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**GEOLOGY OF THE
SOUTHERN MACHAKOS
DISTRICT**

**DEGREE SHEET 52, S.W. QUADRANT
(With Coloured Map)**

by

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FOREWORD

The Machakos area was the first district in Kenya, apart from the coastal belt, in which there was any permanent European settlement. The proximity to Nairobi and to the railway and the principal up-country road naturally led to its being prospected for mineral deposits early in the European history of the Colony. With the exception of the goldfields of western Kenya it has been perhaps the most prospected part of the country. The results of the efforts that have been spent on it have, however, been disappointing. Numerous minerals of value have been discovered but, as is shown by Mr. Baker in his report, none has led to notable production, except in the case of building sand recovered from several sand-rivers in the area. Excellent mica has been produced, but in relatively small quantities, and it is possible that with proper facilities a small mica industry could be resuscitated. It is not expected that the industry would be large, as the pegmatites that contain the mica are usually not of great size. Other minerals that may become of commercial value, given suitable markets and suitable operating conditions, are kyanite, vermiculite and talc. The discovery of kyanite schists that may ultimately be of value is recent and it is possible that more close prospecting of the Machakos Hills, which are of such a nature that strenuous work is required for their examination, may lead to the finding of other, perhaps more valuable, deposits.

The mapping of the southern Machakos area, though necessarily carried out in reconnaissance style, has yielded most valuable information on the structural geology of that part of the country. For many years it has been known that the direction of strike of the rocks in parts was contrary to that prevalent in neighbouring tracts. Mr. Baker has now shown that there are, in fact, two groups of marked concentric structures, centering round masses of granitoid gneiss, within the area mapped. Mr. Baker offers an explanation of these remarkable structures, which superficially resemble the pattern of concentric ripples caused when a stone is dropped into a pool of water, but it is probable that much more detailed examination will be required before an entirely satisfactory explanation can be found. In some parts of Africa such structures are genetically connected with alkaline intrusions or carbonatites, with which peculiar and often valuable minerals are associated. In Machakos, however, there appear to be no such rocks at surface nor evidence that they are present below ground.

Nairobi,
5th November, 1952.

WILLIAM PULFREY,
Chief Geologist.

ABSTRACT

The report describes an area of about 1,250 square miles in central Kenya, some 45 miles south-east of Nairobi, bounded by the latitudes $1^{\circ} 30'$ and 2° S. and longitudes 37° and $37^{\circ} 30'$ E. Physiographically the area may be divided into three major units, (a) the Kapiti lava plain in the western part, where the lavas rest on the lightly dissected sub-Miocene peneplain, (b) the undulating Masai country in the south-west which represents the sub-Miocene peneplain in a late-youthful stage of dissection and (c) the hills of the Ukamba reserve which rise up to 6,500 feet and whose summits are often the remnants of the end-Cretaceous peneplain.

The rocks exposed in the area consist of intensely folded Basement System gneisses and schists which include limestones, amphibolites and quartzites as well as the predominating biotite granitoid gneisses. These rocks have been both metamorphosed and granitized to a considerable degree. Overlying the Basement System rocks in the western part of the area is the Kapiti phonolite, a lava of Miocene age. In the south and south-east parts there is a total of seven olivine basalt vents with associated lavas, these being of late Pleistocene age. Much of the area in the west is covered by black cotton soil while in the east sandy and brown earths, murrams and local iron laterites predominate.

A detailed account of the petrography of the rocks is given and their structures and metamorphism are discussed.

Deposits of actual or potential economic value containing such minerals as kyanite, talc, vermiculite, muscovite and garnet are described and the existing water supply situation is discussed.

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MAP

Geological Map of the South Machakos district (Degree Sheet 52, S.W. quadrant),
 Scale 1:125,000 At end

GEOLOGY OF THE SOUTHERN MACHAKOS DISTRICT

I—INTRODUCTION

General

The southern Machakos area as defined for the purpose of this report is the south-west quadrant of Degree Sheet 52 (Kenya), and is bounded by latitudes $1^{\circ} 30'$ and 2° S. and longitudes 37° and $37^{\circ} 30'$ E., and is some 1,250 square miles in extent. A geological reconnaissance of this area was made between December, 1949, and September, 1950. The objects of the work were to construct a geological map and to evaluate such mineral deposits as had already been discovered and, furthermore, to delineate wherever possible favourable geological formations that warrant closer investigation.

The eastern half of the area falls into the Kamba Native Land Unit and is administered from Machakos, while that part of the area south of the railway is Masai country and is administered from Kajiado. European farms occupy the central part of the area between the Kamba and Masai reserves.

The Wakamba country in the eastern half of the area is mountainous and thickly populated. Maize, sugar-cane and other crops flourish on the upper parts of the highest mountains, and in general the crops on the hills are good whereas those on the lower ground frequently fail owing to lack of rain. Wattle forests have been planted on Kilungu and Mbooni hills.

The climate in the area is pleasant and similar to that of Nairobi except at levels about 4,000 feet where the heat in January and February becomes considerable.

The following table of rainfall figures illustrates the variations in rainfall. The first six stations in the table lie generally in the western flat-lying part of the area, while the remaining seven stations are situated in the hilly eastern part.

Name of Station	Total rainfall in 1950	No. of rainy days	Average yearly rainfall	No. of years recorded
Konza, Kapiti Plains Estate	15.87	44	20.99	8
Konza, Railway Station	8.54	26	17.63	34
Konza, Masai Grazing Scheme	12.63	32	—	—
Portha Estate	18.23	45	24.25	30
Kiu Station	16.00	46	22.04	43
Kima, Marwa Sisal Estate	18.06	43	24.75	20
Kilima Kiu	15.00	53	24.24	36
Machakos, District Office	25.63	84	35.58	55
Machakos, Government African School	16.76	44	31.89	8
Mbooni Mission	34.76	99	38.29	8
Kilungu Dispensary	29.35	65	39.29	17
Kiteta Government School	25.56	29	23.90	9
Okia Government School	28.63	—	36.41	19

The area as a whole is well served by roads. The Mombasa-Nairobi railway and road pass through the area and, in the farmlands, roads and tracks are numerous. Few, if any, parts of the area are more than six or seven miles from a dry-weather road or track but most of the roads become impracticable during the heaviest rains.

Rock outcrops are numerous in the hills but rare on the Kapiti plains. Since few of the rivers are completely choked with alluvium they give the most valuable geological information and were traversed wherever possible.

Methods of Mapping and Maps

The topography of the geological map was taken from preliminary plots South A 37/H III S.W., etc. (scale 1:50,000). Form-lines, which are not always accurate, were taken from the Army map E.A.F. No. 1637, 1945 (scale 1:250,000) and corrected wherever possible. Geological field information was plotted on air photographs or on kodatrace flight-strips and subsequently reduced on to the 1:50,000 maps by means of a Trorey anharmonic rectifier.

Photogeology

Stereoscopic examination of the air photographs revealed much geological information which indicated the structural grain of the country. Thus over considerable parts of the area lines of strike and dip of the foliation were visible and have been plotted on the map. In the present area, however, it was not possible to distinguish between varieties of Basement System rock by means of the air photographs.

The edge of the Kapiti phonolite where it forms a scarp was accurately mapped from the aerial photographs and the shape and extent of the basaltic volcanoes in the southern part of the area is well shown on them. Differences of soil type and vegetation are also clearly discernible on the photographs and can sometimes be related to geological structure, as in the case of the Tulimani limestone complex.

Previous Geological Work

The caravan route used in the latter half of the last century by the first East African explorers ran through the area approximately along the present site of the railway line, but few of the earlier travellers recorded any geological information.

J. W. Gregory (1896, pp. 227, 215)* was the first to mention the Kapiti lava plains and the Archæan gneisses near Iveti and Machakos. In 1908, H. B. Muff (Maufe) published an account of a traverse along the railway and mentioned the Kapiti lavas and the Archæan gneisses between Machakos and Sultan Hamud.

Gregory continued his geological exploration and in 1921 published his book *The Rift Valleys and Geology of East Africa*, in which he described the Kapiti phonolite and also the leading features of the Basement System rocks. He referred to "cross-fractures" in the Ulu mountains, showing that he had recognized the unusual east-west strike of the gneiss in parts of the southern Machakos area. Gregory regarded the volcanoes Mwani and Kelembwane as Lower Pleistocene in age (op. cit. p. 207) and considered the Kapitian lavas to be of upper Cretaceous age.

In the last fifty years much information regarding the mineralogy of the area has been gained as a result of the activities of prospectors. More recently Dr. W. Pulfrey of the Mines and Geological Department has written unpublished reports on talc, muscovite, vermiculite and kyanite deposits in the area.

Acknowledgments

Thanks are due to the administrative officers of the district for much help, and to Mr. and Mrs. P. H. Cull of Sultan Hamud and Mr. and Mrs. L. Mousley of Kiu for hospitality.

II—PHYSIOGRAPHY

The area can be divided into three distinct physiographic units:—

The Kapiti plains.

The Masai country of low undulating hills.

The mountains of the Ukamba reserve.

*References are quoted on p. 39.

The chief features, including planar land surfaces, are shown diagrammatically in Fig. 1.

The Kapiti plains in the western part of the area are extremely level, being cut only by seasonal stream channels. The level of the plain is broken by three inselbergs—Wami, Theki and Kyumbi—and slopes upwards to the east, becoming more undulating, till it merges into the mountainous area in the Ukamba reserve.

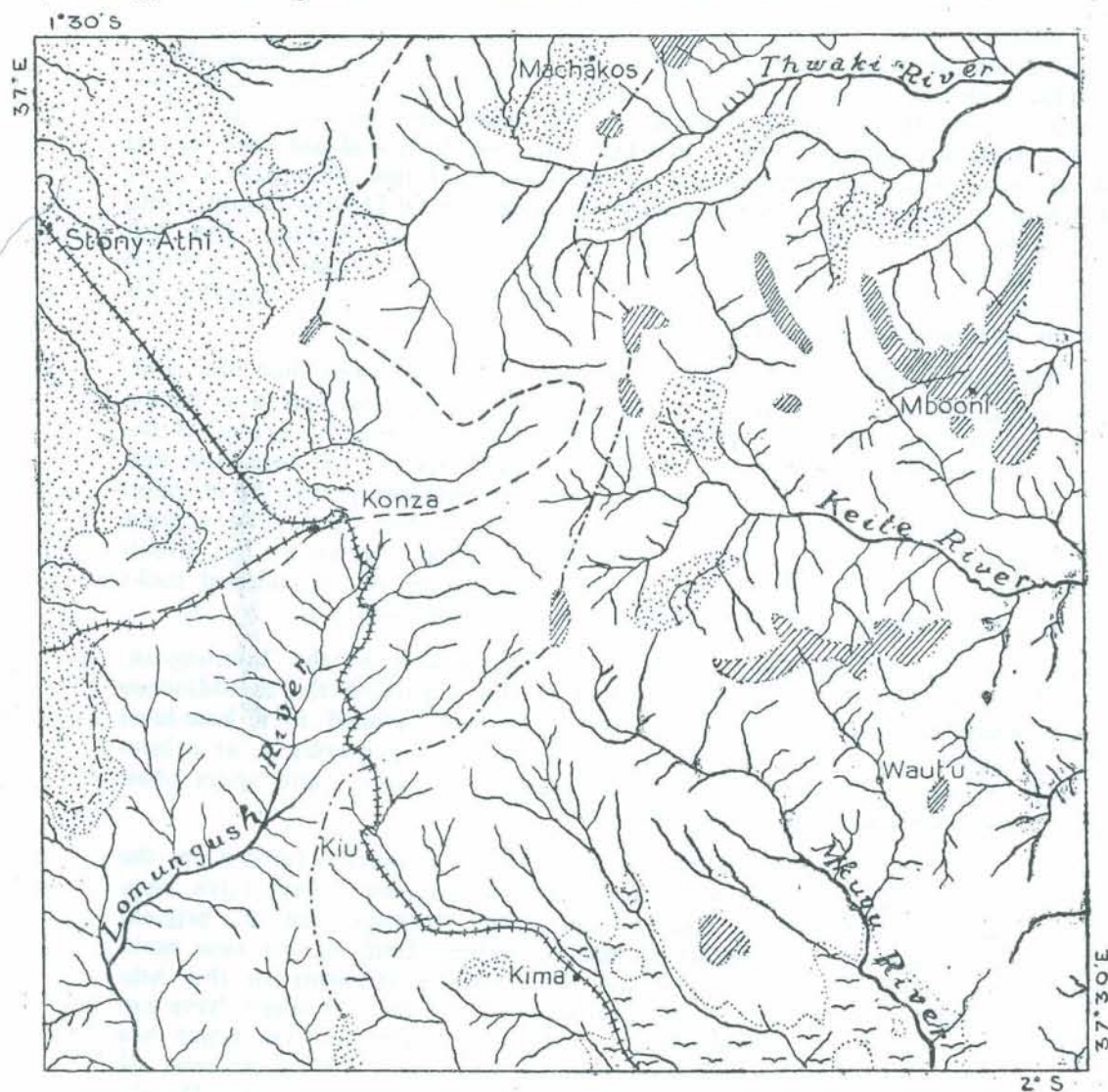


FIG. 1.—Erosion surfaces in the southern Machakos area.

The Masai area in the south-west is low-lying but undulating with even summit levels and flat-topped ridges suggestive of a dissected plain. Hillsides are convex and the drainage is of an arborescent pattern, the streams having a marked concavity of their gradients in the upper parts.

The Ukamba area consists of several hilly nuclei such as Kilungu, Mbooni, Kalama, Masokani and Momandu. These hills are composed of the harder rocks of the Basement System. Their shape is largely controlled by the structure of the rocks of which they are composed and by the major rivers that drain them. The summits of the hills show a rough concordance of altitude that indicates that they are relics of a peneplain.

The nature of the physiography is perhaps more easily understood by considering the geographical history of the area. The mountains of the Ukamba reserve, with their even summit heights, represent the remnants of the oldest land surface preserved in the area. The surface is approximately 6,400 feet above sea level and has been termed the end-Cretaceous peneplain (Dixey, 1948, p. 6). Erosion of this plain gave rise to a belt of highlands running through the present hill masses of Ol Doinyo Sabuk, Iveti, Momandu, West Kilungu and Olopinyo, and westwards towards Kajiado. This belt of highlands appears to have constituted a watershed of some magnitude, as evidenced by the course of the Athi river which runs round its northern tip and turns southwards to collect the drainage on its eastern slopes.

Early Tertiary erosion to a base-level some 2,300 feet lower than the end-Cretaceous surface led to the formation of marginal plains both east and west of the hill-belt and to the isolation of many inselbergs. These plains, classed together as the sub-Miocene peneplain, are now at heights of 5,350 and 4,800-4,200 feet west and east of the watershed respectively. At the beginning of the Miocene period the eruption of the Kapitian plateau phonolites on the west of the watershed resulted in a great part of the sub-Miocene surface being covered by lava. The surface of the Kapiti plains is still flat, as only a small amount of downward erosion of the resistant rocks of which they are composed has taken place in post-Miocene times.

To the south-east of the Kapiti plains the drainage area of the Lomungush, Selengai, Il Keju and Kiu-Kwawatingila rivers is clearly a part of the sub-Miocene surface that, being unprotected by a lava capping, is being eroded to a base-level some 800 feet below the original surface at 5,300 feet. The topography is at a late-youthful stage of dissection and has characteristic flat-topped ridges and spurs often covered by black peneplain soils.

