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MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE SIMBA–KIBWEZI AREA

DEGREE SHEET 59, N.E. QUARTER

(with coloured geological map)

by

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FOREWORD

The appearance of part of the Simba-Kibwezi area is well known to many residents of Kenya, as it is traversed by the East African railway and by the main road from Mombasa to Nairobi. It is an area that has, however, attracted little attention from prospectors and miners, except for those engaged in winning superficial limestones for calcining to produce building lime. Dr. Saggerson draws attention to the occurrence of other minerals in the area, but unfortunately there appears to be little likelihood of the known occurrences becoming producing deposits.

The area is most remarkable for the manifestations of volcanic phenomena that can be seen mainly in its western half. Lava flows of various ages are present and numerous small volcanic cones, which in part belong to the volcanic field of the Chyulu range. A wide range of volcanic phenomena can be seen, including pit-craters, bombs, lava tubes and spatter cones. More than 350 volcanic vents have been traced in the area.

The volcanic rocks are of considerable importance in connexion with water supply. Most of the rain falling on the volcanic rocks percolates downwards through them, but some of it is again brought to light at large springs along the northern margin of the lava-fields, as at Simba, Kiboko, Makindu and Umani. These springs are of vital importance in the economy of that part of the country.

Nairobi,
7th August, 1959.

WILLIAM PULFREY,
Commissioner (Mines and Geology).

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ABSTRACT

The report describes an area of approximately 1,200 square miles extent in the Southern Province of Kenya bounded by latitudes 2° 00′ and 2° 30′ S. and longitudes 37° 30′ and 38° 00′ E. The northern and western parts of the area consist of the sub-Miocene peneplain from which rise several inselbergs whose bevelled tops are residuals of the end-Cretaceous peneplain. At least one hill summit was a monadnock in Mesozoic times.

Half of the area consists of highly folded and faulted Basement System gneisses and crystalline limestones, of Archaean age. Two series are recognized, the rocks of both being characterized by the high-grade index mineral sillimanite. A Tertiary phonolite lava flow forms a prominent feature in the north-eastern part of the area. South of the railway volcanic cones and olivine basalts of Pleistocene to Recent age overlie the gneisses unconformably. Superficial deposits, which include limestones, soils, sands and alluvium have accumulated since the cessation of volcanicity.

A detailed account is given of the petrology of the rocks and the metamorphism and granitization of the Basement System are discussed. The structure of the area is also described.

The economic possibilities with respect to mineral deposits are discussed and the water-supplies of the area are reviewed.

GEOLOGY OF THE SIMBA-KIBWEZI AREA

I—INTRODUCTION

The area described in this report is situated between 90 and 120 miles south-east of Nairobi and comprises the north-east quarter of degree sheet 59 (Kenya). It is bounded by latitudes 2° 00′ and 2° 30′ S. and by longitudes 37° 30′ and 38° 00′ E. and has an area of approximately 1,200 square miles. The area mapped is that of sheet No. 174 of the Directorate of Colonial Surveys.

The object of the geological reconnaissance, which was made between the months of August, 1956, and January, 1957, was to make a geological map and to assess the possibility of the existence of mineral deposits of economic value, mainly in the crystalline gneisses and limestones of the Basement System that form a little more than half of the area.

Maps.—In the preparation of the geological map aerial photographs, on a scale of approximately 1:30,000 and taken by the R.A.F. in 1948, were used. A base map was constructed from topographical detail plotted onto kodatrace overlays of runs of aerial photographs, controlled by the Survey of Kenya's trigonometrical stations scattered throughout the area. Final reduction of the kodatrace strips was made photographically, the resulting map being used in the field.

The form-lines shown on the map were based on barometer readings taken at varying intervals during the survey and are approximate only. Heights were constantly checked against known altitudes on the railway and of trigonometrical beacons, and corrected for diurnal variation.

It should be noted that a number of the trigonometrical stations recently established and named by the Directorate of Colonial Surveys are known by other names to the local Africans. These latter and usually better known names have been shown on the map, with the Survey name inserted in brackets beneath.

Owing to poor exposures in the area to the north of the present one it was not possible to map in such great detail there (Dodson, 1953)* as in the Simba-Kibwezi area, where the Kiangini river provides an excellent section and reveals the presence of soft pelitic rocks that were not mappable in the neighbouring area. In the north-eastern corner of the Sultan Hamud area (Searle, 1954) the same rock types as in the north-western corner of the present area were recognized, but a difference in naming them has given rise to an apparent discrepancy in geological boundaries. The mapping of the Simba-Kibwezi area was based on new co-ordinates supplied by the Survey of Kenya that were not available when the area to the east was mapped (Walsh, 1963) and hence slight differences in the positions of the geological boundaries occur along the boundary east of Kibwezi.

Communications.—The Kenya-Uganda railway and the Mombasa-Nairobi road pass from north-west to south-east across the area and are the principal lines of communica-

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* References are quoted on pp. 69 and 70.

tion. The Sultan Hamud-Loitokitok and Emali-Loitokitok roads pass through the south-west corner of the area. A number of roads that pass northwards from the main road serve the more densely populated locations near Machakos, Makueni and Kitui, and Ikutha which lie to the north-west, north and north-east of the present area. In addition numerous motorable tracks, which are used regularly by game hunters, extend into the area from the principal roads and are to be found north of the railway. Other tracks constructed by the Game Department have penetrated into the lava country to the south of the railway.

Population.—The area lies in the Southern Province of Kenya and is administered from district headquarters at Machakos, Kitui and Kajiado. The boundaries between districts are indicated on the map. The portion of the area within the Kajiado district forms part of the Masai native land unit and here the members of that nomadic tribe graze their cattle over savannah country. The remainder of the area falls into the Kamba native land unit, but is only populated near Ithumba and between Makindu and Mbuinzau, where cattle are watered and crops grown that are sufficient to maintain a small scattered population. Elsewhere only occasional groups of native huts are seen, generally near the three large rivers, the Athi, Kiangini and Muoni, or in small villages along or close to the main road and railway.

The area, which abounds in game of all kinds including rhinoceros, buffalo and magnificent herds of elephant, has attracted hunters for many years and some of the best trophies in Kenya have been obtained here. In recent years the Game Department has been most active and poachers are finding it increasingly difficult to kill the larger animals and dispose of the ivory and horn to illegal dealers at the coast.

At Nguu the African district council has established a ranch under European supervision through which the local Africans are able to sell some of their stock for profit. The profits from the ranch will help to finance the council's schemes aimed at assisting the Africans of this part of the Machakos district.

A small vegetable farm is cultivated by an Indian farmer at Kiboko.

Climate and Vegetation.—Rain falls mainly in the periods February-May and October-December, at the change of the monsoons. The following table, based on the records of the East African Meteorological Department, shows the rainfall recorded at five places in the area:—

Station	Total Rainfall in Inches 1952	Total Rainfall in Inches 1955	Numbers of Rainy Days 1955	Heaviest Single Rainfall in 1955	Average Annual Rainfall	Years Recorded
Simba Rly. Station	20·79	16·09	23	2·30	23·16	24
Simba, Nguu Hill	19·14	16·01	39	2·41	25·35	5
Kiboko	—	16·72	39	2·08	—	1
Makindu Met. Stn.	20·05	15·05	67	2·90	24·10	51
Kibwezi (Dwa Plantation) ..	14·79	14·19	42	2·00	24·58	36

Over the Basement System rocks in the unpopulated areas the vegetation consists of thick bush with low trees, except along the principal river-courses where a more luxuriant vegetation flourishes. Much of the volcanic area south of the railway consists of grassland, but near Kibwezi recent lava flows are covered by dense forest, in part infested by tsetse fly.

Rock Exposures.—Exposures of Basement System gneisses are poor and mainly confined to the river-courses and on the few hills where erosion is active. Apart from the hills infrequent outcrops are scattered on the interfluves and consist of small pavements or ribs of resistant quartz-rich gneisses. South of the railway the lavas have been partly eroded, particularly in the east between Kiboko and Kibwezi, a factor that often makes traversing difficult over the rough and bouldery volcanic terrain.

Acknowledgments.—The author thanks the Game Department for assistance in providing armed game-rangers, the police at Sultan Hamud and Kibwezi for protection, and the European staff at the African district council ranch at Nguu for hospitality. Thanks are also due to the District Engineer, East African Railways and Harbours, who kindly permitted the use of a railway house at Makindu during the heavy rains experienced during November and December, 1956. B. H. Baker kindly photographed various rock sections during a short visit to the area. The photographs are reproduced in Plates II-VI.

II—PREVIOUS GEOLOGICAL WORK

One of the earliest travellers in Kenya was L. R. von Höhnel who passed through the area in 1888 on his way to the coast after a journey to central and north Kenya. Although he does not specifically refer to the area in his report (von Höhnel, 1890) the accompanying map shows the positions of Mbuinzau and the Chyulu range, the presence of *"lava birnstein"* at Kibwezi where he camped for two days.

In 1893, J. W. Gregory (1896, pp. 78-81) made his first journey through Kenya from Mombasa and camped at Kibwezi, the Makindu river (Kiumbi river), Kiboko river and Nguu hill. His journey took him through part of the Kibwezi forest where he examined the irregular ropy structures preserved on the rough lava surfaces. In a later account (Gregory, 1921, p. 198) he again referred to the Kibwezi olivine basalts and to the Chyulu range which is made up of scores of volcanic cones.

Gregory (*op. cit. pp.* 186-188) also gave an account of the Yatta Plateau and considered it to be a lava flow that followed the course of a valley. A short description of the olivine basalt collected at Kibwezi was given by Prior (1903, p. 248).

In 1902, E. E. Walker (1903), a British Government geologist, passed through the area and examined the olivine basalts at Kibwezi, the limestone deposits and water-supplies at Umani, the Makindu river limestone deposits and the outcrops at Mbuinzau hill. He described Mbuinzau as composed of "pink granulitic gneiss with many coarse pegmatite veins, containing quartz, felspar, white mica and either magnetite or ilmenite". He also examined the river deposits in the vicinity of Mbuinzau but found no trace of alluvial gold.

A few years later in 1905, H. B. Muff (Maufe), then of the Geological Survey of Great Britain, made a geological survey along the railway from Mombasa to Kisumu. In his report published in 1908 (pp. 21-23) he also commented on the lavas and volcanic cones south of Simba station. He examined the limestones at Makindu, suggesting that after calcination they would yield a lime suitable for building purposes. He also recognized that the area to the north-west of Makindu is underlain by Basement System gneisses.

In 1910 G. L. Collie (1912) made a journey from the coast to Uganda. He commented on the volcanoes and lava fields overlying gneisses near Simba (p. 304). Krenkel (1911) also remarked on the olivine basalts overlying gneisses at Simba and Kibwezi (p. 257) while the map accompanying a report by Behrend (1918) indicates the approximate distribution of the gneisses and volcanic rocks of the area.

During the month of April, 1926, E. J. Wayland, then Director of the Geological Survey of Uganda, inspected red earth deposits and the limestones at Makindu and later reported on their economic use (Wayland, 1926). The following year the Imperial Institute in London published a number of analyses of samples collected by Wayland during his visit to the Colony (Imperial Institute, 1927).

In 1938, Dr. I. B. Pole-Evans, of South Africa, passed through the area while making a survey of the Machakos district in connexion with means proposed to deal with soil erosion and regeneration of grasslands. He described the serious effects of soil erosion, destruction of the land by termites and the exhausted nature of the country, which he considered to be due to misuse of the land by the inhabitants (Pole-Evans, 1939, pp. 4-12). Part of his survey included a visit to the Yatta plateau.

In a report by C. Uhlig and F. Jaeger (1942) their map shows, very approximately, the boundary between the lavas and Basement System gneisses.

The Makindu limestone deposits were again visited in 1945, on this occasion by W. Pulfrey. In his report (Pulfrey, 1945) he concluded that the limestones would be suitable for burning to produce agricultural or building lime.

Dr. B. N. Temperley, of the Hydraulic Branch, Ministry of Works (with the assistance of R. C. Jones) carried out a groundwater investigation of the area between the Kiboko river and Mzima Springs during the period 1954/55. His report (Temperley, 1956) gives an exhaustive account of the water supplies between Kiboko and Kibwezi and in addition lava sequences at various localities are mentioned.

During the early part of 1950 B. H. Baker collected specimens of the lava at Kibwezi for the East African Industrial Research Board in connexion with tests on lavas for ceramic uses.

The coloured geological map of East Africa on the scale of 1:2,000,000 published in 1954 incorrectly shows the distribution of volcanic rocks in the area.

In July, 1956, P. Joubert examined limestone deposits at Umani Springs (south of Kibwezi), in response to a request by the Chief Conservator of Forests.

III—PHYSIOGRAPHY

The Simba-Kibwezi area can be divided into two distinct regions, the areas underlain by Basement System gneisses and the volcanic region which lies mainly to the south of the railway (Fig. 1).

Nearly half of the area is covered by Pleistocene to Recent basalt lava-flows that have been extruded from volcanic vents, of which 367 were recognized. These vents are associated with volcanic cones that form the north-westerly extension of the Chyulu volcanic range, the extreme northern end of which comprises part of the present area (five miles to the south-west of Kenzili). The cones, which range from 50 to 1,000 feet in height, are conspicuous features of the landscape (Plate VIIa) and are usually in linear groups having a N.W.-S.E. trend parallel to that of the Chyulu hills. The

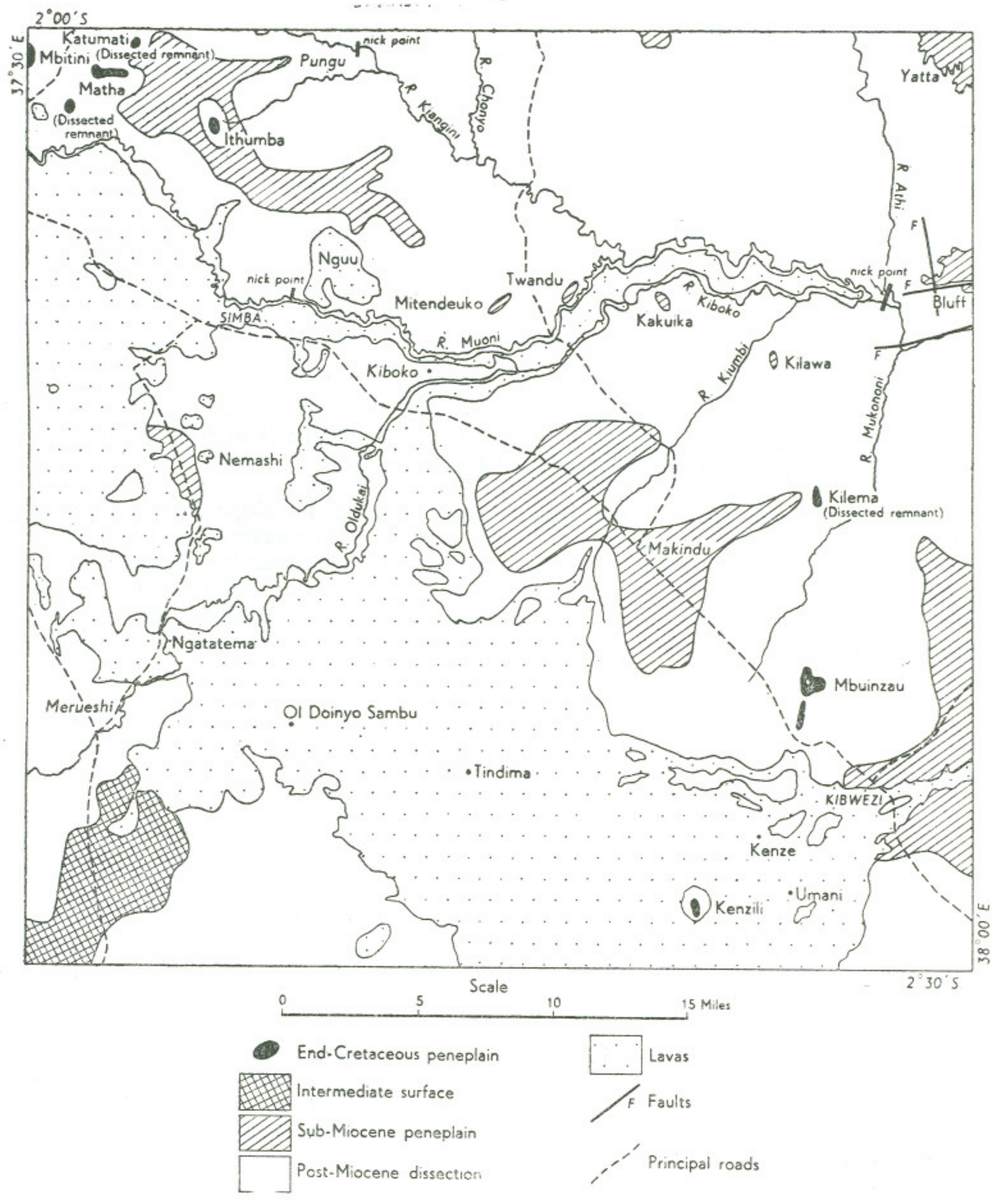

Fig. 1—Physiographical map of the Simba-Kibwezi area

largest volcanoes form the Tindima-Migululu group (which is visible from the main road at Makindu), the main hill rising to approximately 5,000 ft. (Plate I). It is one of the many high cones, several of which are composite vents. Other striking peaks include Ol Doinyo Sambu (Mbea, 4,400 ft.), Kenze (3,765 ft.), Umani (3,710 ft.) and the cones to the south-west of Kenzili. The cones of the Simba area have been partly eroded and are readily distinguished from the more recent nearly perfectly preserved vents between Kiboko and Umani.

To the north of the railway the area is one of low relief and is drained by three large rivers, the Athi, the Kiangini and the Muoni, and their tributaries. This thickly bushed, sandy plain is broken by a small group of hills in the north-west corner of the area and by numerous inselbergs of which Ithumba, Mbuinzau and Kilema (Kikweo) are the most prominent (Plate IIa). Gregory (1894, p. 296) considered this plain to represent the westerly extension of his "Nyika plateau" broken by "isolated bosses such as Bwinzau". In the eastern part of the area the configuration of a number of low granitoid ridges between Kibwezi and the Athi river is influenced by the north-south strike of the Basement System gneisses.

West of Ithumba the hills rise rapidly from the plain, the slopes having an angle of up to 35°. The bahada (Balchin and Pye, 1956, p. 170) flanking the hill fronts is composed of coarse detritus and boulders and is deeply dissected by short steep-sided gullies. The bahada gives way imperceptibly into the alluvial peripediment which has a gradient of about 3°. Rarely is a rock pediment exposed in these areas and the transverse profile of the mountain fronts closely resembles that figured by Balchin and Pye (*op. cit.* p. 176, fig. 2D).

