATIONS

Fig. 1. Erosion surfaces .. 3

Fig. 2. Structures and mineral belts .. 15

MAP

Geological map of the south-east Machakos area: scale 1:125,000 .. .. .. at end

Foreword

The report on the south-east part of the Machakos area is the fifth report published since the Geological Survey of Kenya was expanded with the assistance of the Colonial Development and Welfare Vote. The southern part of Machakos area proper, to the west, has also been mapped and a report will be published in the near future, while a report on the mapping of the Kanziko area, on the east, is in preparation.

Unfortunately, the reconnaissance search of the south-eastern Machakos area has not revealed the presence of numerous small mineral deposits such as are known in the country south of Machakos town. It appears unlikely that the area will prove to have any economic importance in the future, so far as mineral deposits are concerned. It is, however, the site of the Makueni land settlement scheme and, as such, is an area of the greatest importance in the Colony.

The area is traversed by the well-known phonolite-covered Yatta plateau. The lava has always been regarded as the remains of an extensive flow that found its way down a valley in middle Tertiary times, but Mr. Dodson has discovered evidence that suggests a different origin. He believes that the lava overlies a zone of faulting of Tertiary age, and that it is unlikely that at any part of the plateau it flowed for more than a short distance. He also considers that flows moulded by valleys are rare.

Nairobi,
2nd September, 1952.

WILLIAM PULFREY,
Chief Geologist.

ABSTRACT

The area described is bounded by latitudes 1° 30′ S. and 2° 00′ S., and by longitudes 37° 30′ E. and 38° 00′ E. Apart from the rugged ground along the western boundary, the area consists of flat, low-lying country. Remnants of two former plains represented by summit levels of hills are recognizable and a Pleistocene to Recent plain appears to be still in a stage of development. A short account is given of the physiography of the Yatta plateau and a tentative hypothesis of its origin, different from the classical theory, is offered.

The rocks described comprise: (1) Gneisses and schists of the Basement System, with abundant pegmatite and quartz veins, (2) Ancient basic intrusives including amphibolites and a pyroxenite, (3) Tertiary phonolite of the Yatta plateau, (4) River conglomerates, soils, gravels, etc., (5) Pleistocene olivine-basalt.

GEOLOGY OF THE SOUTH-EAST MACHAKOS AREA

I—INTRODUCTION

The area described in this report is the south-east quadrant of degree sheet 52 (Kenya), bounded by meridians 37° 30′ E. and 38° 00′ E. and by parallels 1° 30′ S. and 2° 00′ S., of which the extent is approximately 1,250 square miles. The whole of the area is native reserve, the portion east of the Athi River being part of the Kitui district, and that west of the river part of the Machakos district. Where inhabited the area is occupied by Africans of the Ukamba tribe. Cultivation of crops and stock-keeping are practised in the northern, western and, to a lesser extent, in the eastern sections. Due to the erratic rainfall, general poverty of the soil, and the primitive agricultural methods used, crop yields are low. Recently attention has been focused on the south-eastern portion where, under the control of the African Land Settlement Board, the Makueni settlement scheme is being developed. The object of the scheme is to resettle members of the Ukamba tribe, hitherto living in the congested localities in the western part of the area. Bush-clearing and cultivation schemes have been put into practice under the supervision of European officers to prevent the deterioration of soil as had happened in neighbouring cultivated areas. It appears that the energetic efforts of those responsible will make possible an increasing amount of settlement in areas uninhabited till now.

The area was geologically surveyed between March and September, 1950, with the object of preparing a reconnaissance map and in an attempt to discover mineral deposits, or geological conditions favourable to mineral occurrences. Unfortunately, the work that it was possible to carry out in the time available did not reveal any deposits of economic value.

Mapping was carried out on tracings of aerial photographs and on field sheets (scale approximately 1/64,000) based on the 1/250,000 military map Machakos E.A.F. No. 1637 (1945). Later the information obtained was replotted on the four 1/50,000 preliminary plots of sheet SA37/H-IV. With a single exception, namely in the case of the Yatta phonolite, the accurate demarcation of junctions and contacts proved impossible. The reason for this is due firstly to an insufficient number of exposures, and secondly because of the gradation of the various rock types of the Basement System of which the area is largely composed.

Acknowledgments: The writer wishes to express his thanks to the officers of the Makueni settlement scheme for whose kindness and assistance he is greatly indebted, and to the District Commissioner of Kitui for help and hospitality.

II—PREVIOUS GEOLOGICAL WORK

Little geological work has been carried out in the area previous to the present survey. J. W. Gregory (1921, p. 186)* gave an account of the Yatta Plateau ascribing its origin to a volcanic flow which followed the course of a valley, concluding, "It is therefore clear that either the existing band of lava is the remnant of a wider sheet or it must have been confined like a stream between the banks of a valley".

An official reconnaissance of the Makueni district was carried out in 1938 by C. S. Hitchen, primarily to investigate the possibility of underground water supplies. A tentative, idealized section was included in his unpublished report, representing the geology of the area between the 37° meridian and the Yatta Plateau. He considered the crystalline schists and gneisses of what he called the "Machakos Metamorphic Complex" (forming the hills on the west of the area) to be of sedimentary origin. In support of this assumption he described the local existence of crystalline limestones and graphitic schists, suggesting the latter are metamorphosed carbonaceous or oil shales. The abrupt change of topography east of the Nzaui range he ascribed to a corresponding change in

* References are quoted on p. 20.

the geology. He concluded that the Makueni area is occupied by an ancient granite mass which contains occasional "rafts" or "roof pendants" of highly metamorphosed and recrystallized sediments, generally similar to these of the Machakos hills. The granite was described as a biotite-microline type, displaying a faintly gneissose structure.

In 1945 W. H. Reeve, while engineer-geologist in the Public Works Department, carried out a hydro-geological survey of the proposed Makueni settlement area. He remarked on the abrupt change of topography in the vicinity of the western boundary: "The most noticeable feature of the topography of this region is the abrupt change which occurs east of a line connecting roughly, Nzueni, Unoa, Nthangu and Ikua". Concerning the local geological structure Reeve agreed with the outlines previously suggested by Hitchen.

The only published work on the geology of neighbouring areas is by J. J. Schoeman (1948), who described the quarter-degree area immediately to the north of the present one. Comparison of the present map with Schoeman's reveals certain differences in the identification and classification of some types of rock. The chief difference is one of opinion on the origin of some of the more leucocratic bands of gneiss, Schoeman regarding them as of magmatic intrusive origin while the writer is of opinion that they represent an advanced stage in the metasomatic alteration of sedimentary rocks *in situ*. Other differences between the two maps are in terminology only. The differences in the symbols used is due to recent standardization of symbols used in East African official geological publications.

The following correlation table may be found useful:—

Area west of Kitui Township J. J. Schoeman		Area south-east of Machakos R. G. Dodson	
Sg	Pelitic and semi-pelitic schists and gneisses with granite injections.	Xs′	Biotite gneisses liable to local variation in mineral composition and banded gneisses.
Sp	Pelitic and semi-pelitic schists and gneisses without granite injections.		
g^{o}	Granite ortho-gneiss as closely-spaced sheets.	Xs″	Compact, resistant bands of biotite gneiss.
		Xna	Granitoid augen gneiss.
Hs	Hornblende-schist.	Xh	Amphibolite.
g^{c}	Semi-calcareous gneiss.	Xsd	Hornblende- and diopside-rich gneiss.
Phk	Phonolite.	Tvp	Phonolite.

III—PHYSICAL FEATURES

Three erosion surfaces can be distinguished in the area, two being represented by remnants only (Fig. 1). There is no fossil evidence of the ages of the surfaces, but because of their elevations and conditions they are considered to represent the end-Tertiary, sub-Miocene and sub-Cretaceous peneplains recognized by Shackleton (1946, p. 3) and Dixey (1948, figs. 2 and 3) in Northern Kenya, and later by Schoeman (1948, p. 3) immediately to the north of the present area.

The most youthful surface, a broad, relatively flat plain lying south-east of the Machakos hills and extending to the Athi River, occurs at an altitude of between 3,000 and 3,300 feet and appears to be still developing. It is apparently extending by a process of lateral development, away from the principal drainage channels, suggesting that it is forming by pediplanation (King, 1951, p. 47). Along the course of the Keite and Athi rivers still younger plains have developed, though in all instances they are confined to small stretches of the valleys.