The sub-Miocene surface east of the watershed was originally formed in the valleys between the major hills (see Fig. 1). These flat-bottomed valleys have been incised as a result of post-Miocene rejuvenation of the drainage and the original surfaces remain as large terraces deeply incised by gullies. Both of the two main eastwardly-flowing rivers, the Thwaki and the Keite, whose gradients to the Athi river are shorter and steeper than those of the rivers west of the watershed, have cut back through the divide. This is conspicuously shown by the Thwaki river which has captured the present Ekiwe-Potha-Kamutwa river system south and south-west of Machakos. The Ekiwe-Potha-Kamutwa rivers now drain eastwards into the Thwaki through the Maruba gorge, immediately south of Kilima Kimwe, and form a cataract that falls some 500 feet in a few hundred yards. The relic terraces of the sub-Miocene surface slope eastwards, being at 4,800 feet near Machakos and at 4,300 near Kiteta. They become more and more indistinct as one travels eastwards and a new cycle of erosion is almost complete in the areas nearer the Athi river.

The Sultan Hamud valley, drained by the Kwawatingila and Mkuyu rivers has suffered aggradation in mid-Pleistocene times. This is considered to have been due to the blocking of the valley by basaltic lava-flows in the vicinity of Enali. The valley

itself was partly infilled at this time by flows of olivine-basalt from Kelembwane and Mwani craters and the valley floor consists in various places of basalt, alluvium and unbedded sands at a level of 4,000 feet. Since the formation of this surface the rivers have cut channels about ten feet deep into the plain.

Many of the rivers appear to have become choked with sand in relatively recent times. This is considered to be due to a greatly increased rate of erosion as a result of a semi-arid climate rather than to aggradation as a result of tectonic depression.

III—SUMMARY OF GEOLOGY

Summary of Geology

The greater part of the area is occupied by rocks of the Basement System, which are generally considered to be of Achæan age. They are represented in the area by a stratified succession of originally sedimentary rocks all of which have been metamorphosed, some granitized to a greater or lesser extent, and which were invaded by basic igneous rocks prior to metamorphism. As a result of an east-west compression the original sediments were folded and depressed into the lower parts of the earth's crust where, due to elevated temperatures and pressures, the rocks were regionally metamorphosed, partly granitized and had a foliation impressed on them. This foliation, where observed in undoubted paragneisses, is found to be parallel to the planes of original composition and bedding.

Granitization, or the process whereby solid rocks are converted to rocks of a granitic character without passing through a magmatic stage (Read, 1944, pp. 46-47), is evidenced by the predominantly granitoid character of most of the rocks and by microscopic evidence, which indicates that alkali elements have been introduced into the fabric of the metamorphic rocks. The ultimate result of this granitization is that many heterogeneous rocks have been converted to a uniform granitoid gneiss.

The post-Archæan and pre-Tertiary history is one of repeated uplift and extensive erosion. The end-Cretaceous peneplain represents one of the "halt-stages" in that erosion, as also does the sub-Miocene peneplain. In early Miocene times crustal disturbance accompanying the formation of the Rift Valley caused great outpourings of phonolite lava which now cover the sub-Miocene peneplain in the western part of the area.

A second volcanic episode followed the phonolite eruptions during the upper Pleistocene. This vulcanicity built the great Chyulu range of basaltic volcanoes, and its north-western limit is represented in the present area by seven vents. There were no great lava flows associated with these vents, the main eruptives being basaltic ash. Basalt flows also occurred but were minor in importance and are usually confined to the vicinity of the vents.

Recent events have given rise to soils and laterites of various types and the rivers and streams have continued to incise their pre-existing channels. The increased aridity of the last few decades has resulted in the denudation of the country of much vegetation and in increased soil erosion.

IV—DETAILS OF GEOLOGY

1. Basement System

For convenience the Basement System rocks are described under the following headings:—

Sedimentary—

(a) calcareous rocks,

crystalline limestones,

anthophyllite rocks,

hornblende-diopside granulites,

amphibolites and quartz-felspar-hornblende gneisses;

(b) psammitic rocks,
quartzites and muscovite-quartz schists,
biotite gneisses;

(c) pelitic and semi-pelitic rocks,
biotite schists,
kyanite-staurolite gneisses,
hornblende-biotite-garnet gneisses.

Migmatitic—

banded and streaky gneisses of mixed appearance,
pegmatites,
aplites.

Granitoid—

homogeneous, massive quartz-felspar-biotite-muscovite gneisses,
“augen” gneisses.

Division of the Basement System rocks into the above four groups is not easy and often neither field nor laboratory criteria alone are sufficient to classify a given rock.

Much of the Basement System is bedded, and regular sequences of beds can be traced for considerable distances. In non-granitoid rocks such as the quartzites near Kiu, some beds on Wami hill, and rocks in other areas (e.g. Bear, 1952, pp. 4, 17), relic sedimentary features such as bedding, conglomeratic horizons, and arenaceous rocks with typically clastic grains are found. Also much of the banding in the gneisses is so uniform over distances of several hundred yards that it must be concluded that it is due partly, at least, to original differences in the composition of a sedimentary series. The migmatites and granitoid rocks are considered to have arisen by varying degrees of metasomatism of the originally metamorphosed Basement System rocks.

The granitoid gneisses represent the end products of the metasomatic process and in some cases became mobile at the height of metasomatism.

True pre-orogenic igneous rocks are rare while post-orogenic intrusive rocks of Archæan age are absent.

(1) REGIONALLY METAMORPHOSED ROCKS

(a) *Calcareous Sediments*

Crystalline Limestones.—Crystalline limestones (marbles) were found in the form of thin bands or lenses, varying from a few inches to two or three hundred feet in thickness, in Mbooni location where the limestone series forms Tulimani and Thosyeni hills. The series includes two persistent beds of limestone and several smaller lenticular bodies. A further limestone lens occurs near Makabete village, and a band runs parallel to the main road north of Kima station. The limestones are considered to be part of one stratigraphical zone as they are all associated with a characteristic kyanite-graphite-garnet-muscovite gneiss.

The Tulimani limestones are often pure white in colour and occasionally contain small knots of tremolite. The band near Kima is fine-grained and contains dark calc-silicate bands. Analyses carried out by various private organizations have shown that the limestones in the area are dolomitic.

Anthophyllite Rocks.—A thin band of compact dark-green anthophyllite rock (specimen 52/262) is found on the southern brow of Kiu Kubwa hill. It is composed of a dense interfelted mass of anthophyllite needles some of which reach 15 mm. in length.

A similar rock (specimen 52/226) but containing hornblende occurs as a thin band about one mile south of Wautu village. It is a hornblende-anthophyllite rock, the hornblende occurring as stout unorientated columns forming three-quarters of the rock by volume.

Hornblende-diopside Granulites.—Two specimens of this rock-type were collected but the assemblage is probably common in the marginal or semi-calcareous parts of the limestone bodies. One specimen, 52/249, was taken from the Kima limestone, the other 52/256 from a thin band on the south end of the Ngaamba ridge. They are both fine-grained, granular rocks consisting mainly of hornblende, diopside and microcline. Their approximate modal compositions* are as follows:—

	52/249 Per. cent	52/256 Per cent
Hornblende	30	40
Diopside	30	30
Microcline	20	25
Calcite	10	5
Quartz	10	—

Amphibolites and Quartz-felspar-hornblende Gneisses.—Amphibolites are common among the ungranitized banded rocks. Specimen 52/302 is characteristic of these rocks and occurs as a bed two feet thick in the Ngwane valley north of Mwanya hill. It is a grey-green rock with isolated porphyroblastic crystals of garnet and kyanite visible in hand-specimen. The green hornblende has a marked poikiloblastic habit and encloses small equigranular quartz grains like those that comprise the matrix of the rock. In thin section it is seen that epidote is common as minute granules scattered throughout. Lines of opaque flakes are thought to be graphite and one small garnet was seen. Rocks of this type frequently contain small amounts of plagioclase, for example specimen 52/278 from the Ekiwe valley south of Kilima Kimwe, which is a hornblende-plagioclase-quartz-rutile gneiss, while others contain scapolite (specimen 52/219, by the roadside about nine miles south of Opete). The modes of these two rocks are:—

	52/219 Per cent	52/278 Per cent
Hornblende	60	60
Quartz	20	30
Plagioclase	—	5
Biotite	—	tr
Epidote	10	—
Rutile	—	5
Scapolite	10	—

By increase of felspar the amphibolites sometimes grade into quartzo-felspathic hornblende-bearing gneisses. With the addition of potash the rocks take on the appearance of laminated leucocratic gneisses, when the hornblende is partly or completely converted to biotite, as in specimen 52/216.

Hornblendic microcline-bearing granitoid gneisses are rare. One example was found in the marginal zone of the Mbooni granitoid dome. A thin section of this rock (specimen 52/285) shows replacive plagioclase and microcline forming about 25 per cent of the minerals, and hornblende remains as skeletal crystal relics associated with granular epidote.

(b) *Psammitic Rocks*

Quartzites and Muscovite-quartz Schists.—Two quartzite lenses outcrop conspicuously at Kamaku and on another smaller hill to the south-west. The quartzite (specimen 52/263) is microscopically banded, with muscovite and biotite flakes visible on the foliation surfaces. In thin section this quartzite is seen to contain approximately ten per cent of kyanite in the form of small columns and anhedral grains. The kyanite sometimes occurs as clusters of larger subhedral grains apparently replacing quartz.

* All modal compositions quoted are volumetric.

A small exposure of muscovite-quartz schist occurs by the Machakos-Konza/Nairobi-Mombasa crossroads. This rock (specimen 52/275) contains 20 per cent of replacive oligoclase.

A pyrite-bearing biotite-muscovite quartzite (specimen 52/306), found at the ford of the Keite river north of Kitandi village, is particularly interesting since it contains up to 1.6 dwts. of gold. The rock is fine-grained and light grey in colour with the micas visible on the foliation surfaces. It has a slight colour lamination parallel to the foliation.

Biotite Gneisses.—Some of the widespread quartzo-felspathic gneisses, such as those on Wami and Kyumbi hills, are recognizable as being derived from arenaceous sediments. The rocks are hard and fine-grained and occasionally exhibit graded bedding. Large clastic quartz grains are seen to protude from their weathered surfaces and, where they are arranged in lines clearly indicative of original bedding, it is interesting to note that the lines coincide with the traces of the foliation planes in the rocks.

The biotite gneisses are often locally granulitic and on Kasikeu hill are crumbly, buff in colour, and stained with iron. Rib-like and flaggy outcrops are often found in these rocks though they are sometimes massive, as is seen in the south-west face of Kiu Kubwa.

Parts of a muscovite-schist band exposed on the Nduluni ridge show signs of having been derived from psammitic rocks. The quartz-muscovite schists and gneisses on Nduluni change gradually to micaceous quartzo-felspathic gneisses towards Kianini hill.

(c) *Pelitic and Semi-pelitic Rocks*

Biotite Schists.—Schists consisting almost entirely of micas are found as small slips in the southern foothills of the Nduluni ridge, particularly near Kilimandui. The biotite schists alternate with biotite gneisses and locally some small slips of vermiculite have developed. These biotite schists pass westwards along the crest of the Edido ridge but increase in felspar content, becoming biotite gneisses on the south-western slope of Kenzi hill.

Kyanite-staurolite Gneisses.—Staurolite was seen in three specimens, in two of which it was accompanied by kyanite. The specimens, which were taken from three widely separated localities, have the following modes:—

	52/227	52/259	52/289
	Per cent	Per cent	Per cent
Quartz	50	45	45
Felspar	25	—	—
Biotite and Muscovite	20	20	17
Staurolite	3	25	35
Kyanite	2	10	—
Accessories	—	—	3

52/227.—In valley about three-quarters of a mile south-south-west of Wautu.

52/259.—Mukaa.

52/289.—R. Mumozye, two miles east-south-east of Tulinani.

The three rocks are similar in that the quartz has a gneissose habit and biotitic partings. The staurolite is yellow-brown, pleochroic, and occurs in poikiloblastic

crystals enclosing quartz. Both staurolite and quartz show a marked preferred orientation of optic axes. In specimen 52/227 the kyanite occurs as small subhedral grains scattered throughout the quartz matrix, but in specimen 52/259 it occurs in large anhedral crystals of poikilitic habit. Plagioclase is present only in 52/227, being inequigranular but probably sedimentary in origin. It is twinned on the albite law and is andesine (An_{31}). Garnet is also seen in the hand-specimen but was not cut by the slice.

A related rock is specimen 52/220, from a point about three-quarters of a mile north-east of Wathini, which has hornblende in place of staurolite but in other respects is similar to the staurolite-bearing types.

Hornblende-garnet-biotite Gneisses.—Garnetiferous rocks are found principally in the zone of hornblendic paragneisses north and east of Ndatai hill and in the Kwambou river east of Mayani. The majority of the rocks of this zone are melanocratic biotite-garnet gneisses and schists with garnet porphyroblasts distributed in bands (specimen 52/245). Interbanded with the garnetiferous gneisses are hornblende-bearing rocks. It appears that garnet has formed in some bands by the change hornblende $\rightarrow$ biotite and garnet. It was frequently noticed that the garnetiferous beds are also distinguished by the presence of muscovite, and it is considered that the previously mentioned paragenesis was largely caused by alkali metasomatism which also gave rise to the muscovite. In general the biotitic rocks are associated with leucocratic gneiss.

Garnetiferous hornblende gneisses are also seen on the north-east brow of Tulimani hill. The rocks are dark green in colour, somewhat weathered, and crowded with dark maroon garnets. Considerable quantities of garnets are found as float below this exposure.

A distinctive garnet-kyanite rock was found near the junction of the Kiu and Mombasa roads. The rock contains large euhedral porphyroblastic crystals of kyanite coated with graphite. Garnets occur as smaller individuals associated with muscovite and biotite. A weathered kyanite-muscovite schist seen in a borrow pit by the main road two miles north-west of Sultan Hamud is probably a local facies of this band. A kyanite-amphibolite associated with the Tulimani limestones is considered to belong to the same horizon as the previously mentioned rocks on account of the similarity of the mineral assemblage and its constant association with limestone.

(2) MIGMATITES

Turner and Verhoogen (1951, p. 294) define migmatite as a rock "... 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 become megascopically recognizable". This interpretation of the term migmatite is used in the present report but it must be pointed out that the scope of the word is somewhat restricted since there are many "mixed" rocks in the Basement System where the mixed condition is only recognizable in thin sections. Perhaps a suitable name for such rocks would be "permeation gneisses". It is difficult, however, to make such a distinction rigid since the migmatites of the southern Machakos area are considered to have arisen as a result of differential permeation. Many differing opinions exist on the nature of the "granitic component" that forms a part of migmatites (see Read, 1944, p. 62). Read has shown that Sederholm's original use of the term migmatite required the admixture of granite magma but the writer follows Turner and Verhoogen in considering that "... it is not appropriate to insist on the participation of magma in the evolution of migmatites, for there are many geologists to-day who believe that the most typical members of the migmatite family have originated without the intervention of any silicate melt phase". As mentioned in the succeeding chapter, it is considered that the migmatites developed by metasomatism during the penultimate stage of granitization. The stages recognized in the southern Machakos area are represented by the following rock series: metamorphic rocks—banded gneisses—migmatites—granitoid gneisses.