In the south-western part of the area near Merueshi a number of limestone ridges have proved more resistant to erosion than the surrounding gneisses. The upstanding ridges are conspicuous in an area of low relief, but unlike the crystalline limestone hills in other parts of Kenya are devoid of thick vegetation.

The most reliable geological datum in the area is the surface overlain by the Yatta plateau lava, which is seen in two places east of the Athi river. In neighbouring areas Schoeman (1948, p. 3) and Dodson (1953, pp. 3-4) considered that the phonolite forming the plateau flowed over the sub-Miocene peneplain and that its base has an average gradient of about 15 ft. to the mile. In the extreme north-east corner of the area, the base of the flow has an elevation of approximately 2,925 ft. Further south, at Bluff, the base of the lava lies at about 3,100 ft., but it is considered that post-Miocene faulting has raised the level of the sub-Miocene surface here. The peneplain, which has an elevation between 3,800 and 3,000 ft. sloping to the east-south-east at approximately 20 ft. per mile, is considered to bevel a large part of the area north of the railway, to a lesser extent west of Nemashi, and also south of Merueshi. It forms the plain between the hills at Matha and Nguu and can be recognized in the vicinity of Makindu and Kibwezi. The inselbergs of Mitendeuko, Twandu, Kakuika and Kilawa are relics of the same surface.

At Merueshi a bevel lies at 3,800 ft., about 200 ft. higher than the bevel north of Nguu, suggesting that here a remnant of a somewhat older surface is present.

Another, higher, surface is represented by a bevel on Mbuinzau. This bench has an elevation of about 4,000 ft. and lies approximately 1,000 ft. above the sub-Miocene peneplain. The summits of Mbitini, Matha, Katumati, Ithumba, Kilema and Kenzili, which are also about 1,000 ft. above the peneplain, are probably also denuded remnants of the same surface. In western Kenya the end-Cretaceous peneplain is considered to lie 1,500 ft. above the sub-Miocene bevel while in north-east Kenya the same surfaces have a separation of 1,100 ft. (Baker and Saggerson, 1958, p. 5). It is probable that the hills mentioned represent residuals of this older surface which, like the sub-Miocene surface, slopes to the south-east. The summit of Mbuinzau was probably a monadnock, at least 500 ft. high, in late Mesozoic times.

The post-Miocene period has been one of vertical lowering of the land, with erosion mainly confined to the principal river-courses. Rejuvenation of their courses, which has occurred at least twice since Miocene times, is due to the grading of their beds to the end-Tertiary peneplain (recognizable to the east of the present area) and to later uplift, probably in Pleistocene times. A bench approximately 300 ft. below the sub-Miocene surface was seen along the course of the Kiangini river east of Pungu. Nick-points, of which the position of the main ones are shown in Fig. 1, are present in all the large river-courses and the rock barrier in the Kiangini river at the ford on the Simba-Makueni road is an excellent example. It is at these localities that the ability of the rivers to abrade their channels during heavy rains is demonstrated. Potholes are common and at the Kiangini nick-point, plunge-pools have formed at the base of waterfalls (Plate II*b*). One of the largest potholes has a diameter and also a depth of more than 10 ft.

Outpourings of lava in the Tertiary-Recent period have considerably influenced the drainage of the area. In Miocene times the area was drained by two major rivers, the Muoni (with its large tributaries, the Kiangini and Kiboko) and the Yatta river, of which the course is presumed to underlie the Yatta plateau. The Yatta flowed south-eastwards across the sub-Miocene peneplain and was joined by the Muoni river, the confluence being situated four miles east of Bluff. Gregory (1921, p. 186) described the Yatta plateau as a lava-flow which had followed the course of a valley. With this idea the author concurs. It is considered that in Miocene times the Yatta phonolite flooded the course of the Yatta river and also the lower reaches of the Muoni river. The Muoni river was thus diverted round the lava tongue, and two lateral streams developed along the flanks of the phonolite, now represented by the Tiva river on the east and the Athi on the west. Subsequent downcutting along these courses has resulted in the present plateau feature. Late Tertiary (pre-Muoni basanite times) faulting affected the Yatta phonolite and an E.-W. fault developed two miles south of Bluff. The southerly-flowing Muoni and Athi rivers (their combined course being influenced by the regional strike of the country rock) were able to erode rocks in the fault-zone more rapidly than the gneisses to the south and so developed an east-west course for about six miles. This right-angled bend in the Athi simulates an elbow of capture but in fact its position has been determined by the tongue of phonolite at Bluff round which the Muoni was originally diverted and partly by the fault-zone.

In early Pleistocene times the first basalt outpourings from the Sultan Hamud area (further west) flooded the Muoni valley to a point about four miles west of Bluff. The Kiangini and Kiboko rivers were diverted by the lava and formed lateral streams along the flow, entering the Athi as a single river near the lava snout. They have now incised their courses to depths of 70 ft. below the base of the basalt. At the time the Muoni valley was flooded by lava the Athi and Muoni rivers had incised their courses 350 ft. below the base of the Yatta phonolite.

With the outpourings of Recent lava the old Kiboko river was flooded with basalt the old river-course now lying beneath the lava surface. Two new rivers, the Oldukai (Greater Kiboko) and a new Kiboko river developed, the new Kiboko river flowing along the southern border of the lava and joining the Oldukai at the swamp north of Kasufi and two miles upstream from the Makindu-Makueni road-drift. The Oldukai, whose head-waters the Selengai and Bissel rivers drain the area to the west, now flows north-easterly along the northern fringe of the basalts, eventually forming a major tributary of the Kiangini river. The trend of the river is controlled by the lava outcrop and not by the strike of the underlying Basement System gneisses as suggested by Temperley (1956, p. 20). No streams cross the lavas, rain falling on them disappearing underground to emerge later in springs at the lava front at Kiboko, Makindu and Kibwezi.

IV—SUMMARY OF GEOLOGY

The sequence of geological events and the succession in the area mapped is:—

Age		Formation	Earth Movements and Erosional Phases
Recent		Soils, sands and alluvium.	Earthquakes and faulting in historical times.
		Kunkar limestones.	Erosion mainly confined to river-courses. Re-excavation of river deposits.
		Travertines.	
		Olivine basalts of the Chyulu hills.	N.W.–S.E. and N.–S. faulting.
Pleistocene	M–U (?)	Olivine basalts of Ngatatema.	Rejuvenation with subsequent vertical lowering of river-courses.
	L	Olivine basanites and basalts of Simba.	N.W.–S.E. faulting.
Pliocene			Faulting of Yatta area. End-Tertiary erosion after rejuvenation of river-courses.
Miocene		Yatta plateau phonolite.	Sub-Miocene peneplanation.
Cretaceous			End-Cretaceous peneplanation.
		Unconformity	
Precambrian		Intrusive rocks	
		Intrusive contact	
Archaean		Kasigau Series, Kurase Series (Basement System)	Intense folding and faulting accompanied by granitization and migmitization.

The Basement System rocks in the Simba-Kibwezi area are mainly gneisses, schists, granulites and crystalline limestones of originally sedimentary origin. Two series can be recognized, the Kasigau and Kurase Series, and these occupy approximately half the surface of the area. The Kurase Series is characterized by dolomitic limestones that form conspicuous features in the south-west part of the area. Mainly north of the railway the rocks of the Kasigau Series contain the high-grade index mineral sillimanite, which frequently occurs in garnetiferous and muscovite-rich rocks interbanded with graphite gneisses. These rocks are poorly exposed and form the few scattered monadnocks or outcrops in the principal river-courses where a fairly continuous section can be recognized. After their deposition, the Archaean rocks were highly folded and faulted and subsequently granitized, but evidence of migmatization is rare. At least two periods during which pegmatites were introduced into the gneisses can be recognized.

A single post-Basement System metamorphic dyke, possibly of Precambrian age, was seen to have invaded gneisses of the Kasigau Series.

Between Cretaceous and mid-Tertiary times the area was subjected to peneplanation which resulted in the formation of the end-Cretaceous and sub-Miocene surfaces. A phonolite lava considered to be of Miocene age occupies an original valley that crossed the sub-Miocene peneplain. The lava, which forms the Yatta plateau, is a conspicuous feature in the north-eastern part of the area. This period of extrusion was followed by further faulting.

During the early Pleistocene period basaltic lavas were extruded from a large number of vents in the Sultan Hamud-Simba area. Then followed a period of explosive activity that was responsible for the formation of the volcanoes at Ngatatema in the south-western part of the area. Few lava extrusions are associated with this later period of volcanic activity.

This was followed by another volcanic episode which built up the Recent lavas and volcanic cones of the Chyulu range, of which the Tindima hills form a part. From these volcanoes poured numerous lavas of *pahoehoe* and *aa* types, which flowed in a north and north-easterly direction, occupying most of the principal valleys between Kiboko and Kibwezi. Many of the vents are situated along fault-lines and it is evident that faulting took place throughout the period of extrusion and has continued after the cessation of volcanic activity. Thin travertines were formed in swamps at the northern fringe of the lavas and north-flowing rivers draining these, deposited kunkar limestones along their courses. This process is continuing at the present day.

Erosion subsequent to the mid-Tertiary period has been a result of repeated rejuvenation with deep incision of the main river-courses and the extension of their tributaries. Superficial deposits present, which include soils, sands and alluvium are products of sub-aerial denudation under semi-arid conditions.

V—DETAILS OF GEOLOGY

1. The Basement System

Apart from a number of orthogneisses the rocks of the Basement System of the Simba-Kibwezi area consist of metasediments of pelitic, semi-pelitic, calcareous, semi-calcareous and psammitic origin, of uniform metamorphic grade and characterized by the presence of the index mineral sillimanite. The gneisses are often poorly exposed but good sections occur in the principal river-courses and occasionally on hill slopes. The regular sequence of beds, the presence of crystalline limestones and the fact that bands although outcropping sporadically can be traced for considerable distances across the area, are considered to be proof of an original sedimentary succession. All the gneisses possess a strong foliation parallel to the banding in the rocks and only in small areas has the fabric been obliterated. In such areas the rocks are migmatitic and evidence of local injections of thin sheets of granitic material can be seen. These migmatites are of restricted occurrence.

The writer has previously (Saggerson, 1962, p. 10) established two rock series, which were named the Kasigau Series and the Kurase Series in the Kasigau-Kurase area, some 90 miles south-east of the present area. The Kurase Series was correlated with the Turoka Series of Parkinson (1913) and Joubert (1957, pp. 30-32). In the present area the rocks of the Basement System can also be conveniently divided into two similar series and it can be shown that at least part of the Kurase Series and the whole of the Kasigau Series are represented. The stratigraphical succession of the system in the area is as follows:—

	Kasigau Series	Thickness (*approx. feet*)
8. Upper semi-pelitic group	Hornblende-biotite gneisses with thin amphibolites (Yatta).	4,000
7. Upper pelitic group	Sillimanite, graphite and garnet gneisses with hornblende-biotite gneisses and subordinate granitoid gneisses and amphibolites (lower river Kiangini section)	5,500
6. Psammitic group	Granitoid gneisses with subordinate garnet-biotite gneisses and hornblende-biotite gneisses (Mbuinzau).	3,500
5. Lower pelitic group	Sillimanite, graphite and garnet gneisses with hornblende-biotite gneisses and subordinate granitoid gneisses and granulites (upper river Kiangini section)	3,400–10,000
4. Middle semi-pelitic group	Hornblende, biotite, garnet and granitoid gneisses with sillimanite and graphite bands (Ithumba-Matha)	13,000
3. Semi-calcareous group	Hornblende- biotite gneisses, calc-silicate granulites, amphibolites, crystalline limestones and augen gneisses (Simba)	5,500
2. Lower semi-pelitic group	Hornblende, biotite and garnet gneisses (Ol Katetemay)	6,000
	Kurase Series	
1. Crystalline limestone group	Three crystalline limestones with thin interbanded sillimanite and banded gneisses (Merueshi)	11,000

Thicknesses quoted are only approximate and there are numerous gaps in the recordable sequence owing to lack of exposures. In no part of the area was any evidence seen of the bases or tops of the two series. It is probable that in the Kasigau Series a more complete succession can be recognized in the Simba-Kibwezi area than in the Kasigau area, where Upper pelitic and semi-pelitic groups are absent or concealed beneath Quaternary soils. The approximate positions of the boundaries between the two series and the subdivisions of the Kasigau Series are shown on Fig. 2.

The characteristic rocks of the Kurase Series of the present area are three crystalline limestones each approximately 500 ft. thick outcropping near Merueshi. These limestones, which can be traced into the neighbouring area to the west (Searle, 1954), have been severely deformed into a number of overturned folds (Fig. 14, p. 48). It is considered that they are the north-westerly extension of the crystalline, dolomitic limestones of the Kasigau-Kurase area (Saggerson, 1962) and represent the three major limestones of the Upper Limestone Group recognized by Joubert (1957, pp. 31-32) in the Namanga-Bissel area, 45 miles to the west of Merueshi. In all the areas mentioned pelitic sediments and quartz-rich rocks are interbanded with the limestones.

Near Ol Katetemay banded gneisses of the semi-pelitic origin are thought to comprise the basal beds of the Kasigau Series. The equivalent beds in the type area (Saggerson, 1962) are overlain by Quaternary soils and are nowhere exposed. One of the characteristic bands of the series is a hornblende-garnet-scapolite gneiss of distinctive appearance. A similar rock outcrops in the river Engejuolongonjine two miles south-east of Simba township. The gneiss forms part of the semi-calcareous group which can be correlated with the beds exposed on Kasigau, Sagala and Rukinga (Saggerson, 1962, p. 13). This group, which also contains a crystalline limestone band, hornblende gneisses and thin amphibolites is richer in biotite as the top of the sequence is reached and passes into the semi-pelitic gneisses of the Matha area, where schistose biotite gneisses are common. A prominent band is the granitoid gneiss of Ithumba which probably occupies the same stratigraphical position as the Nzaui granitoid gneiss mapped by Dodson (1953) in the south-east Machakos area. The sub-

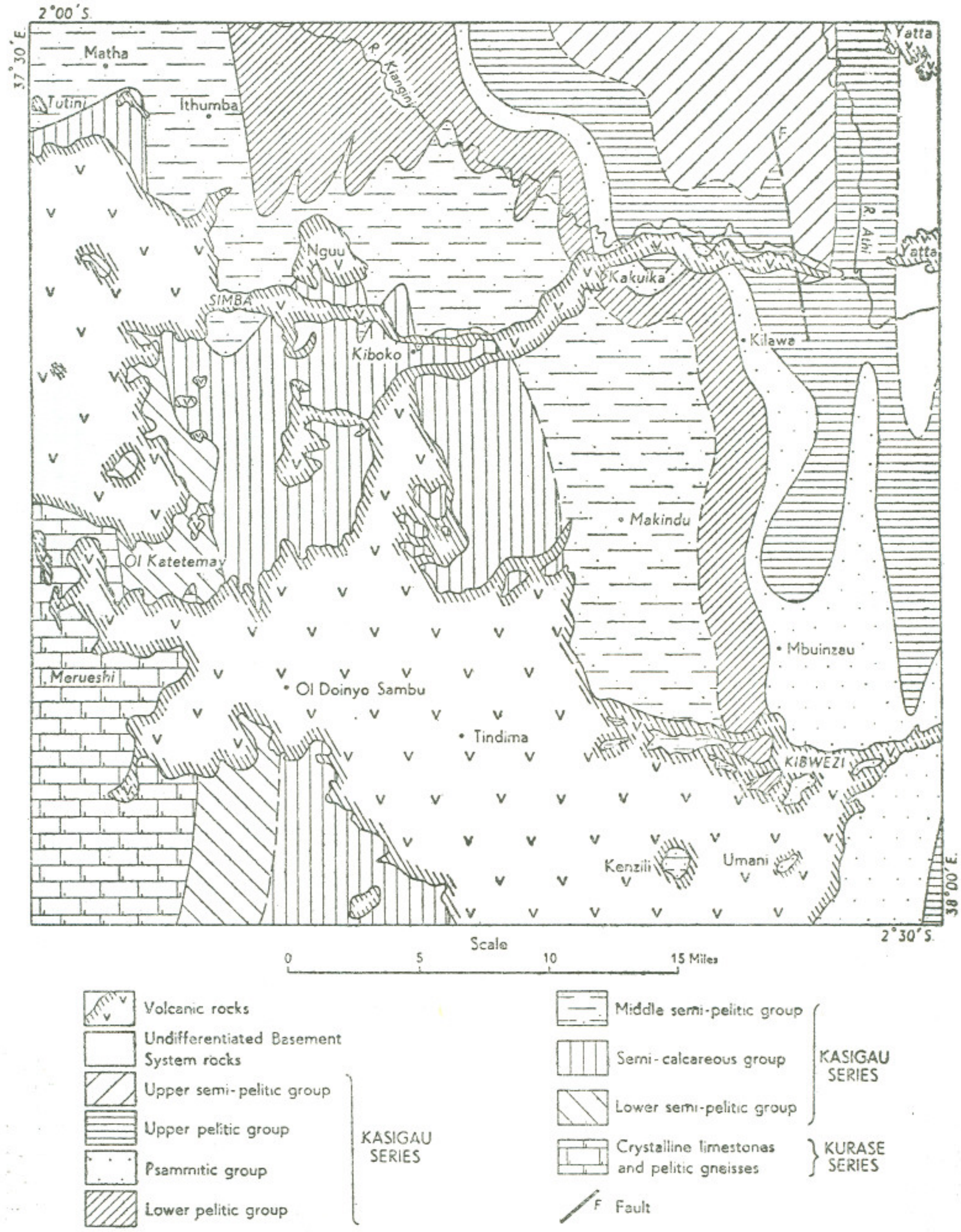

Fig. 2—Simplified geological map of the Simba-Kibwezi area

division of the Kasigau Series has been facilitated by the persistent nature of sillimanite- and graphite-bearing beds across the area, so providing good marker horizons, while the Mbuinzau leucocratic granitoid gneisses are also distinctive in a highly banded sequence. The pelitic gneisses containing sillimanite and graphite are correlated with similar beds on the Maungu hills in the Kasigau area.

An attempt to correlate Basement System gneisses of the Simba-Kibwezi area with those neighbouring areas is given in the table overleaf.

