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GEOLOGY OF THE FORT HALL AREA

DEGREE SHEET 44, S.W. QUARTER
(with coloured geological map)

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MAP

Geological map of the Fort Hall area (degree sheet 44, SW. quarter). Scale 1:125,000 at end

FOREWORD

This report describes the geology of an area situated between Nairobi and Mount Kenya; it is served by main routes linking Nairobi with Nyeri and Embu, and covers parts of the well populated agricultural districts of Thika, Fort Hall and Kirinyaga, together with a section of the upper Tana valley.

Approximately one-third of this area is underlain by Precambrian crystalline rocks; the remaining two-thirds is covered by volcanic accumulations originating from the Rift Valley and Mount Kenya. The earliest lavas entered the area from the west during the Miocene Period; they were phonolites which flowed freely eastwards along existing valleys and through gaps in hill barriers and were subsequently covered by deposits of ash and flows of basalt. During the late Tertiary and Pleistocene Periods further flows of phonolite, trachyte and basalt extruded from Mount Kenya entered the area from the north and now cover the plains between Sagana and Embu.

The Precambrian rocks have suffered advanced metamorphism and include granitoid gneisses of replacement origin. No economic minerals were recorded from the Precambrian apart from small deposits of magnesite and kaolin. The volcanic succession contains tuff-beds providing considerable reserves of building-stone and also carries ground-water reserves giving good borehole yields and capable of further development. The main rivers are perennial and of stable flow, providing a limited hydro-electric potential.

Nairobi,
14th September 1965.

L. D. SANDERS,
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ABSTRACT

The report describes an area in central Kenya approximately 1,200 square miles in extent, bounded by latitudes $0^{\circ} 30' S.$ and $1^{\circ} 00' S.$, longitudes $37^{\circ} 00' E.$ and $37^{\circ} 30' E.$ The area lies east of the Aberdares and south of Mount Kenya and includes the administrative centres of Fort Hall and Embu.

Topographically, the Kakuzi-Ithanga mass and its northern continuation of granitoid gneisses and associated biotite gneisses forms a barrier across the area from north-east to south-west. To the west of the barrier a considerable thickness of Tertiary phonolites, basalts and pyroclastics have accumulated, while to the east a fairly flat low-lying area of Basement System rocks has been preserved, which is covered in the north-east by a thin layer of younger Tertiary and Pleistocene lavas.

A description of the various rock types, their structure and their probable ages is given. The metamorphism and granitization of the Basement System is discussed, and an account given of the economic minerals of the area.

GEOLOGY OF THE FORT HALL AREA

I—INTRODUCTION

The area described in this report is quarter-degree sheet 44 SW. Kenya, (Directorate of Overseas Surveys sheet No. 135), bounded by latitudes $0^{\circ} 30' S.$ and $1^{\circ} 00' S.$, and by longitudes $37^{\circ} 00' E.$ and $37^{\circ} 30' E.$ These co-ordinates enclose an area of about 1,200 square miles in central Kenya north-east of Nairobi and south of Mount Kenya.

The geological survey was carried out between February and August 1958, with the object of preparing a geological map and evaluating any mineral deposits.

Maps.—Geological information was plotted in the field on to air photographs at a scale of approximately 1:30,000 and subsequently transferred to preliminary plots South A 37/B III NW., NE., SW., and S.E. (scale 1:50,000), the first three of which are contoured. Form lines for the south-eastern quarter of the area were taken from 1:250,000 maps of the GSGS 4801 Series.

Climate and Vegetation.—Temperatures vary with altitude, the climate on the higher volcanic country in the west is generally cooler than that of the lower lying Basement System country of the Tana and Thika valleys. Rainfall over much of the area is fairly high. It is mainly controlled by altitude, being lowest in the area east of the Kakuzi Hills south of the Tana River, and increasing northwards and westwards towards the lower slopes of Mount Kenya and the Aberdares. Rainfall records for the area are given in Table I.

TABLE I—RAINFALL IN THE FORT HALL AREA
(From records of the East African Meteorological Department)

Station	Years Recorded	Total Rainfall in 1955	Total Rainfall in 1956	Total Rainfall in 1957	Average Yearly Rainfall
Embu, District Office	49	28·80	40·04	48·42	40·75
Embu, Agricultural School . .	14	35·33	50·79	56·93	42·69
Embu, Mwea	2	—	29·89	42·34	36·12
Fort Hall, District Office . .	54	—	52·97	52·74	45·86
Fort Hall, Kahuhia School . .	16	42·00	—	74·70	55·39
Fort Hall, Tana Power Station	25	29·88	35·55	47·89	33·61
Fort Hall, Gateigoro School . .	10	42·78	70·70	78·65	57·90
Kerugoya Hospital	20	—	53·99	71·93	54·47
Makuyu, Sisal Ltd.	35	31·99	43·13	43·72	34·73
Makuyu, Maji Kiboko	32	32·50	41·69	45·11	37·84
Makuyu, Swift Rutherford . .	22	34·91	41·55	54·46	38·71
Makuyu, Karatina Estate . .	17	34·38	44·61	52·89	37·76
Makuyu, North Kitito Estate	16	30·55	40·65	44·38	36·46
Makuyu, Mananja Ltd. . . .	12	31·84	40·85	45·18	39·14
Maragua, Icacaki Mission . .	6	37·46	49·51	61·89	45·94
Mitubiri, Kitito	25	37·55	39·58	49·01	37·39
Sagana, Maize Control	14	34·47	49·97	53·40	40·28
Thika, Muthuri Estate	39	34·75	42·39	50·31	37·67
Thika, Gethumbwini Ltd. . . .	33	40·75	45·32	58·23	40·26
Thika, Bendor Plantations . .	31	34·27	39·66	48·66	35·99

The natural vegetation of the area has been largely replaced by sisal and coffee estates in Thika District and by intensive valley cultivation of maize and coffee west of Fort Hall. Irrigation of the black cotton soil on the plains south-west of Embu, between the Nyamindi and Thiba rivers and on the site of the former Nguka swamp, allows the cultivation of rice. Regions not under cultivation include the plains of black cotton soil, the forested areas north-west of Embu (Njukini Forest), the thickly wooded belt on the fringes of the Tana and Thika rivers, papyrus swamps near the Thika road south-west of Makuyu, and the open thorn-bush country of the Ithanga Hills and the Thika valley.

Wild life in the area has been greatly reduced largely due to the extensive cultivation, and is now mainly confined to small areas between converging permanent rivers, such as between the Rupingazi and Nyamindi rivers and the Nyamindi and Thiba rivers, where miniature "game parks" have been preserved.

Population.—The greater part of the area is inhabited by the Kikuyu and Embu peoples who thickly populate the Fort Hall, Embu and South Nyeri districts. The Wakamba inhabit the south-east corner of the area between the Thika river to the west and the Tana river in the north. Migration of the Wakamba has, however, taken place to the north of the Tana, and small communities occur in Embu district at Karaba and Riakanau.

Communications.—The Fort Hall area has adequate road and rail communications. Rail transport is provided by the Thika-Nanyuki railway which passes through Makuyu, Maragua, Fort Hall and Sagana. The major road in the area is the Thika-Nyeri road, which by-passes Fort Hall by way of the new 300-foot Tana bridge. Junctions from this major road give access to Fort Hall and Embu. The Kikuyu districts are provided with a complex pattern of roads which allow any locality to be reached by several alternative routes.

The main geographical boundary in the area, the Tana river and its major tributary the Sagana, is crossed by the Gatiki bridge near Tumu Tumu Hill, the Sagana bridge at Sagana and the New Tana bridge just east of the Maragua confluence. A fourth crossing is provided by a ferry service at the Thika river junction (Masai Crossing) which charges a toll of fifty cents per person, or a shilling when the river is in flood.

Rock Exposures.—Rock exposures, apart from the granitoid gneisses of the Ithanga-Kakuzi Hills region and the pyroclastics near Fort Hall, are poor due to thick soil cover on the volcanics in the undulating Kikuyu country in the western and northern parts of the area, and the formation of black cotton soil on the plains north of the Tana river. In the Sagana region geological boundaries are defined by marked topographic changes between the volcanics and the Basement System rocks and the parallelism of drainage to these major boundaries. Soil variations are also of value in the delimitation of rock types. This is particularly true of the volcanic boundaries north of Fort Hall, where the poorly exposed granitoid gneisses usually give rise to a quartz-rich pink soil.

II—PREVIOUS GEOLOGICAL WORK

Several of the early travellers in Kenya passed through the Fort Hall area, particularly those on expeditions to Mount Kenya. The best known of these are Count Teleki's expedition of 1887 and the exploration of the Tana river by Capt. Dundas in 1891.

The earliest geological accounts of the area were given by Gregory (1894, pp. 293-294, and 1896, pp. 195-199), who on his return journey to Machakos from Lake Baringo and Mount Kenya in 1893 passed east of Tumu Tumu Hill to the lava plains north of the Tana. A full account of the geology was published some years later (Gregory, 1921, pp. 156-161) and included geological descriptions obtained from a second survey made in 1919.

The geological succession was established as follows:—

- Phonolitoid kenyte.
- Basalt.
- Kenytes of Mt. Kenya
- Kapitian phonolite.
- Unconformity—.
- Basement gneiss.

Prior to publication of Gregory's work in 1921, a brief description of the geology in the Fort Hall and Thika regions had been given by Muff (1908, pp. 22, 38).

As part of a gravity survey over the Rift Valley a gravity station was established at Fort Hall by Bullard (1936) and a further description of the geology between Nyeri and Fort Hall was given by Shackleton (1945, p. 23).

A geological map covering about 124 square miles of the volcanic rocks between Mitubiri and Makuyu in the south of the Fort Hall area is included in a Ministry of Works hydrological report giving ground-water data for the area between Nairobi and Fort Hall (Gaevarts, 1957).

III—PHYSIOGRAPHY

1. Topography and Drainage

The main physiographic features of the Fort Hall area are shown in Fig. 1. The most conspicuous topographic feature in the area is a line of hills of granitoid gneiss and associated biotite gneisses stretching from the south-south-east towards the north-north-west, where they are buried under volcanics near Tumu Tumu. To the east of these hills the volcanics are generally thin, while to the west they increase in thickness towards the Aberdares.

Exposures of Basement System rocks are mainly confined to the south-east quarter of the area. In the Basement System areas the granitoid and biotite gneisses give rise to some prominent hills reaching an altitude of 5,702 feet at Ithanga, and 5,400 feet at Kakuzi. Smaller isolated hills such as Muthuru (4,194 feet) are usually formed by meta-dolerites. The lowest part of the area is the Tana valley which falls to below 3,500 feet.

At the edge of the volcanic field west of the Kakuzi hills and north of the Tana river the volcanic surface is a well-defined plain largely covered with black cotton soil. This plain is well developed on the Kapiti phonolite and the Mount Kenya basalts. To the westward and northward the volcanics thicken and the ground rises, giving way to an undulating belt of country dissected by numerous river valleys typical of the lower slopes of Mount Kenya and the Aberdares. Occasionally this general pattern is broken by a volcanic vent or a steep sided gneissic inlier as at Molinduku.

The major river in the area, the Tana, is fed by three distinct drainage systems. These are (a) temporary streams rising on Basement System hills, (b) permanent streams rising on Mount Kenya north and east of the Tana, and (c) the permanent streams which flow from the Aberdares south and west of the Tana. The most important of the Mount Kenya rivers are the Sagana, Thiba, Nyamindi and Rupingazi rivers, while those flowing from the Aberdares include the Thika, Maragua, Mathioya and Gura rivers.