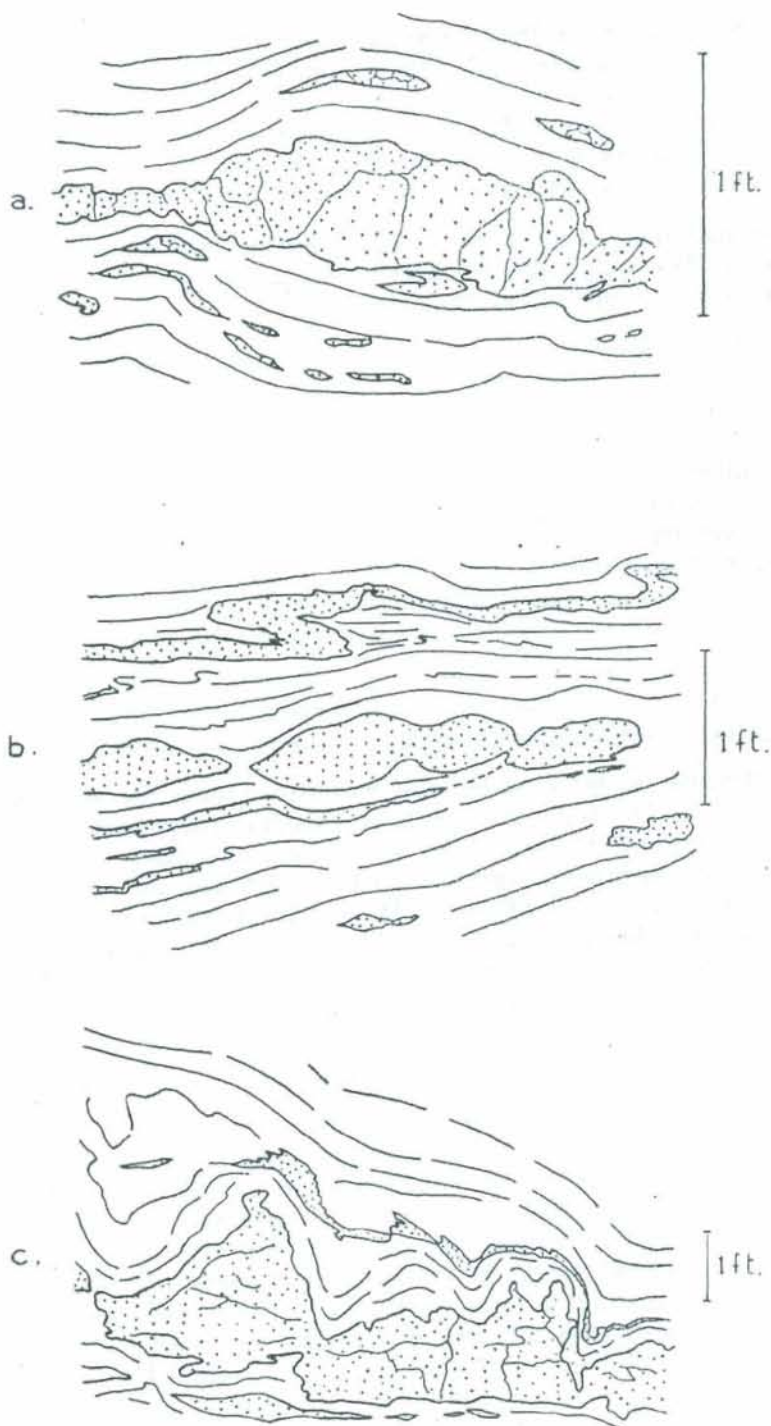


FIG. 2.—Structures in migmatites (redrawn from photographs).

- (a) Quartz lens in hornblende-biotite gneiss. Nzaini river, one mile north of Kee.
- (b) Pegmatitic veins in hornblende migmatite. Section on vertical face looking north-east, Mkuyu river below Opete.
- (c) Concordant pegmatite, contorted. Stream immediately north of Nguli ridge.

Considerable variation in the shape and size of quartzo-felspathic bodies in migmatites is found. They occur in the following forms—

- (i) micropegmatitic or quartzose lenticles conforming to the foliation of the host-rock and displacing it;
- (ii) quartzo-felspathic granulites and aplites, as stringers and irregular bands that usually conform to the foliation of the host-rock but appear to replace it;
- (iii) cross-cutting aplite veins;
- (iv) cross-cutting pegmatites.

These quartzo-felspathic bodies are considered to have been formed in the order listed. Those of the first type are possibly due to the segregation of quartzo-felspathic material from neighbouring rocks by a process of metamorphic differentiation. The rocks of the veins and lenses differ only slightly from the biotite gneisses described in the preceding section. Quartz, oligoclase, microcline, muscovite and biotite are the normal minerals in these aplitic, pegmatitic and granitoid bodies but as a rule they are lighter in colour than the metamorphic host-rocks in which they occur. They are characterized by the presence of variable amounts of microcline, which is seen to be replacive in thin sections.

A micropegmatite vein (specimen 52/251), from a little over one and three-quarter miles south of the Kiu branch-road junction with the Nairobi road, typical of the small cross-cutting veins three or four inches wide, contains microcline 50 per cent, quartz 20 per cent, muscovite 20 per cent, acid plagioclase five per cent. The quartz grains are irregular in habit and are much replaced by feldspar; sheaves of muscovite penetrate all the other minerals. The microcline has characteristic cross-hatched twinning and appears to replace quartz and plagioclase.

Specimen 52/281, from the Ngwane river in Mbooni location, is characteristic of the aplitic lenses and streaks commonly found in the migmatites. The rock is fine- to medium-grained, consisting of anhedral grains of quartz, albite, microcline and a few flecks of biotite. The feldspars are in general larger than the quartz grains and tend to replace them. Microcline is common as small interstitial grains. As is common among the migmatites the constituent crystals show marked hypidiomorphism and replacive relationships to one another.

A micropegmatite (specimen 52/223), from the Motheni stream near Mukaa village, is interesting in showing the replacement textures clearly. Here also the quartz was replaced first by twinned plagioclase and later both quartz and plagioclase were partly replaced by microcline. In one case plagioclase develops two small crystal faces against quartz. The relic nature of the quartz is shown by the fact that it has frilled and lobate margins, while adjacent quartz individuals in a felspathic base are frequently similarly optically orientated. Spongy skeletal crystals of muscovite replace some of the plagioclase.

A rock that may be called "transitional" between migmatite and homogeneous granitoid gneiss occurs in the stream south of Kitandani hill near Opete village. The rock (52/215) has small wisps of biotite gneiss but for the greater part is uniform and leucocratic. The thin section shows that it is coarsely granular with common incipient microcline porphyroblasts. Microcline is also present in some of the plagioclase as small vermicular myrmekitic bodies and it replaces plagioclase to a marked degree. Brown biotite accompanies the quartzo-felspathic constituents.

A good general account of the petrography of the migmatites has been given by Schoeman (1951, pp. 13-16) and his descriptions hold good for similar rocks found in the present area. Schoeman, however, applied a wider meaning to the term "migmatites"

than is used in this report and classed some rocks, now called granitoid gneisses among his migmatites. The microscopic characters of both classes of rock are, in fact, very similar.

The metamorphic component of the migmatitic rocks is variable in character and is usually more or less melanocratic. The host-rocks are almost invariably considerably granitized and are often biotite gneisses or hornblende-biotite gneisses. They contain a considerable amount of quartzo-felspathic material, also show most of the replacement textures described above, and are characterized by a lack of uniform bedding and by the presence of streaks and lenses of melanocratic gneiss. In some cases, as near Kiu station, the leucocratic rock is subordinate and is seen as anastomosing lenses in a melanocratic host-rock. With increase of the felspar content the rocks become predominantly granitoid in appearance and the darker gneisses remain as streaks. The leucocratic migmatites often grade into uniform granitoid gneisses across the strike and, less frequently, along the strike also. The transition from dominantly melanic to dominantly leucocratic migmatites, and finally to homogeneous granitoid gneiss, is well seen on traversing up the west face of Masokani.

(3) GRANITOID GNEISSES

The granitoid gneisses are homogeneous and unbedded, and often outcrop in tors, as large slabs or blocks on the summits of hills, or form more or less flat exfoliation pavements. They are distinctive only in the field since in hand-specimen they often resemble the bedded quartzo-felspathic gneisses. The main outcrops occur on Mbooni, Kalama and Momandu hills and also in the region of Opete village, the Mbooni and Opete outcrops being large and sub-circular with the surrounding gneisses curving round their outcrops. The shape and relationship of the larger bodies of granitoid gneiss suggest that they are granitoid domes resulting from the viscous upwelling of granitic material. The Kalama, Momandu and Kilima Kiu bodies are lenticular and conform roughly to the strike of the surrounding rocks. They may be interpreted either as granitic material injected into the succession as sills, or as granitized meta-sediments.

The granitoid gneisses are buff to dirty cream in colour and medium-grained. They are extremely uniform in composition and almost always have the following mineral assemblage—quartz-oligoclase-microcline-biotite-muscovite. Their microscopic characteristics are essentially the same as those of the leucocratic medium-grained parts of the migmatites. The thin sections show allotriomorphic and replacement textures, the latter being indicative of all grades of intensity of replacement. Microcline is an essential mineral and is invariably accompanied by turbid albite-oligoclase, both feldspars together usually forming 50 per cent or more of the rocks by volume. Some thin sections (e.g. that of specimen 52/294) show a tendency for the microcline to develop a porphyroblastic habit while in the western part of the Momandu-Mbebo mass true microcline-porphyroblast "augen" gneisses are found.

Pegmatites are few in the granitoid masses and only rare pygmaic pegmatite veins are seen. Quartz lenticles and "schlieren" are more common and appear to cross-cut the foliation.

The foliation of the Opete and Mbooni masses is much more pronounced at their margins than elsewhere. It is always parallel or sub-parallel to the margins and has a quaquaversal dip regardless of structures in the surrounding rocks. Wavy foliation is seen in some exposures near Opete and is sigmoidally folded. It was noted that the sigmoidal folding of the foliation in the Opete mass is in the same sense as the folding of the pegmatite veins in the adjacent migmatites.

(4) "AUGEN" OR MICROCLINE PORPHYROBLAST GNEISSES

These rocks are confined to the western part of the Momandu-Mbebo mass and to two exposures on the top of Kabani hill. They are massive well-foliated rocks, throughout which more or less idiomorphic microcline porphyroblasts are scattered. Closely-spaced biotitic streaks comprise the melanic constituent of the rock. The rocks are coarse-grained and have the appearance of gneissose granites. On Mbebo and the small tor to the west the rocks outcrop as conspicuous pavements on which is seen a pronounced northwardly pitching lineation, due to the alignment of the microcline porphyroblasts.

In thin section the Kabani rock (52/291) is found to have features generally similar to those in the granitoid gneisses. The texture is inequigranular, there being irregular lenticles of interlocking quartz grains surrounded by plagioclase and also much quartz as inclusions in plagioclase. Many of the irregular adjacent quartzes have a common optical orientation, indicating that quartz has been digested by feldspar. Some of the larger microcline individuals are full of more or less rounded and lobate quartz blebs and contain as well small orientated plates of biotite. The microcline phenocrysts have no sharply defined faces but have marginal inclusions of quartz, plagioclase and epidote. Part of the slice consists of granular untwinned plagioclase containing small inclusions of epidote. Small plates of biotite, granules of epidote and rarely granules of sphene are scattered through the slice.

Thin sections of specimen 52/304, from the same type of "augen" gneiss at Mbebo, show similar features but has minor amounts of muscovite. Some of the plagioclases have symplektitic textures and clear albite rims. The Mbebo "augen" gneiss grades eastwards into a coarse but even-grained granitoid gneiss without feldspar porphyroblasts and this, in turn, grades into banded gneisses of metamorphic appearance.

Whether or not the Kabani and Mbebo "augen" rocks represent gneissic granites is difficult to say. Such contacts as were seen are gradational and these rocks appear to have been subjected to the same diastrophic forces as the rest of the rocks in the area.

Small exposures on the southern face of the Mua hills consist of coarse to medium-grained leucocratic gneisses which develop a porphyroblastic facies locally. A thin section of the rock (52/294) shows microcline porphyroblasts and features similar to those described above.

2. Tertiary Volcanics—The Kapiti Phonolite

The Kapiti phonolite is found in the western part of the area, where it forms the surface of the Kapiti plains. Outcrops of the lavas are few except at the scarp of the Amaradike plateau and in stream valleys. In the neighbourhood of Stony Athi station the lava outcrops on the surface of the plain as rounded exfoliated boulders. The rock is hard and of a dark grey colour with a microcrystalline groundmass in which white or greyish anorthoclase phenocrysts are common and reach a size of 30 mm. Yellow-green waxy-looking nepheline phenocrysts are less frequent than those of feldspar but the two varieties of phenocrysts make up about ten per cent of the rock by volume. The phonolite has a holocrystalline-porphyrific texture (e.g. thin sections of specimens 52/272, 52/272A, 52/267). The anorthoclase phenocrysts are generally clear, unaltered and idiomorphic though corrosion of the terminal faces was noted in some cases. They are twinned on the Carlsbad law. The nepheline phenocrysts vary in size from ten to 20 mm., are subhedral, and contain marginal inclusions. They show little alteration. The groundmass consists of interfelted elongated feldspar prisms up to half a millimetre in length, the angular spaces between them being filled by coloured melanocratic minerals and isotropic feldspathoids. The ferromagnesian minerals are of two kinds—a brown sodic amphibole, occurring sparsely, and a green dusty sodic pyroxene, probably aegirine-augite. No olivine was seen. The groundmass has occasional euhedrons of nepheline in a mass of isotropic material of lower refractive index. Iron ores are

associated with the melanocratic minerals but are minor in amount. In some slices there are three generations of feldspar and two of nepheline; the order of crystallization is similar to that of the plutonic representatives of the phonolites, i.e. the nepheline—egirine—augite—interstitial feldspathoid (possibly analcime). A few small amygdaloids in the rock are filled with calcite.

These rocks are very similar to those described by Miss Neilson (Gregory, 1921, pp. 392-393), but she does not give a description of a phonolite from the type area at the Kapiti plains. The phonolites from the present area are virtually identical to those described by Campbell Smith (1951, p. 238) except that they have no olivine. The description of the Yatta phonolite given by Schoeman (1948, p. 36) corresponds exactly to the features seen in the phonolites of the Kapiti plains and is confirmation that the Yatta phonolite was contemporaneous with the Kapiti plains lavas. This is supported by the fact that both lavas rest on the sub-Miocene surface.

A small outlier of decomposed phonolitic tuff was seen resting on gneiss astride the Kiu-Kajiado road two miles south-east of the Amaradike plateau.

3. Pleistocene Volcanics—Olivine Basalts

The Machakos area contains seven olivine basalt vents, forming the north-western representatives of the Chyulu basalt ranges. The two largest vents are Kelembwane and Mwani, both situated in the Kwawatingila valley, north-west and north-east respectively of Sultan Hamud. Kelembwane is composed entirely of a highly vesicular black olivine basalt, the earlier flows of which covered the valley floor towards Sultan Hamud. Mwani crater consists principally of basaltic ash and agglomerate resting on an early basalt flow. The Maune basaltic vents in the south-eastern corner of the area are relatively small and consist mostly of vesicular lava.

There is considerable variation in the basalts discharged from the various vents. The basalt (52/292) of the most southerly of the Maune craters is a dark grey rock, parts of which carry xenoliths and xenocrysts of Basement rock. In thin section the basalt is seen to be micro-porphyrific-holocrystalline. Subhedral corroded augite microphenocrysts reaching two millimetres in size are common and are set in a grey matrix that is dusted with iron oxides. The augites generally have colourless cores and pale-greenish brown margins and occasionally show hour-glass and simple twinning. In many of the larger pyroxene phenocrysts numerous minute black inclusions are seen in the cores of the crystals. Olivine is present as small clear granules, but is subordinate to pyroxene in amount. The matrix is composed largely of iron ore and feldspar microlites but the latter are too small to be determinable.

The thin section is interesting in that there are several xenocrysts of quartz, feldspar and microcline in the basaltic host-rock. The xenoliths are surrounded by reaction coronas of greenish microcrystalline material and the plagioclase xenocrysts have lost their twinning. A microcline xenocryst retains its cross-hatched twinning at its core but is untwinned at the margins.

The Kelembwane basalt is similar to that of Maune but has fewer and smaller augite phenocrysts. The groundmass is coarser-grained and consists principally of feldspar microlites and a pale-brown pyroxene. The feldspar is albite-twinned and slightly zoned, the margins being labradorite and more sodic than the cores (bytownite, An_{71}).

