

REPORT No. 23



COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

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

EXPLANATION OF DEGREE SHEET 44, SE. QUADRANT

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MAP

Geological map of the area to the south-east of Embu. Scale 1:125,000 ..	At end
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FOREWORD

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

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

NAIROBI,
6th February, 1952.

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ABSTRACT

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

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

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

I—INTRODUCTION AND GENERAL INFORMATION

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

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

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

B

COMMUNICATIONS

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

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

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

NATURE OF THE COUNTRY

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

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

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

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

EXPOSURES

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

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

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

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

Other features of assistance in the mapping are:—

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

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

PREVIOUS GEOLOGICAL WORK AND PROSPECTING

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

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

II—PHYSIOGRAPHY

The area can be divided into four physiographical units:—

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

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

DRAINAGE

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

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

EROSION HISTORY

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

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

III—SUMMARY OF GEOLOGY

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

1. The Basement System

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

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

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

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

* References are listed on p. 39.

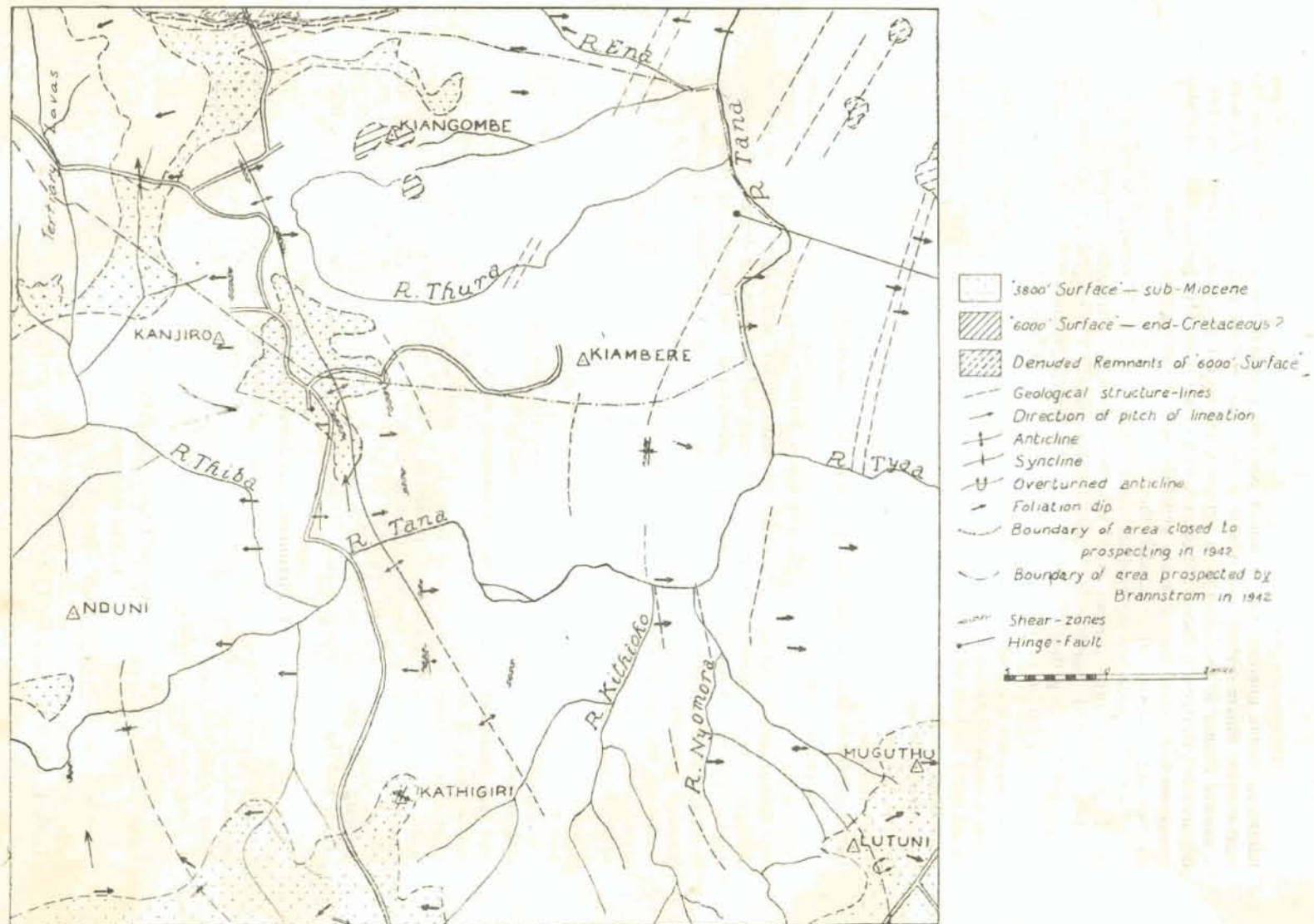


Fig. 1—Erosion surfaces and chief structural elements of the area south-east of Embu.