A feature of the drainage pattern in the Fort Hall region is the coincidence of major geological boundaries with river valleys. This is well illustrated by the Tana-Sagana river which enters the area just west of Tumu Tumu and flows southwards parallel to the edge of the granitoid gneiss hills north of Fort Hall, before turning east

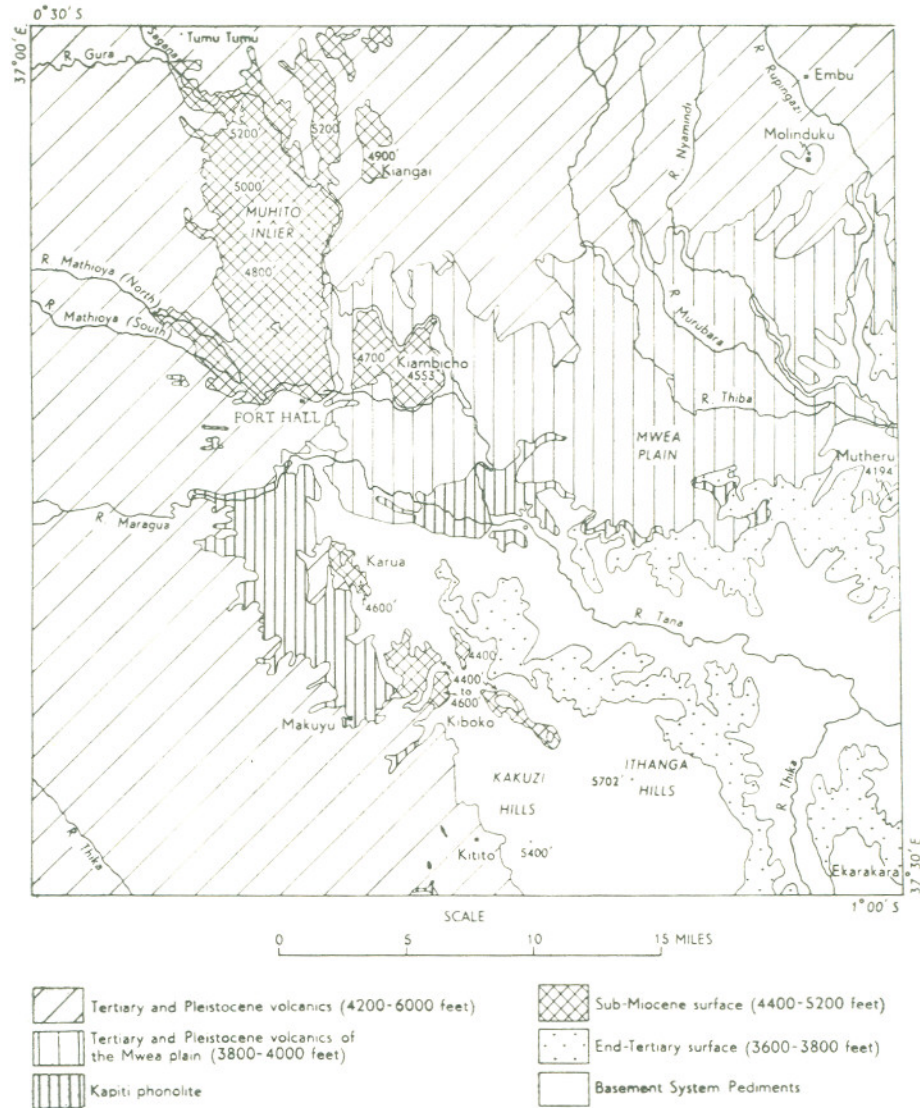


Fig. 1—Physiography of the Fort Hall area

then southwards again round Kiambicho, where it follows the boundary between the Basement System and volcanic rocks until it finally leaves the area in an easterly direction north of the Ithanga hills.

The position of the Thika river is controlled by the dip slope of the Aberdares volcanics in the extreme south-west of the area and by the watersheds of the Kakuzi and Ithanga hills further east. Most of the other permanent streams in the area are directly controlled by the dip slope of the lavas from Mount Kenya and the Aberdares.

2. Erosion Surfaces

Two distinct erosion surfaces differing in altitude by about 800 feet can be recognized in the Fort Hall area. The higher (sub-Miocene) surface rises from 4,600 feet in the south-east to about 5,200 feet in the north-west and has an average gradient of 12.5 feet per mile. It is represented by a number of bevelled Basement System inliers

north of Fort Hall, some flat-topped hills and ridges south-east of Fort Hall, and by the sub-Kapiti phonolite surface near Kitito. The lower (end-Tertiary) surface varies between 3,600 feet and 3,800 feet in altitude and is developed in the Tana and Thika valleys and underlies much of the volcanic rocks north of the Tana river.

The sub-Miocene Surface.—This bevel has been widely recognized in Kenya. East of the Rift Valley it rises in altitude towards the north-north-west as illustrated by the sub-Kapiti phonolite surface of the Yatta Plateau to the south of the present area (Schoeman, 1948, p. 3). In the North Machakos-Thika area (Fairburn, 1963, p. 4) the surface rises from 4,250 feet to about 4,800 feet, and its projection shows close agreement with the summits of several hills north of Fort Hall (Fig. 2), so that the upper erosion surface seen in the Fort Hall area is evidently of sub-Miocene age.

Elsewhere in Kenya it has been assumed that the base of the Kapiti phonolite marks the level of the sub-Miocene peneplain (Shackleton, 1945, p. 23). Mapping of the base of the phonolite in the present area illustrates that this is not always the case, the Kapiti phonolite rests on the sub-Miocene surface near the Genia river (see Fig. 2), but further north towards the Maragua river the base of the phonolite falls steadily from 4,600 feet to 4,300 feet, while the nearby sub-Miocene bevel stands at 4,700 feet. The divergence cannot be explained by faulting since faulting subsequent to deposition of the phonolite would also have affected the sub-Miocene surface. It is deduced that the surface was considerably eroded before eruption of the Kapiti phonolite, which then flowed down a deep valley (the Maragua Gap) near Fort Hall. The buried valley is located midway between the present Maragua and Mathioya valleys just south of Fort Hall where an abnormal thickness of volcanic rocks has been proved in bore-hole C.2683 (Fig. 3). Further evidence that the Kapiti phonolite of the upper Tana river region flowed down existing valleys is provided by thin beds of fluvial siltstones and sandstones, too small to show at the scale of the map, which underlie the Kapiti phonolite near the new Tana Bridge.

The end-Tertiary Surface.—This appears as a distinct shelf standing at an altitude of 3,300 feet at the northern end of the Ithanga and Kakuzi hills, and can also be seen north of the Tana valley where it emerges from beneath the Kapiti phonolite and volcanics of the Mwea plain (Fig. 1). In places it is covered by a thick layer of sand and gravel locally providing a semi-permanent aquifer.

The surface slopes gently eastwards at a gradient of less than 10 feet per mile and has been much reduced in extent by incision of the Tana and Thika rivers.

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL HISTORY

The geological succession in the area is as follows:—

Recent	Soils and alluvium
Pleistocene	{ Sandstones Thiba basalts —Unconformity—
Tertiary	{ Tumu Tumu trachytes Mount Kenya phonolites Laikipian basalts Trachytic tuffs Simbara Series (porphyritic olivine-basalts and basaltic agglomerates) Kapiti phonolite —Unconformity—
Precambrian	{ Metamorphosed and granitized rocks of the Basement System.

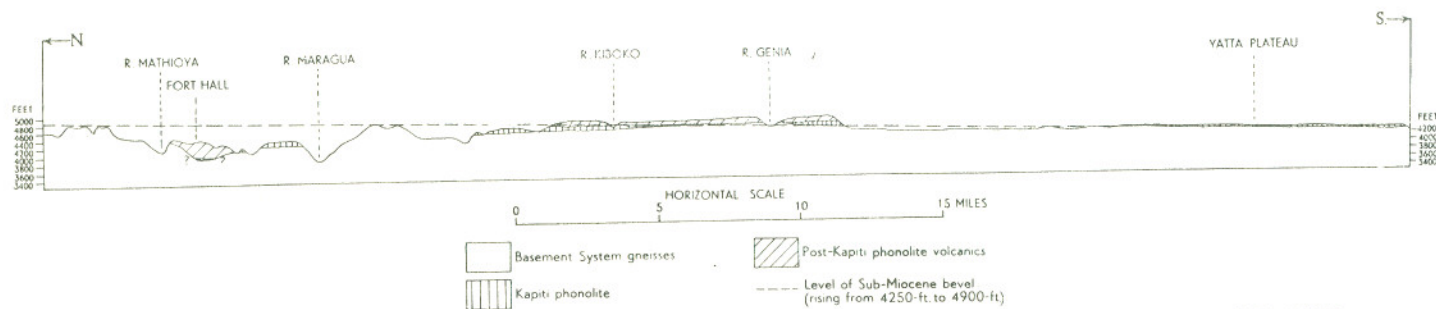


Fig. 2—Section showing the relationship of the Kapiti phonolite to the sub-Miocene bevel between the Yatta Plateau and Fort Hall

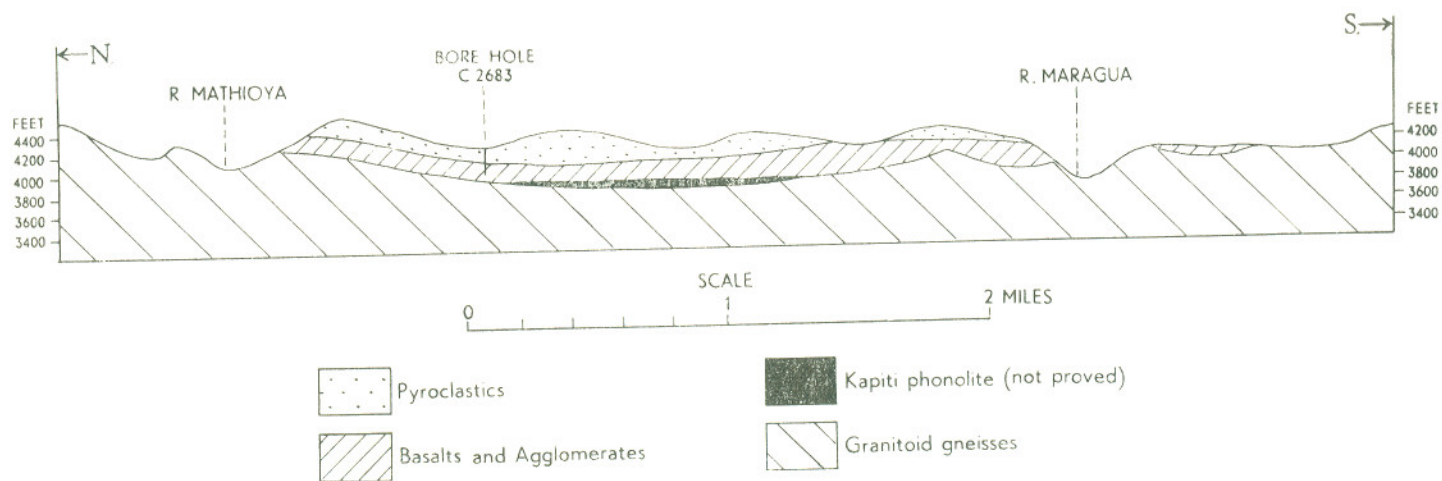


Fig. 3—Section across the Maragua Gap

Basement System rocks are mainly exposed in the south-eastern quarter of the area and also appear as inliers protruding through the volcanic rocks near Fort Hall. They were formed by recrystallization of original mixed sedimentary sandstones and shales into which lenses and sills of basic igneous rocks were intruded.

The long period of time intervening between the metamorphism and recrystallization of the Basement and the first extrusion of Tertiary lavas was one of repeated uplift and erosion attended by development of the peneplained erosion surfaces already described.

At the beginning of the Miocene the Fort Hall area must have been an undulating plain studded with minor hills such as Muthuru and Molinduku with a higher group of hills rising some 1,200 feet above plain-level in the present area of the Ithanga and Kakuzi hills. Before extrusion of the earliest Tertiary lavas the plain was uplifted and a considerable valley was incised along the present site of the Maragua gap to the south of Fort Hall, at the same time the southern margin of the Muhito inlier stood as a scarp overlooking the valley.

The first lava flood of Kapiti phonolite erupting from the eastern flank of the Rift Valley was evidently halted by the barrier of the Ithanga and Kakuzi hills and continuing eastward flow was diverted through the Maragua gap, so that in this area the sub-Miocene surface was not covered by Kapiti phonolite. The bulk of the succeeding Simbara basalts and agglomerates are also restricted to the west of the Kakuzi hills and the Muhito inlier. The effectiveness of the latter as a barrier is illustrated by outliers of Simbara agglomerate near Fort Hall and the overlap of younger porphyritic basalts on older Simbara agglomerate near the Gura river. The passage of the Simbara basalts probably caused final filling of the Maragua gap.

The end-Tertiary erosion surface was well developed before the deposition of trachytic tuffs overlying the Simbara volcanics west of the Kakuzi-Muhito barrier, since similar tuffs rest directly on Basement System at a much lower level to the east of this barrier. Laikipian basalt then flowed into the area from the north-west, entering the area around the northern end of the Muhito inlier, and was followed by the first eruption of lavas from Mount Kenya. The first flows were of phonolite which rest directly on the Basement System, and were followed by trachytes entering the area from the north-west.

A long period of erosion following the emplacement of the trachytes led to maturation of the end-Tertiary surface over an extensive area between the Muhito inlier and the Mount Kenya phonolite north of the Tana river. Succeeding lava flows from Mount Kenya (the Thiba basalts) flooded the whole of this part of the end-Tertiary plain and filled many of the river valleys excavated in older volcanics. Their deposition on the mature end-Tertiary surface dates the Thiba basalts as Pleistocene. Damming of drainage from the Aberdares by the Thiba basalts led to accumulation of silts and sandstones covering an area of several square miles to the west of Kiambicho.

Tertiary to Recent tectonic activity in the area was slight; faulting is mainly confined to the oldest Tertiary lavas (the Kapiti phonolite), and in recent times geological processes have been limited to soil formation, excavation of river valleys and the re-excavation of Basement System inliers.