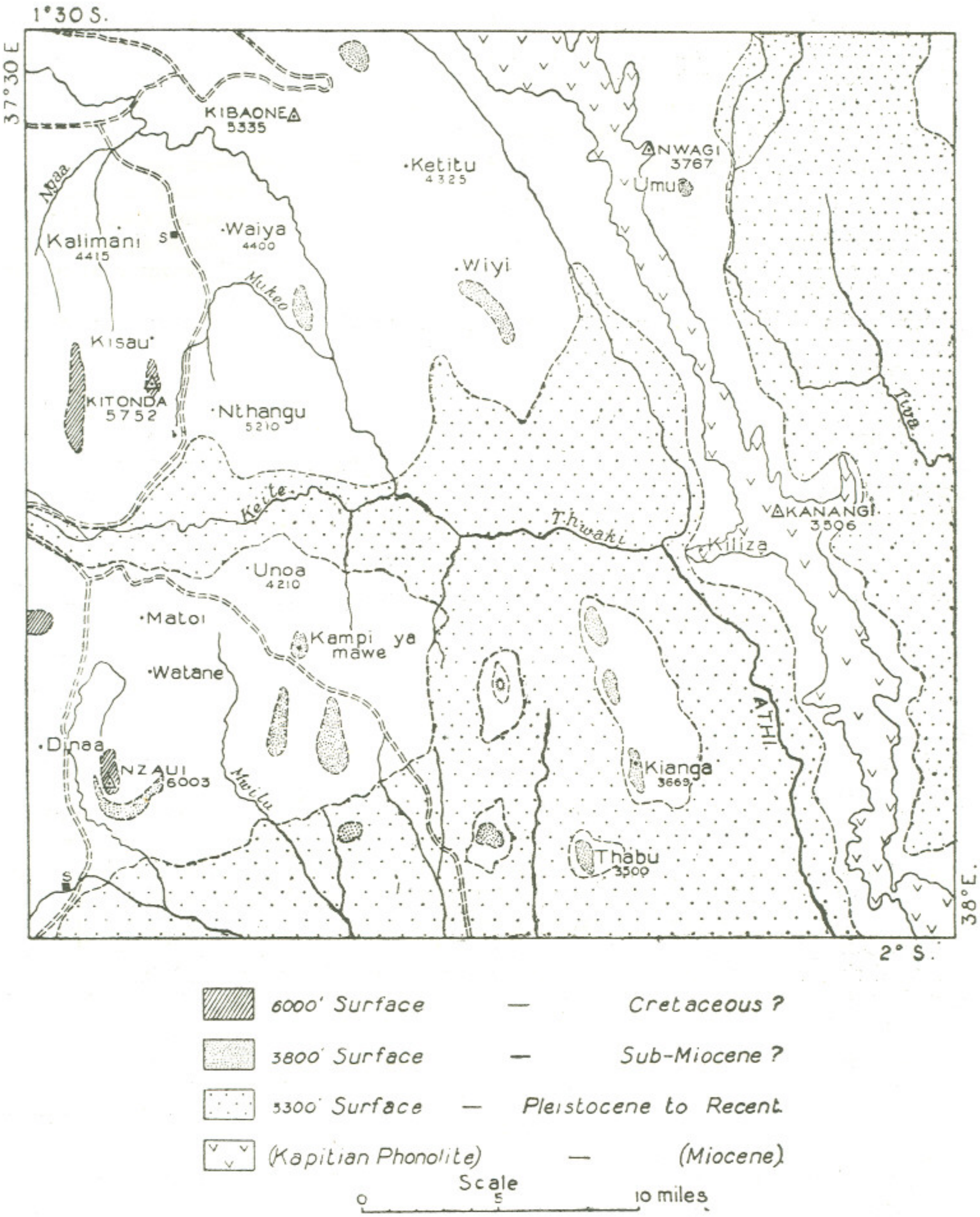

FIG. 1.—Erosion surfaces in the south-east Machakos area.

The monotony of the "3,000-foot" bush-covered plain is broken only by the inselberg remnants of an older plain, now represented by the tops of hills such as Makueni, Katambua, Kianga, Thabu, Poi, Mandoi and Mubau. The form of these hills varies, though generally they are narrow rounded stumps and occasionally flat-topped. The uniformity of their heights indicate that they are relics of an older plain surface, now almost completely destroyed by erosion. This is further substantiated by corresponding platforms on most of the larger hills in the western part of the area. A fine example of such a remnant occurs on Nzaui where, approximately half-way up the eastern flank, a well-defined shelf occurs. The surface is also preserved beneath the phonolite lava-flow that forms the Yatta plateau.

Finally, higher flat-topped hills near the western boundary of the area correspond in height, and are the remnants of the oldest recognizable peneplain in the area. There are only four of them within the limits of the area (Ikua, Ikangabi, Kitondo and Nzaui), though a large number of hills further west possess corresponding summit levels, and are the remains of the same erosion surface.

As would be expected, rock types have to a great extent influenced the topography. North of the Keite River for example, where there are more resistant gneisses, the surface is far more irregular than usual. The abrupt change in topography along a north-south line parallel to the western boundary may be attributed firstly to the abundance of resistant granitoid gneiss masses which form the hill ranges west of the topographical break, and secondly, to the situation of the main channel of the drainage system in the south-eastern corner of the area. Because of the distance from the principal river, the hill ranges in the west are as yet unaffected by the formation of the most youthful erosion surface.

The topography is well dissected by a mature drainage system of which the Athi is the principal river and alone has a perennial flow. The Tiva, Keite-Thwaki and Kikiune rivers seldom flow for more than a few months in the year. Indications are, however, that in the geological past conditions were far wetter and the rivers bigger and more persistent.

The drainage pattern appears to have undergone striking changes. Gregory (1921, p. 188) noted the possibility of the existence of west to east flow of rivers before the emplacement of the Yatta Plateau, considering that "some of the west-east tributaries of the Athi may follow the courses of rivers that flowed eastward across the site of the Yatta into the deserts north of the Sabaki. Thus the Keite-Twaki may be the original head-streams of the Thowa". The outline of the Yatta Plateau lends strength to this suggestion for, on the east bank of the Athi opposite of the Thwaki-Athi confluence, a spur of phonolite projects westwards at Kiliza. Unfortunately the basal contact is obscured by dense vegetation and transported material so that the search for fluviatile deposits under the phonolite is difficult. However, it is possible to establish that the phonolite in this locality is about twice as thick as it is immediately to the north and south. Furthermore on the eastern side of the plateau a corresponding spur occurs, curving round from an easterly direction to an approximately northern direction, i.e. towards the direction of the Tiva River. It seems probable, as Gregory suggested, that the Keite-Twaki originally continued on a west-east course, perhaps to join the Tana River, and it is likely that it was at that time the principal river in the area. In support of this possibility is the fact that while the present-day flow of the Keite-Thwaki is far less than that of the Athi, its wide meanders and large alluvial deposits indicate a more mature river course.

Following the emplacement of the Yatta Plateau phonolite, the drainage system underwent profound modification. It is suggested that the Keite-Thwaki, obstructed by the phonolite, was diverted southwards, following what must originally have been a narrow valley running in the direction of the Kiboko.

Extending from the northern boundary to the south-eastern corner of the area, the Yatta Plateau contrasts sharply with the surrounding plains. It extends for many miles both to the north and south of the area, forming a prominent land-mark for a distance of approximately 170 miles, from Ol Doinyo Sabuk in the Thika area to the Galana valley east of Tsavo. The plateau has a south-easterly slope of twenty-six feet to the mile between the northern boundary of the area and Nzekakia, after which it falls at approximately twelve feet to the mile (Gregory, 1921, p. 187). In contrast with its even upper surface, the margins of the plateau are highly irregular and furrowed by deeply incised valleys. Its width ranges from approximately 5 miles to about 400 yards. Ignoring local exceptions the estimated thickness of the lava capping is about 35 feet.