Table I—Correlation of Basement System Gneisses in the Simba–Kibwezi Area with those in Other Parts of Southern Kenya

Namanga–Bissel Area (Joubert, 1957)*	Simba–Kibwezi Area (Present Report)	South Kitui Area (Saggerson, 1957)*	Kasigau–Kurase Area (Saggerson, 1962)
	Kasigau Series Upper semi-pelitic group 4,000 ft. Upper pelitic group .. 5,500 ft.	Biotite-hornblende gneisses and alternating semi-pelitic and psammitic gneisses of the Tiva river section .. .. .. 12,000 ft.	not exposed
	Psammitic group .. .. 3,500 ft.		*Kasigau Series* Granitoid gneisses of Kizima .. 1,500 ft.
	Lower pelitic group .. 3,400–10,000 ft.		not exposed .. .. 7,500 ft. Pelitic gneisses of Saseie, Nyangala and Makiboro .. .. 3,800 ft.
	Middle semi-pelitic group 13,000 ft.		Hornblende, biotite gneisses and kyanite gneisses of Kulikila .. 1,700 ft.
Banded gneisses of Martiumisigio (position doubtful)	Semi-calcareous group .. 5,500 ft.		Hornblende, biotite and garnet gneisses and calc-silicate granulities of Kasigau, Sagala and Rukinga .. .. .. 4,150 ft.
	Lower semi-pelitic group 6,000 ft.	Semi-pelitic gneisses .. 7,000 ft.	not exposed .. .. 4,000 ft.
Turoka Series Limestone Group } 10,000 ft.	*Kurase Series* Crystalline limestones with sillimanite gneisses .. 11,000 ft.	Crystalline limestones with pelitic gneisses .. .. 9,000 ft.	*Kurase Series* Pelitic gneisses containing sillimanite .. .. .. 3,500 ft. Crystalline limestones .. .. 2,000 ft.
Quartzite Group			Pelitic gneisses containing sillimanite .. .. .. 2,500 ft.
Lowest Group Bnaded Gneiss Group	—	—	—

*In the Namanga–Bissel area the rocks of the lowest group, the Banded Gneiss Group, bear a strong resemblance to the Kasigau Series (*see* Joubert, *op. cit.*, pp. 11–19 and 31) and it is suggested that in fact both the Kurase and Kasigau Series are present in that area. As a result of recent mapping in eastern Kenya it is now considered possible that the limestone-bearing rocks in the South Kitui area (Saggerson, 1957) are the lateral equivalents of the Kurase Series.

(1) Metamorphosed Calcareous and Semi-calcareous Sediments

(a) *Crystalline Limestones*

The main limestone outcrops occur in the south-western corner of the area near Merueshi, where they form low but conspicuous features in an area of poor relief. Another limestone outcrops one mile south-east of Simba township. Unlike similar crystalline hills in other parts of the country they are not covered by dense bush, though this is a measure of the amount of rainfall this part of the area receives rather than the lack of suitable soil overlying the limestones. Exposures of limestones are usually to be found on the hill crests while the flanks of the ridges are covered by surface limestones (kunkar). Where the river Engejuolongonjine cuts across the strike of the Simba limestone fairly good exposures are to be found in its banks.

The three limestone bands forming part of the Kurase Series at Merueshi are each estimated to be approximately 500 ft. thick, though variations in the thicknesses are common and in many places it is not possible to determine the true width of the bands at the surface because of the overlying kunkar. The beds usually dip moderately to the east or south-east, but some westerly readings were recorded.

Banding in the limestones is rarely seen except at Simba, where thin screens of biotite-rich gneisses provided reliable dip measurements. The limestones are grey or grey-blue to white medium-grained rocks often containing disseminated graphite flakes, which are rarely concentrated into thin bands. In specimen 59/357* from Emungutan quartz, flakes of a pale mica and apatite were also recognized. Analyses of two crystalline limestones from Simba and Emungutan, quoted on page 54, indicate that the limestones are dolomitic.

(b) *Calc-silicate Granulites*

A number of calc-silicate granulites occur as thin bands in all groups of the Kasigau Series and are generally associated with hornblende and hornblende-biotite gneisses of the semi-calcareous group. The Muoni and Kiangini river sections reveal the best exposures, where the melanocratic granulites are readily seen in highly banded rock sequences. Few of the calc-silicate bands are traceable for great distances, although it was possible to use them as marker horizons in the noses of folds.

The calc-silicate granulites are dense, melanocratic, equigranular rocks often exhibiting banding but in some specimens, like 59/297 from the river Kalie, two miles N.N.W. of Twandu, banding and foliation are absent. Thin sections indicate that they are xenoblastic aggregates of plagioclase, pyroxene, scapolite, garnet and epidote. The characteristic mineral is a bright, blue-green diopside occurring as subidioblastic crystals and often showing alteration to hornblende. In specimen 59/267 from the river Muoni, four miles N.N.E. of Simba, the pyroxene, however, is faint to almost colourless brown. The plagioclase in these rocks, which is a medium andesine, shows albite twinning and frequently contains numerous inclusions. The proportions of scapolite vary considerably and in specimen 59/267 forms 30 per cent of the rock. Garnet speckles most of these rocks and occurs as orange-pink crystals containing chadacrysts of quartz, felspar and epidote. Hornblende is occasionally an alteration product of the pyroxene and is a green, strongly pleochroic variety. In specimen 59/267, however, it forms good folia and is intergrown with pyroxene. Idioblastic epidote is commonly associated with the calc-silicate granulites and is pale yellow-green to nearly colourless, forming variable proportions in different rocks. An unusual rock, 59/277, outcrops in a gully near the summit of Matha, where the granulites contain abundant lustrous iron pyrites.

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* Numbers prefixed by 59/ refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

(c) Garnet-hornblende Para-gneisses

A characteristic garnet-hornblende gneiss outcrops in the river Engejuolongonjine, two miles south of Simba. The rock, which forms a prominent band in an area of poor exposures, is distinctive for its garnet content, and is similar to a rock described by Saggerson (1962, p. 13) from the Kasigau-Kurase area, where it forms large upstanding rock masses. A thin section of specimen 59/350 shows the rock to consist of a crystalloblastic aggregate of andesine, quartz, garnet, hornblende and biotite. Scapolite, which is common in the Kasigau specimen, was not found in the slide of the specimen examined from the present area.

(d) Hornblende Gneisses and Plagioclase Amphibolites

Biotite-free hornblendic rocks of the area are considered to be metamorphosed semi-calcareous rocks, typical examples outcropping in the river Muoni, north-north-east of Simba. Others are interbanded in all groups of the Kasigau Series and represent beds richer in lime than their neighbours. Field relationships and the fact that the semi-calcareous rocks conform to the regional structural pattern are considered to be evidence of their sedimentary origin. The hornblende gneisses are generally mesotype rocks and display a banded aspect due to the preferred orientation of the hornblende crystals. Linear structures, which are common in the gneisses, are obliterated in the more homogeneous plagioclase amphibolites into which they frequently grade. The amphibolitic varieties must not be confused with meta-intrusives, though hand-specimens may be identical. In migmatitic zones both rock types form disrupted bands and lenses and in the case of the amphibolites, schlieren (Plate V (*a*) and (*b*)). Many instances were noted where the hornblendic rocks contained garnets, though this mineral is sporadic in such gneisses and rarely persistent along the strike.

Thin sections show the hornblende gneisses to consist of interlocking grains of plagioclase, hornblende and quartz with accessory magnetite, apatite and epidote. The hornblende is strongly pleochroic from pale yellowish green to deep green and forms about 20 per cent of specimen 59/255 from the Muoni river north of Simba. Oligoclase felspar in this rock is often untwinned and replaced along its margins by interstitial quartz. Magnetite is a prominent minor constituent.

With increase in hornblende content these gneisses grade into plagioclase amphibolites, which are granoblastic rocks containing between 50 and 75 per cent of hornblende. The plagioclase in specimen 59/256 from the Muoni river was identified as medium labradorite.

Numerous epidote streaks and thin lenticles are associated with both types of rock and though some owe their origin to impurities in the original calcareous rocks others have formed in response to shearing movements parallel to the banding and foliation.

(2) METAMORPHOSED PELITIC SEDIMENTS

The metamorphic equivalents of original pelitic sediments are widespread in all groups of the Kasigau Series in the area and to a lesser extent in the Kurase Series, though few outcrops were found interbanded with the crystalline limestones of the latter series. The occurrence of sillimanite and graphite in these gneisses is a feature of rocks of pelitic origin, as have already been described from various parts of Kenya. The development of porphyroblastic garnet is notable in many bands, while quartz-sillimanite *faserkiesel* and thin quartz-sillimanite bands are to be seen in gneisses exposed in the upper part of the Kiangini river. In the neighbouring area to the west, Searle (1954) recognized and mapped pelitic gneisses north-east of Emali, and they are here considered to be equivalent to the lower part of the Kasigau Series at Tutini, near the north-western corner of the present area. Sillimanite was found at the Muoni river ford on the Emali-Makueni road during the present survey in the area mapped by Searle.

(a) Biotite Gneisses

Biotite-rich schistose gneisses in the area are characterized by a well-marked foliation shown by the parallel arrangement of dark biotite folia. The biotite gneisses are medium-grained hornblende-free rocks and usually brown in colour but, with increase in biotite, grade into dark lustrous schists that weather easily. Outcrops in river and stream sections are poor, and the gneisses are rarely exposed on interfluves. Rocks of argillaceous origin characterized by graphite and sillimanite are everywhere associated with these gneisses.

In thin sections (for example specimen 59/307 from the river Kiboko) flakes of strongly pleochroic brown biotite are contained in a xenoblastic aggregate of quartz, oligoclase and microcline. The oligoclase is partly sericitized and is replaced by quartz and microcline. Rare sphene, iron ore and apatite are accessory, the latter in part replacing the biotite.

(b) Graphite Gneisses

Graphite gneisses outcrop in numerous localities along the principal river-courses, and are associated with garnet, biotite and sillimanite gneisses in the pelitic groups of the Kasigau Series. Three main horizons were traced in the upper and middle reaches of the Kiangini river and a number of thinner bands were noted in the eastern part of the area. The bands consist of schistose graphite gneisses, frequently interbanded with biotite and biotite-garnet gneisses. In some instances, such as one mile north of Masumba school (near Ithumba), graphite comprises more than 10 per cent of the rocks. The gneisses weather easily and without close examination it is difficult to separate them from some biotite gneisses, though a silvery appearance is characteristic of graphite-bearing rocks.

A typical specimen is 59/257 from three miles north of Simba, which in thin section reveals an association of quartz, medium andesine, biotite and graphite. Rutile is a common accessory in this rock, and was also seen in specimen 59/291 from the river Mkambwambeo. Although rutile was noted in other rock types it occurs more frequently in the pelitic gneisses and in particular in the graphite-rich types, a feature also recognized in similar rocks of the Kasigau-Kurase area (Saggerson, 1962, p. 15). An unusual specimen (59/287) was obtained from the river Kiangini, one mile north of Masumba school. This gneiss is characterized by the presence of grey graphitic nodules that impart a "knotted" appearance to the rock on weathered surfaces. An identical rock was described by Saggerson from Mwachinjoro (*op. cit.* p. 15). A large pale green nodule from specimen 59/287 measures about one inch in diameter and consists of a single porphyroblast of cordierite set in matrix of irregular quartz grains with sillimanite, oligoclase, graphite and pale orange-brown flakes of biotite. Rutile, apatite and a small amount of epidote are accessory. Sillimanite is concentrated in brown fibrous sheaves which are in marked contrast to the colourless needles enclosed within the quartz and cordierite. All the quartz crystals contain sillimanite and only in rare cases does it penetrate their margins. The cordierite is colourless and has an irregular border against the quartz which it replaces in lobe-like embayments. Colourless sillimanite needles, often aggregated in clumps, are enclosed by the cordierite and are considered to have replaced it (Fig. 4*c*).

(c) Biotite-garnet Gneisses and Granulites

Numerous biotite-garnet gneisses and granulites occur throughout the Kasigau Series but are more frequently interbanded with the biotite and sillimanite gneisses. They vary from leucocratic, coarse-grained, massive rocks to well-foliated dark rocks containing small or sparsely distributed garnet porphyroblasts. Granulitic garnet bands form thin screens between more easily weathered biotite-rich types. Many of the bands resemble the biotite gneisses of semi-pelitic origin, but are characterized by the presence of deep-red garnets. In some cases as in specimen 59/303 from the river Kiangini, 1½ miles east of Nango, the gneisses are profusely spotted with garnets that reach a size of nearly 0.5 in.; in others pin-head size garnets are abundant. Their distribution in many of the rocks is sporadic—some exposures show garnets concentrated in bands or clusters, in others only two or three garnets are present over a few square yards. They occur as subhedral or rounded crystals, though their typical form is not always seen in thin sections. Specimens of biotite-garnet gneiss collected include 59/250 from Muoni drift at Simba, 59/292 from two miles south of Twandu, and 59/303 and 59/324 from two miles N.W. of Mikuyuni.

In the thin slices of these rocks examined, the garnets are pale-coloured crystals, often sieved and cracked, of sub-idioblastic habit containing chadacrysts that include hornblende, biotite, muscovite, quartz, felspar, magnetite and leucoxenized ilmenite. The garnet is associated with quartz, microcline and plagioclase which is usually oligoclase, but in specimen 59/303 was identified as calcic andesine. In leucocratic varieties such as 59/250, microcline is the dominant felspar and replaces both oligoclase and quartz. The felspars, which are frequently anti-perthitic, are cloudy with alteration products, mainly sericite. Small pools of clear quartz are contained within the microcline. Quartz is present in variable proportions in different examples and is seen to replace the plagioclase. Greenish brown biotite with strong pleochroism builds large flakes, usually exhibiting a preferred orientation; the mica is occasionally chloritized (59/303 and 59/324).

(*d*) *Biotite-sillimanite Gneisses*

Two examples of biotite-sillimanite gneiss outcrop in the river Muoni north of Simba (59/258), and at Emungutan (59/356). They form thin bands of well foliated and easily weathered rocks, not more than a few feet in width. The Muoni rock is a melanocratic biotite gneiss in which quartz-sillimanite sheaves of silken appearance are scattered on foliation planes. The sillimanite needles lie in a granoblastic aggregate of quartz, oligoclase and strongly pleochroic biotite with accessory magnetite, apatite and graphite. In specimen 59/356, however, the sillimanite is thickly concentrated in quartz-rich folia and is composed almost entirely of felted mats of fibrolite in which orientated graphite and brown biotite flakes are present. The intervening quartz folia also contain sillimanite needles, which occur as small clusters or as separate crystals.

(*e*) *Quartz-felspar Gneisses with Quartz-sillimanite* Faserkiesel

A reddish pink quartz-felspar gneiss profusely spotted with ovoid quartz-sillimanite *faserkiesel* is interbanded with granitic gneisses and garnetiferous sillimanite gneisses in a 400-yd. section exposed in the river Kiangini north of Pungu. Plate III (*a*) illustrates the projecting *faserkiesel*, which measure up to two inches in length and are conspicuous on the weathered rock surface. The major axes of the *faserkiesel* parallel the lineation in the host-rocks. The *faserkiesel* (59/283A) consist of a base of quartz forming large sutured grains, filled with radiating bunches and dense felted masses of sillimanite hairs and needles. Relics of muscovite that has been largely replaced by sillimanite are present. A second occurrence was examined at Esoitiekiringol where a leucocratic band containing *faserkiesel* is overlain by granitoid gneiss.

(*f*) *Garnet-biotite-sillimanite Gneisses*

Dark garnetiferous sillimanite gneisses outcrop frequently along the river Kiangini, east of the Muoni drift at Simba and near the river Athi. The presence of large porphyroblastic garnets measuring up to two inches was frequently observed, the garnets being restricted to certain horizons. Sillimanite is ubiquitous in those rocks containing large garnet porphyroblasts.

The garnet is present in variable quantities along the strike and comprises up to 30 per cent of some bands. It forms sub-idioblastic grains in a coarse association of quartz, felspar, biotite and sillimanite concentrated in sheaves and folia (Fig. 4*a*). Thin sections of some specimens (e.g. 59/288 from the river Kiangini and 59/299 from the river Chonyo) reveal that the sillimanite occurs as clusters of large needles and occasionally as large crystals, fibrolite masses being absent. Biotite forms strongly pleochroic, well developed flakes sometimes associated with muscovite. Another interesting specimen is 59/283 from north of Pungu. The rock, which has been severely folded (Fig. 3), is finely banded consisting of alternate bands of leucocratic quartz-sillimanite gneiss and biotite-garnet gneiss. The former is an aggregate of large quartz crystals with radiating mats of sillimanite hairs. The sillimanite occurs interstitially, enclosed by quartz and to a small extent as a replacement of biotite (Fig. 4*b*).