The sequence of events in the geological evolution of the area can be summarized as follows:—

QUATERNARY	{	13. Formation of recent deposits
		12. Pleistocene lavas
	{	11. Maturation of the end-Tertiary peneplain
		10. Eruption of basalts, agglomerates, trachytes
		9. Faulting
TERTIARY	{	8. Extrusion of Kapiti phonolite
		7. Erosion of sub-Miocene peneplain
		6. Rejuvenation, formation of sub-Miocene peneplain
		5. Formation of end-Cretaceous peneplain
		4. Period of uplift and erosion
	{	3. Regional folding and metamorphism
PRECAMBRIAN		2. Intrusion of basic igneous rocks
		1. Deposition of marine sediments

V—DETAILS OF THE GEOLOGY

1. Basement System

For descriptive purposes the Precambrian rocks are classified as follows:—

(1) Non-Granitic Rocks

(a) Metamorphosed sediments

- (i) Biotite gneisses
- (ii) Quartzo-felspathic gneisses and granulites
- (iii) Garnetiferous gneisses and granulites
- (iv) Pelitic schists and gneisses
- (v) Muscovite-biotite schists and gneisses
- (vi) Sillimanite schists

(b) Metamorphosed intrusives

- (i) Meta-dolerites
- (ii) Anorthosites
- (iii) Amphibolites
- (iv) Hornblendites
- (v) Plagioclase amphibolites and epidiorites

(2) Granitic Rocks

(a) Granitized sediments

Granitoid gneisses and related biotite gneisses

(b) Granitic intrusions

Pegmatites and quartz veins

(1) NON-GRANITIC ROCKS

(a) Metamorphosed Sediments

(i) *Biotite gneisses*.—The biotite gneisses of this group are well foliated and contain more quartz and less feldspar than some of the massive granitoid rocks with which they are associated. Outcrops are common in the south-eastern part of the area, in the Thika and Tana rivers. Specimen 44/957*, from the Tana river west

* Specimen numbers 44/1957, etc., refer to material in the regional collections of the Geological Survey, Nairobi.

of Masai Crossing, is a typical medium-grained biotite gneiss containing abundant black biotite and streaks of iron-stained quartz. Microscopically the minerals are seen to be arranged in sub-parallel orientation with quartz as the most abundant constituent. The larger quartz grains are irregular in shape and enclosed in a much finer grained quartzose groundmass. Dusty untwinned plagioclase (oligoclase-andesine) is also fairly abundant and shows considerable breakdown to clinozoisite and epidote, which occur as chadacrysts in the form of needles and small stout yellow-green laths. Biotite is in ragged flakes, pleochroic from light to very dark greenish brown, and associated with rare flakes of muscovite. Accessory minerals are magnetite, sphene and apatite.

(ii) *Quartzo-felspathic gneisses and granulites*.—This group includes a highly variable range of rock types poor in mafic minerals. Usually the quartzo-felspathic gneisses show a marked foliation due to the narrow banding of felsic minerals. The foliation layers are often separated by a thin covering of platy mica, of which muscovite is more abundant than biotite. Specimen 44/906, from the Thika river, is a fairly fine grained granular rock with no marked grain orientation, although a linear arrangement is shown by zones of quartz which differ slightly in grain size. The essential minerals are quartz with subsidiary orthoclase, perthite and sodic plagioclase. Microcline is not present. Muscovite is fairly common, and is often partly intergrown with small shreds of biotite. Specimen 44/946 from south of the Tana at Mutithi is very similar but has a highly developed banding of coarse and fine grained quartz. Accessory minerals include iron ore and epidote.

The granulites are illustrated by specimen 44/952, collected north-east of Riakanau, a white sugary granular rock with the appearance of a friable quartzite speckled with biotite and spots of epidote. In thin section the specimen consists of quartz and alkali feldspar in granoblastic texture with muscovite, biotite and epidote.

Petrologically the quartzo-felspathic gneisses and granulites are very similar to the biotite gneisses, being poor in alkali-feldspar and rich in quartz. Both these groups probably represent the metamorphism of a variable sequence of psammitic sediments, with little or no felspathization.

(iii) *Garnetiferous gneisses and granulites*.—The garnetiferous rocks are stratigraphically the oldest exposed rocks in the area forming the core of an anticline in the Thika river (Fig. 7). They differ from the quartzo-felspathic gneisses only in having almandine as an essential component.

(iv) *Pelitic schists and gneisses*.—This group includes a poorly defined group of schistose rocks exposed as two discontinuous bands within the Ithanga hills granitoid gneiss. Both bands, where typically developed, consists of a series of steeply dipping biotite schists and associated semi-pelitic gneisses, showing little or no indications of granitic alteration. The southern exposure of schists, at the edge of the map, is formed mainly of biotite schists with some muscovite-biotite schists and subordinate gneisses, all showing a well defined foliation. Traced northwards the typical schistose foliation is lost, and the rocks are replaced by hard platy gneisses which have evidently suffered considerable granitization.

(v) *Muscovite-biotite schists and gneisses*.—A variable sequence of schists, gneisses and granulites, characterized by the presence of muscovite, form an anticlinal structure in the Thika valley. The sequence also contains local developments of sillimanite-muscovite schists, which are described later. The majority of the schists and gneisses included in this group show little alteration by the addition of alkalis, and like the granulites and quartzo-felspathic gneisses are strongly quartzose, with mica and only scarce feldspar. They probably derived from the metamorphism of a series of pelitic and semi-pelitic sediments.

Specimen 44/904 from the Thika river is a typical member of the series, a fine grained schistose rock composed of quartz, muscovite and biotite. Quartz, which forms about 80 per cent of the rock, occurs in an equigranular mosaic of grains whose average length is about 0.1 mm., orientated with their long axes parallel. Flakes of biotite and shreds of muscovite varying in size up to 1.0 mm. give a fine grained lineation on foliation surfaces.

Included within the normal micaceous schists are occasional zones of granulite and granitoid gneiss, and these usually contain conspicuous muscovite. Specimen 44/956, also from the Thika river region, is an example of a felspathic muscovite granulite in which quartz is subordinate to feldspar. The principal minerals are orthoclase, microcline, sodic plagioclase, quartz and muscovite. The orthoclase shows a high degree of alteration to sericite and clay minerals, while the microcline is fresh and shows replacive textures.

(vi) *Sillimanite schists*.—Exposures of sillimanite schist are present within the muscovite-biotite schist zone on the west bank of the Thika river near the southern boundary of the area. The schists consist essentially of quartz, muscovite, biotite and sillimanite. Sillimanite, which has formed at the expense of large flakes of muscovite, is present as long slender fibres, forming sheaves radiating away from the muscovite. Biotite is of secondary importance occurring as irregular flakes partly intergrown with muscovite. Quartz with occasional inclusions of needle-like sillimanite forms the groundmass of the rock interstitial to the larger whorls of muscovite and sillimanite.

(b) *Metamorphosed Intrusives*

Rocks derived from the metamorphism of basic dykes, sills and sheet intrusions occupy a considerable area north-east of the Ithanga hills and include meta-dolerites, anorthosites, amphibolites, hornblendites, epidiorites and plagioclase amphibolites. The meta-dolerites and hornblendites are resistant to erosion and usually form ridges or small hills; Mutheru hill is a feature formed in this manner, and several of the minor hills near the confluence of the Tana and Thika rivers stand on the outcrops of metamorphosed basic intrusives.

(i) *Meta-dolerites*.—These are coarse or medium grained granular rocks with a distinct igneous texture. Specimen 44/951 from Mutheru hill contains conspicuous prisms of feldspar in a matrix of altered pyroxene and accessory pyrite. Original pyroxenes are largely replaced by pale green hornblende. The feldspar is a labradorite containing abundant needles of clinozoisite.

Specimen 44/947 from west of Mutheru is of finer grain and shows a more advanced stage of metamorphism. Pyroxene is completely replaced by uraltic hornblende, and some of the labradorite is replaced by a crystalloblastic mosaic of oligoclase. Clinozoisite is an abundant accessory.

(ii) *Anorthosites*.—Outcrops of anorthosite were recorded in a series of small hills situated two miles north of the Tana river at the eastern margin of the area. The anorthosite is adjacent to outcrops of metadolerite and possibly represents a feldspar-rich differentiate from original dolerite. Specimen 44/959, taken from one of the outcrops, is a grey or greenish rock mottled by ferro-magnesian minerals. Labradorite is the most abundant mineral constituent accompanied by fibrous pale green hornblende, clinozoisite and epidote.

(iii) *Amphibolites*.—Amphibolites are well exposed along the southern bank of the Tana, near its confluence with the Thika river. Specimen 44/907 from this locality is a dark green schistose rock containing a foliated mass of actinolite crystals packed with minute inclusions of iron-ore; the remaining accessory minerals are chlorite and apatite. The majority of amphibolite outcrops seen in this locality are schistose, containing abundant actinolite to the exclusion of hornblende, and were evidently formed by shearing and recrystallization of the margins of hornblendite bodies.

(iv) *Hornblendites*.—These are massive medium-grained dark green to black rocks best exposed between the Muthini and Kathaguni rivers on the north bank of the Tana near Riakanau. Specimen 44/950 from one of a series of small hillocks in this locality contains more than 90 per cent of hornblende in stout interlocking prisms. The hornblende is sieved with minute inclusions of granular iron-ore and also contains relict patches of augite. Accessory minerals are pale yellow epidote, colourless clinozoisite and chlorite.

(v) *Plagioclase amphibolites and epidiorites*.—These rocks occur in bands and lenses in the Basement System between the Kakuzi hills and Ekarakara. The plagioclase amphibolites are strongly foliated and interstratified with broader zones of more massive epidiorite in which original igneous textures are not entirely destroyed by metamorphic recrystallization. Hornblende is the principal mineral constituent of both rock types and is generally darker in colour and more pleochroic than the variety commonly found in the meta-dolerites. The accompanying felspar is andesine containing clinozoisite and epidote inclusions. Biotite is a common constituent in some of the plagioclase amphibolites together with accessory sphene, chlorite, apatite and iron ore.

(2) GRANITIC ROCKS

(a) *Granitized Sediments*

Granitized gneisses and related biotite gneisses.—Granitoid gneisses form the Kakuzi and Ithanga hills occupying the southern part of the area, and underlie the volcanic rocks north of Fort Hall where they appear as extensive inliers at Muhito and Kiambicho. West of the Muhito inlier similar granitoid gneisses are seen along the floors of the valleys and also in the Chania river east of Nyeri, so that much of the Basement System beneath the volcanic cover in the western part of the area appears to consist of comparatively uniform granitoid rocks.

The gneisses are pink or grey in colour. Those showing no marked foliation are mapped as granitoid gneisses distinct from the biotite gneisses which are well foliated and contain more biotite. Typical unfoliated granitoid gneisses are exposed on Ithanga, Njigi, Ekarakara, and in the Muhito inlier where it is crossed by the Mathioya river north of Fort Hall. Foliated biotite gneisses of granitoid composition form the Kakuzi hills and a wide belt of country extending northwards to Thaba-Thaba.

Essential minerals of the gneisses are microcline, orthoclase, soda-plagioclase, quartz and biotite, with accessory iron-ore, muscovite, sphene, apatite, zircon, hornblende and epidote. Perthitic and myrmekitic textures are common in the feldspars; microcline is the dominant felspar in most specimens and often shows replacive textures with both plagioclase and quartz. The textures of the granitoid gneisses suggest that they are syntectonic rocks produced by migmatitic processes during metamorphism and granitization.

(b) *Granitic Intrusions*

Pegmatites and Quartz Veins.—A few narrow pegmatitic veins and quartz lenses were noted in the granitoid gneisses. In all cases they were unmineralized.

2. Tertiary and Pleistocene Volcanics

The volcanic succession in the Fort Hall area is given on p. 5. The precise ages of some of the Tertiary volcanic formations are in doubt, but it is inferred that the oldest lava (the Kapiti phonolite) is of Miocene age, and that subsequent volcanic deposition spanned the Miocene and possibly continued into the Pliocene.

Lavas and pyroclastic rocks cover nearly three-quarters of the area, and were evidently more extensive before excavation of the Muhito inlier by the Sagana river and tributaries.

(1) THE KAPITI PHONOLITE

The largest exposures of Kapiti phonolite in the area occur to the south and south-east of Fort Hall where they rest on Basement System rocks. Younger volcanics overlies and overstep the phonolite which appears as an inlier in the Mukungai valley some five miles west of Fort Hall; this is the most northerly known outcrop of Kapiti phonolite in Kenya, and lack of similar phonolite exposures in the valleys further north suggest a termination here.

At Punda Milia and Karaba the phonolite is similar in appearance to the Yatta phonolite described by Schoeman (1948, p. 36), and contains abundant translucent phenocrysts of anorthoclase and greenish nepheline. At Maragua and in the Mukungai valley exposures are fine-grained and anorthoclase phenocrysts are comparatively rare. Microscopically the phonolite compares with descriptions given by Smith (1931, p. 238). In addition to phenocrysts of anorthoclase and nepheline most specimens also contain microphenocrysts of olivine, anorthoclase, augite and nepheline included in the ground-mass. Specimen 44/945 from Karaba contains euhedral crystals of olivine with rims of iron-hydrate and pseudomorphs of calcite replacing the olivine, and corroded crystals of green augite were seen in specimen 44/935 from the Mukungai valley.