The lava at the rim of the Mwani crater (52/208) has only a few augite phenocrysts, which are hypidiomorphic but corroded. Surrounding the digested augites there are often golden brown spongy masses of biotite. Olivines are numerous as small grains and are margined by a green chloritic alteration product. The matrix is fine-grained and has rather larger grains of iron oxide than in the preceding rocks. An ellipsoidal amygdale in this rock is filled with spherulitic zeolite and calcite.

The volcanicity associated with Busiani crater, in the south of the area, produced ash almost entirely. In addition to the ash that forms the vent, which is outside the present area, the ash is found as scattered sheets on hill-slopes and as washed material in valley bottoms. It is red-brown to chocolate brown, highly iron-stained, unbedded, and consists of small rounded particles of highly vesicular altered olivine basalt. The fragments range from the size of a pea to fine dust.



- | | | | |
|--|-----------------------------|--|--------------------------------|
| | Black cotton soils | | Chocolate-brown volcanic soils |
| | White or pink sands | | Grey sandy soils |
| | Red murram, red sandy soils | | |

FIG. 3.—Generalized soil map of the south Machakos area.

The olivine-basalt vulcanicity is clearly of the same age and type as that which led to the formation of the Chyulu range. The relatively undened nature of the vents and the fact that they rest on a relatively recent erosion surface suggested to Gregory (1921, p. 189) that they were of Lower Pleistocene age. No positive evidence for dating the vulcanicity has been found in the present area but the morphology of the vents, and the fact that the Mwani and Kelembwane lavas in the Kwawatingula valley have undergone little erosion, lead the writer to consider them as of Upper Pleistocene or Recent age.

4. Pleistocene and Recent Sediments

It is possible that pebble sheets found at various places on the Kapiti plain are of late Pleistocene age. The pebbles are all sub-rounded, consist of vein quartz, and have a light reddish-brown surface stain. They vary in size between four inches to one or two inches and have a white sandy matrix in some places, while in others they occur as sheets in friable black cotton soil. The pebbles may have originated from the watershed in the central part of the area and have been carried westwards by the drainage. Their well-rounded nature suggests, however, that they have travelled further than from the watershed a few miles to the east, and it is possible that the pebbles represent reworked sheets of earlier age that rested on the sub-Miocene peneplain during its formation.

Recent soils in the area are variable, their character depending on the drainage of the area in which they are found. The Kapiti plains are covered by black cotton soil in which are bands of quartz pebbles and calcrete horizons.

In the hillier parts the soils are red murrums and brown types, while on the steeper hill-slopes white or pink sandy soils predominate. In the numerous deep erosion gullies on hill-slopes considerable thicknesses (up to 75 feet) of unbedded red-brown soils of loessic appearance are often seen. On the ash deposits and on the basalts of Mwani and the Maune vents rich red-brown volcanic soil has developed. The alluvial plain surrounding Mwani crater is covered by white unconsolidated sand in the east near Mukuyuni, while near Kasikeu it is capped by hard murram.

A soil map (Fig. 3) shows the approximate distribution of soil types. A description of some soil types in the area is given by Gracie (1930, pp. 32-38).

V—METAMORPHISM AND GRANITIZATION

The sequence of events that resulted in the regional metamorphism and granitization of the Basement System rocks of the area is considered to be as follows—

- (i) sedimentation;
- (ii) downwarping of sediments;
- (iii) intrusion of basic igneous rocks;
- (iv) orogenesis; compression and folding accompanied by regional metamorphism;
- (v) granitization;
- (vi) cooling and achievement of stability.

That the Basement System rocks represent vast successions of metamorphosed sediments is generally agreed, and Umbgrove (1947, p. 82) suggests that the various migmatite belts composing the continental masses are the roots of ancient mountain belts that came into being as a result of the compression and folding of geosynclinal sediments. The Mozambique belt of which the Precambrian rocks of eastern and central Kenya at least are supposed to form part (Holmes, 1951, p. 256) may well have originated in such a fashion.

Depression of the rocks into deeper parts of the crust, assisted by folding, gave rise to regional metamorphism. The grade of metamorphism reached in some parts of the area is indicated by the mineral assemblages found in the non-migmatized rocks. The mutual stability of calcite and silica immediately places an upper limit to the temperatures that were reached during metamorphism. Thus the total absence of wollastonite, spinel and calcic plagioclase in meta-calcareous schists indicates that pressure-temperature conditions appropriate to the pyroxene-hornfels facies (Turner and Verhoogen, 1951, pp. 441-446) were not attained. The existence of pyroxene-hornfels facies mineral assemblages and sillimanite in other parts of Kenya indicates that higher grades of metamorphism have been reached in those places.

The majority of the metamorphic rocks in the area fall into the amphibolite facies and, more specifically, into the cordierite-anthophyllite sub-facies. Neither cordierite nor andalusite is known in the Basement System rocks of Kenya. These minerals are only found in stable potash-free regional metamorphic assemblages and their complete absence can hardly be explained by assuming there to have been no potash-free sediments. Both minerals convert to muscovite or biotite in the presence of potash and their absence may perhaps be explained by concluding that very few if any of the supposedly non-granitized rocks have been completely unaffected by potash metasomatism (Turner and Verhoogen, 1951, p. 447).

Many of the biotite gneisses and quartz-feldspathic granulites fall into the potash-rich division of the cordierite-anthophyllite sub-facies. Mineral assemblages typical of these rocks are—

muscovite - biotite - plagioclase - microcline - quartz
biotite - hornblende - plagioclase - microcline - quartz.

The existence of tremolite-dolomite assemblages such as those in the Tulimani region suggests that the prevailing temperature conditions were those of the lower part of the cordierite-anthophyllite facies.

Other rocks found in the area fall into the staurolite-kyanite sub-facies. The representative assemblages found are—

quartz - kyanite - staurolite - biotite
anthophyllite - hornblende
plagioclase - hornblende - almandine - biotite - quartz
diopside - garnet - calcite - microcline - quartz.

Epidote-bearing rocks generally fall into the garnet-diopside-hornblende sub-facies. The appearance of epidote in amphibolites is considered to be due to high stress which resulted in plagioclase becoming stable, with the fixation of lime in epidote. The frequent occurrence of epidote lenticles in amphibolites and even in some quartz-feldspar-hornblende-biotite rocks suggest such an origin for the epidote.

Some assemblages appear to fall into a lower facies—the albite-epidote-amphibolite facies. Such assemblages are—

quartz - albite - microcline - hornblende - epidote
quartz - albite - biotite - muscovite - epidote.

The rocks are not at all widespread and the epidote is frequently found concentrated in diffuse lenticles, indicating they may be derived from higher-grade rocks by shearing.

That some effects of granitization followed the regional metamorphism is indicated by the common observation that metamorphic mineral assemblages are modified and

converted to soda- and potash-bearing types. Mineral changes thought to be due to granitization are—

hornblende $\rightarrow$ garnet + biotite $\rightarrow$ epidote + biotite, silica $\rightarrow$ oligoclase,
plagioclase $\rightarrow$ microcline.

Whether the granitization, however, was ultimately the cause or the result of regional metamorphism is difficult to decide, but it is apparent that granitization began only when the rocks had been metamorphosed to a considerable degree and it is unlikely that it could have taken place on such a large scale unless the rocks had been at a high temperature and sensitive to changes of chemical equilibrium. The disequilibrium resulting from granitization makes it impossible to apply the facies principle to granitized rocks. The progressive introduction of exotic components into a metamorphic rock must result in a continuous disequilibrium of the mineral assemblages and this is well shown by the replacement textures commonly seen in the migmatites and granitoid gneisses.

It is probable that granitization came about as the result of alkali metasomatism. Metasomatism was defined by Lindgren (1933, p. 91) as "... the process of practically simultaneous capillary solution and deposition by which a new mineral of partly or wholly differing chemical composition may grow in the body of an old mineral or mineral aggregate". The solutions or vapours which act as the carriers for the "new" elements are aqueous solutions and not silicate melts. In the present area there is no evidence of the injection of granite magma in the sense of injection of a fluid of igneous origin. The reasons for excluding granite magma are partly given in the section dealing with migmatites. Many of the quartzo-felspathic bodies in migmatitic rocks are replacive in character, as also are many of the small ramifying aplitic veins (see Fig. 2, p. 10). Both the field and microscopic evidence point to a process of intimate selective permeation and replacement within the migmatites. It is considered that the alkali metasomatism (of the type defined by Lindgren) resulted principally in feldspathization, and microscopic evidence indicates that acid plagioclases formed first (soda metasomatism) and that subsequently microcline was developed (potash metasomatism).

The "migmatites" described by Schoeman (1951, pp. 11-16) are to a large extent banded and streaky and not all of them would be classified as migmatites by the present writer. Schoeman (op. cit., p. 12) considers that part of the leucocratic component of the banded gneisses is granite orthogneiss. But he described replacement textures of considerable intensity in the same rocks and it is considered that, had granite magma played any role in the formation of migmatites such replacement textures would be absent or rare. Also the medium to fine grain and absence of typical granitic porphyritic or idiomorphic textures make it difficult to consider the leucocratic portion of the migmatites of the present area as granite orthogneiss. Moreover, where the migmatites lose their even banded character, becoming streaky and having interfingering bodies of gneiss of various compositions, the field relations frequently indicate a replacive origin for the leucocratic rock component, in that the host-rocks are often not at all displaced.

Gorai (1951) has found by a statistical study of plagioclases in volcanic, plutonic and metamorphic rocks, that igneous granites have a high proportion of plagioclases with carlsbad, albite-carlsbad and other more complex twins. Twinning of plagioclase in either migmatites or granitoid gneisses is extremely rare in the present area, the only common occurrences being in some amphibolites which may well have been of igneous origin.

The regular banding of much of the metamorphic succession is therefore considered to be due primarily to the differences of original composition and not to migmatization. This view has been put forward by other writers dealing with comparable rocks (Read, 1948, pp. 187-189; Backlund, 1950, pp. 34-35).

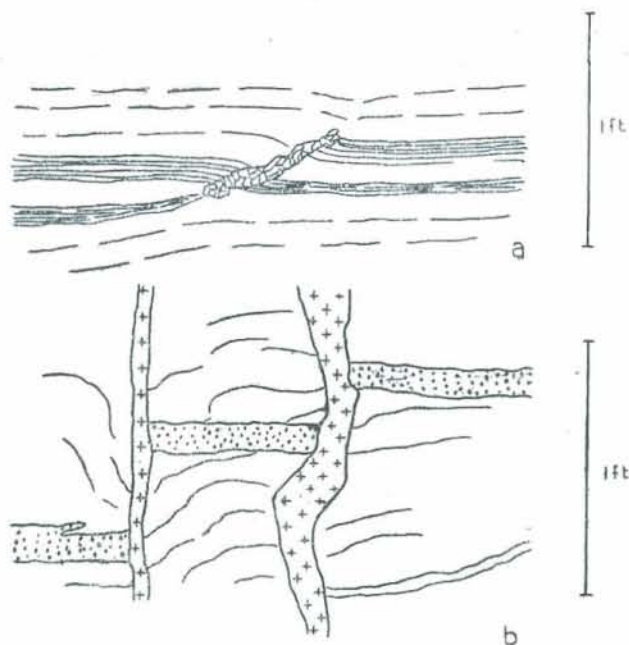


FIG. 4.—Pegmatites in shear-zones, South Machakos Area. (Redrawn from photographs.)

(a) Pegmatite lenticle in small shear. Nzaini river, one mile north of Kee.

(b) Small fractures infilled by micropegmatite. Ekiwe river, south-west of Kilima Kimwe.

The influence of shearing in the formation of small pegmatitic bodies is illustrated by Fig. 4. In many other cases it was observed that small pegmatitic or quartzose lenticles had formed along shear-planes. Different shearing stresses acting along original bedding planes may have influenced the distribution of metasomatically introduced alkalis, and thus have been the cause of some of the banding in the gneisses. In this connexion Schmidt (1932, pp. 183-187) has put forward an interesting hypothesis, suggesting that differentiation of originally homogeneous metamorphic rocks into laminated bodies may be due to the segregation of minerals with different reactions to stress. Thus quartz, calcite and albite, that can readily adjust their crystal lattices to the imposed stresses, separate from the micaceous or amphibolitic minerals, which adjust themselves by reorientation of their c-axes into the slip directions. It is possible that this process, in conjunction with other methods of metamorphic differentiation may account for the laminated character of some of the slightly granitized rocks, particularly where the banding is irregularly developed.

It is concluded that alkali metasomatism, following on isochemical regional metamorphism, resulted in the selective enrichment in alkalis of certain bands of rock, such as those of arenaceous and semi-pelitic composition, emphasizing banded successions. Further metasomatism gave rise to excess intergranular fluids which crystallized along planes of shear as ovoid "boudins" or stringers of pegmatite. Up to this point the process may be considered to be one of differentiation, in that the introduced material was fixed in certain bands or individual points rather than distributed evenly throughout the rocks. Rocks in this state are considered to have been capable of irregular incompetent contortions and limited plastic flow. At a still later stage of metasomatism a process of homogenization began which resulted in the regular bands or lenticles becoming diffuse. The resultant rock types are then found as scattered interfingering lenses of more or less leucocratic appearance. The final product of this process is granitoid gneiss, a completely homogeneous rock that was capable of plastic deformation, but too viscous to inject or stope the surrounding rocks which themselves yielded by plastic flow.

The larger pegmatites formed subsequently to the main period of metasomatism and cross-cut the rocks, probably being injections of pore fluid into tension fractures. That such pegmatites are frequently of local origin is suggested by the occurrence of garnet pegmatites, kyanite pegmatites and muscovite pegmatites in rocks rich in these minerals.

VI—STRUCTURES

The main structural features of the area are shown on Fig. 5. The present area differs considerably from other areas of Basement System rocks that have been mapped in Kenya in that the strike directions are not parallel and trending generally north-west-south-east or north-south, but swing around two nuclei of granitoid gneiss. The most outstanding feature is the concentric arrangement of strike directions about the Opete granitoid gneiss. The concentric pattern is more marked to the west of Opete while to the east sharp folds are packed against the granitoid dome, the folds pitching steeply northwards.

The principal folds are the Kawanini syncline, the Masokani monocline, the Mbooni axis and a more diffuse synclinal axis centred on Kiu and Momandu.

The Opete dome is surrounded by folds closely packed about its margin, the largest being the Kawanini syncline. This structure appears to be a normal syncline at its nose on Kawanini hill, where it pitches northwards, but its western limb as seen in the Kimutheni river becomes reversed, possibly overturned, and the fold becomes an isoclinal overturned syncline. Moreover the axis of the fold curves from a north-west-south-east to a north-south and finally an east-south-east-west-south-west direction, the total change in direction amounting to approximately 120 degrees. The Masokani monocline pitches southwards, its western limb being almost vertical near Wautu while the eastern limb dips gently to the east.

The Mbooni dome occupies the core of what may be pictured as a broad pitch culmination, the eastern and south-eastern sides of which are vertical. The principal axis of the pitch culmination runs roughly north-west-south-east and pitches steeply northwards on the northern edge of the structure. The axis culminates northwards in a carinate fold represented on the ground near Kaani by a zone of vertical rocks.

The tectonics of the area thus appear to be dominated by two dome-like structures whose centres are infilled by granitoid gneiss. Folds are packed about these bodies and the predominant dip of the surrounding folds is quaquaversal. The folds are often carinate and vertical on the eastern and south-eastern faces of the domes. Since it is considered that the Opete and Mbooni masses, among others, may have been in a plastic state at the height of metasomatism, it is possible that the surrounding structures were initiated by the viscous upwelling of migmatitic material. It is also possible that, as temperatures diminished, leading to the solidification of the granitoid masses, continued compressive forces packed the relatively competent surrounding schists around the domes.