Owing to its elongated, gently sloping form, Gregory (1921, p. 186) ascribed the formation of the plateau to a lava-flow which had followed the course of a valley. He suggested that the lava had protected the underlying gneiss from the erosion that had lowered the contiguous rocks to the present surface. In summing up the case for a valley lava-flow he stated, "The local irregularities in gradient are, however, insignificant compared to the persistence of its downward slope for its length of 180 miles. This fact combined with its narrowness indicates that the lava of the Yatta Plateau flowed down a river valley". This hypothesis was later supported by J. J. Schoeman (1946, p. 6). It fails, however, to satisfy several requirements. It seems highly improbable that a single lava-flow could continue to flow for a distance of about 170 miles. Moreover, the thickness of the flow seldom exceeds 50 feet and the possibility of a lava-flow of that dimension continuing for such a distance seems yet more unlikely. In addition the internal properties of the phonolite must be considered. To enable the growth of phenocrysts, frequently up to a size of two inches such as occur in the Yatta phonolite, the parent magma must have undergone slow cooling in a reservoir before emplacement. The partly cooled lava supporting numerous phenocrysts, may, in the writer's opinion, have been fairly viscous. Examination of the phonolite in thin section reveals a fine-grained groundmass, indicating rapid cooling of the lava subsequent to extrusion, again suggesting that it could not have flowed far. In the event of a lava-flow following the course of a valley the lava would invade the tributary valleys for a short distance. A spur of phonolite does correspond approximately with the Keite-Thwaki valley, but at no other lateral valley is there evidence of a branch of the flow. Although basal contacts of the lava were examined at twenty-nine localities no underlying valley deposits were found, the sub-phonolite floor being invariably biotite gneiss.

Since it appears improbable that the Yatta lava flowed down a valley an alternative explanation of the mode of emplacement is required. At several localities adjacent to the outcrop of the phonolite the underlying gneisses were found to be brecciated along lines parallel with their strike, which is also parallel to the elongation of the phonolite. At some localities as many as five lines of brecciation were found within half a mile of the plateau edge. None of these planes of dislocation contains phonolite but it is suggested that they represent the marginal parts of a shatter-belt along the axis of which phonolite was extruded through a series of feeding fissures concealed beneath lateral flows. It is considered that surface flow did not extend for a distance greater than 500 yards in the area concerned, the flow being principally in a south-south-easterly direction. Factors difficult to account for in the hypothesis of a valley lava-flow, as detailed above, are adequately accounted for by the hypothesis of an extrusion from a fault-line fissure. If the suggested original drainage pattern (p. 4) is accepted, the presence of the long, narrow, phonolite outcrop can only be explained by a fault-line fissure erruption. The line of emplacement of the phonolite would then correspond with the strike of the country-rock, but lie contrary to the trend of the drainage. Perhaps the only example of a valley flow is at the spurs of phonolite which correspond with the suggested original course of the Keite-Thwaki river.

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL HISTORY OF THE AREA

The area is mainly occupied by rocks of the Basement System, though lavas and sediments of much younger age are also present. The approximate ages of the various groups are as follows:—

4. Recent—Soils, gravels alluvial deposits etc.
3. Pleistocene—Basalt.
2. Miocene (?)—Kapitian phonolite.
1. Archaean—Basement System.

Basement System.—The predominant rock of the Basement System is a microcline-rich biotite gneiss of which the mineral composition remains constant over a wide area. Textural differences attributed to a greater or lesser degree of mobilization account for a series of rock types of similar mineral composition ranging from banded gneisses to homogeneous granite. East of the Yatta Plateau a broad band of gneiss with a notable content of lime-bearing minerals crosses the area. Muscovite-bearing rocks are fairly abundant, particularly in the western portion of the area. Associated with the largest body of muscovite schist is a band of pyrite-bearing muscovite quartzite. Amphibolite occurs mainly as a large body with a very elongated outcrop in the proximity of the Athi River.

Kapitian Phonolite.—The lava is a coarsely porphyritic type readily identified in the field. Its position as a cap on the Yatta Plateau makes it a conspicuous feature in the eastern part of the area. No underlying fossiliferous sediments were found that would have assisted in an exact determination of its age, but on analogy with similar lavas in other parts of Kenya it is considered to be probably Miocene.

Pleistocene.—A basalt lava flow, which originated from a minor volcano in the adjacent quarter-degree sheet area on the west (52 S.W.), enters the present area for a short distance.

Recent.—A large proportion of the area is blanketed by a thick mantle of residual or, in some cases, transported soils. The typical soils are sandy and contain little organic matter. At a few localities restricted development of black cotton soil has taken place.

The sequence of events in the geological history of the area is summarized in the following table:—

1. Deposition of sediments of the Basement System in a subsiding geosyncline.
2. Basic intrusive phase.
3. Orogenesis, of which four phases can be recognized:
   (*a*) Metamorphism.
   (*b*) Alkali metasomatism.
   (*c*) Partial mobilization during the main phase of tangential compression.
   (*d*) Injection of quartz and pegmatite veins.
4. Vast period unrecorded in the rocks of the area.
5. Erosion culminating in the development of the end-Cretaceous (?) peneplain.
6. Rejuvenation of drainage leading to the formation of the sub-Miocene peneplain.
7. Faulting with the extrusion of the Kapitian phonolite, followed by rearrangement of the principal drainage system.
8. Development of the end-Tertiary peneplain.
9. Minor volcanic activity.

Basement System sedimentation

Judging from their present mineral constitution it is concluded that the original sediments of the Basement System in this area consisted mainly of felspathic sandstones and shales. The sedimentary nature of the rocks is confirmed by the rounding of most of the zircon crystals in them. Zircons separated in heavy mineral concentrations from random samples of Basement rocks showed:—

	Per cent
Well-rounded zircons	78
Slightly rounded zircons	9
Unrounded zircons	13

No definite conclusion was reached concerning the relationship of the foliation to the original planes of stratification.

Basic Intrusive Phase

The occurrence of metamorphosed basic intrusions among the meta-sedimentary rocks is apparently an example of the often recorded basic intrusive phase which follow deep burial and fracturing of the lowermost strata in a geosynclinal trough.

Orogenesis

The presence of kyanite (and of sillimanite in the adjoining areas) and the dominance of rocks that have suffered strong alkali metasomatism over those that have merely undergone isochemical change indicates that the sediments and basic intrusions were involved in a orogenic cycle. The progressive loss of the banded structure in the metasomatized rocks is believed to be due to partial mobilization under directed pressure and to indicate that the pressure reached its peak at a late stage in the process of metasomatism. During the final phase of compression quartz and pegmatite veins were injected into the rocks.

Post-Archaean History

There is no evidence of the geological history of the area for the period between the Archaean orogenesis and the uplift that led to the formation of the end-Cretaceous peneplain (Shackelton, 1946, p. 2). The period of tectonic quiescence in which the end-Cretaceous peneplain was formed was followed by regional uplift, when rejuvenation of the drainage system caused rapid erosion with the consequent destruction of much of the plain surface, and the formation of a second, lower plain. This plain corresponds with the African plain of King (1948, p. 450) and is part of the most widespread and perfect planation recognized in Africa. In Kenya it has been called the sub-Miocene peneplain (Shackleton, 1946, p. 4).

The writer believes that, subsequent to the planation, stresses acting on this block of country produced wide zones of fracturing and brecciation. A fracture system developed along the site of what is now the Yatta Plateau and permitted the extrusion of the lava along an irregular fault-line fissure. The fractures cut across the chief valley of the area, leading to modifications of the drainage that have already been detailed.

Minor uplift followed the vulcanicity of the Miocene period, leading to renewed erosion and the development of the youngest planed surface recognized, the end-Tertiary peneplain.

V—DETAILS OF GEOLOGY

1. Basement System

For convenience of description the rocks of the Basement System may be classified as follows:—

(1) Meta-sediments—

- (*a*) Crystalline limestones;
- (*b*) Quartzites
- (*c*) Muscovite-schists;
- (*d*) Diopside and hornblende-bearing gneisses.

(2) Migmatites—

- (*a*) Banded gneisses;
- (*b*) Biotite gneisses;
- (*c*) Granitoid gneisses;
- (*d*) Granitoid augen gneisses;
- (*e*) Granites.