The ground-mass of the Kapiti phonolite contains anorthoclase in abundant small laths, together with minute crystals of augite, aegirine, cossyrite, kataphorite, nepheline, analcite and iron-ore. Vesicles in the phonolite are filled by calcite, kaolin and natrolite.

The Kapiti phonolite was one of the earliest lava flows to be extruded on the eastern flank of the present-day Rift Valley and extends outside the Fort Hall area towards Kajiado in the south-west (Joubert, 1957, p. 33), and also caps the Yatta plateau for a distance of some 170 miles towards the south-south-east in a narrow outcrop seldom reaching more than three miles in width (Sanders, 1963, p. 7). The phonolite must originally have covered a surface area of at least 4,000 square miles.

Eastward flow of the lava in the Fort Hall area was restricted by a barrier of granitoid gneiss extending through the Kakuzi hills and the Muhito inlier. Southward continuation of this barrier outside the present area is found in Ol Doinyo Sapuk, the Kanzalu Range, Kangundo hill and the Mua hills. Restricted flows of phonolite found eastward outlets through gaps in this barrier of hills at Mitaboni between Kangundo hill and the Mua hills and at Maragua in the Fort Hall area, but the main eastward exit was near Ol Doinyo Sapuk and gave rise to the phonolite capping of the Yatta plateau (Fig. 4). It has been estimated (Walsh, 1963, pp. 6-9) that the phonolite could have flowed for the length of the plateau in about seven months, and Gregory (1921, p. 186) suggested that this flow was confined by an original south-eastward trending valley. Evidence for the existence of a pre-volcanic valley is provided from the northern end of the Yatta plateau where a borehole passed through some 500 feet of phonolite without reaching Basement; since the thickness of phonolite exposed at the edges of the plateau here is less than 100 feet, median thickening of the flow can only be explained by the presence of a valley profile on the sub-volcanic surface, or by the possibility that a feeder-fissure was intersected by the borehole.

(2) THE SIMBARA SERIES

Shackleton (1945, p. 2) describes the Simbara Series from the type areas of Sattima and Niandarawa as consisting mostly of basalts with abundant parallel plagioclase phenocrysts. Away from the main eruptive centres he recognizes the Simbara basalts as being represented mainly by agglomerates composed of porphyritic felspar basalt, melanocratic basalt with olivine and augite, and lesser amounts of basalts of other types. The agglomerates were examined by Shackleton at Saba Saba and Makindi. In the present area it has proved possible to subdivide the Simbara Series into two parts,

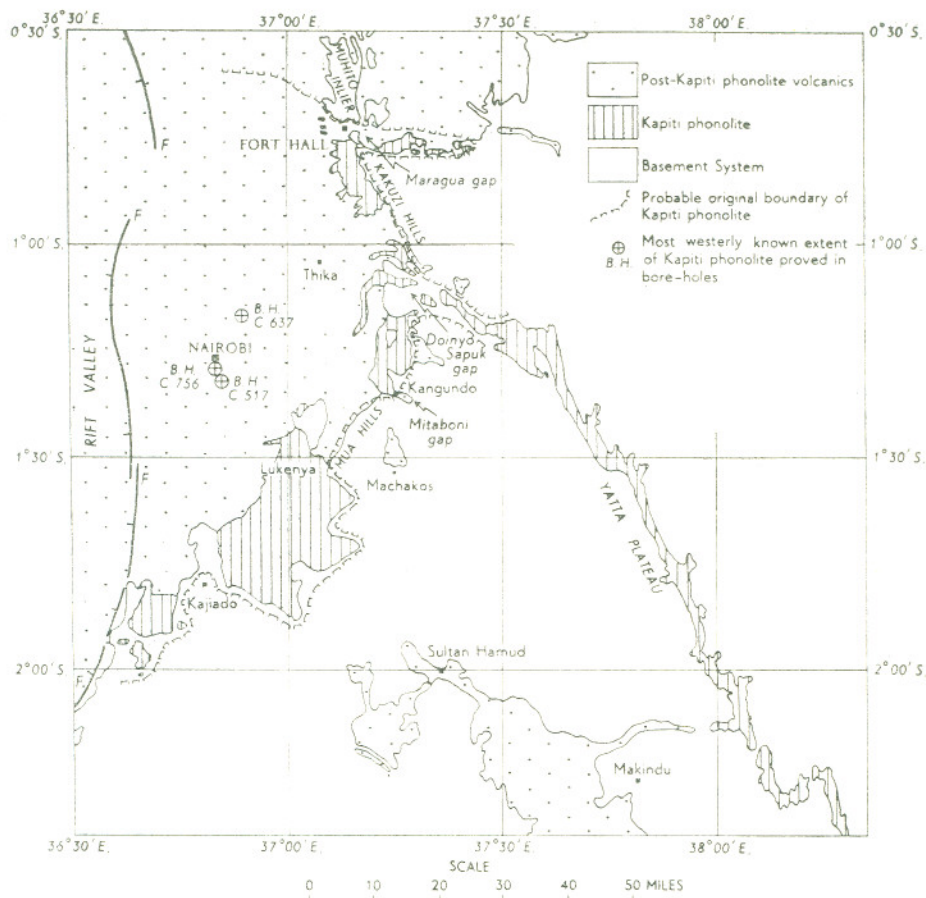


Fig. 4—Distribution of the Kapiti phonolite in Kenya

an upper series of porphyritic olivine basalts with agglomerates and a lower series dominantly composed of basaltic agglomerates but with occasional lava flows. The division between the two parts of the Simbara Series is nowhere distinct, there being a gradual passage from one to the other; but where the sequence is clearly seen the division is made at the base of the earliest sheets of highly porphyritic olivine-augite basalt.

(a) *Basalt Agglomerate Series*

The lower subdivision, Basalt Agglomerate Series, is present in the Sagana, Gura and Mathioya valleys, where it overlies granitoid gneisses of the Basement System, in the Mukungai valley and the Maragua Gap on Kapiti phonolite, and over a considerable area south of Maragua river where it again overlies the Kapiti phonolite and generally underlies tuffs and agglomerates of the Upper Athi Series. The series includes a succession of basaltic agglomerates containing both porphyritic felspar basalts and melanocratic basalts which occur south and south-west of Fort Hall, and also a series of brecciated basalts with rare porphyritic felspar basalt in the valleys north-west of Fort Hall.

The basalt agglomerates are well exposed in road cuttings between Saba Saba and Thika and in rail cuttings near Makuyu. Particularly near Makuyu, sections through the agglomerates show a well developed bedding. Many of the basalts present in the

agglomerates are highly vesicular, the most characteristic of which is a vesicular porphyritic felspar basalt which is a typical Simbara-type basalt. Specimen 44/894 from near Mitubiri is a vesicular grey basalt with small phenocrysts of felspar and flakes of iddingsite. The felspar, a rather sodic labradorite, forms laths varying in length from 2 to 4 mm. which are grouped together in small sub-radial clusters. Iddingsite in the rock forms bright red-brown pleochroic pseudomorphs after euhedral olivine. Subhedral crystals of brownish augite occur as smaller phenocrysts. The groundmass consists of slender laths of plagioclase with granular brownish augite, specks of iddingsite after olivine and rod-like growths of iron ore.

Another specimen of porphyritic felspar basalt from the Gura Valley (specimen 44/927) is very similar, except that olivine has been replaced by antigorite. Iron ore is again rod-like and skeletal, and is probably ilmenite.

Examples of coarsely porphyritic melanocratic basalts with phenocrysts of olivine and augite are more common in the Porphyritic Olivine Basalt Series, but samples also occur in the basaltic agglomerates. Specimen 44/948 from south of Tana Mutithi is a fine-grained black basalt with large phenocrysts of black augite and green olivine. The thin section shows the large euhedral crystals of augite, up to 5 mm. in length, to have a poikilitic habit with respect to olivine. Olivine phenocrysts, subordinate in amount to augite, occur in unaltered euhedral crystals smaller than the pyroxene, and tend to be seriate towards the groundmass. Scattered smaller phenocrysts of labradorite are fairly common. The groundmass is very fine grained, with plagioclase, granular augite, subhedral iron ore and possible secondary analcite. Occasional vesicles in the rock are filled by carbonates and analcite.

The characteristic basaltic agglomerates south of the Maragua river are less common to the north, where the Basalt Agglomerate Series west of the Muhito inlier is mainly represented by brecciated basalts. These brecciated basalts are often highly weathered and many, such as specimen 44/928 from the Gura valley, contain an abundance of secondary analcite. Other examples of basalts have reached the stage of claystones and at one locality in the Muthioya (north) valley highly weathered basalts have been worked for building stone.

Specimen 44/928 is a pale grey highly vesicular basalt with the vesicles partly or wholly filled by analcite. The analcite is slightly anisotropic and granular in nature, and fills primary vesicles and possibly secondary vesicles left by the removal of olivine phenocrysts. Phenocrysts in the rock are small laths of felspar partly replaced by secondary analcite. The groundmass is almost isotropic due to the presence of much analcite and an abundance of finely granular iron ore formed as alteration products. Felspar can still be seen along with augite, but the original olivine has now been completely altered to iron ores, iron hydrates and iddingsite.

One of the few true lava flows within the basalt agglomerates outcrops to the west bank of the Sagana river near Tumu Tumu. This lava flow, of black fine grained basalt, is about 20 feet thick and displays well developed columnar jointing. North of the present area in the Sagana Valley near the Sagana Falls the columnar basalt is much thicker and has been described by Baker (Report in preparation).

(b) Porphyritic Olivine Basalt Series

The Porphyritic Olivine Basalt Series has been defined as a basaltic group overlying the Basalt Agglomerate Series whose base is marked by the first appearance of persistent flows of porphyritic basalt. It is probable that this group is a descriptive grouping and not a true time group. Towards the south-west corner of the area the porphyritic basalts are not so distinctive and the base of the series is marked by the appearance of fine grained columnar basalts.

The Porphyritic Olivine Basalt Series is restricted to the western edge of the area, where it mainly overlies the basalt agglomerates. Just south of the Gura river the porphyritic basalts overstep the agglomerates and rest directly on the granitoid gneisses of the Muhito inlier. North of the Gura river the porphyritic basalts are either poorly exposed or covered by the younger Laikipian basalts.

Both the Basalt Agglomerate Series and the Porphyritic Olivine Basalt Series are represented by brecciated basalts, but the Porphyritic Olivine Basalt Series is characterized by an abundance of highly porphyritic basalts in thin flows. The porphyritic basalts contain dark green euhedral phenocrysts of olivine and euhedral phenocrysts of augite. Olivine is usually more abundant than augite, but occurs in smaller crystals. Together the two minerals as phenocrysts can make up more than 50 per cent of the lava. Miss Neilson (Gregory, 1921, p. 405) has described one of these porphyritic basalts from the Aberdares, which she designates Craiglockhart-type basalt. Weathered surfaces of the porphyritic basalts are a rich red-brown in colour and studded with black phenocrysts, giving a "fruit cake" appearance.

Microscopic examination of the porphyritic basalts shows that although olivine phenocrysts are characteristic of all specimens, there is a range in composition from feldspar-rich basalts to highly magnesium-rich basalts approaching picrites and dunites. Four basalt lava types were recognized:—

- (i) Porphyritic basalts with phenocrysts of olivine, augite and subordinate feldspar.
- (ii) Porphyritic basalts with phenocrysts of olivine and augite.
- (iii) Porphyritic basalts with phenocrysts of feldspar more abundant than olivine and augite.
- (iv) Porphyritic basalts with phenocrysts of olivine and feldspar.

In three of these four groups olivine is usually more abundant than any of the other phenocrysts.

(i) Basalts of this group usually have olivine as the most common phenocrysts, but conspicuous large phenocrysts of augite and numerous smaller phenocrysts of plagioclase also occur. Olivine is colourless or pale yellow or brown, in large euhedral or sub-hedral crystals up to 7 mm. in length. Some rounded crystals are corroded and partly absorbed into the groundmass. Alteration to serpentine is slight, occurring in cracks and at the margins. Enclosures within the larger olivines contain small rounded crystals of olivine and zeolite-filled cavities. Augite forms large sub-hedral crystals, rather brownish in colour, the colour deepening towards the crystal edges. Small feldspar phenocrysts are abundant, and are seriate to the groundmass. Extinction angle determinations indicate that the feldspar is labradorite, and rather more calcic than the feldspars of the Basalt Agglomerate Series. The groundmass is of fairly coarse grain with abundant plagioclase, some small euhedral olivines and much brownish granular augite. Accessory minerals include iron ore, antigorite as an alteration product, and secondary analcite.