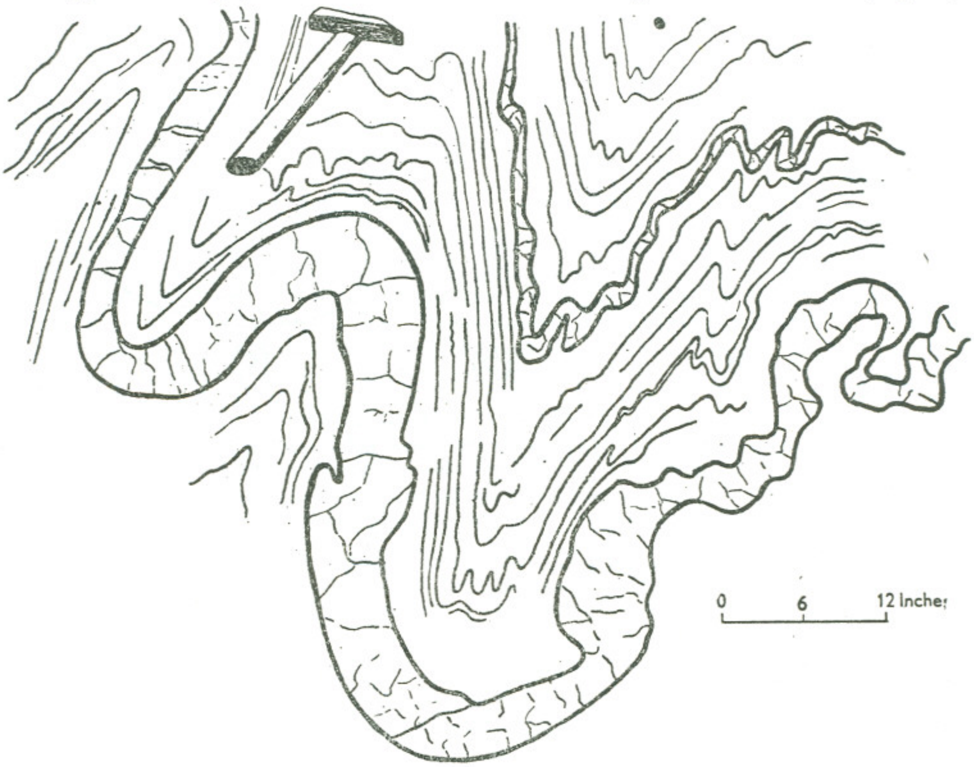
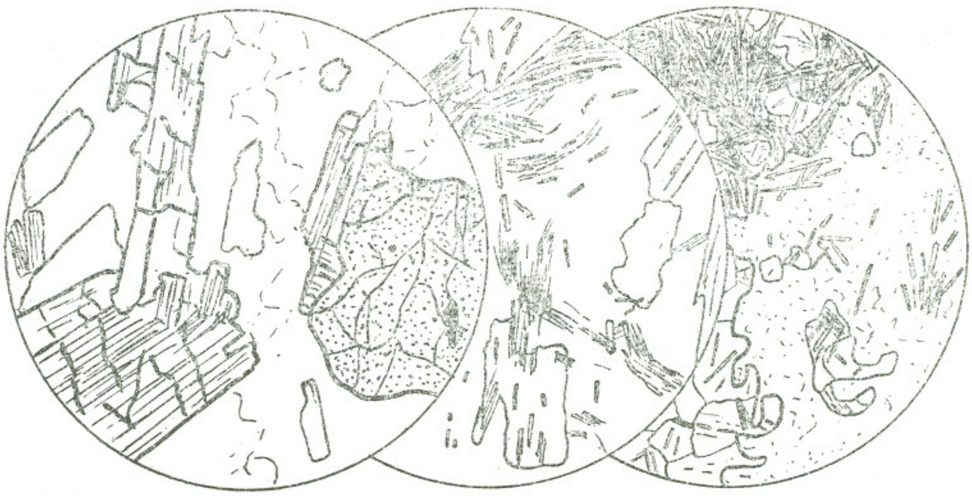


Fig. 3—Sharply folded garnet-biotite-sillimanite gneisses in the river Kiangini, north of Pungu. Quartz-sillimanite bands and streaks, which are represented by thin black lines, are associated with garnet-biotite gneiss. The drawing was traced from a photograph

(3) Metamorphosed Semi-pelitic Sediments

(a) Biotite Gneisses

A number of pale brown, sugary-textured biotite gneisses outcropping in gullied stream-courses at Mwanyani and in the western sections of the Muoni river are considered to be derived from sediments of semi-pelitic origin. They differ from the pelitic biotite gneisses in containing less well-developed biotite folia and by their more leucocratic appearance. They are not associated with graphite, sillimanite or garnet gneisses. Microscope examination shows that they consist essentially of orientated biotite flakes in mosaics of quartz and felspar. Muscovite occurs in many of the bands, usually concentrated on foliation planes, imparting a white lustrous appearance to some of the rocks, though it rarely forms significant proportions in such gneisses. In specimen 59/269 from the Muoni river, the biotite is pleochroic from yellow to blackish brown. Microcline is the most common felspar and has replaced and embayed untwinned oligoclase, which also forms islands within the microcline. Both felspars are cloudy owing to sericitization. Not all sections contain muscovite; it is present as large plates in a few slices but in others it occurs as small ragged laths rarely replacing other minerals. Accessory minerals include sphene, apatite and titano-magnetite.



(a) (b) (c)

Fig. 4—Microscope drawings of thin sections of sillimanite gneisses:—

(a) Garnet-sillimanite gneiss. Specimen 59/309, three miles south-west of Bluff. Stout blades of sillimanite are associated with biotite, garnet and quartz.

(b) Biotite-sillimanite gneiss (garnet appears in the hand-specimen). Specimen 59/283 from the river Kiangini north of Pungu. Sillimanite occurs in fibrous sheaves and replaces biotite.

(c) Quartz-sillimanite-cordierite nodule containing graphite. Specimen 59/287 from the river Kiangini, north of Ithumba. The cordierite occurs as a single crystal replacing quartz, and is in turn replaced by sillimanite.

(*b*) *Biotite-hornblende Gneisses*

Biotite-hornblende gneisses are widely distributed and probably the most frequent rock type in the area. They are interbanded with all the other gneisses, grading quickly into them with increase or decrease of one or more of the essential constituents. Similar rocks have been described from many parts of Kenya and few differences from them were noted in the rocks of the present area.

The biotite-hornblende gneisses are striped and banded mesotype rocks, grey in colour, exhibiting good foliation but never schistose. Those in which hornblende is preponderant are harder and more even-grained, their textures approaching closely those of hornblende granulites of which a number of occurrences were noted. In thin slices of specimens 59/253 and 59/266 (from the river Muoni near Simba), 59/282 (from the river Kiangini at Masumba), 59/304 and 59/305 (from three miles west of the Athi-Kiangini confluence) and 59/331 from Kenzili, hornblende forms stout prisms that are poorly terminated and pleochroic from yellow-green to deep green. The mineral shows little alteration and in some sections is seen to contain small pools of clear quartz, giving it a crudely sieved appearance. Mixed with it are grains of black iron ore, plates of biotite, quartz and felspar. Biotite with strong black to yellow-brown dichroism builds abundant flakes, usually clustered or showing a preferred orientation. In some slices biotite replaces hornblende, while in 59/304 chlorite and calcite are alteration products of the biotite. These minerals are set in a base of quartz and felspar. The felspar is generally oligoclase forming irregular twinned and untwinned crystals that contain quartz pools or are replaced along their margins by quartz. Potash felspar is never abundant and invariably consists of poorly developed grains of microcline replacing plagioclase. Myrmekite present in specimen 59/331 is built against oligoclase and microcline. Sphene and apatite in rounded grains are accessory.

(c) Garnet-biotite-hornblende Gneisses and Garnet-hornblende Gneisses

Garnets are well developed in biotite-hornblende and hornblende gneisses that occur between Simba and the river Kiangini in the neighbourhood of Chethembula. Other notable occurrences outcrop at Kibwezi and in the Athi river section. The rocks, which differ little from the biotite-hornblende gneisses just described, are characterized by a sprinkling of deep-red garnets, some measuring over 3 mm. Microscope examination of typical specimens (e.g. 59/318 from Kibwezi and 59/259 from Simba) shows grains of pale pink to deep pink garnet, cracked and containing chadacrysts of quartz. The garnets, which have poorly developed crystal faces, are associated with the hornblende and biotite in a granoblastic mosaic of quartz and plagioclase. In the thin slices examined the plagioclase was determined as andesine or calcic oligoclase.

(d) Garnet-biotite-hornblende Paragranulites

A number of hard well-jointed granulitic rocks outcrop in the middle stretches of the river Kiangini and in the river Chonyo. They are usually mesotype rocks, with streaks of granular, glassy quartz and are easily separated from other gneisses of semi-pelitic origin by their lack of distinct foliation and their tendency to form smooth rock-pavements or wall-like outcrops. Their origin is obscure, but it is likely that their granular appearance is due in part to movement and faulting during periods of folding.

(4) Metamorphosed Psammitic Sediments

Few metamorphosed psammitic sediments were recognized in the area. A number of granitoid gneisses and some migmatites, are considered to represent original psammitic bands, but such rocks are described in the following section.

(a) Quartz-felspar Gneisses

Two thin quartz-felspar gneiss bands were mapped, one outcropping in a gully at Tutini, south-east of Mwanyani, and the other in the river Mkambwambeo. They are well-jointed flaggy rocks, which are iron-stained on joint and foliation surfaces and do not form conspicuous outcrops. Muscovite is concentrated in thin folia along which the rocks are easily split. In thin sections, flakes of biotite and muscovite are seen to be associated with quartz and plagioclase, which form a xenoblastic mosaic of irregular interlocking crystals. Specimen 59/290 from the River Mkambwambeo is highly felspathic, while in specimen 59/274 from Tutini pyrite is a common accessory.

(b) Garnet-quartz-felspar Gneisses

A number of granitoid-type gneisses characterized by the presence of garnets form conspicuous outcrops in the Kasigau Series, particularly where it outcrops in the eastern part of the Kiangini and Muoni river sections and in the Athi river. Like the granitoid gneisses the garnet-quartz-felspar gneisses form tors, ribs and inselbergs and are conspicuous among the weathered members of the upper semi-pelitic group of the Kasigau Series. Excellent examples of these rocks form Katuluni, seven miles west-south-west of Bluff where a homogeneous, poorly foliated rock is profusely spotted by garnets that render it extremely hard, making the collection of good hand-specimens difficult.

Microscopically the rocks consist of interlocking crystals of microcline, plagioclase and quartz with garnet and scattered flakes of muscovite and more rarely biotite. Specimen 59/300 from Katuluni is a typical example in which microcline microperthite and medium oligoclase have replacive margins against intergranular quartz. The microcline also replaces the oligoclase. Sericite, iron ore and biotite are accessory and are present in variable proportions in different specimens. That some of these rocks have been partially granitized is indicated in specimen 59/298 from Mbupo in which 85 per cent of the felspar is microcline.

(5) Migmatites and Granitized Rocks

(*a*) *Migmatites*

Many of the gneisses that outcrop along the courses of the Muoni and Kiangini rivers have been partly migmatized, though they retain their banded appearance and are not considered here. At certain localities, however, notably at the Kiangini drift north-east of Ithumba and in the river Muoni two miles east of the Simba-Nguu track, intense migmatization has nearly obliterated the rock fabric (Plate IV (*b*)). These are local occurrences and not persistent over wide areas as is so common in some other parts of Kenya. In the Kiangini section migmatization has been accompanied by the introduction of numerous granitic sheets, pegmatites and aplites and the formation of boudinage structures associated with disrupted bands of amphibolite (Plates V (*a*) and (*b*)). At the second locality the river-course crosses a completely exposed rock section over a distance of 300 ft. Here the migmatites have developed as a result of metasomatism and by injection of granitic material from hornblende- and biotite-rich gneisses, which are garnetiferous in part. Numerous amphibolitic lenses and pods and biotite folia are present in the migmatites, though other bands are persistent sheets concordant with the foliation of adjacent gneisses. In some instances the contacts between the inclusions of original rock and invading rock are sharp, but often the inclusions appear as ghosts or relics in the granitic rocks. Wavy foliation can be attributed to movement while the rocks were plastic.

(*b*) *Augen and Felspar-porphyroblast Gneisses*

The appearance of porphyroblastic felspars, particularly in zones of migmatization, indicates the initial stages of granitization. Felspar augen are developed in the area mapped in biotite and hornblende gneisses that have been invaded by thin *lit-par-lit* injections. In some instances the felspar porphyroblast gneisses are due to granitization of a particular bed, usually of psammitic origin. Other occurrences of augen gneisses are not so simply explained. They have probably arisen through late growth of potash felspar prophyroblasts from inter-granular fluids that invaded banded gneisses of semi-pelitic origin. The augen are not confined to any one horizon, but are scattered in rocks of differing composition.

A pink felspar-porphyroblast gneiss outcrops at Lombo on the north side of the Nairobi-Mombasa road five miles east of Simba. Here the rock is typically granitoid and is characterized by the presence of pink rectangular felspars, some over an inch long. The porphyroblasts form eyes, which consist of single potash felspar crystals or sometimes are aggregates of several crystals. In some instances the porphyroblasts are concentrated in small pods and form over 70 per cent of the rock. Along the strike the band changes in character and in the river Engejuolongonjine the rock is a dark augen gneiss with evenly spaced felspar porphyroblasts. The band reverts to its granitoid character in the small outcrops at Esteti. The rock retains a faint directional tendency, amphibolite schlieren and biotite folia in the granitoid portions of the band suggesting the original foliation that was present in the rock prior to granitization. With increase in felspar content these rocks grade into leucocratic rocks that closely resemble the granitoid gneisses. The development of some granitoid gneiss lenses has undoubtedly taken place in this manner, the rocks being notable for their abundance of potash felspar porphyroblasts.

(*c*) *Granitoid Gneisses*

Granitoid gneisses form distinctive and resistant outcrops that include tors, rock slabs and whale-backs and comprise most of the inselbergs seen in the area. The principal outcrops include Ithumba (Plate I (*a*)), Mbuinzau, Kilema and the numerous rock ribs between Bluff and Kibwezi. Many of the granitoid gneisses are thin bands measuring only a few tens of feet in thickness but are prominent in highly-weathered rock sequences in river-courses, and proved useful marker horizons. The large outcrops of Mbuinzau, Kilema and neighbouring hills are due to repeated folding, the granitoid gneisses occupying the noses of many of the folds. Intervening semi-pelitic bands have been pinched in the folds and now outcrop along the flanks of the structures. Lateral variations were traced along the strike of some granitoid bands of which one example is the band at Methengo, two miles north-west of Twandu, where garnet-hornblende gneisses grade into the granitoid gneisses of Mitendeuko.

Migmatitic granitoid gneisses are represented by the outcrops at Ithumba and Kibwezi in which original banding or foliation is preserved in the form of amphibolite schlieren, ovoid biotite-rich folia and by streaks of biotite and hornblende alternating with quartz-felspar sheets in a granitic rock. Where such rocks have suffered intense granitization they are homogeneous. The granitic component of these rocks is coarse-grained with granoblastic texture, as is seen in specimens 59/276 from Matha and 59/285 from Ithumba. Microcline-microperthite is the felspar in the former specimen and partly replaces quartz and often encloses pools of that mineral. Lamellar-twinned oligoclase is also present together with flakes of strongly pleochroic bitotite. Accessory sphene and iron ore were seen in most specimens examined.

The granitoid gneisses in the eastern part of the area are considered to be granitized psammitic sediments, their distribution conforming to the structural pattern of the metamorphosed sediments. They are homogeneous leucocratic rocks, hard, quartz-rich, iron-stained and spotted by pink iron-staining. Thin sections of specimens from various localities that include Mbuinzau, Kilema and Tumango (59/272, 59/293, 59/311, 59/312, 59/313 and 59/314) resemble those taken from the granitic portion of the migmatitic granitoid gneisses and show typical xenoblastic aggregates of quartz, plagioclase, microcline and less commonly biotite and hornblende. Plagioclase which was determined as oligoclase (sodic andesine in specimen 59/314 from Mukononi) is present in variable amounts in different specimens and sometimes forms the main felspar, as in specimen 59/312 from Kilema, while in others microcline preponderates. The plagioclase is usually turbid due to staining and sericitic alteration products. Microcline forms a significant proportion of many of the rocks and is seen to replace quartz and plagioclase, lobing into them along crystal margins or enclosing them as small grains. Quartz, which displays undulose extinction in a number of specimens, occurs as xenomorphic and rounded grains; it replaces plagioclase though it is in turn replaced by microcline in some slides. It is often enclosed as clear rounded pools within the potash felspar or forms an essential constituent of myrmekite. Biotite and hornblende are frequently present and have a tendency to idiomorphism. The two minerals do not form significant proportions in the gneisses except when concentrated in folia that are remnants of original banding in the rock. Zircon, sphene, apatite and iron ore are accessory. Titano-magnetite nodules measuring up to two inches in length characterize the granitoid gneisses at Mbuinzau and good examples can be seen at Kabolole on the north side of the mountain. The nodules probably represent iron-rich segregations in an originally sandy deposit. No evidence was seen in the slides or in the field to suggest an origin by rolling or cataclasis.

(6) Pegmatites and Aplites

Pegmatites and aplites commonly invade all rocks of the Basement System throughout the area but are best seen in zones of granitization and migmatization. A large proportion of the pegmatites and aplites are thin, cross-cutting intrusions that lack foliation structures. Many are lenticular or pod-like segregations that have deformed and replaced the wall-rocks; others are tabular or sheet-like bodies with sharply defined margins, and represent *lit-par-lit* injections without replacement of the host-rock. Many of the conformable pegmatites in the banded gneisses have pinch-and-swell structures (Plate IV (*a*)) or are concentrated in boudins. Dilatation of the country rock has accompanied the intrusion of numerous pegmatites but others have a non-dilational type of emplacement suggesting that these have developed as a result of metamorphic processes rather than from magmatic sources. The problem of emplacement is complicated by the fact that both types of pegmatites are represented in rock pavements a few tens of feet apart. Ptygmatically-folded pegmatites were seen infrequently, but examples are exposed at the drift where the Simba-Nguu track crosses the river Muoni. These pegmatites are discordant veins of primary origin and are the result of injection without movement of the host-rock.

Interesting pegmatite injections are associated with migmatitic gneisses at the Kiangini drift north-east of Ithumba. Here Basement System gneisses are characterized by the presence of numerous sheets of amphibolite that parallel the regional strike. Tension cracks and joints are common in the amphibolites and it is along such ruptures that pegmatites have been localized. Cross-cutting pegmatites are visible in the melanocratic bands illustrated in Plate IV (*a*), while the disrupted amphibolites in Plate IV (*b*) are partly digested by quartz-felspar pegmatites. Fig. 5 illustrates various stages in the break-up and digestion of amphibolite layers. The main injections usually parallel the banding in the rock as a whole, but have been localized along diagonal fractures in the amphibolite layers. With the introduction of granitic material the darker rocks are partly digested and rafts of amphibolite are isolated in a sea of pegmatite. At a later period, small-scale movements have in some cases ruptured some of the bands and pegmatites have invaded the zones of displacement (Fig. 5). The association of boudinage structure and the introduction of pegmatites along tensional cracks suggests that the pegmatites were emplaced during periods of folding and during migmatization. Ramberg (1956, p. 196) considers that, in such instances (as are shown in Fig. 5), "the joints in which the pegmatites formed opened slowly and in pace with the pegmatite".

The pegmatites and aplites are quartz-felspar-rich injections sometimes containing small books of biotite mica, iron ores and occasionally hornblende. With the exception of the copper-bearing aplites which have invaded graphitic gneisses exposed in the Mkambwambeo river (near its junction with the Kiangini river) little mineralization accompanies the pegmatites.