(3) Intrusives—

- (*a*) Plagioclase amphibolites;
- (*b*) Amphibolites;
- (*c*) Pyroxenites;
- (*d*) Pegmatites.

Among the meta-sediments the crystalline limestones, the quartzites and the muscovite schists show no sign of having had their original bulk composition changed by alkali metasomatism, though the diopside and hornblende-bearing gneisses, which contain 20 to 50 per cent of alkali felspar, may owe their present composition partly to the addition of material. Under the head migmatites are classed the remaining rocks of sedimentary origin the bulk composition of which appears to have been changed by alkali metasomatism and irrespective of whether the host and the introduced component are megascopically distinguishable or not.

(1) META-SEDIMENTS

(*a*) *Limestones.* -A narrow lens of crystalline limestone extends from the South Machakos district into the north-western corner of the area close to the Tawa-Meu road. Other associated bands apparently terminate before reaching the boundary. Microscope examination of thin sections of a specimen (52/404) revealed a compact, medium-grained marble with a small percentage of iron ore and muscovite as accessory constituents.

This limestone, along with others in the adjoining area, was sampled and analysed by the representative of a Company interested in the possibility of cement manufacture. Though the results of the analysis have not been made available it is understood that the limestone contains too great a percentage of magnesia for use in the manufacture of Portland cement.

An intensive search failed to reveal any continuation in the area of the well-defined belt of metamorphic rocks, including crystalline limestones and kyanite schists which approaches the north-western corner from the west.

(*b*) *Quartzites.*—Thin bands of quartzite occur at Kilala and Kitonda on the western side of the area. More resistant to weathering than the surrounding biotite gneiss, the quartzite has protected the underlying rocks forming Kilala hill. The extension of the band south-west of Kilala is obscured by the alluvials of the Keite River.

Microscope examination of a slide (52/374) revealed that the rock has a compact, equigranular texture, and consists mainly of quartz but with appreciable amounts of pyrite, kyanite and muscovite. The pyrite occurs as small to medium-sized pyritohedra. While in the hand-specimen the rock appears non-directional, under the microscope it is seen that the muscovite and kyanite crystals are orientated in parallel planes. The approximate mineral composition* is as follows:—

	Per cent
Quartz	76
Muscovite and kyanite	17
Pyrite	7

West of the area, eleven samples from the continuation of the quartzite band were taken by B. H. Baker for gold assay. The highest yield obtained was 1.06 dwts. per ton, while four of the tests gave negative results. Two samples taken from the present area and tested also yielded negative results.

(*c*) *Muscovite Schists.*—Muscovite is abundant as an accessory mineral in the local Basement System rocks, and small quartz-muscovite lenses which frequently contain as much as 80 per cent of muscovite are numerous. Two main occurrences of muscovite-bearing rocks were found within the area. The first, associated with the pyrite-bearing-muscovite quartzite in the vicinity of Kilala, consists of numerous lenses of muscovite schist. The second, in the north-western corner of the area, immediately south of the Thwaki River, is a lens of muscovite schist extending in an east-west direction. In both cases muscovite constitutes about eighty per cent of the rock with quartz and felspar making up most of the remainder. The size of the muscovite plates varies, though seldom is a diameter of one inch exceeded. An interesting fact is that muscovite taken from the two outcrops described, showed different physical properties. The muscovite from Kilala has a slightly greater specific gravity (>2.9) than that from near the Thwaki (<2.9), and is also slightly harder. In both cases the determinations were made on grains free from inclusions. No muscovite occurrence in the area is considered of any potential economic value.

(*d*) *Diopside- and Hornblende-bearing gneisses.*—East of the Yatta Plateau, a broad band of psammitic para-gneiss extends from the northern boundary to the south-eastern corner, where the geology is obscured by a covering of black cotton soil. Although mapped as a single band of rock, several rock-types occur within it, the principal being diopside gneiss and hornblende gneiss.

* All modes quoted are volumetric.

(i) *Diopside-bearing gneiss.*—A dark blue rock, containing visible garnets, constitutes the bulk of the band in its southern portion, specimen 52/427 being representative. Thin sections reveal a compact, equigranular texture with a certain amount of fine interstitial material. The estimated composition is as follows:—

	Per cent
Quartz	25
Orthoclase	21
Plagioclase	18
Diopside	17
Garnet	15
Magnetite, ilmenite and apatite	4

Extreme strain effects, obvious in most of the constituent minerals are attributed to the fact that the specimen was taken from a band of rock occurring in close proximity to a zone of brecciation. The quartz grains are rounded, due to the rolling that accompanied shearing, which also resulted in the production of interstitial material composed of quartz and felspar surrounding the larger grains. The orthoclase is largely altered to sericite, the replacement having developed along cleavage planes, and albite twinning in the plagioclase has been almost completely obliterated. The composition of the pagioclase was estimated to lie between An_{20} and An_{30} (oligoclase).

Diopside occurs as irregular clusters of pale green grains. The garnet occurs in trapezohedra and is larger than any other of the constituents, varying between 2 mm. and 4 mm. in diameter. Optical and chemical tests indicate that it is grossularitic though the presence of iron suggests that it contains a proportion of the andradite or almandine molecule.

(ii) *Hornblende-bearing gneiss.*—In the vicinity of Umu Hill, the gneiss is characterized by an abundance of hornblende, and a total absence of diopside. A particularly resistant ridge of this rock extends for approximately 2½ miles. Specimen 52/422 is typical, and contains the following approximate proportions of minerals:—

	Per cent
Quartz	6
Orthoclase	49
Plagioclase	22
Hornblende	15
Clinozoisite	7
Accessory minerals	1

In some cases the dark minerals account for as much as 30 per cent of the rock. The hornblende is a dark green variety. Clinozoisite occurs as irregular aggregates. The plagioclase felspar is oligoclase with a composition between An_{20} and An_{30}. With occasional exceptions in the form of mafic mineral concentrations, the rocks are generally felsic, and the mafic types and calc-silicate rocks described by J. J. Schoeman (1946, p. 15) north of the area are absent.

(2) MIGMATITES

Various writers, for example Holmes (1919) in Mozambique, and Shackleton (1946) and Schoeman (1948) in Kenya, have described gradational series representing increasing degrees of granitization among the migmatites. In the present area such a series has again been recognized, and for descriptive purposes, is divided into the following stages—

(*a*) banded gneisses;
(*b*) biotite gneisses;
(*c*) granitoid gneisses;
(*d*) granites.

All the granites in the area are included with the migmatites as the writer considers that they are all of metasomatic origin and developed *in situ*. Transitions from one rock type to another in the series can be most clearly observed in the south-western corner of the area.

(*a*) *Banded Gneisses.*—Banded schists and gneisses, with alternating bands rich in felsic and mafic minerals, constitute a fairly small proportion of the rocks of the area. They are less resistant to erosion than the other gneisses and their outcrops are frequently followed by valleys. Owing to the heterogeneous nature of the banded-gneisses, weathering is selective. The mafic bands are weathered at an early stage, while the felsic bands remain relatively unaltered, producing a ribbed effect. The individual bands vary from less than an inch to several feet in thickness. Minor folding is often seen and frequently felspathic augen have developed within the distorted mafic bands. The most abundant ferromagnesian constituent is always biotite, though where concentrations of calcium have been sufficient, hornblende and diopside have also developed.

Specimen 52/331, taken from a mafic band east of Nzaui, has the following approximate constitution:—

	Per cent
Quartz	26
Felspar (mainly orthoclase)	37
Biotite	28
Diopside	5
Sphene	2½
Magnetite, apatite, zircon	1½

Specimens taken from the Matiliko area contain an appreciable proportion of hornblende and have microcline as the dominant felspar. No diopside or sphene was, however, found in them.

In contrast, the felsic bands seldom contain more than 10 per cent of biotite. Specimen 52/323, from the south-western corner of the area is a microcline-rich type with the following mode:—

	Per cent
Quartz	21
Orthoclase	27
Microcline	38
Plagioclase	5
Biotite	3
Chlorite, sphene and muscovite	2
Calcite	4

Analyses of similar rocks gave much the same results except for the presence of calcite, which was not recorded in any other specimen taken from that locality. Both calcite and chlorite appear to be alteration products. In slide 52/323 both prochlorite and penninite were identified and in several thin sections examined, flakes of biotite were found to be partly altered to chlorite.