(ii) The basalts of this group have phenocrysts of olivine and augite but only rare phenocrysts of plagioclase. The scarcity of plagioclase and the abundance of olivine and augite makes these rocks picrite basalts. Specimen 44/914 from the Maragua valley is a highly porphyritic picrite basalt with large phenocrysts of olivine and augite in a very fine-grained groundmass. The olivine forms pale brown euhedral crystals which are rather more abundant than the larger phenocrysts of faintly pleochroic greenish augite. Both olivine and augite have cavities filled by a fibrous zeolite, probably natrolite, while the olivine occasionally displays a poikilitic habit with the groundmass. Rare microphenocrysts of labradorite are also present. The very fine-grained groundmass consists of small tabular feldspars, granular greenish augite, irregular pleochroic brown

hornblende, iron ore and specks of iddingsite. Natrolite-filled vesicles are fairly common, and interstitial analcite and larger pools of analcite are also present. Basaltic hornblende or a related amphibole, pleochroic from yellow to red-brown, is also present in the groundmass of 44/929 from the Mugoro river.

(iii) The only specimen represented by this group is specimen 44/931 from near the Suru Suru river, a fine-grained basalt with abundant feldspars but only rare phenocrysts of olivine and augite visible in the hand-specimen. In the thin section olivine is represented by one large euhedral crystal showing alteration to iddingsite and iron ore, and a few small phenocrysts. Augite, pale green in colour, is also scarce. Phenocrysts of labradorite up to 3 mm. in length make up about 50 per cent of the rock, in criss-cross orientation. The fairly coarse-grained groundmass of tabular brown augite, fine plagioclase, sub-hedral iron ore and occasional altered olivine is interstitial to the plagioclase phenocrysts. Granular analcite, some of it clearly secondary, is again very abundant.

(iv) The only representative of this group is a highly porphyritic basalt with no true groundmass visible in hand-specimen. The specimen, No. 44/934 from south of the Poyo valley, has a greater density of phenocrysts than any basalt of the other groups. The phenocrysts, which comprise about 50 per cent of the rock, are of brown sub-hedral olivine locally altered to serpentine. Interstitial to the large olivine crystals, which reach 10 mm. in length, are phenocrysts of labradorite which reach 3 mm. in length. The groundmass to the rock consists of scattered crystals of augite, olivine, iron ore and alteration products filling interstices between the phenocrysts. This specimen is highly basic in composition, and apart from the rather large percentage of feldspar is close to a peridotite in composition.

(3) TRACHYTIC TUFFS

The Trachytic Tuff Series, which includes agglomerates and claystones, are best exposed in the south-west of the area and near Fort Hall. Smaller isolated exposures occur between the Kakuzi and Ithanga hills, on the basaltic plain north-east and east of Fort Hall, and in the Nyamindi, Sagana and Gura valleys.

Strong similarities in rock types and geological setting enable a correlation to be made with the upper part of the Athi Series of the Thika area (Fairburn, 1963, p. 22). The exposures in the Sagana and Gura valleys in the north-west also enable a correlation to be made with the Nyeri and Kinangop tuffs in the Nyeri area to the north-west of the present area (Shackleton, 1945, p. 3). Shackleton mapped exposures of the tuffs as far north as the Pesi river, where they overlie Thomson's Falls phonolite, while the Athi Series occur as far south as the Nairobi river, an overall distance of about 85 miles.

Commonly the tuffs overlie basalt agglomerates of the Simbara Series, as is the case north of Thika and near Fort Hall, but they also rest directly on Basement System gneisses in the Kakuzi hills region, and on Kapiti phonolite east of Maragua. They are overlain by Laikipian basalts in the Gura and Sagana valleys, Mount Kenya phonolite near the Nyamindi-Rupingazi junction, Thiba basalts east of Sagana, and by the Tumu Tumu trachytes north of Sagana.

The most complete record of the trachytic tuffs is provided in the Thika and Kayam valley in the extreme south-west of the area where the following sequence can be recognized resting on Simbara agglomerates:—

- Grey trachytic tuff.
- Welded tuff with obsidian.
- Upper Thika building stone.
- Grits (Lake beds).
- Agglomerate and hard tuff with crystals.

This sequence, which is about 100 feet in thickness, agrees closely with that recorded at Thika (Fairburn, 1963, p. 18) except that in the present area the Lower Thika building stone is missing and the sedimentary grits are only locally developed.

The most widespread band in the above sequence is that of grey trachytic tuffs which are probably the equivalent of the Nyeri tuff. Another important band is the building stone found north of Mitubiri and east of Kakuzi but it is not known whether this represents the lower or the upper building stone of the Thika valley.

The tuffs and agglomerates are mainly light coloured trachytic tuffs with variable quantities of inclusions such as pumice, glass shards, crystals and obsidian. Campbell Smith (1931, p. 218) described some of the tuffs collected by Maufe near Fort Hall as pantellerites. He recognized in them abundant broken phenocrysts of anorthoclase, occasional rounded crystals of quartz and fragments of devitrified glass. The building stones are light grey and fine grained, highly isotropic in thin section with little or no pumice and a few crystals of feldspar. Most of the tuffs have appreciable quantities of pumice in flattened streaks, crystals of feldspar and aegirine and patches of quartz, while the welded tuffs have large flattened blebs of obsidian. Felspathic grits made up of volcanic erosion products are exposed in the Gitathuru valley.

(4) LAIKIPIAN BASALTS

The Laikipian basalts were first mapped and named in the Nyeri area by Shackleton (1945, p. 3) and described by him as a series of mainly non-porphyritic basalts many of which show hackly fracture and widely spaced columnar jointing.

The Laikipian basalts in the Fort Hall area cover the north-west corner of the area, where they overlie Simbara basalts and agglomerates, and at one locality trachytic tuffs. Exposures in the basalts in the west of this area are rare, and mapping is mainly based on float evidence. South and south-east of Tumu Tumu the Laikipian basalts are well exposed and display typical vertical columnar jointing. In this region they are overlain by Tumu Tumu trachytes which overstep the basalts further south. They are essentially olivine alkali-basalts and analcite basanites. Specimen 44/1318 from south-east of Tumu Tumu is a fine-grained analcite basanite containing microphenocrysts of euhedral olivine in a very fine-grained groundmass of augite, plagioclase, iron-ore and analcite.

As already mentioned (p. 7), the small area of basalt underlying the Mount Kenya phonolites south-west of Molinduku (Fig. 5) may be Laikipian basalt or is possibly an early basalt flow from Mount Kenya. Specimen 44/967B from this locality is an olivine basalt differing considerably from the normal alkaline-rich Laikipian basalts. Labradorite feldspar is abundant in the groundmass with large plates of ophitic pink augite, and analcite is absent.

(5) MOUNT KENYA PHONOLITES

The name Kenyte was proposed by Gregory (1900, p. 209) for the porphyritic lavas forming the central plug of Mount Kenya. In his description Gregory describes the Kenytes as having a "black glassy groundmass with scattered phenocrysts of glassy feldspar". Later authors (Bear, 1952, and Schoeman, 1951) have used the term kenyte for phonolitic lava flows from Mount Kenya, which although closely related to the rock of the plug differ in having a holocrystalline groundmass. In this report such lavas are referred to as phonolites, not kenytes.

Some phonolites collected by Gregory from Mount Kenya were described by Prior (1903, p. 235). These phonolites are characterized by the amount and variety of soda-amphibole (cossyrite, kataphorite and arfvedsonite) and of soda pyroxene (aegirine and aegirine-augite). All contain anorthoclase and nepheline.

The Mount Kenya phonolites are restricted to the north-east corner of the area and are mainly confined to the north and east of the Nyamindi river. They generally rest directly on the Basement System, as can be seen in the lower parts of the Rupingazi and Nyamindi rivers. South-west of Molinduku the phonolites rest on olivine basalts and trachytic tuffs (Fig. 5 a-b and e-f), and west of the Nyamindi-Rupingazi confluence they rest on trachytic tuffs. Normally the phonolite-Basement System contact is obscured

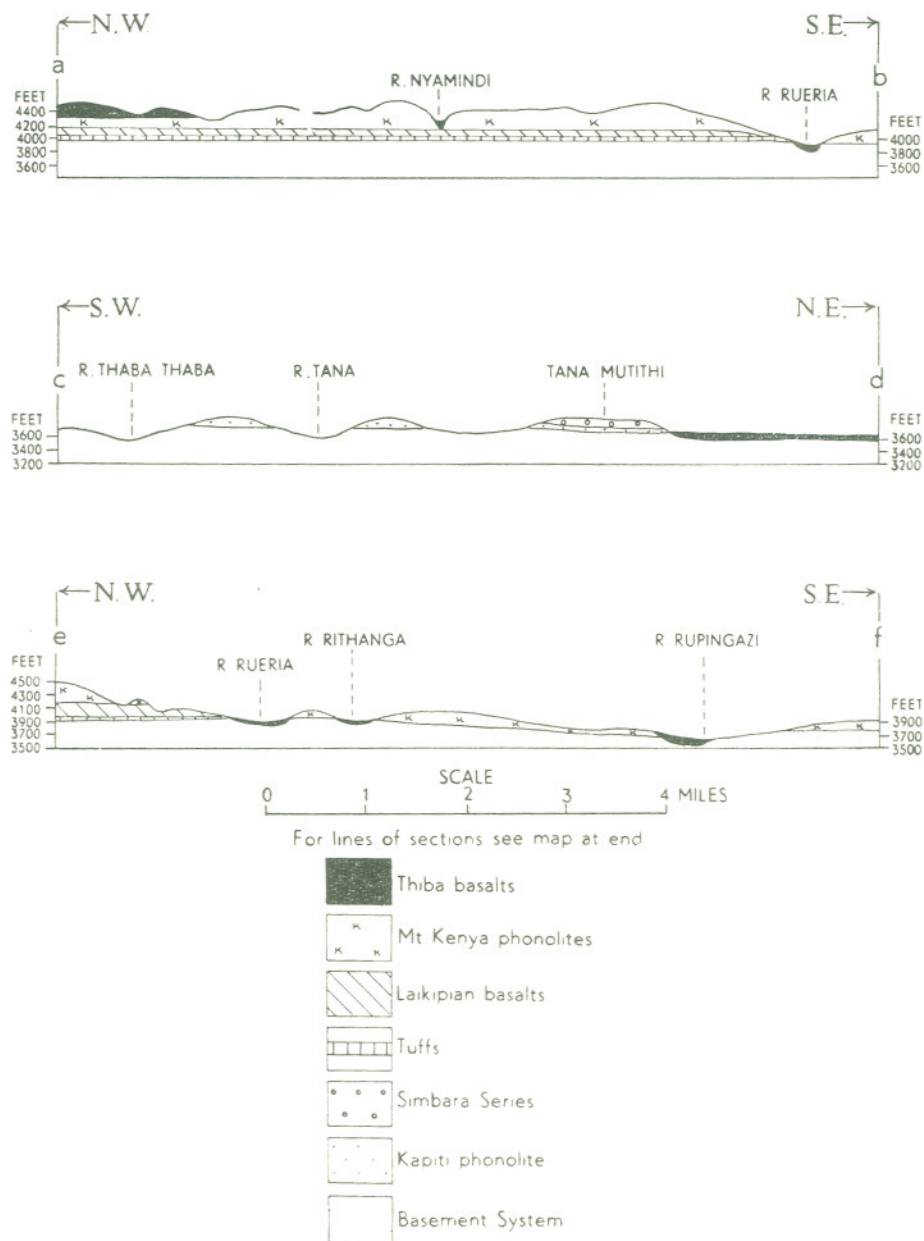


Fig. 5—Sections through the volcanic sequence south of Embu

by the younger Thiba basalts which flooded round the margins of the phonolite. Mapping of the phonolite boundary on aerial photographs is greatly assisted by the growth of thick vegetation along the edge of the lava flow.

Three distinct types of phonolite were recognized in the area, a porphyritic phonolite with rhombic feldspars, a coarsely porphyritic phonolite with tabular feldspars, and a non-porphyritic platy phonolite. All three types are associated with bands of brecciated phonolite and phonolitic agglomerate.

Specimen 44/936 from the Rupingazi valley is a typical example of the porphyritic phonolite with numerous rhombic phenocrysts of anorthoclase feldspar up to about 3 cm. in length, set in a dark greenish grey finely crystalline groundmass. The rhombic nature of the feldspar phenocrysts makes these phonolites quite distinct from the Kapiti phonolite. Phenocrysts of nepheline are often as abundant as anorthoclase, and in some examples, such as specimen 44/941 from near Daraja Ya Mungu, may be much more abundant than anorthoclase. Both anorthoclase and nepheline form euhedral crystals which are locally partly corroded and rounded by resorption, and commonly contain numerous inclusions of the groundmass in irregular patches. Chadacrysts within the phenocrysts include olivine, augite and more rarely apatite.

Microphenocrysts in the groundmass are common, and include olivine, augite and nepheline. Olivine is fairly abundant in some rocks in euhedral crystals partly altered to antigorite at the margins. In some cases the olivine is completely altered to antigorite or iron ore, and is closely associated with fairly large euhedral crystals of apatite. The optical properties of the olivine suggest that it is a fayalitic variety. Small microphenocrysts of greenish grey augite occur in some of the rocks examined. The most common constituents of the groundmass are anorthoclase feldspar in small laths, brown pleochroic kataphorite, very dark brown cossyrite, aegirine-augite and augite. Other minerals in the groundmass include small euhedral nephelines, interstitial analcite, euhedral apatite, olivine and iron ore.