In connexion with the origin of the granitoid domes it is interesting to note Wegmann's ideas on the structure of some migmatitic terrains. According to Read (1944, p. 69) he says: "A distinction must be drawn between happenings in the non-migmatitic superstructure and the migmatitic infrastructure lying below. The two zones fold in disharmonic fashion, and the migmatite zone comes to fill the arches in the superstructure, as is seen in Greenland. Between the two zones is a transitional zone which is the site of the so-called regional metamorphism. . . . In these compressed arches of the infrastructure, recrystallization is especially intensive. . . ." The general picture outlined by Wegmann is believed to apply to the present area.

The arrangement of folds about the Opete structure suggests that some rotational movement took place, with the Opete dome as axis. Certainly the structures mapped could not have developed as a result of a simple east-west compression such as has been invoked in other areas to explain Basement System structures. Clockwise rotation of tectonic units could possibly have resulted from the application of east-west com-

pressive forces so long as complementary north-west-south-east and north-east-south-west shears were developed as well. The north-west-north-east shear-zone in hornblendic paragneisses near Mayani represents such fractures.

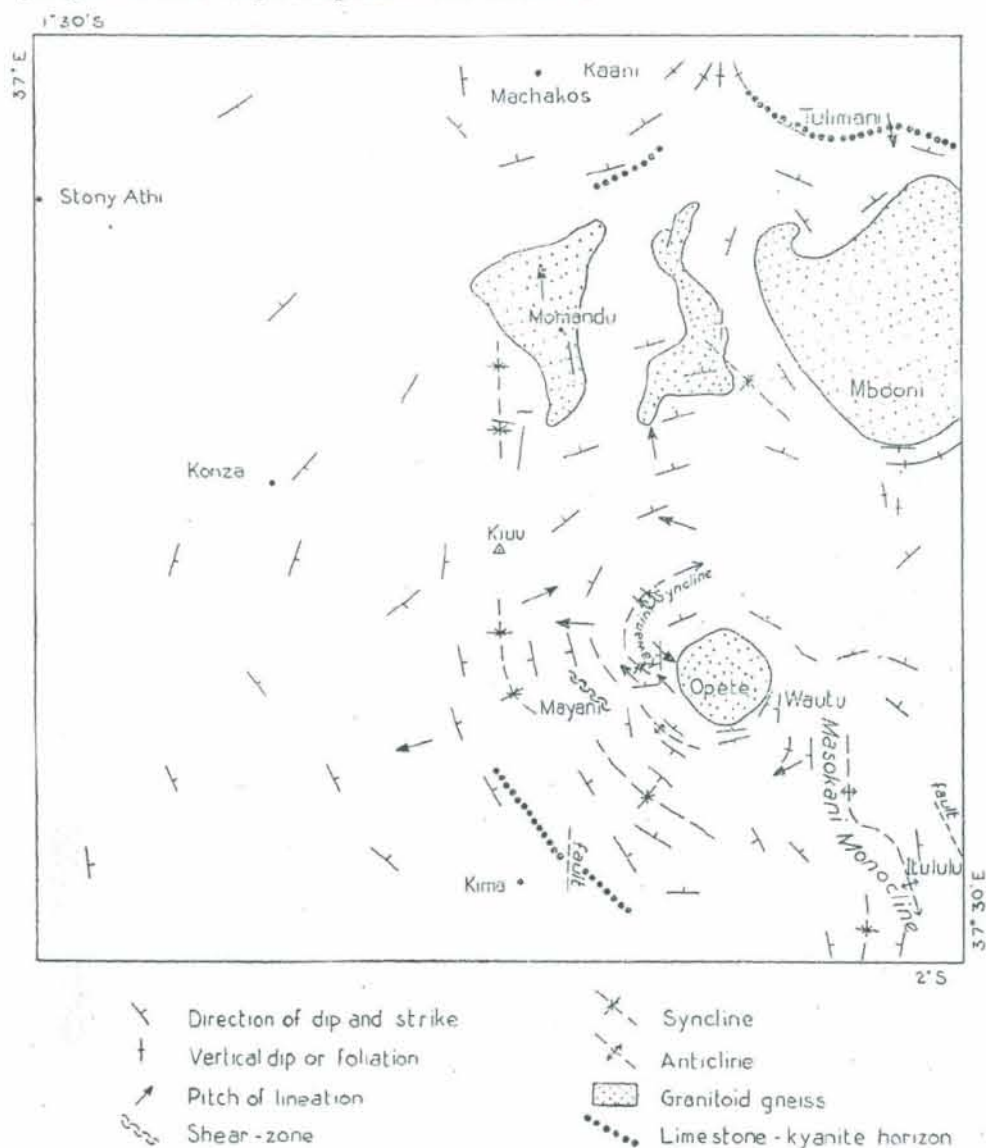


FIG. 5.—Structure Map of the South Machakos District.

Minor structures observed in the area include lineation, wavy foliation and contorted pegmatitic veins. The lineation usually pitches northwards in the northern part of the area but in the south it also pitches to the east and west. Wavy foliation was seen in the Opete granitoid gneiss and overfolded pegmatite veins were seen in a number of places, but are most spectacular near the ford over the Mkuyu river north of Kianini hill. The pegmatite veins are overfolded towards the north-west.

The structural history of the area probably began with the application of east-west compression, which resulted in open simple folding of the rocks. The regional metamorphism which accompanied folding was superseded by granitization, which altered the style of the folding by converting some members of the rock succession into plastic migmatites or granitoid gneisses. As a result of the plastic nature of the more highly granitized rocks updoming of the granitoid gneiss occurred at the two principal centres of granitization—Mbooni and Opete. Continued pressure caused smaller folds to be packed about the granitoid domes and the concentric nature of some of these fold axes may have been influenced by rotational couples resulting from the formation of dominantly north-west-south-east shears.

Two small faults were found, one near Kima, the other on the eastern margin of the area near Itululu. Both are small, probably intraformational, tension faults.

VII—ECONOMIC GEOLOGY

1. History of Prospecting

With the exception of areas in western Kenya, the Machakos district appears to have been more intensively prospected than any other part of the Colony. This is partly due to the proximity of roads and the railway and the ease of access from Nairobi.

The first recorded mining title was that of W. Zeuner, who pegged four claims on Kikamoa hill at Mukaa in March, 1911. Since that date a total of 226 claims have been registered as pegged in the area in the names of 24 prospectors. Zeuner's claims, which were for mica, were abandoned soon after they had been pegged, but in late 1912 W. J. Moynagh and L. Paqualin obtained an unsurveyed lease of approximately 1,012 acres in the Kikamoa vicinity. During March, 1913, Messrs. F. Marquardt, A. Minners, C. Blanke and R. P. Huebner pegged four claims for mica nearby.

Later, in 1913, J. H. Scott, H. G. Cullinan and J. W. Ward pegged a total of eight claims for mica a few miles east of Kiu station and on Mwia hill. Although a little exploration of the mica pegmatites was undertaken no mica production resulted. Also in the period 1913–14, Moynagh associated with T. Deacon, L. Tebay and L. Clark was active on the Kikamoa claims but again no mica production resulted. These claims at Mukaa were subsequently transferred to Newland Tarton & Co., Ltd., of Nairobi.

The outbreak of the first World War caused a pause in prospecting activities lasting until early 1918. At this time the War Office and the Ministry of Munitions in London began to urge the East African Territories to develop their mica prospects, with a view to exporting to the United Kingdom to speed wartime aircraft production. An account of the work carried out as a result is detailed in a later section (p. 24).

In July, 1920, C. M. Kilby and L. O. Hooper pegged adjacent claims on the west slopes of Elima hill in the south-east part of the area. No valuable minerals were found and the claims were abandoned the following year. During 1921, J. Knight and C. P. Connor pegged 11 claims for graphite in the Kamutwa river, five miles south of Machakos but nothing was produced and the claims were abandoned.

There was little prospecting activity in the area during the period 1922–1936, due partly to the diversion of interest to the gold-bearing areas of western Kenya. A. N. Holden and S. Everett, however, pegged claims on the well-known mica pegmatite localities at Kikamoa and Kenzi in 1929 but no mica production resulted. Between 1936 and 1945 there was considerable activity in prospecting and mining mica (p. 25).

Most of the prospecting activity during the 1939–1945 war and after, apart from the search for mica, was concentrated on and around Tulimani hill in the Mbooni location. S. T. Thakore pegged four claims on Tulimani hill in 1943 but allowed them to lapse within a year. During the years 1945–6 C. R. Stokes-Fair pegged 15 claims in the Tulimani vicinity, principally for talc, one claim being for graphite and four for asbestos. A small production of talc resulted from the working of some of these claims, but they were transferred to R. T. Lewis and F. L. Guays and subsequently lapsed

during the years 1947-8, Lewis and Guays produced small quantities of talc from a single claim in Manyala location, near Makabete village, but this also ceased in 1948.

Also in 1948 Cull pegged a block of 20 claims two miles north-west of Sultan Hamud station and an African, Paul Muindi, pegged ten claims on the talc area near Tulimani hill. L. J. Folkard pegged 30 claims on the Manyala talc in 1950 without any recorded production resulting. O. J. Mallitte pegged ten claims for garnet on the Kiluoni river immediately south of Tulimani hill late in 1951 and this prospect is being developed at the moment (February, 1952). P. H. Cull recently pegged 22 claims for kyanite on Mubai hill.

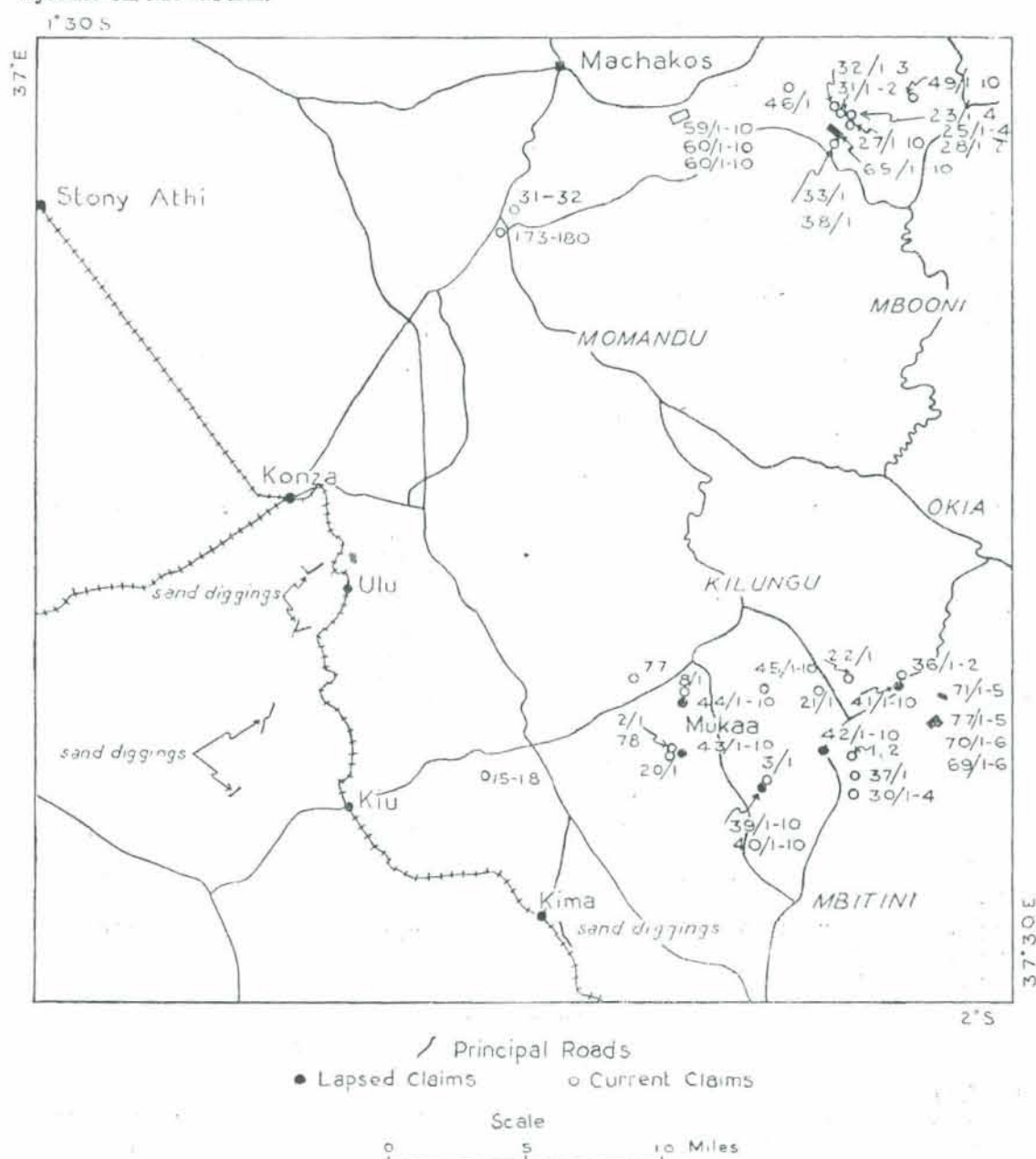


FIG. 6.—Sketch-map Showing the Approximate Position of Mining Claims in the South Machakos Area.

The claims that have been pegged in the southern Machakos district since 1911 are listed in the following table. The approximate positions of the claims are shown on Fig. 6.

No.	Name	Locality	Year
(4 claims)	C. Zeuner	Mukaa	1911
1-6	J. H. Scott	Mwia Hill	1913
7	H. G. Cullinan	Mwia	1913
8	J. W. Ward	Mwia	1913
15-18	W. G. Parker	Kiu	1917
(1 claim)	C. M. Kilby	Elima	1920
(1 claim)	L. O. Hooper		
31-34	J. Knight	Kamutwa	1921
173-180	C. P. Connor	Kamutwa	1921
77	A. N. Holden	Mukaa	c. 1928
78	S. Everett	Kenzi	c. 1928
2/1	P. H. Cull	Kenzi	1936
3/1	P. H. Cull	Nduluni	1936
8/1	A. N. Holden	Kawanini	1938
20/1	E. L. Wright	Kenzi	c. 1942
21/1	E. L. Wright	Kilungu	1943
22/1	E. L. Wright	Kilungu	1943
23/1-4	S. T. Thakore	Tulimani	1943
25/1-4	C. R. Stokes-Fair	Tulimani	1944
27/1-2	C. R. Stokes-Fair	Tulimani	1944
28/1-2	C. R. Stokes-Fair	Ubani	1944
30/1-4	C. R. Stokes-Fair	Masokani	1944
31/1-2	C. R. Stokes-Fair	Tulimani	1945
32/1-3	C. R. Stokes-Fair	Tulimani	1945
33/1	C. R. Stokes-Fair	Tulimani	1945
36/1-2	P. H. Cull	Kilungu	1945
37/1	P. H. Cull	Masokani	1945
38/1	C. R. Stokes-Fair	Tulimani	1946
*39/1-10	P. H. Cull	Kioo	1947
*40/1-10	P. H. Cull	Kioo	1947
*41/1-10	P. H. Cull	Itaa	1947
*42/1-10	P. H. Cull	Wautu	1947
*43/1-10	P. H. Cull	Kianini	1947
*44/1-10	P. H. Cull	Kawanini	1947
*45/1-10	P. H. Cull	Keutaa	1947
46/1	R. T. Lewis and F. L. Guays	Manyala	1947
49/1-10	Paul Muindi	Tulimani	1948
59/1-10	L. J. Folkard	Manyala	1950
60/1-10			
61/1-10	O. J. Mallitte	Tulimani S.	1951
*65/1-10			
*69/1-6	P. H. Cull	Mubai	1951
*70/1-6			
*71/1-5			
*77/1-5			

* Current claims.