In the vicinity of Meu, the composition of the banded gneisses tends to be more basic. The felsic bands are narrow and, in comparison with the banded gneisses elsewhere, contain a greater proportion of plagioclase felspar. In the dark bands hornblende represents an appreciable proportion of the mafic minerals, while quartz seldom accounts for more than 10 per cent of the total composition.

The writer considers that the banding of these rocks represents original alteration of arenaceous and argillaceous layers which have been emphasized by the introduction of alkali felsic material along the psammitic bands. As no chilled zones in the felsic material or "baked" contacts in the mafic material have been observed, it is clear that the introduced felsic constituents had a temperature similar to that of invaded rock. A mixing of the two contrasting layers took place in varied degrees, the more advanced stages of mixing leading to members higher in the granitization sequence. Examination of slides prepared from specimens taken within mafic bands at increasing distances away from contacts with felsic bands show that "mixing" decreases towards their centres. During the early stages of metasomatism, migration was confined to the felsic constituents.

(*b*) *Biotite Gneisses.*—By far the greater portion of the area is occupied by homogeneous, leucocratic, biotite gneisses. Their mineral composition varies to a certain extent according to locality, though a uniform distribution of biotite is a constant feature throughout. The biotite gneisses are believed to have been derived from the banded gneisses and schists which, undergoing more advanced mixing of the ingredients developed a simpler structure with even distribution of the dark minerals. Evidence of derivation from banded gneisses can be seen in the "ghost-structures" of banding within masses of biotite gneiss. Furthermore, contacts between the two rock-types are invariably gradational, though the contacts are seldom confined to particular horizons; rather, the occurrences of banded gneiss appear to "float" within the masses of biotite gneiss.

Biotite gneisses of three types occur in the area, each being characterized by the predominance of a different felspar. Some are rich in microcline, indeed, the larger proportion of the biotite gneisses in the area are composed essentially of microcline, quartz and biotite. In the more granitized gneisses the amount of microcline is apparently proportional to the loss of foliation. Being fairly resistant to weathering, microcline constitutes an appreciable proportion of the light detrital minerals of local river sands.

In specimen 52/326, from Dinaa hill, the microcline occurs as large grains, partly or wholly replacing orthoclase and plagioclase. By contrast, specimen 52/324 (from south-west of Nzaui), in which perthitic intergrowth is frequent, shows replacement of microcline by plagioclase. In addition to the constituents already mentioned the rocks contain quartz and subsidiary amounts of garnet, sphene, zircon and apatite.

While not as abundant as the microcline-rich types, orthoclase-rich biotite gneisses account for an appreciable portion of the total biotite gneisses of the area. In the vicinity of Kibaone the felspar in them is almost entirely orthoclase, with only occasional grains of plagioclase and microcline.

Biotite gneisses with plagioclase as the chief felspar are sporadically developed; for example, in specimen 52/367, from the south-eastern corner of the area, plagioclase (An_{15}) comprises the bulk of the felspar. Additional constituents include quartz and biotite, with smaller quantities of microcline and orthoclase.

Estimated modes of the three principal types of biotite gneiss are given in the following table:—

	52/326	*52/396*	*52/367*
	Per cent	*Per cent*	*Per cent*
Quartz	16	12	20
Orthoclase	20	40	4
Microcline	50	—	2
Plagioclase	3	11	40
Biotite	10	14	29
Hornblende	—	15	—
Accessory minerals	1	8	5

In the northern portion of the area the biotite gneisses and banded gneisses as far east as the Athi River appear to be richer in lime than those further south. In specimen 52/396, from Kibaone, bluish-green hornblende constitutes fifteen per cent of the total composition, while the accessories are the lime-rich minerals, diopside, epidote and sphene. Thin sections prepared from other specimens taken in the same locality have a diopside content of approximately 5 per cent. Sphene and garnet are constant accessories, while occasionally apatite accounts for up to 5 per cent of the subsidiary minerals.

(*c*) *Granitoid Gneisses.*—An advance in the degree of granitization already described leads to the development of granitoid gneisses from the more primitive types. The essential structural differences between biotite gneiss and granitoid gneiss is the disappearance of foliation in the latter. A general orientation of the micas persists, however, yielding a slight gneissic effect. Due to the more intense introduction of felsic material, the percentage of ferromagnesian constituents in granitoid gneiss is often less than that in a normal biotite gneiss. Having developed from biotite gneisses the granitoid gneisses contain, however, the same characteristic minerals in approximately the same proportions. In 52/391, a granitoid gneiss from the north-western corner of the area, the proportions of diopside, epidote, and sphene coincide with those of adjoining biotite gneiss (52/590).

Of the felspars, microcline is generally, but not always, more abundant than orthoclase, while plagioclase is frequently absent. In only one instance was plagioclase found to be the predominant fespar. In specimen 52/384, from the Ikua-Kitonda hills, no microcline was recognized, plagioclase and orthoclase being present in the approximate ratio 3:2. The content of quartz is uniform, the average being about 13 per cent.

(*d*) *Granitoid Augen-gneisses*.—East of the Yatta Plateau a broad band of augen-gneiss is traceable from the northern boundary in a south-south-easterly direction for a distance of about twenty-five miles to a point where, owing to deep soil overburden, surface geology is completely obscured. No contact between this rock type and the adjoining granitoid gneiss was observed, and its position in the granitization sequence is not clear.

Megascopically the gneiss has a coarse augen structure, consisting of eyes of felspar lying in a fine-grained mottled groundmass. Frequently a rim of minute flakes of biotite surrounds the large felspar eyes. Microscope examination of thin section reveals a predominance of perthite, microcline-perthite being more abundant than orthoclase-perthite. There is, however, apparently no segregation of the different types of felspar. Replacement of the perthite has been effected by orthoclase and microcline, both of which have been themselves slightly replaced by myrmekite. Where perthite does not constitute the bulk of the felspar microcline accounts for up to 40 per cent of the total mineral composition, and plagioclase is frequently absent, or present only in minute quantities. Replacement by quartz has led to a patchy appearance in most crystals of felspar in specimen 52/411.

Dark minerals in the rock are biotite and hornblende and, less abundantly, sphene and iron ore. Apatite is also accessory.

(*e*) *Granites*.—The ultimate stage of granitization is the transformation of heterogeneous psammitic and helitic rocks, into homogeneous non-intrusive granites. The chief structural difference between such granites and the related granitoid-gneisses is the loss of orientation of the micas. Contacts between the two types are invariably gradational.

The possibility of the existence of intrusive granite in the area must, however, be considered. The most likely example is undoubtedly the granite forming the tor at Campi-ya-Mawe, just off the Makueni-Settlement Makindu road. Due to the surrounding residual mantle of soil, which extends to a considerable depth, the structural relationship of this granite and the surrounding granitoid gneiss is totally obscured. It is considered, however, that Campi-ya-Mawe is a continuation of a ridge of non-intrusive granite further south-west.

The rock (52/350) has a medium to fine-grained texture and is composed of equidimensional grains, giving the impression that it has been derived from a psammite. As it contains an overwhelming preponderance of felsic minerals the rock may be termed an aplo-granite. In thin section it is estimated that the mineral constitution is:—

	Per cent
Quartz	21
Orthoclase	28
Microcline	44
Myrmekite	4
Biotite, muscovite and magnetite	3

Similar rock occurs due east, at Mathemba, though it contains a greater percentage of mafic minerals.

North-west of Kibaone a body of granite extends to, and includes, the hill of Ndutu. It is more basic than the Campi-ya-Mawe type. Microcline and othoclase are subordinate to plagioclase (An_{20}), and hornblende, diopside and sphene account for approximately 28 per cent of the total mineral composition. The contact between this granite and the surrounding gneisses is gradational.

(3) **Intrusives**

(*a*) *Amphibolites.*—Corresponding approximately with the course of the Athi River a large body of amphibolite, with a maximum width of approximately half a mile, extends across the area for nearly 40 miles, lying parallel with the strike of the gneisses on either side. Several smaller bodies with similar alignment occur nearby in the northern part of the area. The discovery of relic doleritic textures in the largest body of amphibolite at the crossing of the Machakos-Kitui road over the Athi River proves the magmatic origin of the large body. Its continuation further north was described by Schoeman (1948, p. 31) as a meta-dolerite sill because of the lack of banding and owing to the sharp contacts that it displays with the flanking gneisses.