The coarsely porphyritic phonolites are similar to the normal porphyritic phonolites except that the anorthoclase phenocrysts are tabular and much larger, some of them reaching 4 inches in length and an inch in width. The coarsely crystalline phonolites are usually found as large blocks in phonolite agglomerates, often associated with non-porphyritic platy phonolite.

The platy phonolites, of which specimen 44/942 from the Rupingazi valley is typical, differ from the porphyritic phonolites in lacking phenocrysts of nepheline and anorthoclase and showing trachytic texture in the groundmass. Principal minerals are orthoclase or anorthoclase, mossy green aegirine-augite and dark brown to black cossyrite. Iron ore and analcite are also present along with "ghosts" of resorbed nepheline.

(6) TUMU TUMU TRACHYTES

The Tumu Tumu lavas are a group of alkali trachytes which had their origin on the south-west slopes of Mount Kenya and are now exposed in the north-west corner of the present area. Near Tumu Tumu hill the trachytes overlie Laikipian basalts, but further south they overstep on to Basement System granitoid gneisses. At the southern end of the exposure they overlie trachytic tuffs. Baker (report in preparation) in the Mount Kenya area has demonstrated that the Tumu Tumu trachytes are younger than the Mount Kenya phonolites. The trachytes nowhere show stratification or flow-layering, but in a road cutting east of Tumu Tumu hill they display conspicuous horizontal columnar jointing.

Specimens from Tumu Tumu were originally referred to by Gregory (1921, p. 157) as compact dark blue phonolitoid-kenyte, and a more basic type as alkali-basalt or tephrite. Miss Neilson in Gregory (*ibid.*, p. 400) describes the rocks as being characterized by an abundance of small anhedral or grain-like olivines in a trachytic mesh of feldspar laths with interstitial strings and shreds of pale green pyroxene, with a liberal dust of magnetite and a few very small flakes of pale blue pleochroic riebeckite.

In none of the specimens collected during the present survey was nepheline found, and the rocks are, therefore, classified not as phonolites but as olivine alkali-trachytes.

In hand-specimen the trachytes are dark blue-grey in colour, non-porphyrific, and of fine grain. Microscopically the rocks are as described by Neilson, consisting of a trachytic mesh of orthoclase and anorthoclase with analcime and abundant granular crystals of altered fayalitic olivine. The olivine is locally altered to iddingsite or greenish serpentine minerals with iron ore. Pyroxenes present are mainly mossy-like aegirine-augite, but aegirine and greenish augite also occur. Large crystals of apatite dusted with iron ore are fairly common, and closely resemble the apatite described by Shackleton (1945, p. 15) from the alkali-trachyte of Songari hill in the Nyeri area. Magnetite is a very abundant accessory mineral, occurring as small cubes with a few larger irregular grains. Specimens 44/967 and 44/967A from the sides of Tumu Tumu hill contain hexagonal crystals of sodalite.

(7) THIBA BASALTS

The term Thiba basalts has been introduced to describe a fairly uniform series of usually non-porphyrific fine-grained grey basalts erupted from Mount Kenya, and distinct from the Upper Laikipian basalts of Shackleton (1945). They are well developed in a belt of country drained by the Thiba river extending from the southern slopes of Mount Kenya southwards almost to the Tana river. The total area covered by the basalts is approximately 650 square miles, of which half is in the Fort Hall area and half in the Mount Kenya area. Only very small exposures occur to the east of these two areas.

In the Fort Hall area the basalts are flanked on the west by the Basement System inliers of Muhito and Kiambicho, in the east by the undulating country formed by the Mount Kenya phonolites, and in the south by the low ridge of Simbara agglomerates and Kapiti phonolites in the Maragua gap. The basalts are also exposed in the Rupingazi and Nyamindi valleys, and extend outside the area eastwards for ten miles along the Thiba valley (Bear, 1952, p. 30).

Over much of their area the Thiba basalts rest directly on the Basement System with no intervening older volcanics. The Basement System floor, part of the end-Tertiary peneplain, is however rarely seen, and the lava-Basement contact is exposed only near the junction of the Nyamindi, Rupingazi and Thiba rivers, apart from a small Basement System inlier in the Kimangu valley two miles north-west of Kutus. The emplacement of the Thiba basalts on the mature end-Tertiary peneplain dates them as Pleistocene.

Subdivision of the Thiba basalts into varying groups depending upon the presence or absence of small phenocrysts of feldspar and olivine has not been attempted in the Fort Hall area although the subdivision has been made by Baker (report in preparation) in the Mount Kenya area to the north.

The Thiba basalts are light grey to black fine-grained rocks with a slightly speckled appearance. Good exposures of the basalts sometimes reveal hexagonal jointing as in the Rupingazi and Nyamindi rivers. Coarse ovoid vesicles sometimes filled with calcite are common. Phenocrysts are scarce or absent in most specimens, but where present are usually small grains of yellow-green olivine or more rarely euhedral crystals of feldspar.

Olivine present in the basalts, as in specimen 44/915 from the Tana river north of Kiambicho, occurs often in two generations, as phenocrysts up to 2 mm. in length and as smaller micro-phenocrysts. Most of the olivine phenocrysts are euhedral in shape with corroded margins, or where corrosion is advanced, as irregular crystals enclosing grains of iron ore. Alteration of olivine to iddingsite is common, usually marginal or in the case of specimen 44/944 from Wangaru, internally, and many of the smaller olivines have been totally replaced by iddingsite.

Large tabular plagioclase phenocrysts are present in specimen 44/937 from the Rupingazi river with included grains of iron ore, but generally felspar phenocrysts are rare. The plagioclase of both phenocrysts and groundmass is sodic labradorite.

The groundmass is composed of lathy interlocking plagioclase with pleochroic brownish or purple titanite, subhedral iron ore and olivine. Analcite is present in very small amounts as a primary constituent. The titanite is granular or skeletal, sometimes enclosing small granules of iron ore, and in some slides displays a subophitic texture. Olivine is not common in the groundmass except in rocks lacking large phenocrysts, where olivine may become as abundant as titanite.

3. Pleistocene Alluvial Deposits

(1) SANDSTONES

Alluvial sandstones form a flat sandy plain south of the Sagana river to the north-east of Fort Hall. They cover an area of approximately three square miles bounded to east and west by hills of granitoid gneiss. The sandstones appear to overlie the Thiba basalts and possibly represent lake sediments deposited during a temporary damming of the Sagana drainage by the Thiba basalts.

(2) BOULDER AND GRAVEL BEDS

A thick series of boulder and gravel beds extends for several miles along the western bank of the Rupingazi river northwards from the Nyamindi confluence. These coarse alluvial deposits rest on Basement System gneisses and contain abundant debris derived from the Mount Kenya phonolites. In some exposures the derived phonolite boulders are sufficiently large and numerous to give the impression of phonolite outcrops in place.

Absence of basalt boulders in the beds suggests that they were deposited before the extrusion of the Thiba basalts, so that they are possibly of early Pleistocene age. The boulder beds, gravels and grits were evidently laid down from the primitive Rupingazi river, the valley of which was later partly filled by basalt flows.

Recent drainage is re-excavating the Rupingazi valley with erosion and incision of the boulder and gravel beds.

4. Recent Deposits

Recent deposits described here include soils and deposits of alluvial origin formed in the post-volcanic period, and exclude the alluvial deposits described in the previous section.

Soil types derived from the Basement System rocks are usually readily distinguished from soil types derived from the volcanic rocks. This does not, however, apply to the black cotton soils, which owe their origin more to the prevailing physical conditions of formation than to the nature of the underlying rocks. Further subdivision of the soils can be made on the basis of colour and the presence or absence of quartz and humus content; the distribution of the various soil types is shown in Fig. 6.

(1) SOILS ON BASEMENT SYSTEM

Pink quartz-rich soils are characteristic of the Muhito inlier, where in the absence of rock exposure the soils have been of value in mapping the Basement-volcanic boundary. These soils are essentially quartz-rich gravels overlying the deeply weathered granitoid gneisses, which have decomposed to kaolin, quartz and vermiculite. Humus content of the pink soils is very low and they support only a meagre vegetation and very rarely a cultivated crop.

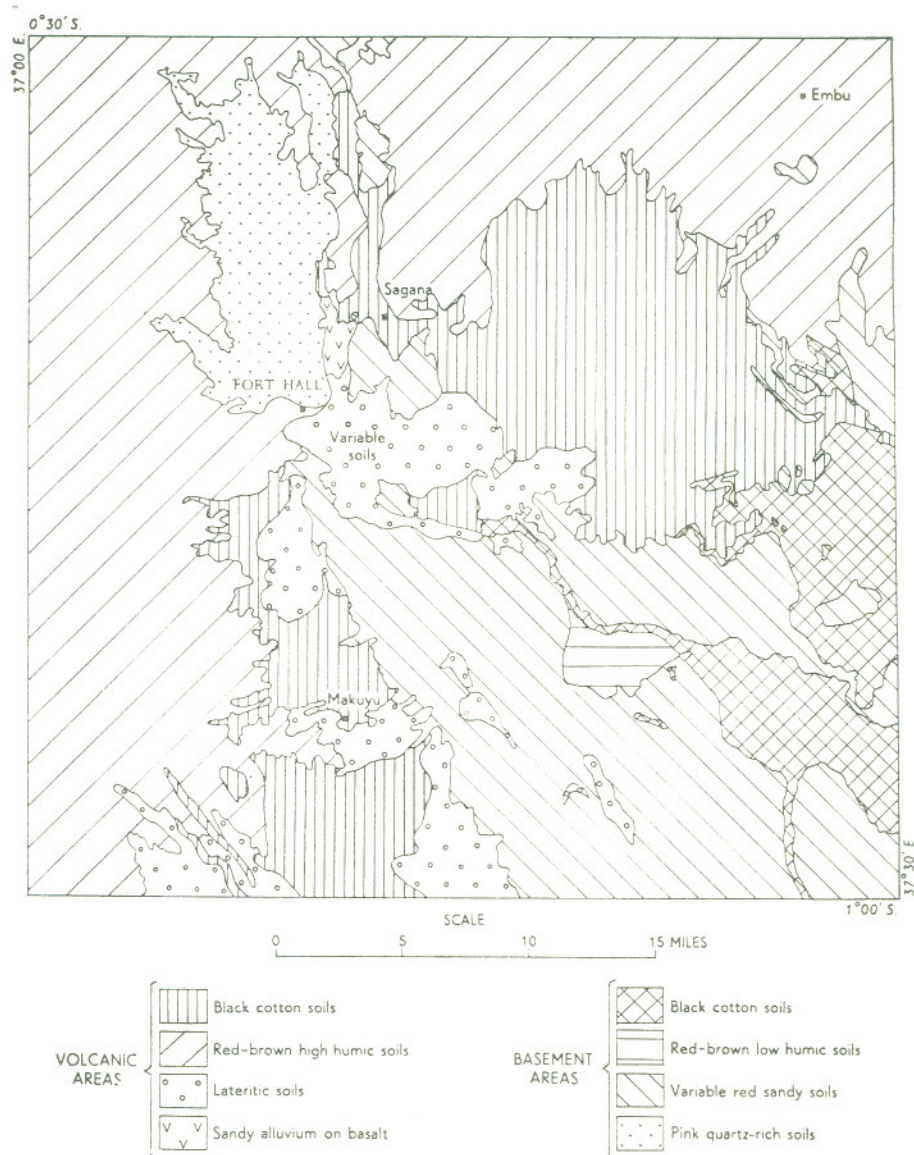


Fig. 6—Soil Map of the Fort Hall Area

Variable red sandy soils are produced from several different types of Basement System rocks. The most characteristic is a quartzose red murram providing good material for road surfacing. Red-brown low humic soils are perhaps the only soils characteristic of a distinct rock type, being produced from amphibolites and plagioclase amphibolites of the Tana river region north of Ithanga. These soils are dark red-brown in colour due to their high iron content, but have a low humus and quartz content. Generally the boundary between the quartzose soils and the red-brown quartz-free soils south of the Tana river is distinct and corresponds to the granitoid gneiss-amphibolite boundary.

Black cotton soils derived from Basement System rocks are found along the eastern edge of the area on an undulating plain largely devoid of rock exposures between the Thiba and Tana rivers. Occasional ridges of meta-dolerite with a red soil cover stand out above the plain. This region of black cotton soil lies on a relic area of the end-Tertiary peneplain and must have developed during stagnant drainage conditions.

(2) SOILS ON VOLCANIC ROCKS

The black cotton soils of the volcanic areas are similar to those developed on Basement System rocks and usually correspond with areas poor in rock exposures. The soils have developed wherever the drainage system is poor, particularly on flat plain regions. Extensive areas of black cotton soil have been formed on the Thiba basalts north of the Tana river, and on the Kapiti phonolites near Maragua and the Simbara agglomerates north of Thika. Usually the passage from black cotton soil to soils of other types is abrupt and follows changes in topography.