(7) Metamorphosed Intrusive Rocks

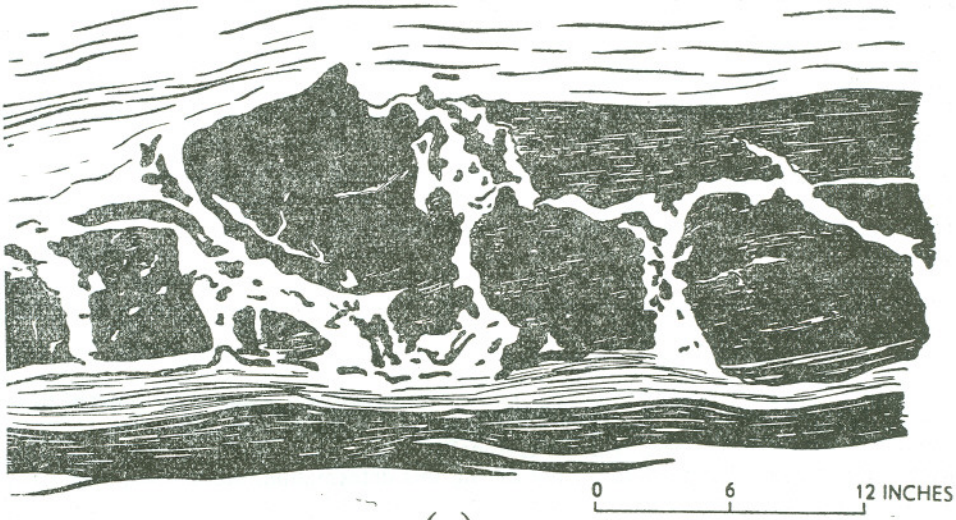
(*a*) *Biotite-hornblende Gneisses*

A partly granitized dyke, dipping 22° to the north-east in a zone of near-vertical banded gneisses (in the river Kiangini, six miles north-east of Ithumba; Plate III (*a*)) is a medium-grained melanocratic rock rich in hornblende and biotite. Measurements taken on northerly-plunging aligned hornblende crystals in the dyke indicate their conformity with the regional pattern. In a thin section of specimen 59/286, apple-green pleochroic hornblende is associated with greenish brown biotite pleochroic from pale green-brown to blackish brown. Xenoblastic plagioclase of composition An_{30} forms a mosaic with quartz grains. Accessory minerals include apatite, iron-ore and pink sphene.

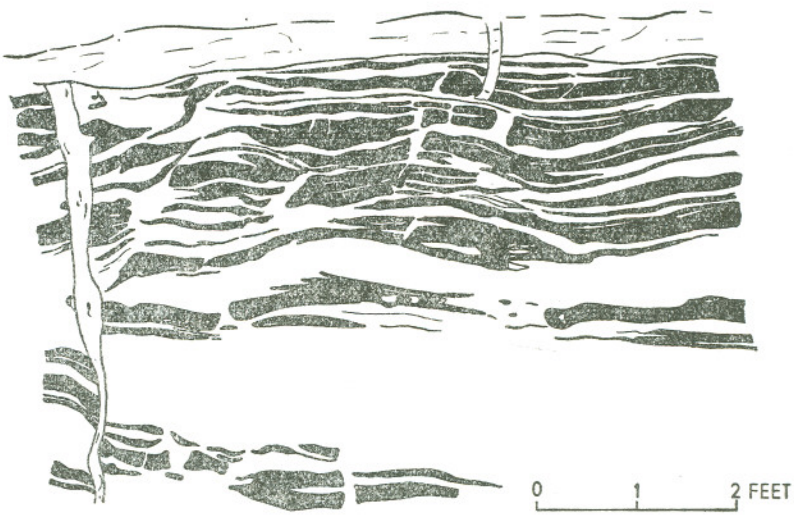
A second discordant intrusion outcrops in the river Muoni at Twandu. This is a mesotype rock with darker streaks emphasized by prominent prisms of hornblende associated with dark biotite flakes. In thin section (59/295) this rock is found to contain approximately equal proportions of hornblende and biotite, but in addition rare pale grey hypersthene is present.

(*b*) *Amphibolites*

Three amphibolitic rocks occur near the northern bank of the Muoni river on the western border of the area, where they are associated with hornblende-rich gneisses. These intrusions are prominent dyke-like bodies, weathering with a bouldery surface, and are melanocratic with occasional spots of iron-stained felspar. It is likely that they



(a)



(b)

Fig. 5—Disrupted amphibolite bands in migmatite exposed in the Kiangini river (redrawn from photographs):—

(a) Pegmatites have invaded and partly replaced an amphibolite band which shows evidence of tectonic rupture.

(b) An amphibolite injected by numerous *lit-par-lit* sheets, faulted and invaded again by pegmatite.

are all connected in depth. The dykes are coarse-grained only slightly foliated rocks and in the hand-specimen closely resemble neighbouring amphibolites. A colourless, probably diopsidic pyroxene, is associated with and often replaced by pale green hornblende and most hand-specimens appear to contain little felspar. In specimen 59/271, the felspar is a medium andesine and does not form more than 10 per cent of the rock. Sphene and magnetite are accessory.

A number of other amphibolites of intrusive origin were mapped in the area, the most prominent being a sill-like body, which can be traced along the west bank of the river Athi. Its northerly continuation is concealed beneath a thick soil cover, but it is thought that the body is the continuation of a similar intrusion mapped in the south-east Machakos area (Dodson, 1953, p. 13). Other dykes are small often concordant intrusions and may be confused with some of the metamorphosed calcareous sediments.

(8) Metamorphism

The rocks of the Basement System in the Simba-Kibwezi area are considered to be metamorphosed sediments that had been invaded by dykes and sills prior to metamorphism. They have been folded regionally along north-south-trending axes and were metamorphosed dynamothermally during this deformation. Homogeneity of structural pattern, the presence of mappable horizons over wide areas and the occurrence of crystalline limestones and graphitic gneisses are considered proof of sedimentary origin. The mineral assemblages of the gneisses are characteristic of the high-grade amphibolite facies and more specifically the sillimanite-almandine subfacies (as defined by Turner, 1948, p. 76, *et seq.*).

The critical mineral, sillimanite, is of widespread occurrence and, indeed, has developed in alumina-rich sediments wherever they occur in rocks of the Kurase and Kasigau Series. Typical mineral assemblages in the pelitic rocks include:—

quartz-biotite-sillimanite

quartz-biotite-garnet-sillimanite.

Sillimanite occurs as stout blades, in scattered clusters and thin folia, and as fibrolitic masses in *faserkiesel* (Fig. 4). East of Kilema in the river Mukononi, sillimanite is developed on shear-planes in a fault zone. In thin section it is observed to replace biotite, muscovite and cordierite and is frequently associated with quartz. In many cases it occurs as small colourless needles enclosed within the host mineral. A single section of about 400 yd. extent in the river Kiangini, north of Pungu, shows sillimanite present in *faserkiesel* (Plate II (*a*)), in thin layers of quartz-sillimanite gneiss (Fig. 3) and in thin folia. The host-rocks are mainly biotite-garnet gneisses which have been invaded by pegmatite segregations. It is considered that the quartz-sillimanite gneisses represent original alumina-rich beds interbanded with other pelitic rocks.

Garnet is a stable mineral occurring throughout the area and is ubiquitous in all rock types except the crystalline limestones. In hand-specimens it is frequently idioblastic, occurring as small pinkish red crystals or as large dull-red porphyroblasts, particularly in the sillimanite gneisses. This variation of the megascopic appearance of the garnets in different gneisses is notable. The crystals are never severely cracked except in shear-zones and are rarely altered.

Muscovite occurs infrequently in the present area, but when it accompanies sillimanite it is replaced by the alumino-silicate. The granitoid gneisses of Mbuinzau are characterized by nodules of titano-magnetite which have probably resulted from a reconstruction of original iron ore minerals present in arkosic rocks, though the introduction of iron may have accompanied alkali metasomatism during the formation of these gneisses. The ubiquitous appearance of garnet in the area suggests in general a sedimentary origin for the iron rather than a magmatic origin, for it is not obvious that this element has been added from eruptive sources.

Granitization in many of the gneisses of the Basement System in the area is signified by the presence of microcline, which is the dominant felspar in the zones of most intense migmatization. Discrete injections of granitic material have also accompanied the alteration of the metasediments, though no large-scale intrusions are present in the area. Injection and permeation gneisses as described by Read (1931, p. 120) were recognized and are most common in a zone from Simba northwards to the river Kiangini. A plastic state was reached in some of the rocks as evidenced by the migmatites in which loss of banding and foliation, the presence of granitic pods and lenses and the disruption of amphibolite bodies are characteristic. The introduction of granitic material and in particular pegmatitic bodies during the period of granitization occurred in three distinct but probably related phases. The first injections occurred before the period of regional folding, as observations made in parts of the area indicated that pegmatites and *lit-par-lit* injections introduced along bedding planes have been involved in movements that distorted pelitic gneisses (Fig. 3). Cross-cutting micro-pegmatites, some of which have been slip-folded along the axes of micro-folds (Plate II (*b*)) developed at the time of folding, are injections belonging to the second phase. The final phase is represented by other and often larger, cross-cutting pegmatites that have invaded and frequently transected the Basement System gneisses after the period of metamorphism and folding. These latest injections may in some cases have a non-dilational mode of emplacement and may be a result of metamorphic differentiation though the emplacement of the majority was accompanied by dilation of the country rocks. The occurrence of quartz-sillimanite *faserkiesel* in two bands and their proximity to thin granitoid gneisses suggest that metasomatically introduced granitic material resulted in their formation, the sillimanite having undergone dissolution probably during the late stage of metasomatism and granitization. That *faserkiesel* were not observed in other parts of the area suggests that intense granitization was confined to restricted zones or to bands that allowed the introduction of granitic material whether by joints, tension cracks or pore-spaces, and that it commenced after the rocks had already been metamorphosed to the extent that sillimanite had formed in pelitic rocks.

In many countries zones of high grades of metamorphism, and in particular those characterized by alumino-silicates such as sillimanite, have been affected by injections of granitic magma. Although this is true in part when considering the Simba-Kibwezi area, the widespread occurrence of sillimanite and garnet suggests that fairly high temperatures and pressures prevailed throughout the area during regional metamorphism and were not merely confined to small zones of migmatitic rocks. In other zones rising temperatures permitted the formation of sillimanite from biotite and cordierite, but conditions were such that equilibrium was not attained.

Diaphthoresis has not played a large part in the alteration of the gneisses subsequent to the main period of folding and metamorphism. In many other parts of Kenya muscovite-bearing rocks are associated with gneisses containing sillimanite and it has been concluded that in many instances the muscovite is a product of retrogressive metamorphism. Alterations leading to the formation of muscovite are conspicuously absent from the sillimanite-bearing gneisses of the Simba-Kibwezi areas. Sericitization of felspars and the alteration of garnets to chlorite are, however, attributable to retrograde metamorphism. The occurrence of an epidote-rich band in a small thrust zone (Plate V (*a*)) in the Muoni river, south-west of Ithumba, can also only be ascribed to retrogressive metamorphism.

2. Intrusive Rocks of Post-Basement System Age

(*a*) Hypersthene-bearing Mica Diorite

A discordant dyke that has invaded crystalline gneisses outcropping on the south bank of the river Athi at Kaipesi, south-west of Bluff, is considered to be an intrusion of post-Basement System age. The occurrence, consisting of large, rounded boulders, weathered *in situ,* strikes nearly east-west. Specimen 59/308 is a heavy, dark brown, medium- to coarse-grained rock having a splintery fracture and, in thin section, exhibiting a hypautomorphic-granular texture. Pyroxene, hornblende and felspar form the major constituents. Two pyroxenes are associated in the rock, one being a grey pleochroic and schillerized hypersthene. The principal pyroxene, however, is a grey to pale green diopsidic augite frequently altered to amphibole and calcite. The hornblende is green to brownish green, strongly pleochroic, and associated with flakes of brown biotite. The felspar is lamellar-twinned sodic andesine with composition approximately An_{34}. Interstitial quartz is uncommon while apatite in large crystals comprises nearly five per cent of the rock.

(*b*) Garnetiferous Peridotite

Associated with the agglomerate in one of the vents of Chanduini, north-west of Simba, were found a number of pieces of grey-green rock tentatively identified as garnetiferous peridotite. It is possible that this rock was originally emplaced in Basement System gneisses that occupied the site of the Chanduini volcano and was subsequently shattered during the volcanic eruption. The peridotite (specimen 59/280) is a coarse-grained holocrystalline rock composed essentially of clinopyroxene, olivine and garnet. The pyroxene is pale brown to nearly colourless with prominent schiller inclusions. The olivine present never shows well-defined crystal form, but occurs as small serpentinized grains. It is older than the pyroxenes for the latter commonly surround it. Colourless garnet is also present and forms a greater proportion of the rock than the olivine. The olivine and garnet, and coarse grains of yellow-green and green spinel (picotite), are surrounded by coronas built between themselves and against the pyroxenes. These coronas are often continuous and are kelyphitic, consisting of brown fibrous serpentine and black iron ore that has formed from the olivine and garnet. The spinel occurs in scattered crystals and is invariably enclosed by kelyphitic borders. The vermicular or dactylic habit of spinel so characteristic in most coronites was not observed in this rock. The presence of spinel as crystal grains probably indicates that it has been preserved during the period of falling temperature by a protective mantle (in this case, kelyphite) as suggested by Bowen (1928, p. 278).

An analysis of specimen 59/280 gave the following result:—

	%		*Norm*
SiO_2	44·68	or	0·56
Al_2O_3	15·79	ab	10·48
Fe_2O_3	3·90	an	37·25
FeO	5·50	di	9·91
MgO	15·74	hy	12·28
CaO	10·32	ol	21·03
Na_2O	1·22	mt	5·57
K_2O	0·13	il	0·15
H_2O+	0·96	ap	0·34
H_2O-	0·80	cc	0·20
TiO_2	0·11		
P_2O_5	0·09		
MnO	0·26		
CO_2	0·10		
BaO	Trace		
Cr_2O_3	0·03		
Total	99·63		

Analysts: W. P. Horne and Mrs. R. Inamdar.

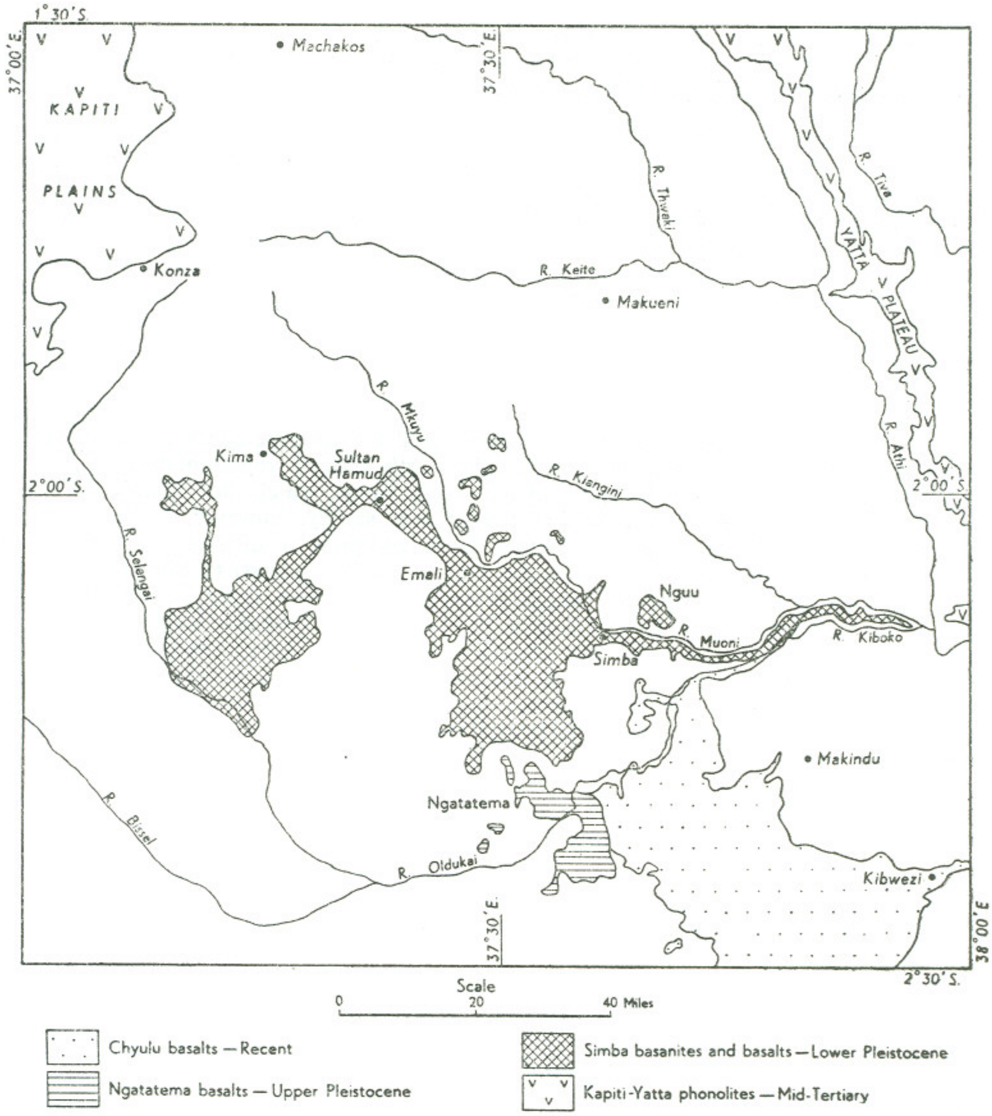


Fig. 6—Distribution of late-Tertiary to Recent volcanics in the Simba-Kibwezi and neighbouring areas

3. Tertiary—Yatta Plateau Phonolite

Kapiti-type phonolite of the Yatta plateau outcrops in two places in the north-east corner of the area, east of the river Athi. The most southerly outcrop forms a large tongue extending westwards from the main flow, now exposed to the east of the present area. The lava is considered to have flooded an old valley that passed across the sub-Miocene peneplain with an average gradient to the south-east of about 15 ft. to the mile. Subsequent erosion of the underlying Basement System gneisses has resulted in a prominent plateau feature capped by phonolite, the thickness of which is estimated to be less than 75 ft., east of Maungoni. A pronounced alignment of felspar phenocrysts on numerous large outcrops examined in the field was seen to parallel approximately the general trend of the phonolite flow. It must be concluded, therefore, that the flow trend was from north-west to south-east and confirms the conclusions reached by Walsh (1963, p. 6) in the neighbouring area to the east.

The phonolite is a fine-grained rock with large white phenocrysts of felspar and nepheline in a blue-black, aphanitic groundmass. In a thin section of specimen 59/372 phenocrysts of much altered anorthoclase and smaller nephelines are set in a holocrystalline groundmass of fluidally arranged felspar prisms, nepheline, zoned aegirine, dark red-brown cossyrite, kataphorite and iron ores. Crystals of kataphorite are extremely common, exhibiting strong pleochroism, X = pinkish brown, Y = pale pinkish grey, Z = yellowish green with Y>Z>X. The rock is similar to Kapiti phonolites described by previous authors. A chemical analysis of an olivine-bearing variety is given by Campbell Smith (1931, p. 240).