Owing to their more felsic composition the smaller bodies are described as plagioclase amphibolites. The difference between the large and the smaller bodies may be attributed either to differentiation within a common magmatic source or to more extensive metasomatism of the smaller bodies due to their proportionately greater marginal area.

Judging from the thin sections prepared from specimens taken at various localities along the large occurrence of amphibolite its mineral composition is, as a whole, fairly uniform. At contacts between the gneissic country-rock and the intrusive amphibolite partial or complete digestion of acid rock has, however, caused a departure from the normal composition. Tongues of the intrusive rock frequently contain an abnormally high percentage of felsic minerals.

In the northernmost exposure of amphibolite, due to incomplete alteration, original dolerite texture is partly retained. Elsewhere the rocks are schistose and medium- to coarse-grained with occasional segregations of coarse-grained hornblende developing within fine-grained portions. A banded effect is occasionally caused by the presence of hydrothermally deposited quartz veins.

The amphibolite differs from the plagioclase-amphibolites mainly with regard to the proportion of plagioclase (An_{30}) present, which seldom accounts for more than 15 per cent of the total composition. While normally predominant, hornblende in specimen 52/371 is slightly subsidiary to diopside. Epidote and clinozoisite are constant accessories, occurring in the approximate proportion of 4 to 1. A limited amount of quartz is present and is of relatively even distribution.

The plagioclase amphibolites are represented by two specimens. Number 52/401, taken from a thin lens on the western bank of the Athi River in the northern section of the area, is notably flaggy in structure. The plagioclase, which has an approximate composition An_{30}, makes up about 40 per cent of the rock, the remaining minerals being blue hornblende, epidote and sphene.

From the Thwaki-Athi intersection a narrow outcrop of fine-grained plagioclase amphibolite extends for a short distance along the Athi in a northerly direction. Dark green hornblende constitutes about half of the total mineral composition, the remaining minerals in order of abundance being: diopside, epidote, oligoclase, calcite, sphene and zircon. The plagioclase is partly replaced by scapolite which in specimen 52/385 is a strongly birefringent (N = .035) type, and is probably the calcium scapolite, meionite.

Garnet occurs in the plagioclase amphibolites only locally but occasionally constitutes as much as 15 per cent of the rock. Quartz similarly is of uneven distribution.

(*c*) *Pyroxenites.*—At the road crossing between Okia and Kilala an outcrop of pyroxenite in the Kyanzibi river-bed extends down-stream for a short distance. Owing to the alluvium which flanks the stream, the relationship of the pyroxenite to the surrounding rocks cannot be seen. It is considered, however, that it extends to Kilala hill and from there across to the western slopes of Kitonda, where a pyroxenite has invaded a pyritic muscovite-bearing quartzite.

Specimen 52/376, from Kilala, is composed chiefly of hornblende, uralitized augite, garnet and a small quantity of plagioclase felspar largely altered to sericite. In contrast with the outcrop in the river bed, the pyroxenite in the vicinity of Kilala is considerably altered.

Specimen 52/379, taken from the outcrop in the Kyanzibi river-bed, is dark green and has a medium-grained granular texture. Microscope examination revealed that it consists predominantly of partly altered augite and hypersthene crystals. The hypersthene is pale green to neutral coloured, with faint pleocroism, and contains lamallae of exsolved clinopyroxene. Both augite and hypersthene have been replaced to a variable degree by a pale green hornblende. Strongly pleochroic brown biotite is the chief accessory mineral, and pyrite occurs in small anhedral grains disseminated throughout the rock. There is a small amount of clear, interstital quartz. Hypersthene is the most abundant mineral in a thin section of specimen 52/390.

Owing to its great variation in metamorphism this pyroxenite is believed to be pre-orogenesis in age.

(*d*) *Pegmatites.*—Pegmatite and aplite veins, while fairly abundant, are largely concentrated in particular localities. The heaviest concentration of pegmatites is in the south-western quadrant, the hills of Unoa, Nzueni and Dinaa being well-dissected by pegmatite veins. The veins are seldom concordant with foliation planes in the gneisses.

Texturally the pegmatites vary from fine- to relatively coarse-grained and occasionally large phenocrysts of felspar occur in the finer-grained types. They are essentially quartzo-felspathic in composition, some containing additional minerals though others are composed entirely of felspar and quartz. The most common type is microcline-rich, containing up to 90 per cent microcline. Quartz veins are more abundant than quartz-rich pegmatites, which rarely carry accessory minerals.

Of the additional minerals, mica is the most widely distributed, and is usually muscovite, occurring either as small disseminated flakes or as "books" up to two inches in diameter. Biotite is less abundant and has developed only as isolated books. Specimen 52/348, from the Keite River north of Unoa hill, contains an appreciable proportion (22 per cent) of magnetite. The pegmatite from which it was taken consists chiefly of microcline, with a small amount of quartz and subsidiary ilmenite, zircon and apatite.

(4) MINERAL BELTS

Subdivision of the migmatites, which constitute the major part of the Basement System rocks in this area, has been largely based on structural and textural features. Any attempt to divide the rocks into types solely on the assemblages of minerals in them would have led to little distinction of varieties throughout the area. Certain minerals, however, are occasionally more abundant than usual in particular belts (Fig. 2), owing often no doubt to compositions inherited from the original sediments. The following are the characteristic minerals that have been distinguished: *Microperthite.* As described above, a broad band of augen-gneiss extends in a north-north-west to south-south-east direction east of the Yatta Plateau. This augen-gneiss is characterized by the presence of microperthite. *Diopside.* Parallel with the augen-gneiss, a band of gneiss, rich in calc-silicate minerals, is typified by the appearance of diopside. At some localities other dark minerals are predominant, for example garnet in the southern part and hornblende in the northern portion while small amounts of epidote, zoizite and clinozoisite are erratically developed throughout the band. Diopside is, however, consistently present in much of the band. *Garnet.* Three unrelated garnet-rich belts can be traced in the area. The most southerly portion of the calc-silicate-rich gneiss frequently contains up to 20 per cent of garnet. In the Nzaui syncline a mafic band composed chiefly of garnet, hornblende and biotite is traceable on both sides of the mountain. Finally Nzueni hill is capped by a melanocratic garnet-bearing biotite gneiss. This garnet belt extends for some miles southwards but the abundance of garnet is subject to extreme variation. *Sphene.* A broad belt of gneisses in which sphene is consistently present forms the Kibaone–Malueni range. Southwards, a further sphene-rich belt, parallel with that of

Kibaone, embraces the hills of Makueni, Kianga and Katambua. The concentration of sphene in this belt is, however, somewhat patchy, the heaviest concentration being in the vicinity of Kianga.