Red-brown high humic soils derived from volcanic rocks are probably the most common in the area, covering extensive tracts of country in the west and north. They are typically developed on the lower slopes of Mount Kenya and the Aberdares, in highly undulating country cut by numerous steep sided valleys. In the west and north of the area this type of soil has developed over most of the deeply weathered volcanic rocks to a considerable depth and is widely cultivated. Lateritic soils are also found in the less dissected semi-plainlands underlain by trachytes or tuffs.

VI—METAMORPHISM AND GRANITIZATION

Metamorphic rocks mapped in the Basement System of the Fort Hall area represent sedimentary, volcanic and basic igneous material originally deposited or emplaced in a marine sedimentary environment.

Subsequent to their deposition the rocks were subjected to mountain building processes and folded under high stress and elevated temperatures sufficient to cause recrystallization and the growth of new minerals. The crystalline rocks now seen at surface were transformed at considerable depths in the crust and have been revealed by the removal of several thousands of feet of covering rocks during prolonged uplift and erosion.

Some of the metamorphosed argillaceous sedimentary rocks contain sillimanite and almandine garnet. They are associated with epidiorites containing oligoclase-andesine, blue-green hornblende, epidote or clinozoisite, rare garnet and accessory quartz, biotite, apatite and sphene. This mineral assemblage occurring in metamorphosed basic igneous intrusions is found to be isofacial with garnet grade metasediments (Wiseman, 1934, pp. 354-417), and the present mineral composition of metamorphosed sedimentary and igneous rocks of the Basement System hence falls within the almandine-amphibolite facies as defined by Fyfe, Turner and Verboogen (1958). This facies is typical of many areas of high grade regional metamorphism in the Precambrian.

Granitoid gneisses of relatively uniform composition and texture form extensive outcrops covering many square miles in this section of the Basement System; they invariably have sharp concordant margins extending parallel to the foliation of neighbouring metamorphic rocks. No thermal effects indicating intrusion can be distinguished at the contacts, and they were evidently formed by metasomatic processes including the migration of alkali constituents and the reconstitution of original sedimentary material to produce replacement bodies having a granitic composition.

VII—STRUCTURE

The principal structural features of the area are foliations and lineations related to Precambrian folding of the Basement System rocks, and Tertiary or Pleistocene faulting of the volcanic rocks.

In the Basement System considerable areas of granitoid gneiss contain relatively few planar or linear features, but the metasedimentary rocks are usually well foliated and often show distinct linear features and minor fold structures.

A major unconformity between Basement System and overlying younger volcanic rocks, and several inter-volcanic disconformities, are mappable structural features of the lavas and pyroclastic rocks, as are the minor faults which have produced displacements within the volcanic sequence.

The structural map (Fig. 7) summarizes the main elements of structure observed in the Basement System, and shows the boundary of unconformity between the latter and the volcanic sequence, together with the distribution of granitoid gneisses and those areas of Basement System masked by soil cover.

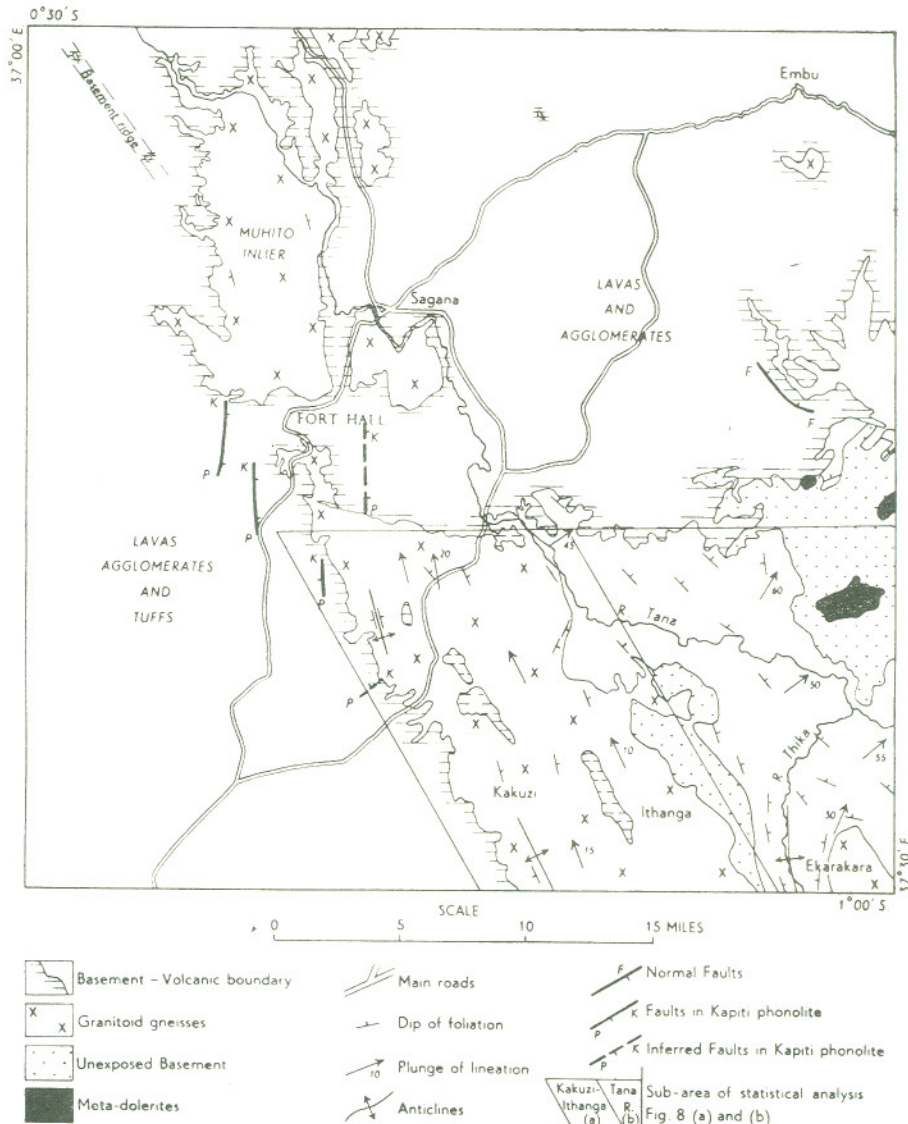


Fig. 7—Structural Map of the Fort Hall Area

1. Foliations, Lineations and Folds

Foliation of the metamorphosed sedimentary rocks is defined by closely spaced layers of differing composition and by the orientation of mica flakes which parallel original sedimentary planes over much of the area. A north-westerly trending regional strike of foliation is common, the foliation surfaces usually dip eastwards at steep angles.

Lineation of the rocks was observed and measured in the plagioclase amphibolites where it is marked by parallel alignment of prismatic hornblende crystals, in the mica schists where it is produced by intersection of micaceous partings and cleavage, and in quartzo-felspathic gneisses where shown by linear streaking of quartz.

The recorded directions of measured lineations show marked variation within the entire area of Basement System rocks covered by this report, but retain a consistency of pattern in the two separate sub-areas of Basement shown in Fig. 7.

In the Kakuzi-Ithanga sub-area lineations plunge consistently north-westward at shallow angles; a stereographic plot indicates a statistical lineation axis plunging 21 degrees on a true bearing of 336 degrees, this is in agreement with a regional fold axis plunging 22 degrees on a true bearing of 342 degrees as determined from the foliation-pole diagram for the sub-area (Fig. 8a). The adjacent Tana river sub-area shows a different structural pattern, lineations trend towards the east-north-east and are generally steeper in plunge. The statistical lineation maxima plunges at 60 degrees on a true bearing of 059 degrees, in close agreement with a regional fold axis plunging at 52 degrees on a true bearing of 067 degrees as determined from the foliation-pole diagram for the sub-area (Fig. 8b).

Agreement between the statistical orientation of lineations measured on the ground and the regional fold axis determined from the orientation of foliation indicates that lineation in each sub-area parallels a major axis of folding. There are hence two separate fold axes in this part of the Basement System.

Statistical orientation of foliation implies that rocks in the Kakuzi-Ithanga sub-area are folded about eastward dipping axial planes with westerly overturn of the fold-limbs. In contrast folds in the Tana river sub-area are either open and symmetrical or tightly compressed and recumbent. In either case the latter folds have axes which are sub-perpendicular to the Kakuzi-Ithanga folds and lie in a common axial plane, suggesting that both fold sets formed contemporaneously during a single phase of Basement deformation.

2. Faults

Much of the faulting in the volcanic rocks displaces only the Kapiti phonolite, and was completed before extrusion of the Simbara Series. Faults in the Kapiti phonolite can usually only be seen in river valleys and are generally covered by younger volcanics on the divides.

Kapiti phonolite, forming scarps and giving rise to waterfalls, occurs at three distinct levels in the Maragua valley south of Fort Hall. The phonolite has been displaced here by two northward striking faults having indicated eastward downthrow of 150 and 350 feet. The westernmost fault is located by an inlier of faulted Basement System seen in the river two miles north of Maragua, and the eastern fault crosses the Maragua valley some two miles below the Wanji Power Station.

A conspicuous Pleistocene fault is followed by the Murubara river approximately twelve miles south of Embu. The fault can be followed for a distance of four miles along the river, where olivine basalts have been displaced downwards on the north-eastern side of the fault and are in contact with a narrow strip of Basement System gneisses forming a basalt capped escarpment along the south-eastern side of the river.

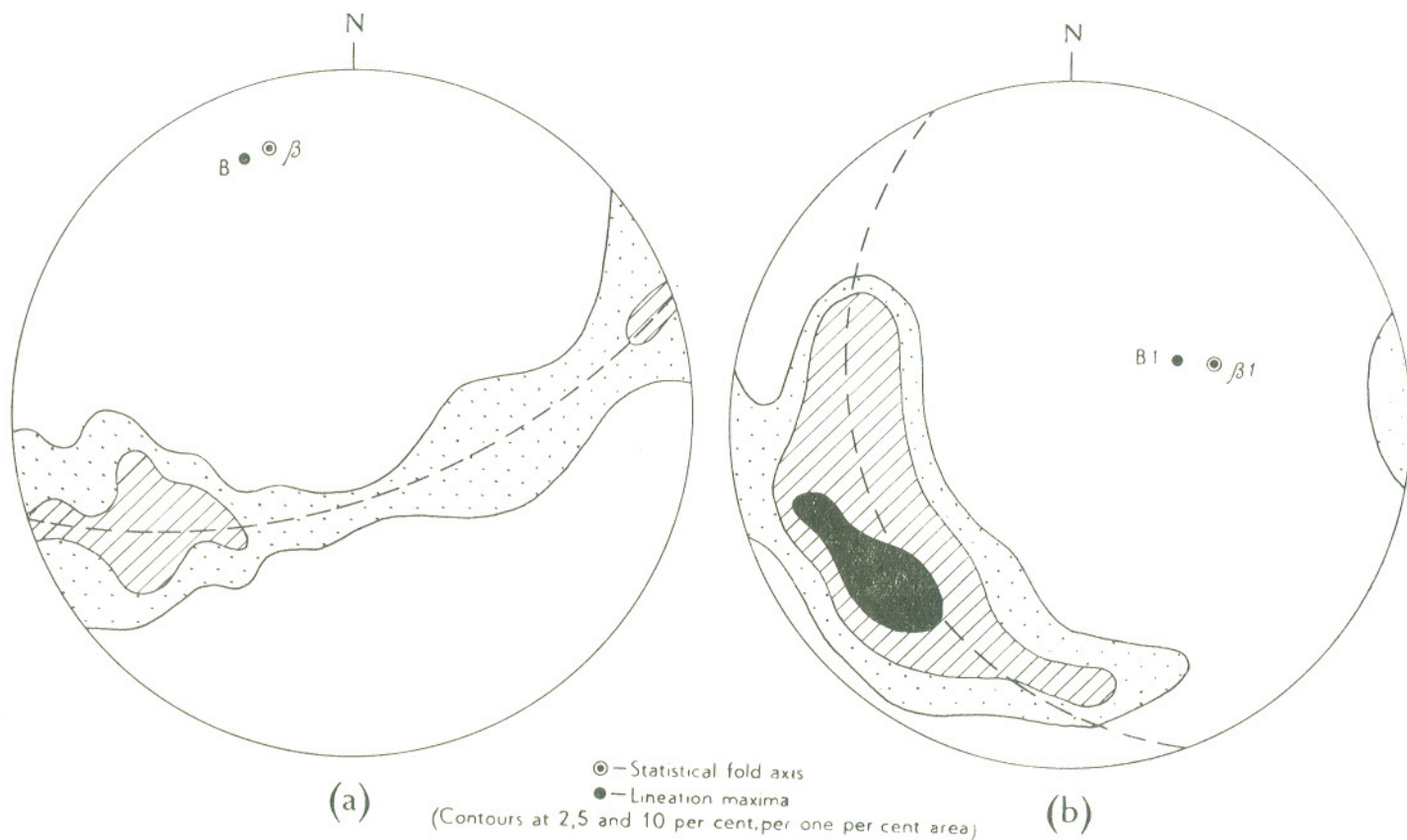


Fig. 8—Statistical orientation of foliation in the Precambrian of the Fort Hall area:—
 (a) The Kakuzi-Ithanga sub-area: B is the lineation maxima.
 (b) The Tana river sub-area: B1 is the lineation maxima.
 (For location of sub-areas see Fig. 7)

VIII—ECONOMIC GEOLOGY

Tertiary and Pleistocene volcanic rocks effectively blanket crystalline rocks of the Basement System in the western and north-eastern portions of the area. Exposed paragneisses and metavolcanic rocks occupying the south-eastern part of the area contain no evidence of post-metamorphic intrusions which might have emplaced mineralized veins, and the survey confirmed a general absence of secondary mineral indications associated with sulphide deposits. The only minerals seen within the Basement System area are scattered occurrences of garnet and sillimanite, too small to have any economic significance, and small amounts of magnesite and kaolinite.