4. Pleistocene Volcanoes

A number of authors in the past have considered the volcanic cones and associated lavas of the Sultan Hamud-Simba area as the north-westerly representatives of, and contemporaneous in age with, the Chyulu basalt range which lies mainly to the south-east of the present area. During the present survey, however, evidence was gathered which indicates that the former lavas comprise a distinct and separate volcanic field extending from Kima (in the area to the north-west) to Simba (Fig. 6). The products of these eruptions, which probably took place during lower Pleistocene times represent, in this part of Kenya, the beginning of volcanic acitivity that did not cease until historic times in the Chyulu range. During Upper Pleistocene times and after volcanic activity had ceased in the Simba area, renewed activity broke out to the South at Ngatatema, where new cones and lavas built up a small volcanic field, overlying the earlier Simba volcanics. It was not until Recent times that the Chyulu basalt range began to grow.

(1) Lower Pleistocene Volcanics—The Analcime Basanites and Olivine Basalts of Simba

Considerable erosion in late-Tertiary times had taken place before the first lavas of the Simba area flooded the old Muoni river. The sub-Miocene peneplain and Yatta phonolite plateau had been partly dissected and the Athi and Muoni rivers had incised their courses by as much as 350 ft. at the commencement of volcanic activity in Pleistocene times. Although the cones surrounding the volcanic vents are fairly well-preserved they have undergone erosion which has considerably modified their appearance. This is in contrast to the products of later eruptions in the Ngatatema and Chyulu areas, which do not display the same degree of denudation. The slopes of the extinct volcanoes are strewn with large lava boulders and bombs that have remained *in situ* after relatively free unconsolidated ash, with which they were deposited, has been washed downhill, now forming an apron of boulder-free detritus and red soil surrounding the cones. A section exposed in the hillside at Nguu and a bore-hole drilled nearby indicate that beds of semi-consolidated lapilli overlie interbedded lava and pyroclastics. It is considered that a considerable lapse of time has passed since the formation of the Simba cones, permitting the erosion and removal of the finer-grained material from their slopes, and that the eruptions in the Simba area occurred in Lower Pleistocene times.

The earliest volcanic rocks, which consist of ash, tuff, lapilli, driblet material, breccias, scoriaceous boulders, bombs and lavas formed numerous cones, many of which grew in clusters along fault fissures, particularly at Ndoinyolendikir, Loinyoliunguso and Mangwa. These define members of an important system of fissures which trend north-west—south-east across the area, and are referred to in a later section. Associated with these eruptions were numerous lava flows that were poured out over a fairly even land surface. The most interesting flow, an analcime basanite which flooded the old east-flowing Muoni river was probably discharged from the large Mwani crater in the Sultan Hamud area. The lava now forms a low plateau of which the plain east of Emali and the ground between the Muoni and Kiboko rivers are a part. At a number of localities along the course of the present Muoni river, flanking the Muoni lava, the basanite is well exposed and sections reveal the lava overlying 2 ft. of grey, baked soil containing quartz detritus, which in turn is underlain by weathered Basement System gneisses (Plate VI (*c*)). In these river-sections the lava varies in thickness and over 30 ft. was recorded in a number of places, suggesting that the centre of the lava that filled the original channel of the old river will be much thicker. In section the basanite has a central massive part (cf. Wentworth and Macdonald, 1953, Fig. 32, p. 60) consisting of columnar-jointed, dense lava with horizontal partings, underlain by layers of clinker one to two feet in thickness. Although the upper part of the flow and surface features have been completely removed by weathering the remaining characteristics suggest that the basanite was a typical flow of *aa* type. At one locality about two miles east of Kiboko station the basanite is thin and overlies soft alluvium. A small stream-course which probably carries water during the rains issues from beneath the lava, and is responsible for subsidence of the lava due to the washing out of alluvium from beneath the flow (Fig. 7).

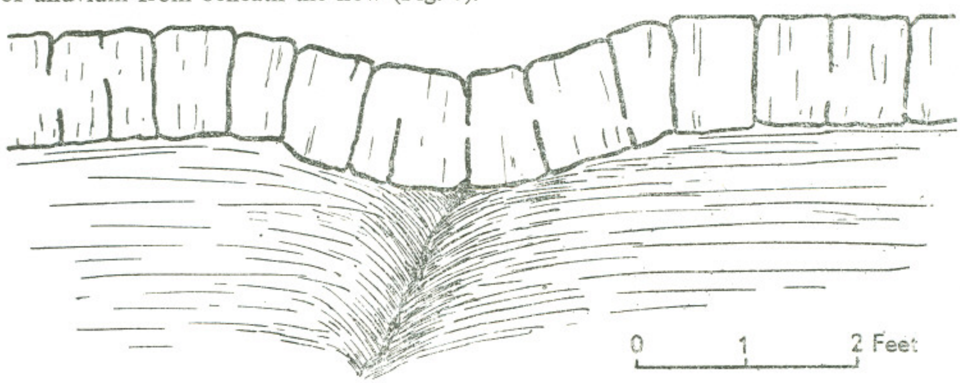


Fig. 7—Subsidence due to washing out of soft alluvium from beneath the Muoni basanite two miles east of Kiboko station

Lavas are intercalated in bedded pyroclasts that make up the composite volcano of Nguu. Good exposures of these lavas are to be seen in the Muoni river south of the Nguu hills. The later lavas, of which only the youngest form outcrops, are olivine basalts which cooled quickly and solidified within short distances of their points of extrusion. Those basalts extruded from the Simba vent (not to be confused with Lengai on which a trigonometrical beacon, named Simba, has been erected) can be seen from the main road where three thin flows are piled up one on the other. These are probably the youngest of the Simba basalts. Elsewhere lava flows are represented by residual boulders in red soil surrounding the cones. Thin sections of lava boulders taken from the pyroclastics forming Ndumoto reveal the presence of analcime, suggesting that at least part of the Muoni basanite was shattered during the growth of this cone.

Analcime basanites.—The Muoni analcime basanite (specimen 59/251 from Simba) is a dense, flinty rock, blue-black in colour, containing microphenocrysts of olivine measuring up to 0.3 mm. in a microlitic groundmass of augite, felspar, magnetite and analcime. In all thin slices examined sub-idiomorphic to allotriomorphic olivines form more than 10 per cent of the rock and show various stages of replacement by bright orange-brown iddingsite, fibrous bowlingite, serpentine, goethite and magnetite. Rounded outlines and embayments are characteristic, showing that magmatic corrosion of the olivines occurred at some stage during crystallization of the rock. Magnetite occurs both as small microphenocrysts and abundantly in the matrix, where it occasionally forms granules arranged in arcuate strings. The felspars are altered prisms of labradorite (An_{60-54}) and are associated with pale brown grains and small idiomorphs of augite in the matrix. Clear, sometimes weakly birefringent analcime forms the ultimate base. Glass is absent. Analcime comprises a notable proportion of the Nguu lavas which are more vesicular than the Muoni basanite. In specimen 59/260 from Nguu, vesicles are filled with quartz, spherulitic calcite and zeolites, scolecite being identified in one instance. The calcite also forms anastomosing veinlets. An analysis of specimen 59/269 from the Muoni flow near Simba is quoted in Table III. A modal analysis of this rock gave:—olivine 14 per cent, pyroxene 39 per cent, plagioclase 26 per cent, magnetite 18 per cent, mesostasis 3 per cent.

Olivine basalts.—Very similar to the basanites are the olivine basalts that comprise the bulk of the Simba lava field, but which are slightly younger in age. Hand-specimens and thin sections of these lavas are very similar except that the basalts are more fine-grained, the olivines are usually more corroded and frequently completely pseudomorphosed by alteration products, while analcime is accessory only. Microphenocrysts of augite are rare and were seen in only one specimen examined (59/345, Ndumoto).

(2) Upper Pleistocene Volcanics—Olivine Basalts of Ngatatema

East of Merueshi, at Ngatatema, basaltic lavas which have been extruded from a number of vents between Hunt and Ol Doinyo Lembagai conceal Basement System gneisses of the Kurase Series and also overly Simba-type olivine basalts and pyroclastics exposed north of Ol Doinyo Sambu (Mbea). The Ngatatema olivine basalts are considered to be intermediate in age between the Simba basalts and the Chyulu basalts and are probably of Upper Pleistocene age. The volcanic cones are never so eroded as the Simba type, but the very loose ash and lapilli comparable with those covering the slopes of the more recent Chyulu cones have been eroded from the Ngatatema cones. Boulder-fields form aprons round the bases of the cones, representing an intermediate stage in their denudation compared with the older and younger volcanoes. Microscope examination of thin slices of these rocks also suggests that alteration is never so intense as in the Simba lavas, and yet they are not so fresh as the rocks of the Chyulu range, though the degree of alteration may not necessarily be related to the age of the rocks.

The Ngatatema basalts contain microphenocrysts of olivine and augite set in very fine-grained groundmasses of plagioclase laths, augite, iron ore and analcime. The altered olivines present a similar appearance to those in the Simba basalts except for the youngest lavas, in which the olivines are automorphic and are only marginally altered. Unlike the Simba lavas microphenocrysts of pale brown augite measuring up to 1 mm. are more common. The augites have a distinct cleavage and in specimen 59/362 from Olgurtam are sometimes disposed radially in stellate groups. Magnetite is abundant but confined mainly to the groundmass. The felspar is labradorite. The basalts can be compared with the Hillhouse Type (Tyrrell, 1913, pp. 324-325). An analysis of specimen 59/354 from Ngatatema is quoted in Table III. A modal analysis of this specimen gave:—olivine 26 per cent, pyroxene microphenocrysts 9 per cent, magnetite 4 per cent, groundmass 61 per cent.

5. Recent Volcanics and Sediments

(1) Volcanics of the Chyulu Range

Volcanic eruptions, which have continued intermittently from Pleistocene times in the Simba-Kibwezi area, took place from a number of centres that occurred successively further south-east, the most recent lavas being poured out in the area near Mzima Springs, 30 miles south-east of Kibwezi. No flows of historic age have been recorded, however, from the present area. Gregory (1921, p. 189) considered the Chyulu volcanics as Lower Pleistocene in age, but the facts that the eruptions were later than those in the Simba area and that the volcanoes have suffered little erosion suggests that a Recent age must be assigned to them. A sample of carbon collected in 1957 from beneath a lava at Umani Springs by R. G. Dodson has been dated by the United States Geological Survey as 480 $\pm$ 200 years (*Amer. Jour. Sci., Radiocarbon Supplement,* Vol. 2, 1960, p. 175). This indicates a very recent age for some of the lavas in this part of the area.

The Recent lavas of the present area form the north-westerly extension of the main Chyulu volcanic field, which has been built up by innumerable eruptions from vents that are distributed along a system of north-west—south-east and north—south-trending fissures and fault-zones (Fig. 8). The distribution of vents has given rise to

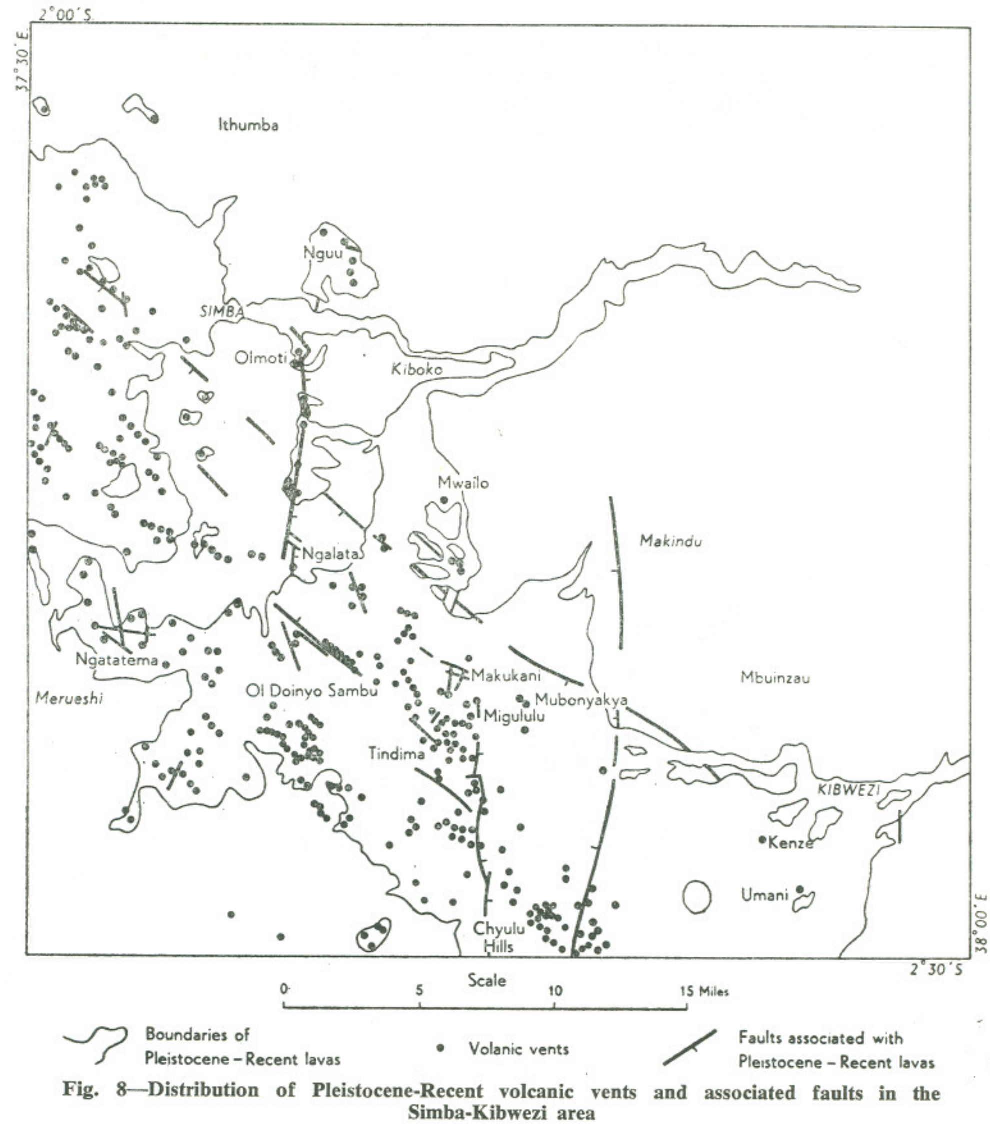


Fig. 8—Distribution of Pleistocene-Recent volcanic vents and associated faults in the Simba-Kibwezi area

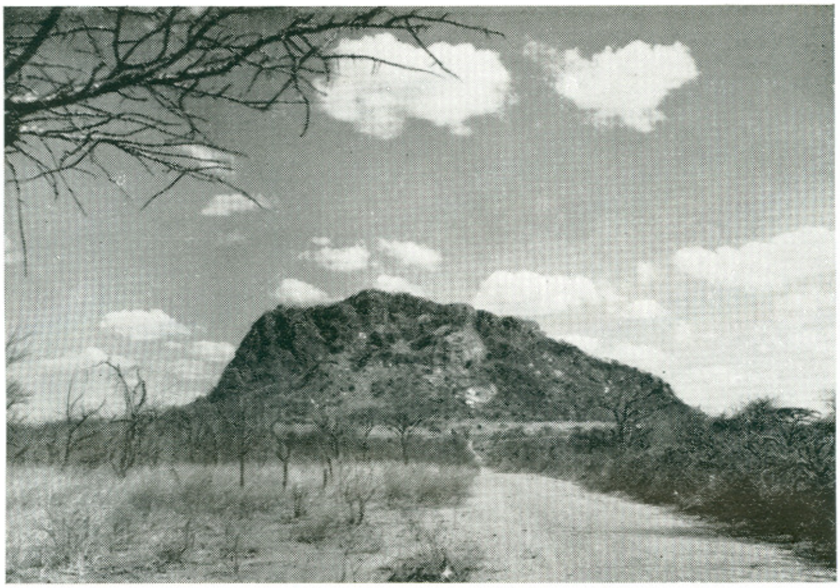
a cone-belt flanked by lava fields the width of which varies from one-half to over six miles. The Tindima-Migululu cone-cluster was the principal centre of eruption, this group of extinct volcanoes being situated on and near an intersection of two zones of the faults. It also falls inside an area bounded by faults whose downthrows are towards the centre of the area. Although the dominant trend is north-west—south-east the north—south trend has played a not inconsiderable part in the localization and alignment of cones, the Olmoti-Ngalata-Ol Doinyo Sambu and Mwailo-Tindima groups being notable. At the surface the fault-zones are marked by lines of cinder cones, scarps, fissures and pit-craters. The fissures vary in width and have been modified by erosion—in one case a mile north of Mubonyakya, a major fissure was found to measure over 30 ft. in width and reach a depth of more than 20 ft. The depth of many of the smaller fissures cannot be ascertained as they are now partly concealed by loose boulders and cinders. Faults are common and are represented by eroded gullies on ash-cones or form low but prominent scarps in the lavas, of which that north of Ol Doinyo Aseba is an excellent example. Here lavas have been displaced to the north, the southerly end of the fault being delineated by nine cones with central vents and associated pit-craters. As in many other instances the fault is partly concealed to the south-east by a more recent lava but reappears again at Mutonaju. No dykes were seen to occupy the fault zones, though it is not unlikely that they exist in depth.

Pit-craters.—Pit-craters are considered to be the result of collapse, mainly along lines of faults and associated fissures (Wentworth and Macdonald, 1953, p. 19). In the present area the largest are of comparatively recent origin, their sides being vertical and without noticeable scree slopes. Throughout the volcanic area numerous pit-craters are seen to be associated with lava surfaces and volcanic vents. The craters vary in size—some are merely oval or circular collapse structures measuring a few tens of feet across on the surface of lavas; others, however, are major structures and form remarkable topographic features. Excellent examples of these occur at Makukani (Fig. 9) approximately nine miles south-west of Makindu. The pit-craters which are sunk below the general level of the lava surface are sub-circular or elongated in plan, their walls being steep or nearly vertical. They represent collapse structures that failed to fill subsequently with lava, and in fact it is not certain that molten lava ever existed in such pits. The Makukani craters are situated along a number of faults that form part of the fault-zone extending from Mwailo to south of Tindima, a distance of eight miles. The largest, a pit 1,500 ft. at its broadest point, occurs on the eastern side of Makukani and has partly breached the side of the cone. It is over 100 ft. in depth, having vertical walls consisting of well-stratified lavas and tuffs; the lip of the crater having been raised, the lavas dip quaquaversally at a low angle. The upper lavas forming the rim are unusual in that they are cellular basalts with vesicles between a half and one inch in diameter. This large pit is joined by an elongated pit approximately 3,000 ft. in length whose position and shape is obviously controlled by two intersecting faults. Yet a third large circular pit-crater occurs within the vent of the Makukani volcano (Plate VII (*d*)) and is also more than 100 ft. deep. Its southern wall is a steep face, but on the north side it is possible to enter the centre as the volcano was breached by a vent on this side. Small pits from which a thin tongue of *pahoehoe* lava has issued and formed a narrow flow, occur within the breached portion of the cone along the line of a north-north-east trending fault.