2. Economic Minerals

(1) Mica

In response to the demand for mica during the later stages of the 1914-1918 War, Captain H. B. Bateman was recruited as Government Mining Engineer and mica mining was started early in 1919 at Kenzi hill, Mukaa, the operations being under the charge of E. Stacey, Assistant Government Mining Engineer. Stacey despatched a first consignment of cut and graded mica of 1,132 lb. net weight to the coast on the 20th March, 1919. On the 19th May, 1919, the Secretary of State for the Colonies ordered expenditure on mica mining on behalf of the United Kingdom Government to

cease, and, as a result, it was decided to close down the mining activity at Kenzi. In winding up the work further consignments of 1,850 lb. net weight and 3,038 lb. gross weight of cut and graded mica were despatched to England on the 26th May, and 14th August, 1919, respectively.

On its arrival in England the mica was commented on by two London firms who reported that much of it was spotted, striated and had been split too thinly. In general the mica was considered to be of fair to poor quality. A total of 2,717 lb. net weight of mica was examined and was valued at £106 12s. The average value of the mica was therefore 11.3 pence/lb. which corresponds to "stained" grade mica No. 6 size at the 1918 prices. Similar mica would have commanded 3 pence/lb. in 1912 and approximately 1.50 to 2.50 per lb. in 1948.

The cost of the mica mining operations undertaken by Kenya Government was considerable and it was decided to publish a notice inviting tenders for the right to take up one or more mineral leases in the areas formerly worked by Government. The tenders for Machakos were to be for five areas: Kenzi, Kilimandui, Ngaamba, Kulu and Kawanini. In the last four areas no mining has been done. There is no record that any tenders for the leases in the Machakos area were received and finally the area was reopened to prospecting.

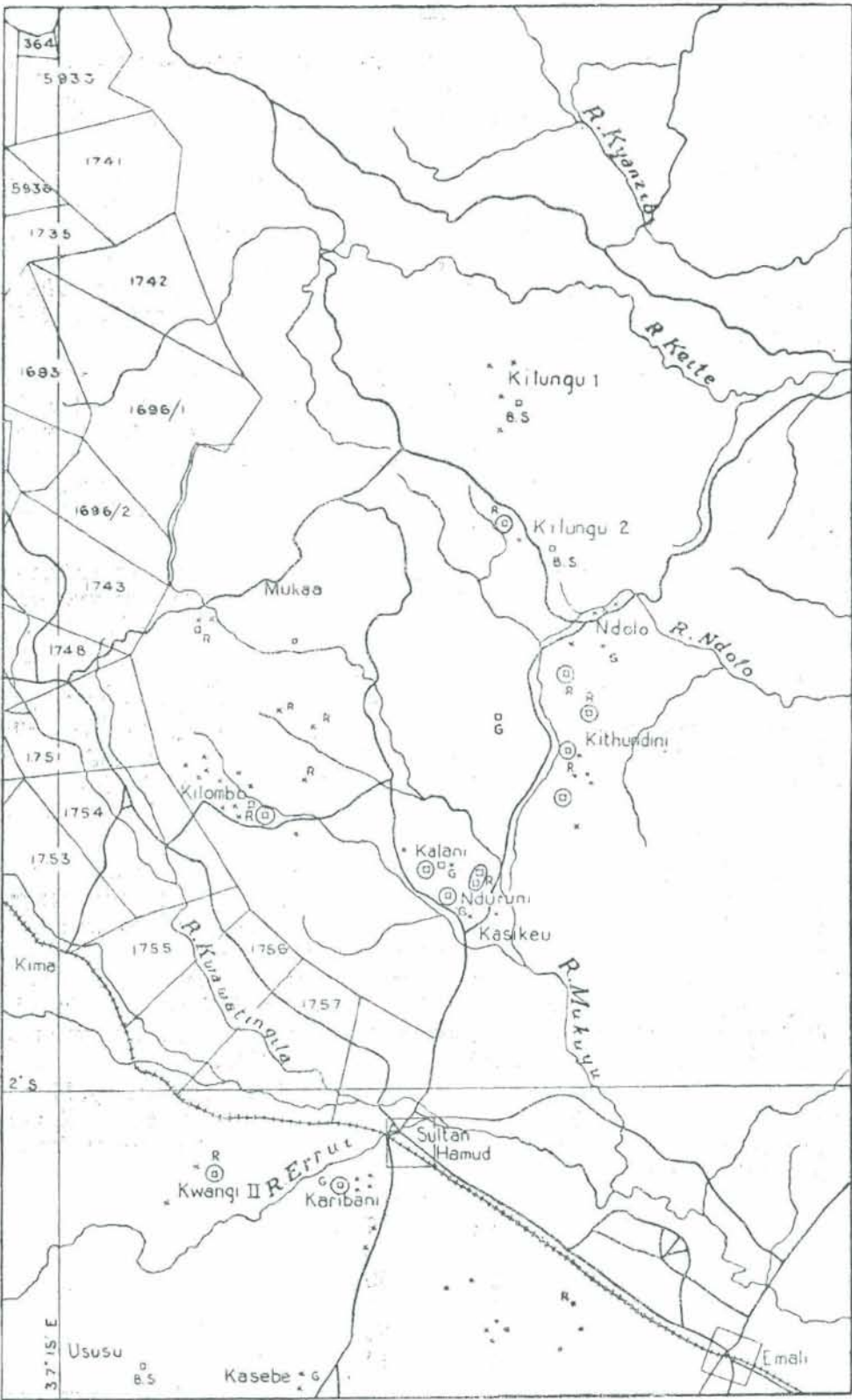
P. H. Cull began prospecting in the area in 1936 by pegging two claims on the old mica prospects at Nduluni and Kenzi. These claims lapsed after one year but were repegged by E. L. Wright in 1942, and A. N. Holden also pegged a claim on Kawanini hill on the mica prospects in 1938, but all the claims lapsed without any mica production having resulted, though some beryl was recovered. Cull began more serious mica prospecting during 1938, his activity being mainly on Kenzi and Kianini hills. Cull was granted Exclusive Prospecting Licence No. 73 over four square miles on Kianini and Kenzi hills in August, 1938, and did some development of the muscovite pegmatite there. As a result of this two shipments of cut and graded mica were made of 1,680 and 1,313 lb. in April and August, 1939, respectively. Cull's licence expired on 1st August, 1939.

The first intimation that the Ministry of Supply in London was again in urgent need of mica came on 10th January, 1941, but no concerted effort to stimulate production was made till 30th June, 1942, when several areas were closed to prospecting by Government Notice No. 585. In Schedule (1) of this Notice an area of 430 square miles, including all the previously known mica prospects, in the south-east corner of the district, was closed to prospecting. Applications for exclusive prospecting licences were invited by means of advertisements in the Press but no applications were received. As a result the closed areas were reopened in December, 1942.

During 1942 P. H. Cull was the only producer of mica in the Colony, his production totalling 4,747 lb. up to the end of 1942. Three shipments made in 1942 averaged Sh. 5.19, Sh. 3.39 and Sh. 1.86 per lb. of cut mica respectively. An average size grading of this mica is given below:—

Size	Per cent
1+	7
2	5
3	10
4	23
5	23
6	32

The Ministry of Supply in London decided to set up a central buying and grading organization in East Africa, with the intention that it should advise and, in some cases, give financial support to promising mica mining concerns. As a result of this decision a branch of Associated Insulation Products, Ltd. (referred to below as A.I.P., Ltd.), was formed in October, 1942, to operate in East Africa, with headquarters in Dar es Salaam,



R Ruby Mica	▲ Prospect	} According to Mica Mining (Kenya) Ltd
G Green Mica	◻ Working	
BS Black Spotted Mica	⊙ Good working	

Scale
0 1 2 3 4 5 miles

FIG. 7.—Mica Prospects in the South Machakos Area. Based on a Map Supplied by Mica Mining (Kenya) Ltd., 1943,

On the 30th June, 1943, an order was made (Defence (Sale of Mica) Order, 1943), to ensure that no mica was sold other than to the newly established A.I.P. (Africa) Ltd. Cull was still the main producer of mica in the Colony but, as the total mica production of Kenya was small, A.I.P. Ltd. did not consider it economic either to value or buy at the Kenya mines or, with one exception, give financial assistance to Kenya mica producers. Cull tried to obtain a licence to enable him to export direct to the United Kingdom but was unsuccessful. A.I.P. (Africa) Ltd., under pressure to develop the Kenya mica potentialities, formed Mica Mining (Kenya) Ltd., and in May, 1943, obtained a special licence over an area of approximately 1,000 square miles in the South Machakos and Sultan Hamud areas. This organization in 1943 produced 2,727 lb. of cut mica valued at Sh. 5,602, giving an average figure of just over Sh. 2 per lb. The licence was abandoned in December, 1943, as there had been a loss of some £6,000 on the operations, and the Company confined itself to prospects in Tanganyika where more profitable mines existed. Cull continued to produce small quantities of mica during 1944 but was unwilling to sell to A.I.P. Ltd. at their valuation, and none of the mica produced at Sultan Hamud appears to have been exported during 1944-45. At the present moment Cull holds 90 claims on almost all the known mica occurrences but there is no mining activity on them.

(2) Talc

Talc deposits are known in the Tulimani limestone succession, where there are two old diggings situated on the northern slope of Thathaeine hill north of Tawa village. The pits are roughly 20 by 30 by 10 feet in size and are sunk in limestone and talc-tremolite rock. The talc is of the fibrous variety with a pale greenish-blue colour and is frequently associated with colourless radiating columns of tremolite. Slips of almost pure talc up to three or four inches long and two or three inches wide are common, but the talcose zone as a whole consists of mixtures of talc and tremolite with talc predominating. This deposit was originally worked on a small scale by C. R. Stokes-Fair but is now disused. As a result of the impurities and the colour of the material it found only a limited local use and none was sent abroad.

Stokes-Fair also discovered a further deposit in Manyala location north-east of Makabete village and this passed into the possession of Lewis and Guays on his death. Lewis and Guays worked the deposit for a short time but, again, the smallness of the tonnage of easily won talc put an end to their operations. The talc, some of which appears to be very pure, occurs in lenses and slips in a shear-zone running through crystalline limestone. Tremolite is present as in the Tulimani occurrences and much of the talc is stained and mixed with soil. Pure talc can be obtained from this locality by hand-picking but it is difficult to eliminate the finer particles of tremolite.

Analyses of the talc from both localities have been made:—

				I	II	III	IV
				<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>	<i>Per cent</i>
SiO ₂	..	..	..	61.85	57.75	60.08	60.87
Al ₂ O ₃	..	..	..	0.69	2.28	1.08	0.38
Fe ₂ O ₃	..	..	..	0.31	3.28	1.78	0.80
FeO	..	..	..		2.09	2.66	0.36
MgO	..	..	..	30.68	27.86	28.66	28.97
CaO	..	..	..	0.67	0.69	0.56	4.20
Na ₂ O	..	..	..	0.16	N.D.	N.D.	N.D.
K ₂ O	..	..	..	0.73	N.D.	N.D.	N.D.
H ₂ O	..	..	..	5.10	6.67	5.29	3.38
TiO ₂	..	..	..	0.22	tr	tr	tr
P ₂ O ₅	..	..	..	N.D.*	—	—	0.80
				100.41	100.62	100.09	99.76

Analyst: A. F. R. Hitchins, Government Chemist.

I. Manyala talc.

II, III, IV. Tulimani talc.

* N.D. = not determined.

A calculated granimetric mode derived from analysis IV is as follows:—

						IV
						Per cent
Talc	..	..	..	..	..	69.95
Tremolite	..	..	..	..	..	23.50
Apatite	..	..	..	..	..	1.92
Magnetite	..	..	..	..	..	1.16
Excess SiO ₂	..	..	..	..	..	2.90
Excess Al ₂ O ₃	..	..	..	..	..	0.38
Excess H ₂ O	..	..	..	..	..	0.09
						99.83
Less F	..	..	..	..	..	0.07
						99.76

In general it is considered that the off-white colour of the talc, the small surfaces exposures and the contamination with tremolite militate against its value for export, but small quantities might be profitably dug for local use. The amount of material mined up to the present appears to have been somewhat less than 200 tons. The record of production is as follows:—

					Tons	Value
						£
1945	..	..	..	..	66	792
1946	..	..	..	..	not recorded	
1947	..	..	..	..	20	210
1948	..	..	..	..	4.96	25
1949	..	..	..	..	83	414
1951	..	..	..	..	Nil	—

(3) Kyanite

In 1947 P. H. Cull discovered an interesting kyanite-bearing pegmatite on the northern slopes of Kioo hill east of Kyatta (Wathini) village. The pegmatite is approximately six or seven feet in thickness and besides the usual quartz and opaque felspar it contains tourmaline, pockets of greenish glassy oligoclase (Game, 1949), sheets of vermiculite, and kyanite. The kyanite crystals are blue and unusually large, being as much as one foot in length and several inches across. The crystals are scattered throughout the rock. Cull has extracted some of the kyanite, but such an occurrence can be of no general economic value in view of the small tonnages available, though some of this kyanite has been sent abroad for use in museums, universities and schools. A dump of kyanite taken from Kioo may be found behind some shops in Sultan Hamud township.

Kyanite gneisses occur in the Tulimani schist zone and are found in vein-quartz segregations on the top of Thosyeni hill. The amount of kyanite available is small, but the hillside is littered with blue kyanite float and it is possible that larger segregations of kyanite may be found in the vicinity.

A further zone of kyanite gneisses was discovered by the writer adjacent to the Nairobi-Sultan Hamud road, from mile 55 to mile 65. The rock is a kyanite-garnet-muscovite-graphite schist, the kyanite occurring as large columns up to two inches in length. Only one outcrop of this rock was seen but the horizon is marked by quantities of kyanite float. An extension of the same kyanite band is found in a borrow-pit by the main road at mile 73, near Sultan Hamud. The rock is a kyanite-quartz-muscovite schist in a very decomposed condition. Above the *in situ* rock, murram and ironstone balls are intermingled with kyanite crystals in a residual gravel. It is considered that small amounts of kyanite could be separated without difficulty at this locality but it is unlikely that the deposit could support large-scale operations. The occurrence was pegged by P. H. Cull in 1948, but the claims have since been abandoned.

Quartz-kyanite schists outcropping on Mubai hill have been examined by Dr. B. N. Temperley of the Mines and Geological Department, and the facts given here are taken from his report. The deposit was discovered by P. H. Cull who, between November, 1951, and June, 1952, pegged 29 claims over it. The locality is reached from the col on the Okia-Wautu road, about eight miles north of Wautu, by walking along a goat-track that follows the crest of the hill.

Kyanite schist occurs in places on the crest of the Mubai ridge and also as alluvial boulders on the sides of the Ndolo river valley. The quartz-kyanite schist outcrops over a length of 600 yards and averages five feet in thickness. It is probably lenticular in form and, assuming that half the schist lens remains underground, the total tonnage of schist available will be about 500,000 tons. The schist boulders occurring about 2,000 yards south of the Mubai ridge in the valley sides were calculated to total 20,000 tons approximately.

Heavy media separation of six samples taken by Temperley gave the following percentages of heavy minerals (kyanite, rutile and ilmenite):—

	Per cent heavies					
A	..	..	..	..	..	27.0
B	..	..	..	..	..	31.5
C	..	..	..	..	..	31.2
D ₁	..	..	..	..	..	28.0
D ₂	..	..	..	..	..	29.2
D ₃	..	..	..	..	..	27.5

Sample C was analysed with the following result:—

	Per cent					
Al ₂ O ₃	..	..	..	..	..	18.87
Fe ₂ O ₃	..	..	..	..	..	1.39
TiO ₂	..	..	..	..	..	0.42

Calculation shows that the sample must contain about 30 per cent of kyanite, indicating that the heavy media results are fairly accurate.