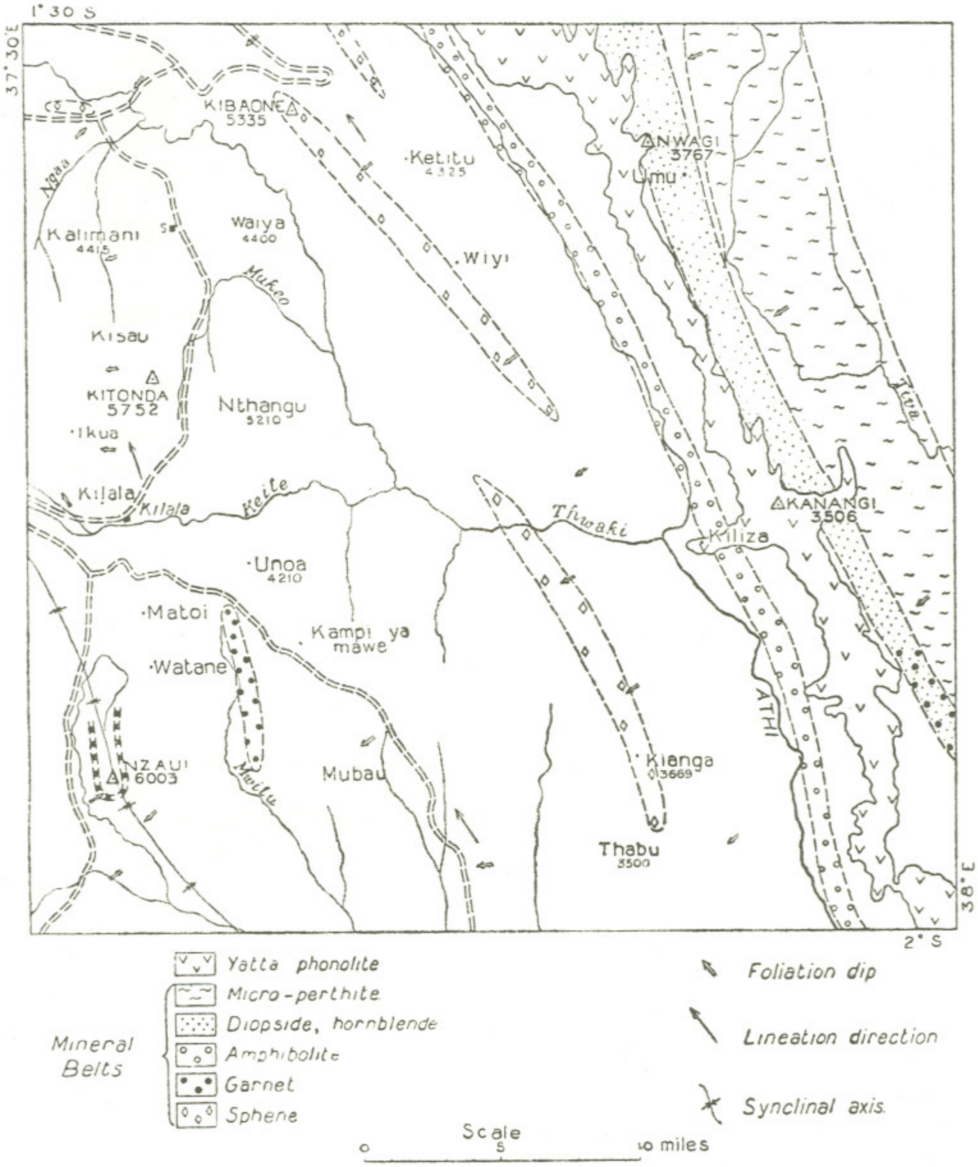

FIG. 2.—Structures and mineral belts in the area south-east of Machakos.

(5) METAMORPHISM

The gneisses and schists of the area have undergone considerable metamorphism. The widespread and consistent occurrence of biotite is not diagnostic of the low-grade metamorphism of the classic biotite zone, the biotite being a green variety stable under higher grades of metamorphism. The index mineral almandine is developed along particular horizons, in the assemblage hornblende—oligoclase—almandine. The absence of kyanite from most of the rocks is possibly to be attributed to a relatively low alumina content in the original sediments. Staurolite was not found and, as the rocks are generally poor in iron, is not to be expected.

In considering the degree of metamorphism, however, the use of the facies classification is perhaps of greater value.

In contradistinction to the typical garnet amphibolites of the amphibolite facies, Korjinsky (Turner, 1948, p. 87) has described a pyroxene-bearing garnet amphibolite sub-facies. The majority of amphibolites in the present area belong to that sub-facies and have the following assemblage: almandine—diopside—hornblende. In smaller bodies the more typical assemblage almandine—hornblende—plagioclase is found. Sphene is abundant in all the amphibolites examined, but small quantities of rutile are also present as is usual in amphibolites. The broad band of calc-silicate-rich gneiss east of the Yatta Plateau provides a further series of assemblages, the most widespread being, epidote—diopside—hornblende.

The assemblages that are considered to have reached equilibrium within the area, may be summarized as follows:—

(*a*) *Amphibolites—* hornblende—almandine—diopside hornblende—almandine—diopside—epidote hornblende—almandine—epidote	plus quartz, oligoclase, sphene, biotite.
(*b*) *Plagioclase-amphibolites—* almandine—hornblende—plagioclase almandine—diopside—hornblende—plagioclase almandine—epidote—hornblende—plagioclase	plus scapolite, sphene, quartz, calcite.
(*c*) *Hornblende and diopside gneisses—* zoisite—diopside—hornblende garnet—diopside—hornblende garnet—zoisite—diopside—hornblende	plus quartz, plagioclase.

The assemblages indicate that the rocks belong to the almandine—diopside—hornblende sub-facies of the amphibolite facies, corresponding with the kyanite zone. Immediately west of the area under suitable conditions the formation of kyanite has been fairly widespread. East of the area the occurrence of sillimanite suggests an increase in grade of metamorphism in that direction.

(6) Structures

The length of Nzaui hill coincides with a north-north-west—south-south-east synclinal axis which is defined partly by the occurrence of similar bands of mafic, garnet- and sphene-bearing gneiss on opposite flanks and partly by the orientation of the foliation. East of the syncline the gneisses have the same strike as the axis, a direction that persists with little variation to the eastern limits of the area and the north-eastern section. In the northern part of the western margin, however, the strike describes an arc concave to the west swinging from north-east—south-west at Kilala to north-west—south-east in the north-western corner.

Except in the south-western corner dips are in general to the west, at angles varying from 20 to 60 degrees. In the neighbourhood of Ikua on the western margin the dip steepens from about 40 to about 65 degrees. In the south-eastern corner of the area dips are eastward at angles varying from 30 to 60 degrees.

At the few localities where it was measured the direction of lineation is close to 340°, the angle of pitch being generally about 20° to north-north-west.

An important structural feature of the area is a brecciated zone in the gneisses running close to and parallel to the Yatta phonolite. For the purposes of the present report it has been interpreted as a fault system and it is believed that the movement was horizontal along vertical planes. The most intense brecciation has produced phyllonites with a slate-like structure and a fine-grained mylonitic texture. The brecciation in less mylonitized types is often recognizable only by microscope examination. During the initial stages of crushing less resistant minerals were fractured, particularly around their edges. Quartz grains remained relatively unaffected, though strain effects in them are notable in the rocks that occur near the limits of the zone of brecciation.

2. Tertiary—Yatta Plateau Phonolite

Megascopically the phonolite of the Yatta Plateau, which corresponds with the Kapiti phonolite of Gregory (1921, p. 99) is a fine-grained rock with medium-sized to large phenocrysts. The texture of the groundmass varies slightly according to the position in the flow both horizontally across and vertically, the phonolite from the centre being coarser in texture than that at the margins. Amygdales and phenocrysts account for up to 20 per cent of the total volume of the rock. The phenocrysts vary in size from 10 mm. to 50 mm. the average being about 30 mm. in length. Amygdales are comparatively rare.

Microscope examination of numerous thin-sections of specimens taken at random between the northern limit of the area and the Kitui-Kibwezi road south-east of the area reveals that there is little variation in the phonolite.

The phenocrysts consist almost entirely of anorthoclase and nepheline, which occur in the approximate ratio of 7:2. Those of anorthoclase are invariably larger than the nepheline crystals, and in hand-specimen can be easily distinguished by their whitish porcellanous appearance which contrasts with the waxy, dull-green appearance of the nepheline. Some of them are slightly replaced by zeolite, and occasionally they are almost entirely altered. Olivine phenocrysts are rare and small, and partly replaced by carbonates. The amygdales are composed predominantly of calcite though zeolite and kaolinite are fairly common in them.

The felsic minerals of the groundmass are anorthoclase and nepheline, and the mafic minerals are aegerine, aegerine-augite, augite, kataphorite and cossyrite. Numerous small flakes of kataphorite occur in all thin sections examined. Cossyrite is equally abundant and occurs as minute crystals disseminated through the groundmass. Patches of analcime are occasionally seen.

3. Pleistocene

(1) *Sediments*

On the broad flats along the course of the Keite and Athi Rivers alluvial deposits consisting of various grades of sand and clay with occasional pebble-beds frequently reach a depth of thirty feet. In the vicinity of Kilala several pebble-bands occur, each showing remarkable rounding of the individual pebbles. The sands and pebble beds are usually well consolidated. No fossil remains were found in these sediments but, on comparison with other areas, they may be considered as of upper Pleistocene age. Approximately half-way up Kilala hill a somewhat discontinuous horizon of pebbles represents sediments deposited during earlier, probably lower Pleistocene times.