Other, similar but much shallower, collapse-structures were seen in vents one mile east of Ol Doinyo Aseba.

Volcanic cones.—Rising abruptly from the lava fields and forming areas of strong topographic expression are hundreds of cones that have formed around volcanic vents (Plates VIII and IX). The cones are composed largely of pyroclastic material ranging from coarse agglomerate and cinders to lapilli and ash. These cinder-cones range in height from 50 to 800 ft., the height usually exceeding the diameter of the rim

Plate I



(a) Ithumba, a monadnock of granitoid gneiss

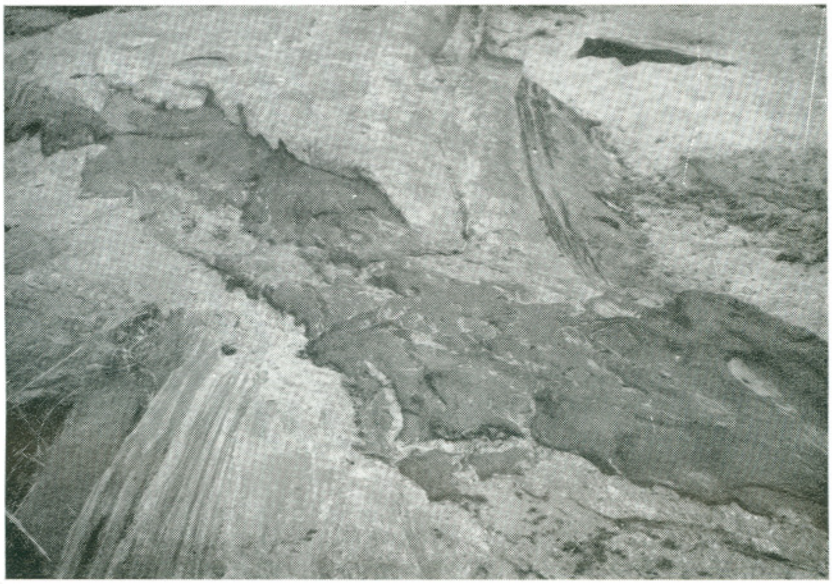
(b) Giant pot-holes in the river Kiangini

Plate II

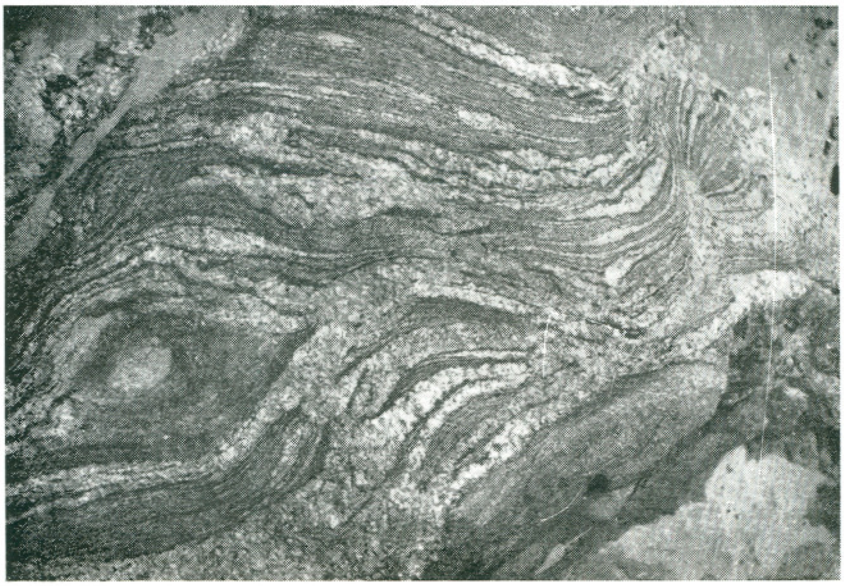
(a) Quartz-sillimanite *faserkiesel* **in quartz-felspar gneiss in the river Kiangini at Pungu**

(b) Slip-folded, cross-cutting micropegmatite with a lineation defined by the crests of small folds in the river Muoni at Tutini

Plate III



(a) Deformed and slightly granitized, cross-cutting dyke in Basement System gneisses in the river Kiangini at Pungu



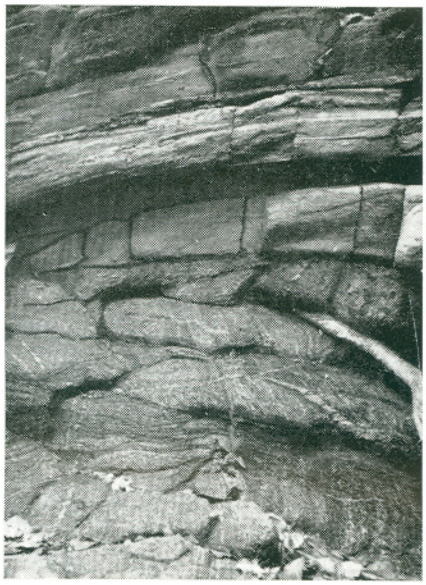
(b) Migmatite in the river Muoni south of Nguu

Plate IV

(a) Isoclinal folds, boudinage structure in pegmatite and pegmatite growing in fractures in banded hornblende gneisses in the river Kiangini at Pungu

(b) Disrupted amphibolite bands in migmatite in the river Kiangini at Pungu

Plate V

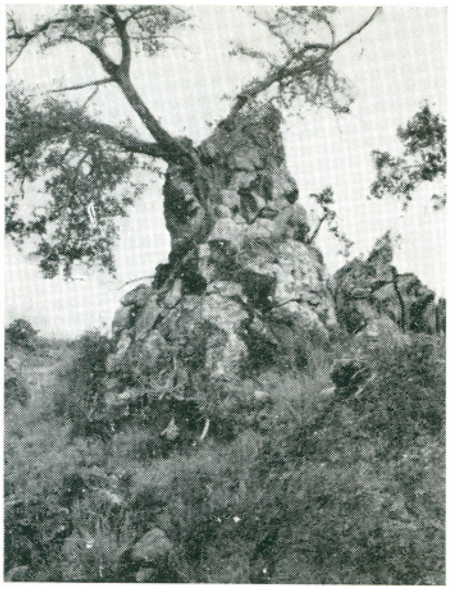


(a) Thrust in biotite-hornblende gneisses in the river Muoni at Tutini. The upper beds which are nearly horizontal (at the right of the picture) overlie beds which dip 55° towards the left of the picture

(b) Mullions in biotite-hornblende gneisses in the river Muoni at Tutini. The mullions are elongated parallel to the local lineation

Plate VI

(a) Mathaioni, an agglomerate-cinder cone with subsidiary vent. In the foreground a tumulus in *pahoehoe* lava



(b) A lava spine on an *aa* lava flow east of Mathaioni

(c) Columnar basalt overlying river deposits, two feet thick, which in turn overlie highly weathered Basement System gneisses in the river Muoni

Plate VII

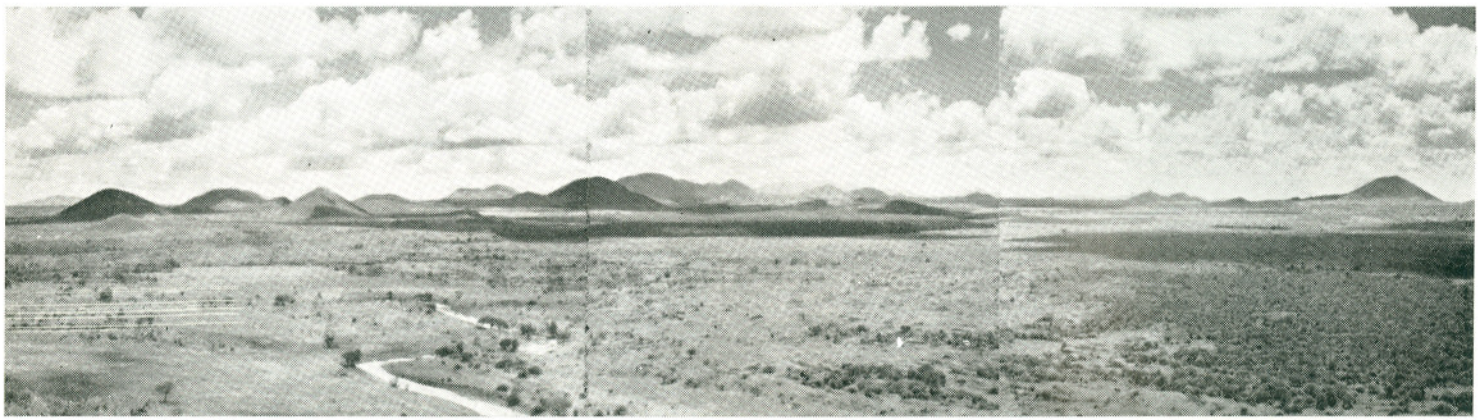
(a) Tunnel in *pahoehoe* lava, Migululu

(b) Arcuate ropy texture on *pahoehoe* lava surface near Mathaioni

(c) Hornito on an *aa* lava flow near Mathaioni

(d) Pit-crater in Makukani vent

Plate VIII



Panorama of the Tindima area. The photograph was taken from Mathaioni looking south-south-east towards the Chyulu hills, which are in the background. In the foreground the sand-river Oldukai (Greater Kiboko) separates lavas on the south from Basement System gneisses overlain by red-sandy soils on the north

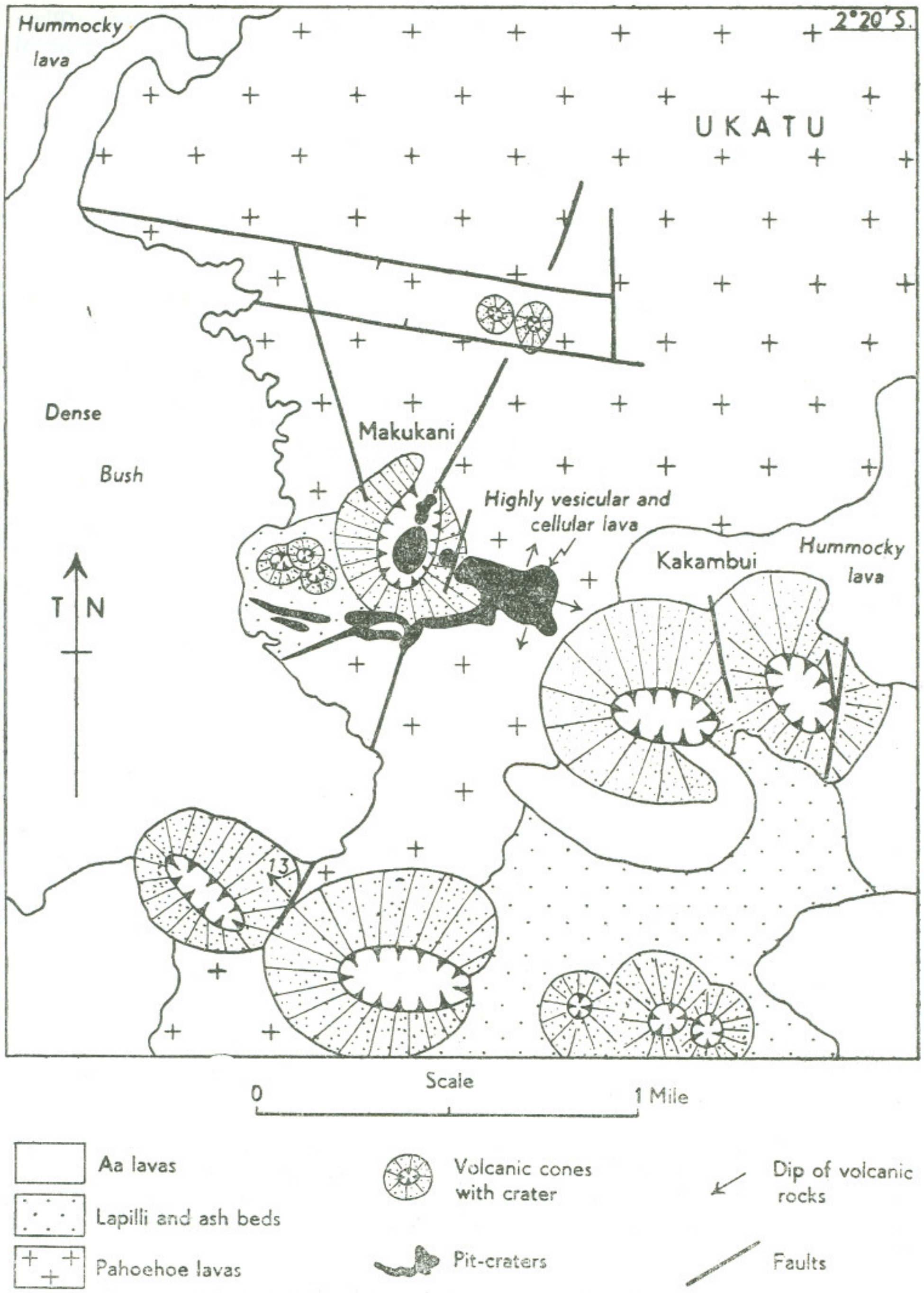


Fig. 9—Pit-craters and associated faults, cones and lavas at Makukani

of the vents. Nearly all the cones are breached by one or more vents (Plate VII (*a*)), the bottoms of the craters being at a higher elevation than the external base in most cases. Some of the vents are centrally situated in relation to the periphery of the base; many, however, are located on the north or north-east sides of the cones, usually on the downhill side, indicating a north or north-easterly prevailing wind blowing at the time of their formation, a maximum of pyroclastic material accumulating on the south and south-westerly rims of the craters. Some cones like Ol Doinyo Sambu are steep-sided, but they rarely slope at more than 30°; others have more gentle slopes and craters of large diameter. A number of the volcanoes are formed of large composite cones with associated vents, and nests of small cones are occasionally seen. Small cones (volcanelloes) on *aa* lava surfaces are the products of eruptions at rootless vents, the cones being built up of ash, driblet and cindery lava.

Pyroclastic formations.—Among the ejectamenta forming the cones, are driblet material, agglomerate, "cinders", ash and lapilli. The most common are the cinders, light pumiceous material in which are embedded large rock fragments that were hurled into the air at the time of explosive activity. Examination of the hill surfaces, particularly in the Chyulu hills south-east of Tindima, indicates that a great deal of the material forming the cones here is ash and lapilli. A typical example of lapilli material is exposed at Nguu (a Pleistocene volcano) where the lapilli, of the order of half an inch in diameter, are present in beds that are coarser at the top than at the bottom. At Mwailo, Mathaioni and Tindima occurrences of ash and lapilli beds over-lying lavas suggest that very recent volcanic activity has taken place, as these beds cannot be accounted for by erosion of nearby volcanoes. On the other hand ash and lapilli beds occurring two miles east of Elmau have probably accumulated as a result of erosion.

Bombs.—Volcanic bombs can be found on any of the cones in the area. The most common is the almond-shaped type such as are figured by Wenthworth and Macdonald (1953, p. 82). These bombs, which were observed to range in size from a few inches to over 4 ft. along the greatest axis, are characterized by a central globose form with twisted ear-like projections. Bread-crust bombs showing shrinkage cracks in the skin are most frequently found on the slopes of the Ngatatema cones. These generally have a fusiform shape, but sub-spherical varieties were observed. Hawaiian-type (pancake) bombs were found sparingly while smooth spherical types were occasionally noted. Spindle-shaped varieties are either smooth-skinned or characterized by shrinkage cracks. Some fusiform bombs are extremely elongated and are similar in shape to an English scythe hone, though much larger. Other bombs are of cored types, containing xenolithic nuclei of foreign material, such as weathered Basement System gneiss fragments. These bombs are usually sub-spherical and of smaller diameter than the other bombs. Fragments of curled and twisted lava also represent ejected material, some being remnants of the ears of almond-shaped bombs though most were probably ejected as small blobs of plastic lava.

Dykes, intrusions, fumaroles.—Prominent agglomerates and vesicular rocks that form ribs of rock on the slopes of some of the volcanic cones may represent dykes. No rocks of definite intrusive origin were noted, however, owing to the fact that exposures in the lavas are poor and much of the area is covered by dense forest and under-growth.

Fumaroles or related phenomena were not seen in the area. An interesting occurrence is the hot-springs that issue from beneath the Muoni basanite south of Nguu. The warm water, which is fit for human consumption, is thought to be heated at depth, the heat source probably being associated with the north-south fault-zone between Nguu and Ol Doinyo Sambu.

Lavas.—The lavas*, of which over 70 basalt flows were recognized, vary in thickness from a few feet to over 50 ft., their greatest thickness occurring near the lower slopes of the now extinct volcanoes. Some of the lavas have travelled only short distances before congealing while others, like those at Kiboko and Kibwezi, flowed many miles along stream-courses, that occupying the Kiboko valley for example having reached a point approximately 23 miles from its probable source at Tindima. Generally the lavas are broad flow units narrowing to where they issued from the vents. Some have been confined to stream-courses or have been guided by depressions between older lavas or restricted in lateral extent by the configuration of the land surface over which they flowed.

The basalts did not build lava cones as are so typical of the shield volcanoes of the Hawaiian islands but were extruded from vents that are usually marked by cones formed of the ejectamenta derived from the initial explosions. During eruptive activity and usually after the cones had been built up, lava upwelling in the vent breached the cones, so forming horseshoe-shaped hills. In other cases the lava issued from the lower slopes of the cones through the unconsolidated pyroclastics; in such cases no breaching of the rim of the volcano has occurred.

It cannot be stated whether volcanicity in the region commenced with violent explosions and the formation of cones, or whether the initial activity was confined to the quiet extrusion of basalt flows. It is certain, however, that explosive activity has been long-continued and cones have been formed throughout the period of volcanicity.

Some of the oldest flows are visible and are probably represented by the lavas at Kiboko and some near Kibwezi. Only the most recent flows are visible in the highest hill region of Tindima and parts of the Kibwezi area and it is in these localities that the basalts are covered by thick dense forest, the Kibwezi forest being a good example. It is unwise to penetrate for great distances into the forests without the assistance of local guides and for this reason the area south of Wikiamba and north-west of Kenzili was not entered during the survey.