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

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

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

2. The Embu Series

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

3. The Tertiary Volcanics

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

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

4. Pleistocene and Recent Deposits

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

IV—DETAILS OF GEOLOGY

1. The Basement System

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

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

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

*Rocks due to recrystallization and additive processes.

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

(1) SEDIMENTS

(a) *Calcareous*

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

(b) *Pelitic and Semi-Pelitic*

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

(c) *Psammitic*

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

(d) *Psephitic*

- (i) Pebbly grit.

(2) VOLCANIC ROCKS

(3) MIGMATITES

(4) MAJOR INTRUSIVES

(a) *Granites*

(b) *Pegmatites and aplites*

(c) *Basic igneous types*

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

(5) MINOR INTRUSIVES

(a) *Dolerites*

(1) SEDIMENTARY ROCKS OF THE BASEMENT SYSTEM

(a) *Metamorphosed Calcareous Sediments*

(i) *Crystalline Limestones*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

44/720—Hornblende pyroxene schist.

44/693—Hornblende porphyroblast gneiss.

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

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

(iii) *Semi-calcareous Gneisses*

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

* All modes quoted were estimated.

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

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

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

(i) *Biotite Gneisses*

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

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

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

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

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

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

(ii) Hornblende Gneisses

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

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

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

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

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

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

(iii) Hornblende-Biotite Gneisses

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

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

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

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

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

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

The hornblende-biotite gneisses are mesotype rocks with granitoid to mildly gneissose structure and dioritic composition. They weather easily, so that outcrops are found only in stream courses. The exposed contacts show no chilled borders and reveal a reticulate veining, that sometimes gives rise to local irregular banding. The gneisses are of simple and remarkably uniform composition, the essential minerals showing little variation in optical and physical properties over the wide area in which they occur. In thin section they are medium-grained xenoblastic granular and only occasionally exhibit a mild gneissosity. Mineralogically they are the same as the plagioclase hornblende gneisses in the adjoining Embu-Meru area, and consist of poikiloblastic hornblende, large crystals of plagioclase, small flaky biotite that not infrequently is partly altered to chlorite, quartz, and subordinate epidote, which often occurs as chadacrysts in plagioclase. Although much of the irregular quartz is secondary, it also occurs as isolated sutured mosaics suggestive of original sand grains. The composition of the plagioclase varies from An_{30} to An_{20} . The accessories include apatite, zircon, calcite, sphene and iron ore.

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

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

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

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

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

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

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

(iv) *Sillimanite Gneisses*

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

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

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

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

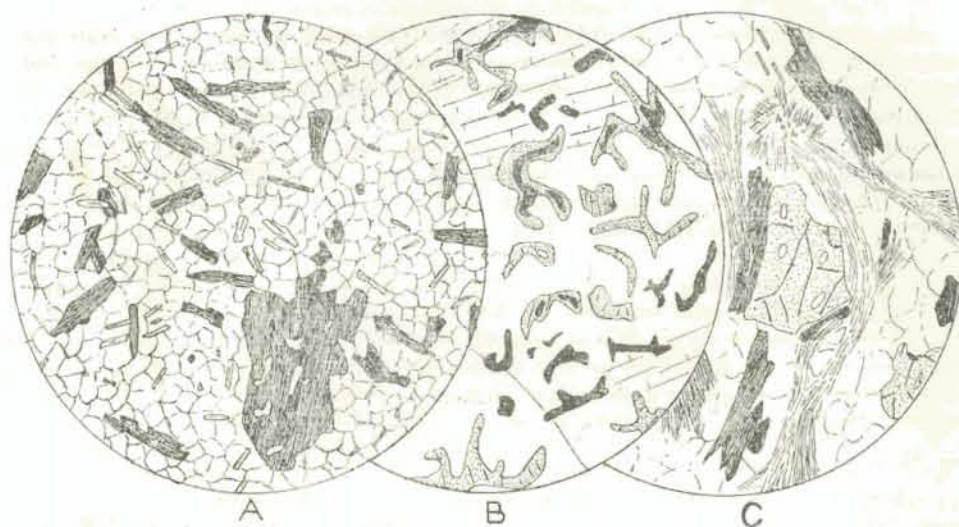


Fig. 2—A. Knotenschiefer. Specimen 44/835, three miles south of Siakago. Ordinary light x 17. The large biotite porphyroblast encloses small chadacrysts of quartz and is embedded in a granoblastic quartz matrix. The small flakes of muscovite show no orientation.