Along the banks of the Athi River in the southern section of the area the gneisses are intermittently covered by cemented gravel containing usually well-rounded, ill-sorted pebbles in a dirty-white matrix. The gravel is tentatively considered as of upper Pleistocene age. The matrix, which is compact and fine grained, is predominantly calcareous, with lesser amounts of kaolinite and quartz distributed locally. A root-like fossil was found in it but identification proved impossible. The pebbles vary in shape and rock type, the most common being of sub-angular to rounded quartz. Rounded pebbles of Basement System gneiss are fairly abundant but none derived from the Yatta phonolite were recognized.

Heavy minerals, separated from ten specimens of the gravel yielded the following assemblage:—

	Per cent
Hornblende	19
Diopside	15
Epidote	13
Magnetite	10
Haematite	8
Clinozoisite	7
Garnet	6
Sphene	5
Ilmenite	5
Biotite	4
Zircon	4
Apatite	2
Stauralite	1
Tourmaline + Sillimanite + Rutile	1

(2) *Lavas*

Several volcanic cones lie a little outside the south-western corner of the area, and numerous transported boulders of lava derived from them are found in the eastward-flowing streams. A small portion of a single flow extends across the western boundary into the area.

A specimen was obtained from the neighbouring area, and found to be a porphyritic olivine basalt. It contains inclusions of Basement System rock up to three inches in diameter.

Microscope examination of a thin section of specimen 52/429 revealed medium-sized euhedral augite phenocrysts, olivine phenocrysts and scattered felspar phenocrysts. The groundmass is fine-grained and composed of plagioclase felspar, magnetite and pyroxenes. The felspar is labradorite, approximately An_{65}.

4. Superficial Deposits

In the south-eastern portion of the area extensive weathering has produced residual and occasionally transported soils of considerable thickness. Elsewhere development of soils has proceeded to a lesser extent. Generally the soil produced is a reddish to yellow gravelly type, the red coloration being due to an overall staining by iron-oxide. This type of soil is essentially acid, supporting a sparse vegetation of scrub thornbush, and attempts at cultivation seldom meet with success.

More advanced weathering produces grey to chocolate-coloured soils, devoid of gravel and invariably more fertile. A fair measure of success has been obtained in the cultivation of such soils.

Deterioration of these soils is rapid, for under improper husbandry the organic content of the soil is soon lost. Further leaching produces a whitish soil, the final product being a barren sand almost devoid of vegetation. In the vicinity of the eastern boundary soil deterioration has advanced to the extent when little can be cultivated in the sandy expanses.

Along the summit plain of the Yatta Plateau occasional patches of soil have developed. They are dark red in colour, and are probably more fertile than those derived from the surrounding basement rocks.

Finally, accumulations of so-called "black cotton" soil occur in areas of internal or ill-defined drainage. The soil is a fine-grained black, clay-like soil, which when dry is hard and fissured by contraction cracks though when wet it is sticky and extremely boggy. The black colour is due to an unusually high organic content. Numerous rounded, calcareous concretions are characteristic of the black-cotton soil accumulations. The concretions are derived from lime-charged waters which, under suitable conditions, precipitate calcium carbonate, the nodules probably representing accumulations around a nucleus. The nuclei usually consist of grains of sand, or occasionally of particles of organic matter. No concentric layers are to be seen in the concretions and only seldom are the nuclei apparent. In numerous specimens of the concretions unidentified fossil remains were seen. They consist of small, hollow, noded rods that may possibly be either fossil rootlets or worm burrows.

VI—ECONOMIC GEOLOGY

1. Minerals

During the investigation of the area described no mineral deposits of importance were discovered. Twenty-seven heavy mineral concentrates were collected from river sands, alluvial and soils, but on examination they failed to reveal the presence of any mineral of economic value. Some years ago fine crystal aggregates of magnetite were recovered near Nzaui and a certain amount of prospecting was carried out. It is probable that the crystals were obtained from a pegmatite and workable supplies are unlikely.

The small body of limestone in the north-western corner of the area, while fairly extensive further west, has too high a magnesia content to be suitable for the manufacture of cement.

Occasional deposits of low-grade kaolin occur in the west-central part of the area, situated between the hills of Ikua and Kitonda. The presence of high percentages of iron-oxide and silica make the deposits valueless.

The only known occurrence of kyanite in the area consists of a kyanite-bearing quartzite, which enters the area from the west for a distance of about a mile and a half near Kilala. The thickness of the band is approximately 50 feet but it contains only a few per cent of kyanite. No sign of any kyanite concentrations were found in it.

2. Water

A hydro-geological investigation of the Makueni settlement area was carried out by the Public Works Department in 1945. Following the investigation a report was prepared recommending several borehole sites. Mention was made of other potential sources of water supply including the following:—

(*a*) sub-surface dams;
(*b*) surface dams;
(*c*) wells;
(*d*) infiltration trenches.

In due course a series of boreholes were sunk and the records of the Public Works Department show the following results:—

Borehole Number	Known as	Depth	Rest Level	Tested Yield	Quality of Water
		Feet		*G.P.H.*	
C.397	No. 1	508	—	Dry	
C.398	No. 2	477	—	Dry	
C.414	Mubau	442	155	1,060	Slightly saline.
C.482	Mubau	442	155	1,060	Slightly saline.
C.437	Unoa	405	50	1,580	Good.
C.446	Unoa	405	60	1,525	Good.
C.454	Hunter's Camp	274	53	1,000	Good.
C.461	Woti	178	25	3,600	Slightly brackish.
C.474	Makueni Hill	134	34	860	Good.
C.488	Malibani	402	44	860	Good.
C.500	Thabu	220	30	1,080	Brackish.
C.518	Poi	432	54	790	Brackish.

In the northern and eastern portions of the area conditions appear far less favourable for the sinking of boreholes.

With the exception of the Athi, all streams flow for but a short period each year, following the seasonable rains. Water is, however, easily obtainable throughout the year by digging in the sandy river-beds. Water is obtained in this way by the local African population, who seldom need to dig deeper than three feet in the sand.

To increase the water supplies it is suggested that the most important step is the construction of dams, especially small, high-walled types. The desirability of building numerous small dams in preference to a few large ones is obvious. Perhaps, most important is the fact that small dams can be built relatively cheaply and without mechanical aid. The advantage of depth in the dam is that the smaller the ratio of surface to volume, the less water will be lost by evaporation.

VII—REFERENCES

Baker, B. H.—"Geology of the Southern Machakos District" (in preparation).

Dixey, F., 1948.—"Geology of Northern Kenya." Report No. 15, Geological Survey of Kenya.

Gregory, J. W., 1921.—"The Rift Valleys and Geology of East Africa." London.

Hitchen, C. S., 1939.—"Report on a Geological reconnaissance of the Makueni fly area." (Unpublished.)

Holmes, A., 1919.—"The Pre-Cambrian and Associated Rocks of Mozambique." Quart. Journ. Geol. Soc., Vol. LXXIV, pp. 31-98.

King, L. C., 1948.—"On the ages of African Land-surfaces." Quart. Journ. Geol. Soc., Vol. CIV, pp. 439-459.

——— 1951.—"South African Scenery." Edinburgh.

Reeve, W. H., 1945.—"Report on the Hydro-Geological survey of a portion of the proposed Makueni settlement area, Machakos District." Unpublished report, Public Works Department, Nairobi.

Shackleton, R. N., 1946.—"The Geology of the Country between Nanyuki and Maralal." Report No. 11, Geol. Surv. Kenya.

Shand, S. J., 1943.—"Eruptive Rocks." London.

Schoeman, J. J., 1948.—"A geological reconnaissance of the area west of Kitui Township". Report No. 11, Geol. Surv. Kenya.

Temperley, B. N., 1938.—"The geology of the country around Mpwapwa." Short Paper No. 14. Department of Lands and Mines, Geological Division, Tanganyika.

Turner, F. J., 1948.—"Mineralogical and structural evolution of the metamorphic rocks." Mem. 30, Geol. Soc. America.

G.P.K. 2002—600—11/52