Heavy mineral concentrates obtained from streams draining Basement System areas were found to contain abundant ilmenite and martite with rare garnet, but no precious-metals or sulphides were recorded.

The volcanic rocks contain uniform tuff beds of considerable extent suitable for quarrying as building-stone, and the coarse granitoid gneisses of the Fort Hall and Ithanga areas provide an unlimited supply of material for road ballast and concrete aggregate.

Porous tuffaceous beds and disconformities within the volcanic sequence of rocks provide aquifers for the collection and movement of ground-water and are of importance in controlling water supply obtained from wells and boreholes.

1. Building and Ceramic Material

Fine-grained compact trachytic tuffs, locally referred to as claystones, occur in the south-west of the area, north of Thika, and also to the west of Fort Hall. They are quarried from horizontally disposed beds measuring between 10 feet and 30 feet in thickness in the Gathamba valley and at Kiangochi, three miles south-west of Fort Hall (Fig. 9). Similar trachytic tuffs are quarried for building approximately three miles east of Makuyu, and from seven miles south-west of Molinduku.

The tuffs are similar in appearance and composition to the building stones of the Thika valley and are probably stratigraphically equivalent to the Upper Thika Building Stone quarried in the Thika and Kayam valleys in the extreme south-western corner of the mapped area. Considerable reserves of similar building stone cover an area of about three square miles on the western slopes of Ithanga.

Clays for brick-making are worked at Kangocho approximately 18 road miles north of Fort Hall. The clays occur immediately to the west of the Fort Hall-Nyeri road and overlie a narrow tongue of granitoid gneiss shown adjacent to the northern margin of the geological map. The gneiss is deeply weathered and overlain by over 20 feet of residual kaolinitic clays containing quartz and vermiculite as impurity. Similar kaolinitic clays occur in pockets on the weathered granitoid gneisses of the Muhito inlier.

Impure organic clays are also used locally to manufacture a dark grey coarse mica-speckled pottery at Gekando, west of Fort Hall, where decomposed kaolinized gneiss is worked from pits in the Mukungai valley and mixed with a stiff blue-grey clay resembling black cotton soil which is obtained from swamps on the Kapiti phonolite near Maragua.

2. Magnesite

Small superficial deposits of magnesite were recorded from some of the metamorphosed volcanic rocks in the eastern part of the area, particularly in the amphibolites approximately five miles north of Ekarakara and on the north bank of the Tana east of Riakanau (Fig. 9); in both localities the magnesite resembles that described from scattered localities further east in the Tana valley (Bear, 1952, pp. 37-38).

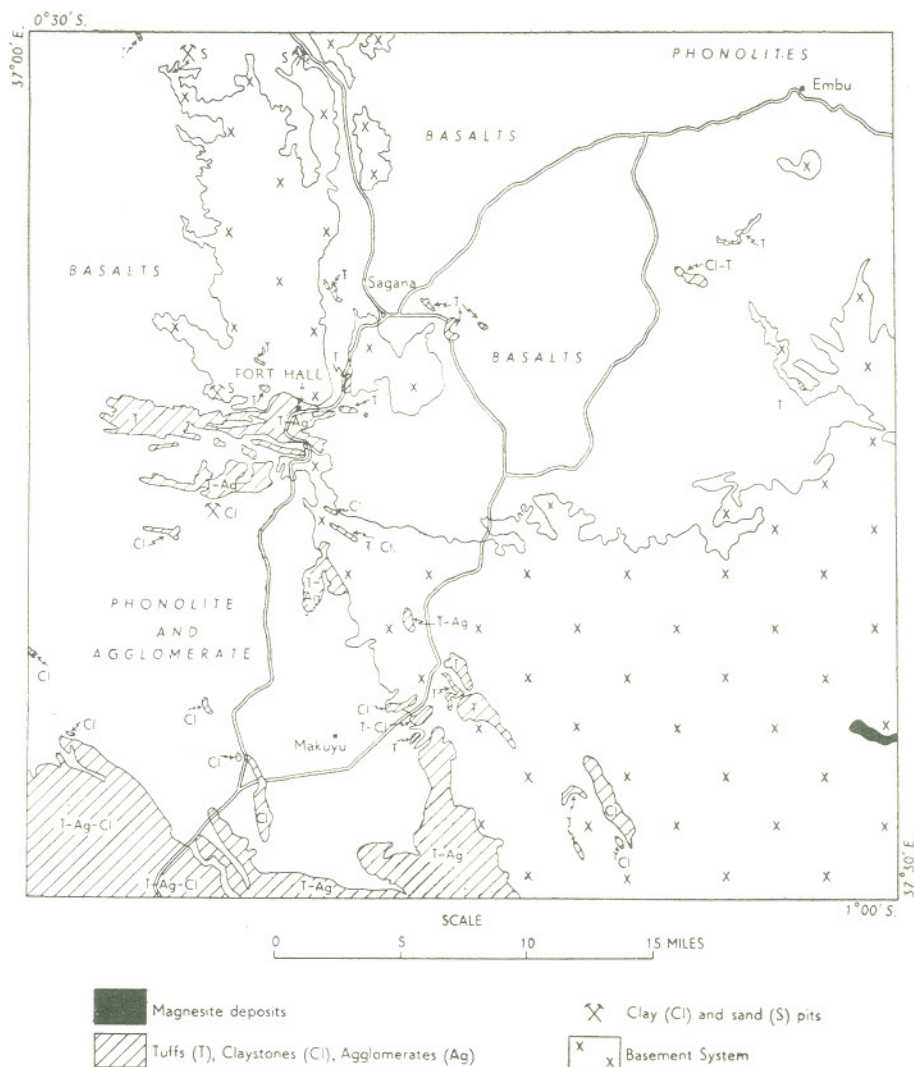


Fig. 9—Deposits of building material and magnesite in the Fort Hall area

The magnesite forms thin discontinuous grey or brown veins in the amphibolites and is partly obscured by surface encrustations of magnesian calcareous laterite. It is generally hard, compact and silicified, and is often stained by iron impurities. The veins and encrustations are too thin to render the deposits of any economic significance.

3. Water

Most of the Fort Hall area receives an average annual rainfall exceeding 35 inches, rising to over 50 inches in the elevated regions flanking the Aberdare range in the western part of the area, and on the southern slopes of Mount Kenya. Relatively high precipitation is retained as ground-water in the volcanic rocks, and run-off is stabilized by forest vegetation in the elevated region so that most rivers are permanent. Seasonal rivers and streams are only found in the south-eastern part of the area where the porous Basement System soils tend to drain freely.

Main drainage of the area towards the south-east via the Tana river and its tributaries, the Sagana, Mathioya and Maragua, is sufficient to provide a limited hydro-electric potential from the swift flowing perennial streams. The Wanji power station of 5,000 kilowatts capacity is operated by water taken from the Mathioya approximately one mile up-stream from Fort Hall, from where it is fed by a tunnel over 3 miles in length to turbine intakes in the Maragua valley, producing a working head of 200 feet. The Lower Tana Scheme generates 8,000 kilowatts from the Merila Dam on the Tana river. Water is carried from the dam by an 11-foot diameter tunnel extending southwards for a distance of 9,000 feet to the Tana power station situated at the junction of the Tana and Maragua rivers.

Small permanent springs are common in many of the higher valleys in the volcanic area and are tapped by pipe outlets through small dams. Springs are also located along the unconformity between the Basement System and overlying volcanic formations, as at Karaba, 16 miles east of Fort Hall, where water issues from below the Kapiti phonolite to feed the Izima river. The base of the Mount Kenya phonolite produces a particularly abundant source of spring water especially where the phonolite rests directly on the Basement as at Molinduku and along the northern side of the Nyamindi valley. Springs are less common in the Basement System area except where aquifers are provided by thin overlying deposits of sand and gravel as are found south of the Thaba Thaba river near its confluence with the Tana.

Most of the boreholes in the area (Table II) are sited in the Kapiti phonolite, or in basaltic agglomerates and trachytic tuffs, and are numerous between Makuyu and Thika, where yields of between 1,000 and 5,000 gallons per hour are obtained from inter-volcanic aquifers and from the base of the volcanic formations. In contrast boreholes sited in gneisses of the Basement System give relatively low yields, rarely exceeding 500 gallons per hour, from the porous zone of weathering in the upper parts of the gneisses.

Rest levels of boreholes in the Thika District indicate a westward rise of the water-table in the volcanic rocks. Towards Makuyu there is a sharp fall in the water-table probably attributable to faults in the Kapiti phonolite.

TABLE II—BOREHOLES IN THE FORT HALL AREA
(From records of the Water Development Department)

Borehole No.	Location	Bedrock	Depth (feet)	Struck Water (feet)	Rest Level (feet)	Yield (gal. per hour)
C72	Makuyu	Phonolite	157	4	2	1,000
C144	Kabati	Tuff and Basalts	175	160	123	2,700
C380	Makuyu	Basalts	470	38	7	1,830
C386	Makuyu	Basalts	346	185; 315	26	1,500
C387	Kakuzi	Tuff	450	8; 351	8	680
C403	Mitubiri	Tuff and Basalts	522	82; 254; 518	98	3,240
C491	Makuyu	Phonolite	237	70	12	5,000
C494	Makuyu	Basalts	89	58	37	3,000
C495	Makuyu	Basalts	88	55; 75	44	3,000
C829	Makuyu	Phonolite	190	15; 185	2.5	4,000
C840	Makuyu	Basalts	150	105	54	7,000
C841	Makuyu	Basalts and Phonolite	265	150	0.5	1,170
C842	Makuyu	Basalts	150	95	45	500
C1083	Makuyu	Basalts and Phonolite	150	100	8	3,500
C1118	Makuyu	Basalts	595	224	210	180
C1119	Mitubiri	Tuff and Basalts	132	85; 112	53	625
C1120	Mitubiri	Basalts	130	85; 110	53	625
C1123	Makuyu	Phonolite	225	200	8	800
C1153	Makuyu	Basalts	225	203	95	2,000
C1154	Maragua	Tuff and Phonolite	284	60	40	10
C1158	Maragua	Tuff and Phonolite	180	80	8	3,500
C1212	Maragua	Tuff and Phonolite	398	70	—	150
C1213	Maragua	Tuff and Phonolite	147	—	—	Nil
C1254	Thika	Tuff	635	300	85	750
C1271	Makuyu	Basalts	250	230	130	1,800
C1273	Makuyu	Basalts	340	320	6	3,000
C1338	Kabati	Basalts	260	165; 259	60	440
C1344	Maragua	Tuff and Phonolite	170	10; 164	10	1,500
C1345	Maragua	Tuff and Phonolite	80	7; 45; 70	6	5,000
C1373	Tana	Gneiss	193	135	111	600
C1375	Tana	Gneiss	152	89	75	600
C1380	Tana	Gneiss	500	480	125	180
C1394	Makuyu	Tuff and Basalts	304	62	43	750
C1421	Thika	Tuff	436	380	94	3,000
C1428	Tana	Gneiss	350	25	3	150
C1457	Thika	Tuff	268	119; 235	106	420
C1477	Tana	Gneiss	193	48	34	38
C1478	Tana	Gneiss	314	49	28	165
C1479	Tana	Gneiss	240	79	67	60
C1484	Tana	Gneiss	240	106	82	875
C1547	Thika	Tuff	589	120; 430; 505	135	350
C1587	Thika	Tuff	407	115; 245; 385	135	2,000
C1616	Thika	Tuff	530	60; 198	108	1,500
C1635	Makuyu	Basalts and Phonolite	342	363; 530	79	500
C1636	Makuyu	Basalts and Phonolite	135	112; 310	19	1,700
C1739	Thika	Tuff	362	117	215	2,800
C1894	Mitubiri	Basalts	225	270	80	770
C1900	Mitubiri	Basalts	198	101	68	1,800
C1996	Mitubiri	Basalts	450	175	97	320
C2044	Mukuruweini	Basalts	610	275; 410	128	720
C2204	Kitito	Gneiss	600	125; 540	—	Nil
C2669	Wamumu	Basalts	160	—	85	180
C2683	Fort Hall	Tuff and Basalts	250	91	145	5,300
C2748	Kitito	Gneiss	429	—	8	600
C2802	Makuyu	Basalts	154	355	10	2,500
C2826	Kakuzi	Gneiss	201	70; 120	—	20
				30		

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