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

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

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

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

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

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

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

44/857A—Sillimanite-staurolite granulite.

(v) *Muscovite Schists*

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

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

(vi) *Micaceous Hornfelsic Types*

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

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

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

(c) *Metamorphosed Psammitic Sediments*

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

(i) *Biotitic Quartz-felspathic Gneisses*

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

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

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

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

(ii) *Quartzo-feldspathic Para-granulites*

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

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

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

(iii) *Quartzites*

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

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

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

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

(d) *Metamorphosed Psephitic Sediments*

(i) *Pebbly Grits*

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

(2) METAMORPHOSED VOLCANIC ROCKS OF THE BASEMENT SYSTEM

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

(3) MIGMATITES

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

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

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

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

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

(4) MAJOR INTRUSIVES

(a) Granites

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

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

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

The estimated modes of some granites are given below:—

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

(b) *Pegmatites and Aplites*

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

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

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

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

(c) Basic Igneous Types

(i) Olivine-pleonaste Norites

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

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

The *olivine* is colourless and usually occurs in large, fresh, cracked plates, frequently showing undulatory extinction and ill-defined twinning. Serpentinization on a large scale is absent, and is only incipiently developed along some of the cracks, with concomitant release of magnetite. Thin veinlets of yellowish bowlingite are common. Optic angle estimations indicate that the olivine has a composition lying between Fa_{25} and Fa_{40} . Coronal rims of hypersthene invariably separate the olivine grains from the plagioclase, and in some cases double reaction rims have formed, the inner hypersthene being surrounded by an outer, usually discontinuous, rim of hornblende. In thin section 44/650 irregular grains of magnetite have reaction rims of hypersthene and cores of olivine.

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

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

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

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

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

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

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

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

(ii) *Hornblende Gabbros*

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

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

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

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

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

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

The approximate modes of the gabbros are:—

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

(iii) Anorthosites

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

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

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

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

(iv) Meta-dolerites and Plagioclase Amphibolites

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

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

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

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

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

(iv) *Ortho-amphibolites*

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

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

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

Some small irregular lenses of coarse-grained *hornblende* are so closely associated with the basic intrusives, particularly at Muthuru and south of Rongori, that they are considered to be genetically related. They probably represent the complete amphibolitization of originally coarse-grained pyroxenites. A lack of any directional textures is attributed to the protection from metamorphism afforded them by the surrounding basic intrusives. The fresh unaltered types are black, the more weathered varieties a dull green. Specimen 44/658, from Muthuru, has a hypidiomorphic granular texture and consists of brownish subhedral hornblende and fresh twinned plagioclase (about An_{50}). Iron ore and apatite are the only accessories. The hand-specimen contains over 90 per cent of hornblende.

(vi) *Chlorite and Tremolite-actinolite Schists*

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

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

(5) MINOR INTRUSIVES

(a) *Dolerite*

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

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

2. The Embu Series

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

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

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

(1) METAMORPHOSED CALCAREOUS SEDIMENTS

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

(2) METAMORPHOSED PELITIC AND SEMI-PELITIC TYPES

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

Knotenschiefer

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

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

Typical knotenschiefer were estimated to have the following composition:—

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

Granulose Types

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

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

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

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

Schistose Types

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

Specimen 44/512B has the following composition:—

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

Gneissose Types

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

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

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

Semi-hornfelsic Types

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

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

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

(3) METAMORPHOSED PSEPHITIC SEDIMENTS

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

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

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

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

3. The Tertiary Volcanics

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

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

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

(1) KENYTES AND ASSOCIATED PYROCLASTIC ROCKS

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

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

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

(2) PHONOLITES

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

(3) OLIVINE BASALTS

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

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

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

Monchiquitic Rocks

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

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

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

4. Pleistocene and Recent Deposits

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

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

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

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

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

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

V—GRANITIZATION

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

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

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

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

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

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

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

VI—METAMORPHISM

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

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

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

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

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

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

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

1. Forsterite —> Serpentine
2. Sillimanite —> muscovite
3. Hornblende —> chlorite + epidote
4. Serpentine —> magnesite + quartz

The minerals shown on the left remain as relics.

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

The Embu Series

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

VII—STRUCTURES

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

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

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

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

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

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

Faulting

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

Lineation

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

Jointing

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

VIII—ECONOMIC GEOLOGY

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

Asbestos

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

Beryl

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

Building Stone

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

Copper

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

Fluorite

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

Garnets

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

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

Graphite

Occurrences of graphite were observed in the following localities:—

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

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

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

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

Limestone

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

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

Magnesite

Occurrences of magnesite were observed in the following localities:—

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

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

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

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

Mica

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

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

Sillimanite

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

Water

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

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

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

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

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

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