Rough tests including tabling and washing were carried out and showed that, although the kyanite could be beneficiated to marketable grade, the tabling had to be repeated several times and was therefore uneconomic.

At the present price for kyanite of £12 per ton f.o.b. Mombasa, the deposit presents a marginal proposition and it will remain so unless the price of kyanite rises or a more efficient method of recovery can be found.

(4) *Gypsum*

Gypsum was discovered below black cotton soil by P. H. Cull near Konza railway station in 1951. As a result of the discovery Cull put down numerous prospect pits with the advice of H. Greenwood-Penny, and the writer later reported on the deposit.

The gypsum occurs as small crystalline aggregates in black cotton soil at a depth of four to ten feet below the surface. It is not found as a distinct bed but rather as a zone of gypsiferous soil which varies from an inch or two to 18 inches in thickness. Unfortunately in many places the gypsiferous bed is replaced or contaminated by calcrete (superficial limestone) and it is considered that very little, if any, commercial gypsum could be produced without washing out the soil impurities.

In the writer's opinion the amount of gypsum available is about 60,000 tons. The total volume of soil overburden is of the order of 470,000 tons (323,000 cubic yards) and this great amount of overburden, together with the difficulties of recovering a high-grade gypsum product, makes the deposit a marginal case. Under these circumstances the prospects for this deposit are not good unless an assured market for crude gypsum is found. Such a market may come into being should cement manufacture take place at Sultan Hamud when gypsum would be needed to act as "retarder" in the cement.

(5) *Garnet*

Garnet is not widespread in the area but occurs principally in the amphibolitic zone east and north-east of Mayani, near Makabete and on Tulimani hill. The Mayani garnets are not sufficiently concentrated to be of economic value.

The Makabete and Tulimani garnets have been examined by Dr. W. Pulfrey (Mines and Geological Department). The Makabete garnet was found to be almandine of dark red to black colour with refractive index about 1.83 and specific gravity of $4.1 \pm$. The hardness was $7-7\frac{1}{2}$ and the crystals were tough with good capillarity when crushed. When crushed with a minimum of impact to pass a 20-mesh screen, the grading was as follows:—

	Per cent
— 20 I.M.M. + 30 B.S.	34.2
— 30 + 60 B.S.	33.3
— 60 + 90 B.S.	9.0
— 90 + 120 B.S.	2.4
— 120 B.S. + 200 Tyler	10.8
— 200 Tyler	9.7
	99.4

A chemical analysis gave the following results:—

	Per cent
SiO ₂	38.9
Al ₂ O ₃	22.0
Fe ₂ O ₃	2.7
FeO	29.3
MnO	0.8
MgO	1.2
CaO	5.4
	100.3

Analyst: Imperial Institute, London.

It was concluded that the garnet was of reasonably good quality, its main drawback being the inclusion of other silicates.

The Imperial Institute, London, also reported on a sample of the material but considered it unsuitable for sale in the United Kingdom in the state in which it was supplied.

The Tulumani garnets were also tested and found to be generally similar to those from Makabete. Gentle crushing to pass a 20-mesh screen gave the following grades:—

	Per cent
— 20 I.M.M. + 30 B.S.	6.1
— 30 + 60 B.S.	48.2
— 60 + 90 B.S.	14.1
— 90 + 120 B.S.	5.2
— 120 B.S. + 200 Tyler	14.1
— 200 Tyler	12.3

The capillarity was somewhat better than that of the Makabete garnet but the amount of impurities present and poor crushing properties rendered the Tulumani garnets a little inferior to those from Makabete. The locality has recently been pegged by O. J. Mallitte.

(6) Kaolin

Kaolinitic earth is found in many places overlying decomposed felspar-rich gneisses of the Basement System. The main areas in which it is found are on the slopes of Kutaa hill near Opete, on the eastern and upper parts of the Kilungu hills, and east of Kasikeu hill. In none of these places does it occur as a redeposited clay, but as a decomposed rock, hydrated *in situ*, so that in each case the kaolin is intermingled with quartz, unaltered felspar and micæ.

Kaolin has been worked to a small extent on Mbooni and at Kikutchwe, north-east of Ndolo market. The former deposit is decomposed granitoid gneiss and the latter is kaolinized pegmatite. The Mbooni deposit is relatively small and contains buff kaolin. The bulk composition of three samples is as follows:—

	Per cent	Per cent	Per cent
Moisture ..	0.85	1.25	0.70
Sand ..	34.15	57.10	47.55
Fines ..	43.05	34.20	41.05
Kaolin ..	20.90	6.80	10.75
Total ..	98.95	99.35	100.05

The kaolin gives a hard brown mottled biscuit when fired at a temperature of 1,400°C. The strength of the refractory product is due to the presence of a small amount of iron oxide as impurities that allowed the occurrence of some sintering. The decomposed pegmatite at Kikutchwe yields a very white pure kaolin when washed or screened, but the quantity is very limited as the pegmatite is only two or three feet wide.

A further extensive deposit occurs on the southern slope of Kikandani hill, north of Opete (Fig. 8). Here granitoid gneisses have weathered to a depth of 30 to 115 feet as exposed in deep gullies. The principal impurity is quartz, unaltered felspar and a little mica. Rough tests indicated that an average of 15 per cent of kaolin can be expected over the deposit and that approximately two million cubic feet of kaolin are present. The deposit is 19 miles from rail at Sultan Hamud.

(7) Vermiculite

Altered vermiculitic biotite occurs sporadically throughout the area in two forms—

- (i) as books in pegmatites;
- (ii) as slips of vermiculitized biotite schist in biotite gneisses and schists.

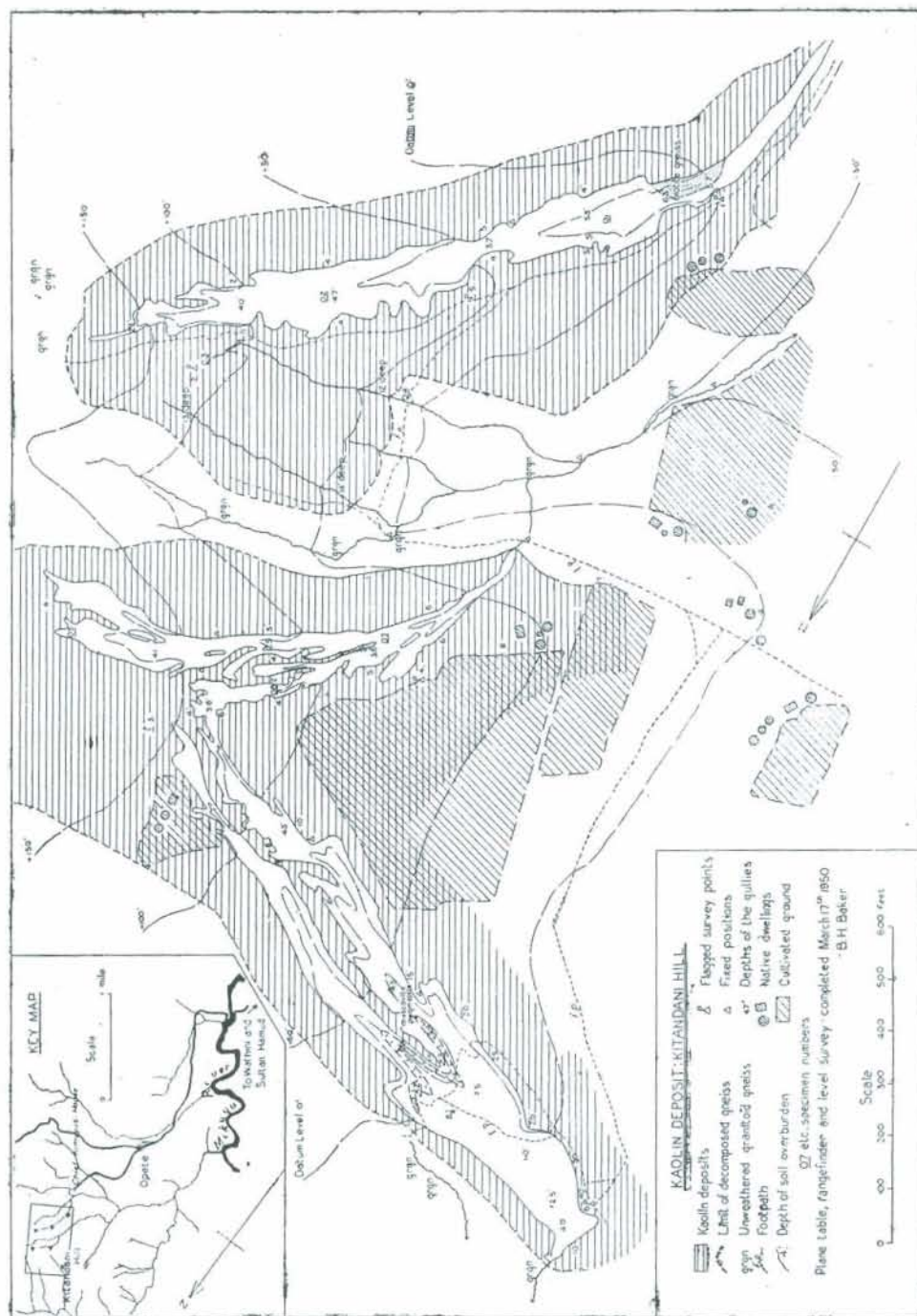


FIG. 8.—Kaolin Deposits, Opete.

The pegmatitic "vermiculite" has been seen in the kyanite pegmatite on Kioo hill, in the kaolinized pegmatite at Kikutchwe and in the mica pegmatite on Kenzi hill. Tests made on "vermiculites" from the first two localities by Dr. W. Pulfrey in 1945 are as follows:—

<i>Crude "Vermiculite"—</i>		1	2	3
Approximate specific gravity		2.49	2.45	2.48
Bulk density, lb./cu. ft.		156	153	153
Apparent specific gravity ($-\frac{1}{2}$ in.) ..		1.013	1.006	1.24
Apparent bulk density ($-\frac{1}{2}$ in.) ..		63	63	77.5
<i>Exfoliated Crude "Vermiculite"—</i>		1	2	3
Apparent bulk density, lb./cu. ft. ..		9.25	9.6	8.4

The "vermiculite" was exfoliated at 950°C. for one or two minutes. The resultant material was graded with the following result:—

	1	2	3
	<i>Wt. per cent</i>		
+ $\frac{1}{8}$ in.	31.9	39.0	58.9
$-\frac{1}{8}$ in. + 30 B.S.	55.2	47.5	36.5
- 30 + 60	10.3	10.9	3.6
- 60 + 90	1.5	1.5	0.5
- 90	1.0	1.0	0.6

1. Ndolo (Kikutchwe).
2. Kioo.
3. Elinythia.

An analysis of the Elinythia "vermiculite" gave the following result:—

	<i>Per cent</i>
SiO ₂	40.27
Al ₂ O ₃	14.86
Fe ₂ O ₃	7.94
FeO	0.95
MgO	19.16
CaO	0.28
Na ₂ O	0.72
K ₂ O	5.94
H ₂ O—	3.10
H ₂ O+	3.96
TiO ₂	2.10
P ₂ O ₅	0.75
MnO	0.06
	100.09

Analyst: H. J. Broughton, Imperial Institute, London.

The analysis shows that the material is a somewhat altered biotite and not a true vermiculite.

None of the pegmatitic occurrences are considered economic. The amount of "vermiculite" available is much too small, this being a feature of all pegmatitic vermiculites.

The "vermiculite" found in biotite gneiss and schists is concentrated in the vicinity of Kilimandui and Karanj hills, on the south face of Nduluni, and in the col between Kioo and Nduluni East. A total of eleven small holes and trenches, most of them being exploratory diggings, have been dug on these occurrences by prospectors. The vermiculitic mica is in small slips no wider than three feet and in many cases it is only slightly weathered biotite; the tonnage is limited and no large-scale opencast working of the deposits is possible owing to their situation and dip.

KAPORONI

True vermiculite is usually a brownish colour, flaky and friable. The flakes are pliable but unelastic and can usually be easily expanded by heating in the flame of a cigarette-lighter or match, when they usually assume a golden or silver colour. The occurrences in the present area are due to surface weathering and great extent in depth cannot be expected. No hydrothermal type of vermiculite comparable with that from Palabora (Gevers, 1948) in South Africa was seen in the present area, though such material is known in association with ultra-basic intrusives at Kinyiki near Mtito Andei, and at Kipiponi in South Kitui. A short account of Kenya vermiculites has been given by Varley (1946 and 1952, pp. 28-32).

(8) Gold

At the ford over the Keite river, north of Kitandi village, a gold-bearing biotite quartzite was discovered. The rock is about seven feet thick and outcrops in the river bed, where the concrete drift is built partly on the quartzite and partly on pegmatite. The quartzite is hard, medium-grained and carries may small grains of pyrite.

Eleven assays were made with the following results:—

				Dwts./ton
52/306	..	..	..	1.6
321	..	..	..	0.2
322	..	..	..	Trace
324	..	..	..	0.4
325	..	..	..	0.2
326	..	..	..	0.1
327	..	..	..	Nil
328	..	..	..	Trace
329	..	..	..	Nil
330	..	..	..	Nil
331	..	..	..	Nil

Analyst: W. P. Horne.

The indication is that the upper part of the bed carries the most gold but this may be a purely local phenomenon. The occurrence is interesting scientifically rather than economically and shows that gold may be present in Basement System rocks though no workable deposits have yet been found.

(9) Rutile, ilmenite, martite, columbite, crocidolite, riebeckite, amazonstone and beryl

All of the above minerals are known from the area, although no economic deposits of them have yet been found. They occur in pegmatites, and the first three are common minor constituents of the schists and gneisses in the area, though concentrations of them are only found in pegmatites. Martite has been found as float on the upper slopes of Kitandani hill where it occurs as small sub-hedral brownish black crystals up to one centimetre in size. Ilmenite and rutile have been reported in small quantities from the Tulumani schist zone.

Crocidolite (blue asbestos) and riebeckite were found some years ago, presumably in pegmatites on the northern ridge of the Masokani range, but the excavations have now become infilled and overgrown. There are fragments of riebeckite, crocidolite and ilmenite lying around the old workings.

Two quarries in amazonite-bearing pegmatites have been excavated on the west flank of Masokani. The northern quarry is about 15 feet deep, and amazonstone has been obtained from the thickest of the pegmatites which also contains tourmaline. The amazonite (a microcline-perthite felspar) is variable in colour; much of it is well-banded in green and white, but some is bluish.

Beryl in small amounts, has frequently been found during the working of mica pegmatites. Some years ago a "blow" of beryl was struck by A. N. Holden, who it is said extracted some 50 tons of the mineral.

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(10) *Building Sand*

Considerable quantities of building sand are removed from dry river-beds by Indian merchants. The sand is dug and loaded into lorries and taken to one of the railway stations where it is consigned to Nairobi. The greatest amount of sand is brought to Konza while lesser quantities are railed from Ulu and Sultan Hamud. The sand is dug from the Lomungush, Kwakolia, Kwakana and Kwawatingila rivers, and it is estimated that approximately 30 tons a day are railed to Nairobi in the dry season.

(11) *Road-metal and Railway Ballast*

At present the only all-weather road is that from Nairobi to Mombasa. Where this crosses the Kapiti Plains and lies on black cotton soil it is surfaced with crushed superficial limestone (calcrete). This is obtainable at most places on the Kapiti plains and numerous pits where it has been extracted are visible by the roadside. The calcrete surface extends from the northern margin of the area to the road-crossing south of Kabani hill in the centre of the area. The rest of the main road is surfaced with decomposed schist mixed with murram but frequently the surface is earth. Should the main road be macadamized suitable metal will probably be available in the lavas, either the phonolite of the western part of the area or the basalt found in the south.

Ballast used by the railway is lava, most of it being vesicular basalt imported into the area.

(12) *Building Stone*

There is no building material comparable to "Nairobi stone" in the area and most of the buildings are either of imported Nairobi tuff, timber or locally made bricks. Most of the European-constructed buildings are of "Nairobi stone", timber or corrugated iron but in the Ukamba Reserve local brick-making has been encouraged by the Administration. Most native villages are built of these bricks, which are made by firing sun-dried murram that has been moulded in wooden moulds. These bricks appear to be adequate for small buildings, but much care would have to be exercised over the choice and firing of murram should the bricks be used for larger structures.

3. *Water Supply*

Approximately 150 boreholes for water have been drilled in the area, the great majority being on the European farms. Details of the yield of the boreholes and other information are given in the table below. Such a large number of holes has been drilled on account of the lack of perennial surface water, although a number of dams have also been built to conserve surface water.

A few general conclusions can be drawn as to the suitability of certain areas for the sinking of water boreholes. Many boreholes have been sunk on both slopes of Kilima Kiu hill and these have nearly always given low yields or have been dry. This is almost certainly due to the fact that the local rock is a relatively impervious biotite gneiss and to the fact that the surface drainage on the hill-slopes is rapid. Near Kiu and Kima stations in the Kwakolia river valley the yields are good. Similarly close to the Potha, Ekiwe and Igieni rivers near to Machakos water yields are generally good.

Boreholes drilled through the Kapiti phonolite west of Wami hill have given low yields of water. This is rather contrary to expectation as it was considered that the decomposed sub-volcanic floor in this area would be a good aquifer. The poor water supply here may be due to the fact that the rainfall is low and the catchment area feeding the sub-volcanic horizon is of low relief, resulting in the loss of much of the scanty rainfall by evaporation.

Unfortunately detailed geological mapping of the European farming area was impossible in the time available due to the lack of exposures, and therefore it is difficult to relate borehole results with geological structure. But it is considered that the nature of the surface drainage and the size of catchment areas, together with the

depth of weathering, are factors more important than hard-rock geological structures in siting boreholes. Geological structure must be taken into consideration, however, and boreholes should be sited on banded pelitic rocks rather than homogeneous biotite gneiss, granitoid gneiss or migmatite. Generally speaking it is considered that boreholes should be sited in large valleys where sub-surface drainage is considerable. Watersheds, however small, should be avoided and also sloping hill-sides close to watersheds.

In the area between Ulu station and Kilima Kiu, where the sub-surface water supply position is bad several successful dams have been built. Dams are also numerous in the native reserve. They are small, made of earth, and serve to supply water for cattle during the dry season. The Africans themselves usually obtain water from holes dug in the dry river-beds where it is usually only two or three feet below the surface of the sand.

In general it is suggested that the large-scale construction of small dams, particularly in native areas, would be the best means of conserving water. A full description of suitable earth dams and the methods of construction is given by Dixey (1951).

RECORD OF BOREHOLES
(Supplied by the Hydraulic Branch, P.W.D.)

No.	Location	Bedrock	Depth	Struck Water	Rest Level	Yield
			feet	feet	feet	gallons per day
C 30 ..	Athi	lava	—	—	90	240
C 31 ..	Athi	"	39	—	—	—
C 109 ..	Bondoni ..	gneiss	146	109 and 125	62	15,000
C 339 ..	Chyumbi ..	"	330	152 and 310	40	21,600
C 73 ..	Kamutwa ..	"	145	100	50	28,800
C 161 ..	Kapiti plains	phonolitic tuff, gneiss	207	—	179	2,400
C 161 ..	Kapiti plains	"	163	129	145	2,208
C 179 ..	Kapiti plains	gneiss	376	172 and 183	161	1,440
C 218 ..	Kapiti plains	"	485	347	37	7,512
C 224 ..	Kapiti plains	"	185	148 and 155	109	19,200
C 111 ..	Kapiti Station	ash, lava	211	—	—	—
C 112 ..	Kapiti Station	lava, gneiss	41	132	118	30,240
C 121 ..	Kapiti Station	gneiss	344	190 and 320	165	28,000
C 74 ..	Kilima Kiu..	"	245	—	—	—
C 88 ..	Kilima Kiu..	"	201	90 and 120	61	3,600
C 92 ..	Kilima Kiu..	"	300	142 and 164	102	4,800
C 98 ..	Kilima Kiu..	"	183	160	150	14,400
C 105 ..	Kilima Kiu..	"	163	45 and 130	34	10,000
C 4 ..	Kilima Kiu..	"	89	—	—	—
C 6 ..	Kilima Kiu..	"	148	115	97	2,000
C 7 ..	Kilima Kiu..	"	117	—	—	—
C 8 ..	Kilima Kiu..	"	220	131	100	3,400
C 9 ..	Kilima Kiu..	"	235	—	—	—
C 10 ..	Kilima Kiu..	"	—	—	—	—
C 11 ..	Kilima Kiu..	"	170	144	91	5,760
C 12 ..	Kilima Kiu..	"	220	200	143	108
C 13 ..	Kilima Kiu..	"	259	170	132	19,000
C 52 ..	Kilima Kiu..	"	222	180	122	45,700
C 74 ..	Kilima Kiu..	"	200	150	130	3,500
C 75 ..	Kilima Kiu..	"	200	—	—	—
C 238 ..	Kilima Kiu..	"	300	82 and 115	72	960
C 242 ..	Kilima Kiu..	"	—	20 and 182	32	768
C 246 ..	Kilima Kiu..	"	212	192	177	1,536
C 323 ..	Kilima Kiu..	"	—	162 and 230	135	500
C 324 ..	Kilima Kiu..	"	—	285	211	49,344
C 432 ..	Kilima Kiu..	"	434	125 and 135	135	38,400
C 509 ..	Kilima Kiu..	"	270	148	105	60,000
C 713 ..	Kilima Kiu..	"	385	350	250	3,600
C 823 ..	Kilima Kiu..	"	480	153 and 200	455	8,760
C 847 ..	Kilima Kiu..	"	520	190	151	13,200
35-D ..	Kilima Kiu..	"	205	177 and 180	130	43,200
C 925 ..	Kilima Kiu..	"	800	620	460	4,320
C 1100 ..	Kilima Kiu..	"	332	252	232	15,360
41 ..	Kima	"	204	135	74	36,000

No.	Location	Bedrock	Depth	Struck Water	Yield	Rest Level
			feet	feet	feet	Gallons per day
49 ..	Kima	clay	89	—	—	—
57 ..	Kima	ash and lava	149	114	30	24,720
C 14 ..	Kima	lava	65	—	—	—
C 15 ..	Kima	gneiss	156	82 and 105	65	48,000
C 16 ..	Kima	"	165	—	—	—
C 17 ..	Kima	"	124	105	65	40,000
C 18 ..	Kima	"	155	125	95	16,000
C 19 ..	Kima	"	210	85 and 170	65	20,000
C 60 ..	Kima	"	—	83 and 100	65	48,000
C 120 ..	Kima	"	—	239 and 340	95	21,600
C 121 ..	Kima	(see C 161, Kapiti plains)	—	—	—	—
C 603 ..	Kima	gneiss	500	200 and 400	70	55,200
C 1131 ..	Kima	"	259	—	—	—
9 ..	Kima Station ..	"	195	110	80	3,360
11 ..	Kima Station ..	"	146	130	101	48,000
C 445 ..	Kiu	"	406	196 and 218	179	34,560
C 612 ..	Kiu	"	100	28	30	48,000
C 1132 ..	Kiu	"	260	170	130	744
28 ..	Kiu Station ..	"	174	82	13	84,000
150 ..	Kiu Station ..	"	171	?	15	117,000
C 427 ..	Kiu Station ..	"	280	—	24	48,000
33 ..	Konza	"	180	65 and 145	38	12,000
45 ..	Konza	"	215	175 and 195	112	40,000
50 ..	Konza	"	182	180	76	15,000
102 ..	Konza	"	109	70	40	70,000
132 ..	Konza	gravel, gneiss	266	197 and 230	167	?
149 ..	Konza	gneiss	352	22 and 330	190	26,000
C 48 ..	Konza	"	464	104	122	10,000
C 629 ..	Konza	"	454	225	204	19,200
C 683 ..	Konza	lava, gneiss	600	229	183	5,520
C 731 ..	Konza	100 ft. lava, gneiss	400	115	275	26,400
C 812 ..	Konza	ash, gneiss	410	265	150	—
C 44 ..	Machakos ..	gneiss	325	324	9	24,000
C 145 ..	Machakos ..	"	215	52 and 207	4	40,800
C 374 ..	Machakos ..	"	—	50 and 120	13	9,336
C 401 ..	Machakos ..	"	111	96	71	90,000
C 433 ..	Machakos ..	"	400	55, 69, 270, 350	71	48,000
C 661 ..	Machakos ..	"	505	320	41	15,840
C 78 ..	Melili	"	74	—	—	—
C 80 ..	Melili	"	192	160	130	14,300
C 294 ..	Melili	"	—	286	36	28,800
C 352 ..	Melili	"	230	155 and 189	28	21,600
C 80-D ..	Melili	"	300	200	101	31,200
C 1092 ..	Melili	"	360	166	141	2,280
C 772 ..	Momandu	"	200	58	25	28,800
156 ..	Mua	"	146	—	—	—
161 ..	Mua	"	221	—	—	—
165 ..	Mua	"	132	84	56	35,000
168 ..	Mua	"	49	24	18	5,000
C 481 ..	Mua	"	268	100	72	21,600
C 883 ..	Mua	"	280	80	70	2,400
C 1130 ..	Mua	"	259	—	—	—
C 1276 ..	Mua	"	550	226	168	7,920
C 687 ..	Mwea	"	480	—	—	—
C 688 ..	Mwea	"	500	320	240	3,360
47 ..	Potha	"	195	150	120	20,000
C 253 ..	Potha	"	180	73 and 160	13	86,400
C 265 ..	Potha	"	131	126	87	21,200
C 405 ..	Potha	"	463	281 and 450	171	38,880
C 473 ..	Potha	"	200	45	26	34,560
C 775 ..	Potha	"	400	202	196	28,800
70 ..	Theki	"	150	100	61	15,000
110 ..	Theki	"	87	—	Abandoned	—
116 ..	Theki	"	275	240	150	72,000
30 ..	Ulu	"	152	142	110	21,000
31 ..	Ulu	"	218	190	169	6,000
35 ..	Ulu	"	170	120 and 150	98	21,000
C 1055 ..	Ulu	"	400	120	111	480
C 1081 ..	Ulu	"	400	—	—	—
15 ..	Wilson farm, K. Kiu	"	152	147	70	57,600
17 ..	Wilson farm, K. Kiu	"	217	110	75	240
20 ..	Wilson farm, K. Kiu	"	151	—	—	—
24 ..	Wilson farm, K. Kiu	"	275	80 and 210	35	4,000

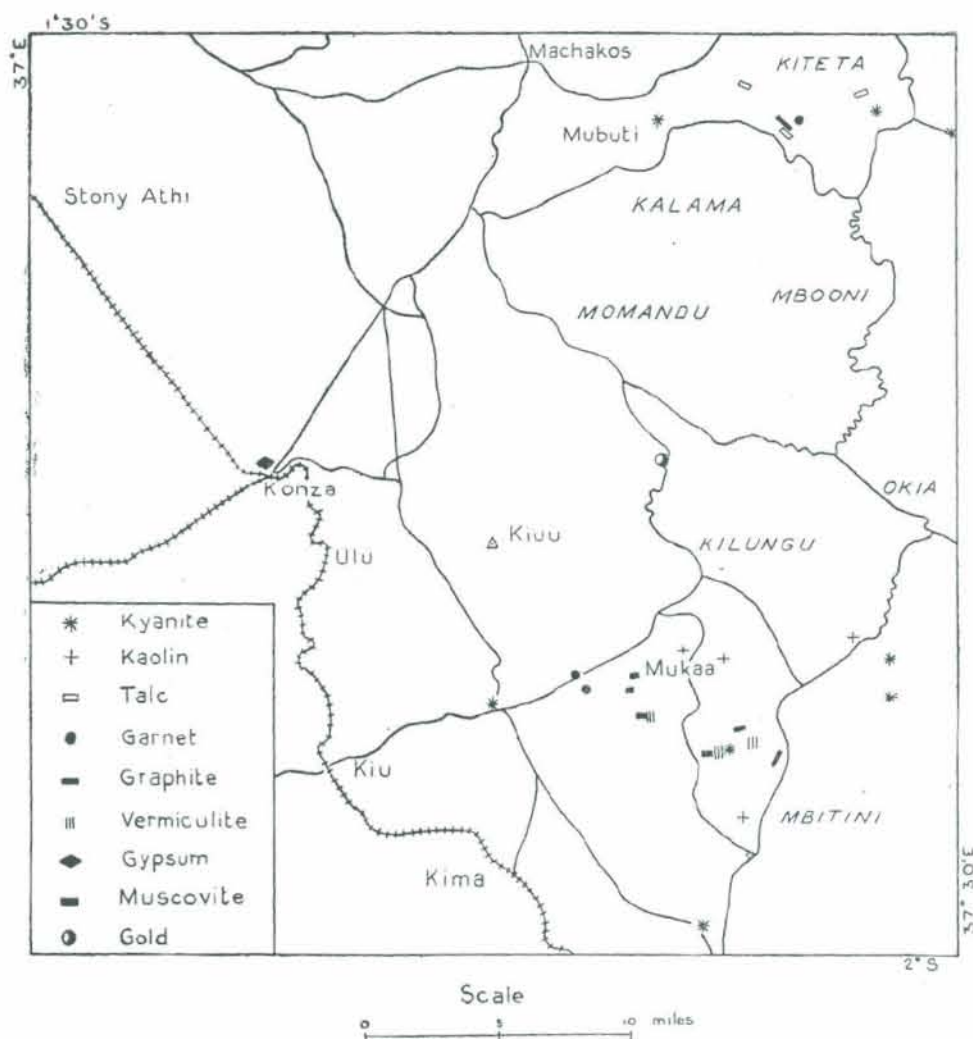


FIG. 9.—Mineral Occurrences in the South Machakos Area.

4. SUGGESTIONS FOR FURTHER PROSPECTING

In the past the main prospecting activity has been near Tulimani and in Mukaa Location.

The Tulimani schist zone has been shown to contain many economic minerals although few, if any, of the known occurrences are considered to be of sufficient size to be economically important. The schist zone peters out half a mile east of Kiteta school but continues westwards to Kaani and finally northwards, outside the present area, towards Kyabuluki hill. The most promising minerals in the zone are kyanite and garnet, and further prospecting may result in the discovery of an economic deposit of these minerals. Asbestos veins are also known in the neighbourhood of the main limestone beds. In general attention should be paid to the zone in the immediate vicinity of the limestones marked on the map.

It is interesting to note that the muscovite pegmatites of Mukaa Location all occur in bands of rock mapped as muscovite schist, or muscovite-biotite gneiss. These muscovite-rich rocks surrounding the Opete granitoid gneiss are possibly the result of muscovite enrichment and it is considered that the presence of large books of muscovite in these pegmatites is directly connected with this enrichment. Further prospecting for muscovite mica should therefore be concentrated in the zones of muscovite-rich rock (marked as *Xsm'* or *Xsm* on the map). This relationship of muscovite pegmatites to granitoid gneiss bodies as demonstrated in the present area should also be borne in mind when other areas are investigated.

Most of the other minerals mentioned in the preceding pages occur sporadically, but many occurrences have not been fully investigated and might repay further attention. Furthermore, prices for raw materials have risen to such an extent in recent years that deposits previously uneconomic might now be profitable. The occurrences of economic minerals known at the moment are indicated on Fig. 7, and also more accurately on the map but it must be emphasized that many of these occurrences have been insufficiently studied and it is not possible to pass adequate judgment on their economic possibilities.

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