The olivine basalt lavas of the area are of three types of which *pahoehoe* and *aa* are the most common, *block* lava being rare. No evidence was seen to suggest that *aa* type passes into *pahoehoe* type or vice versa along the length of any particular lava flow. Typically the *pahoehoe* lava has a smooth or ropy surface while *aa* lava is typified by a rough, jagged, spinose clinkery surface (c.f. Wentworth and Macdonald, 1953, p. 32). The third type which may be termed *block* lava resembles *aa*, but the surface fragments are smoother angular blocks.

Pahoehoe lavas.—The Chyulu *pahoehoe* lavas, of which the best examples can be seen at Kiboko, Ukatu (north of Tindima) and Kibwezi, are characterized by their smooth but well-jointed surfaces and regular vesicles. Only in the most recent flows has the original surface been preserved and on such surfaces sharkskin, filamented, scaly and ropy textures (Plate VII (*b*)), and grooved pavements were all observed, while slab *pahoehoe* was observed in a number of instances. A very recent *pahoehoe* lava forms the north-east flow from Tindima, the surface of which is characterized by channels and tubes.

Some of the tubes, such as that illustrated in Plate VII (*a*), are preserved above the general level of the lava, but in other cases the channels are concealed and only the entrances to cave-like tubes are visible. How far these lava tubes extend underground it is not possible to say, but one cavity over 10 ft. long was examined. The lava tubes represent parts of the original channels along which *pahoehoe* lava flowed, while those preserved on the surface represent *pahoehoe* "toes" that once marked the

* The lavas have been numbered on the coloured geological map and in Table II in order of extrusion from I—XIV and 1—8 depending upon their locality. Lavas thought to have been extruded at approximately the same time have been given the same number.

edges of the advancing lava. In all cases these tubes have been drained leaving a casing of lava a few inches thick. The older *pahoehoe* lavas are characterized by flat pavement-like surfaces such as are seen between Mathaioni and Ngazani. These are in marked contrast to the jagged or hummocky surfaces of the *aa* lavas. Tumuli or pressure ridges (Plate VI (*a*)) that vary in dimensions from a few feet up to 200 ft. in length, up to 10 ft. in height and 5 to 20 ft. in width are commonly associated with this type of basalt and have been described from other localities in Kenya (Temperley, 1955, pp. 416-424). It seems likely that these have developed longitudinally with respect to the advancing flow.

Approximately two miles downstream from the main road at Kiboko there is a sinuous ridge, which on aerial photographs looks like the abandoned meanders of a river. The ridge is a cast of the old river channel beneath it while on the flanks of the channel the *pahoehoe* lava has subsided owing to alluvium having been washed away from underneath it. This type of subsidence has already been illustrated in Fig. 7, and is a common feature throughout the Chyulu volcanics. Temperley (1956, pp. 11-12) records circular collapse structures in Recent lavas at Mzima and numerous similar holes can be seen near the margins of the lava and frequently near snouts of flows. Some of these, however, which are orientated longitudinally with respect to the lava flows, represent lava tubes.

Aa Lavas.—These basalts are noted for the irregularity in the shape of the vesicles and their rough surfaces, those at Kibwezi being covered to a depth of a few feet by loose clinker and boulders. The oldest lavas of this type usually have a hummocky surface, while an intermediate stage of denudation is represented by the most easterly of the Ukatu lavas where the surfaces are covered by only a thin layer of loose boulders and scoriae. Few good sections of the *aa* basalts were seen but judging from accounts of basalt lava-fields in other parts of the world it is apparent that the central parts of the flows will be massive. Near Tindima the surfaces of the *aa* flows are extremely hummocky and examination of the aerial photographs of that part reveals arcuate structures. It is considered that the hummocks have developed on the backs of rapidly advancing lavas that flowed down steep slopes, the typical *aa* surface developing when the flows reached flatter ground. The arcuate structures are lines of hummocks that owe their distribution to drag in the flowing lavas. They have developed in much the same way as does ropy lava, drag occurring on the flanks and the most rapid movement in the centre of the lava stream. Spines, hornitos and monolithic crags of solid, well-jointed lava (Plates VI (*b*), VII (*c*)) are typical features of the *aa* lavas. During the process of formation a number of lava spines became striated, suggesting that the lava during its viscous stage was grooved in passing a projecting surface of more rigid rock.

Block lavas.—The block lavas closely resemble the *aa* type and have not been differentiated on the coloured map. An example of lavas of this type can be seen near Changondu water-hole, south-west of Makindu. These lavas are typified by a more bouldery surface, consisting of loose blocks without clinker.

Distribution and Correlation of the Lavas.—The oldest lava in the Kiboko valley is that exposed between the two bridges at Kiboko (on the main Mombasa-Nairobi road) and it is thought to be of approximately the same age as, if not part of, the lower flows east of Mathaioni. These lavas are overlain by the *pahoehoe* lavas that occupy the Kiboko and Kiumbu (Makindu) valleys. These *pahoehoe* basalts are probably north-flowing branches of the same lava that was extruded from the Tindima region. Two isolated occurrences of *pahoehoe* basalt outcrop near Ol Doinyo Sambu (Fig. 10) and their position beneath younger lavas suggests that they are also (southerly) branches of the main Tindima basalt. An excellent sequence can be examined in the Tindima area, most of the lavas being of *aa* type except for two *pahoehoe* flows. The lavas overlie one another the later lavas being successively shorter, their snouts forming prominent scarps, so that as one approaches the main volcanic cone-clusters one rises

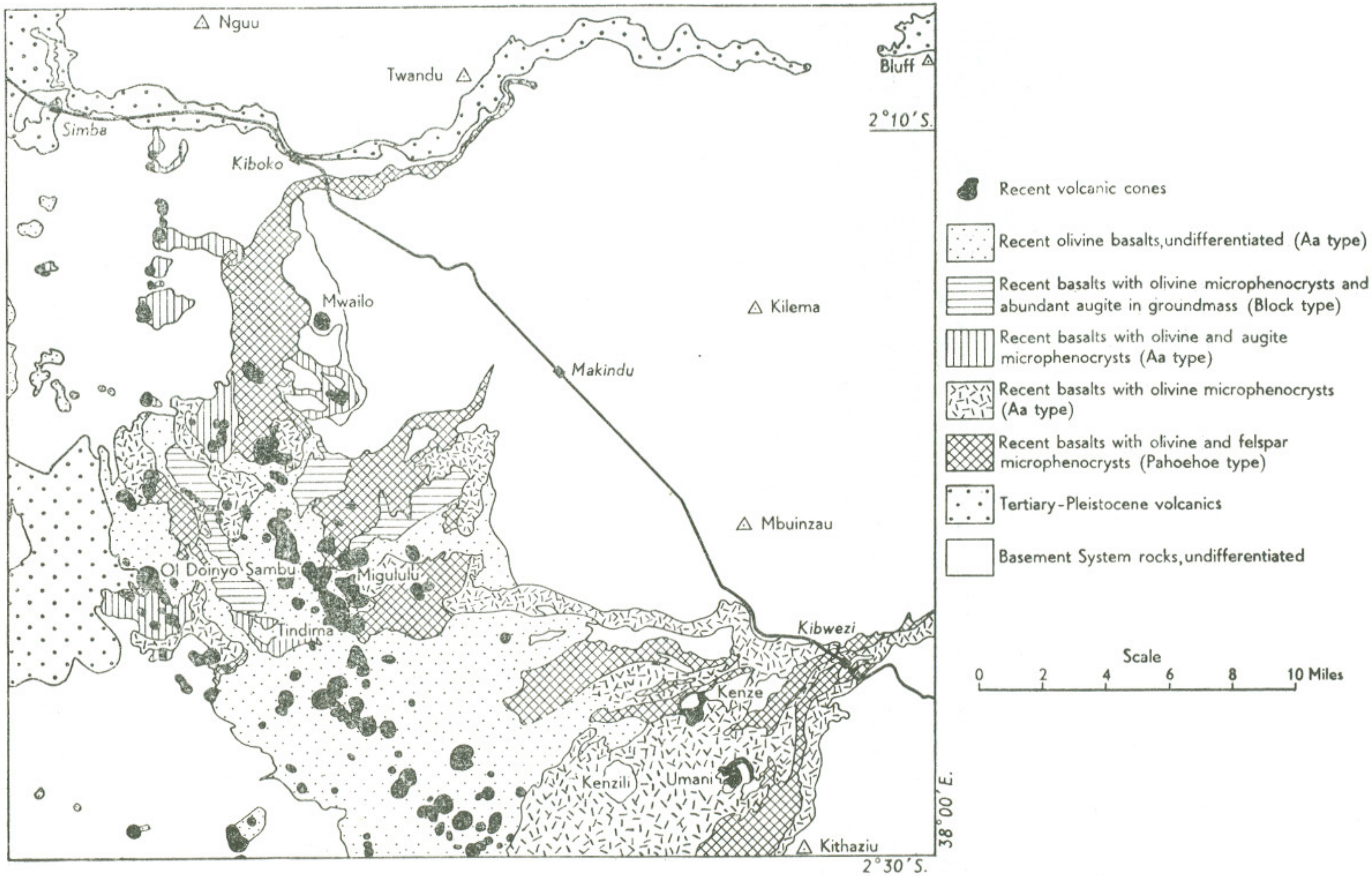


Fig. 10—Distribution of Recent lavas in the Simba-Kibwezi area

in a series of steps. Later lavas of *aa* type were derived from Mwailo, Duani and Mathaioni. The flows are short but are seen to overlie the Kiboko *pahoehoe* lava. Their precise positions in the lava sequence is not certain, but from their nature it is thought that they represent some of the youngest flows in the area. The Duani flows are later than those from Mwailo as the former have flowed round the eastern margin of the already consolidated Mwailo flows.

Very late *aa* lavas were extruded from the volcanoes along the line of the Ol Doinyo Sambu-Nguu fracture. One of these, a lava from Osogat, flowed eastwards onto the Kiboko plains overlapping the *pahoehoe* lava and at one time dammed the Kiboko river. Subsequent erosion has resulted in the development of a small narrow gorge in the lava from Osogat. Three short *pahoehoe* lavas can be seen at Makuani, Mwailo and Ol Doinyo Sambu.

An interesting lava sequence occurs at Kibwezi, where only detailed mapping and examination of aerial photographs reveals the order of extrusion. Credit must be given to B. N. Temperley whose mapping and report on the Kibwezi area in connexion with water-supplies (Temperley, 1956) have been most helpful in deciding the order of extrusion. The early volcanoes of Umani and Kenze and the Basement System island of Kenzili were upstanding hills round which flowed rivers of lava extruded from the Chyulu range to the south of the present area. An early flow which divided into at least three branches was the *pahoehoe* lava west of Kenze. This is correlated with the earliest *pahoehoe* lava further west. Succeeding lavas were of the *aa* type and many reached as far north as Kibwezi township. That used for ballast (for railway purposes) flowed 15 miles down the Kibwezi river from its point of extrusion before consolidation took place. Another *pahoehoe* lava branched to west and east of Umani island, one branch being guided in its course between two *aa* lavas and eventually coming to rest near Chae, north of Kibwezi. *Aa* lavas comprise the remaining basalt flows in the Kibwezi area of which that flowing past Mbuinzau originated from the Tindima area and can be correlated with *aa* lavas there. Some flows ended near Umani while others were diverted round the pile of lavas already formed and now form the western flank of the lavas in the area. One notable *aa* flow is characterized by the fact that it is covered with lichen which although seen occasionally covering some flows, is never common. Table II attempts a correlation of the basalt lavas from different parts of the area. The number assigned to the lavas are those shown on the coloured geological map. It can be seen that most of the basalt lavas of the Simba-Kibwezi area are *aa* type while on only two main occasions were *pahoehoe* lavas extruded. The different lava types have been derived from the same centres though in general the *pahoehoe* basalts have flowed greater distances from their points of extrusion than the *aa* types.

Petrography.—The three lava types although resembling one another megascopically differ in detail particularly when examined in thin section. A most notable difference is that in hand-specimens the *pahoehoe* basalt is characterized by the presence of abundant small pale green microphenocrysts of olivine in a fine-grained groundmass, whereas the *aa* lavas are more even-grained with rare olivine phonocrysts. The main divisions that can be recognized are:—

1. *Pahoehoe-type Basalts*

   Olivine, pyroxene and felspar microphenocrysts. Groundmass with merocrystalline texture.

2. *Aa-type Basalts*

   (*a*) Fine-grained basalts with small olivine microphenocrysts.

   (*b*) Large microphenocrysts of olivine and pyroxene.

   (*c*) Small microphenocrysts of olivine and pyroxene.

3. *Block-type Basalt*

   Olivine microphenocrysts, with abundant pyroxene in the groundmass.

TABLE II—CORRELATION OF RECENT LAVAS IN THE SIMBA–KIBWEZI AREA

Kibwezi Area	Tindima Area	Ol Doinyo Sambu Area	Lavas of other parts
XIV *Aa* lavas of Umani	XIV *Aa* lavas (Kimakiu hills S. of Tindima)		*Aa* lavas of Osagat, Nomau, Olmoti, Elmau, Chyulu hills. *Aa* lavas of Oojini, Duani, Mathaioni.
XIII *Aa* lavas (S.W. of Kenzili)	XIII *Aa* lavas (S. of Tindima)		
XII *Aa* lavas—lichen-covered (between Kenze and Umani)	XII *Aa* lavas (Tindima and S.W. of Tindima)		
XI *Aa* lavas (E. and S.W. of Kenze and W. of Umani)	XI *Aa* lavas (Mabuani)		*Aa* lava of Mwailo
X *Aa* lavas (S.W. of Umani)	X *Pahoehoe* lavas (Tindima)		
IX *Aa* lavas (E. flank of lavas at Kibwezi)	IX *Pahoehoe* lavas (Tindima)	8. *Aa* lavas (Ol Doinyo Engeloreti)	
VIII *Aa* lavas (S.E. of Umani)	VIII *Aa* lavas (Migululu and S. Tindima)	7. *Aa* lavas (S.W. of Tindima)	
VII *Aa* lavas (S. of Mbuinzau)	VII *Aa* lavas (N.E. of Migululu)	6. *Aa* lavas (Ol Doinyo Engeloreti)	
VI *Pahoehoe* lavas (Kenze and S.E. of Umani)	VI *Aa* lavas (E. flank of lavas S. of Makindu)	5. *Aa* lavas (Ol Doinyo Sambu)	
V *Aa* lava (S.E. of Kibwezi)	V *Aa* lavas (Ukatu)	4. *Aa* lavas (W. of Kimakiu, S.E. of Ol Doinyo Engeloreti and Ol Doinyo Sambu)	
IV *Aa* lavas (W. of Kenze)	IV *Aa* and *Block* lavas (Ukatu)	3. *Aa* lavas (Ol Doinyo Aseba and Ngazani)	
III *Aa* lava (Kibwezi—used for ballast)	III *Aa* lavas (Ukatu and Changondu)	2. *Aa* lavas (N.E. of Ol Doinyo Aseba)	
		1. *Aa* lavas (Ol Doinyo Sambu)	
II *Pahoehoe* lavas (W. of Kenze)	II *Pahoehoe* lavas (Kiboko, Changondu)	II *Pahoehoe* lavas (Ol Doinyo Engeloreti and N.E. of Ol Doinyo Sambu)	
I *Aa* lavas (Kenze and Umani)	I *Aa* and *Block* lavas (Kiboko and E. Mathaioni)		

The two types of *aa* basalts containing microphenocrysts of pyroxene pass into each other by insensible gradations.

The *pahoehoe*-type lavas are fine-grained olivine basalts with merocrystalline textures. They are blue-grey vesicular rocks, speckled with tiny phenocrysts of pale green olivine. In thin section, of which 59/322 from Kibwezi is typical, slightly serpentinized microphenocrysts of colourless olivines are conspicuous in subhedral and euhedral crystals up to 2.0 mm. in length. Microphenocrysts of labradorite and pale brown augite are also present set in a matrix rich in augite and abundant grains of black iron ore associated with laths and microlites of labradorite, forming an open mesh. The lava differs texturally in different parts of the same flow and specimen 59/317 from Chae Bridge reveals a porphyritic and intergranular texture while specimen 59/320 from Kibwezi is a fine-grained variety with abundant magnetite. In the former specimen the olivines are marginally altered to orange-brown iddingsite.

Analyses of two *pahoehoe* basalts are quoted in Table III; their modes are as follows:—

	59/294	*59/322*
	%	%
Olivine microphenocrysts	13	9
Felspar	27	19
Pyroxene	28	31
Black Base	32	41

59/294 Kiboko lava snout at Twandu.

59/322 Kibwezi.

The *aa*-type basalts, analyses of which are quoted in Table III, are blue-black, fine-grained, highly vesicular rocks differing from the *pahoehoe* type in colour, vesicularity and the lack of abundant olivine phenocrysts in the hand-specimens. Of the three types recognized, in all but the first, the microphenocrysts form a notable proportion of the rock and in no case was felspar seen but in the matrix. All the *aa* lavas around Kibwezi (59/316, 321, 323, 326, 327, 330) are typical examples of the first variety, while flows at Changondu (59/335), Mathaioni (59/336) and south-east of Ol Doinyo Sambu (59/361) are also representative of this type. The groundmasses of these rocks are holocrystalline and consist of granular augite, tiny laths of labradorite (An_{50-62}) and abundant grains and octahedra of black iron ore. Small but fresh olivine microphenocrysts (10 per cent in specimen 59/327 from two miles north of Umani) are set in this matrix. In some cases there is a suggestion of fluidal orientation of the plagioclase laths. The matrix of specimen 59/330, which was taken from the tachylitic selvedge of an *aa* lava, is devitrified glass.

The remaining two varieties of *aa* basalt closely resemble one another in that all microphenocrysts range in size up to 2 mm. These basalts have a characteristic groundmass of greenish to colourless, green, and brown augite, iron ore and lathy labradorite, with interstitial dark brown to black glass in some specimens (50/328 from Kenze, in which glass is preponderant; 59/337 from Ngazani; 59/360 from Ol Doinyo Sambu). Rare flakes of biotite were recognized in specimen 59/352 from Nemashi. Fluidal textures are not uncommon and some of the rocks contain little or no glass in the groundmass (59/363, two miles south-west of Tindima). In the matrix are set fairly fresh olivines (4 to 15 per cent), mostly of microphenocryst size but some ranking as small phenocrysts, together with microphenocrysts of green, brown and purplish idiomorphic augite (13 to 15 per cent) and magnetite (5 to 14 per cent). The augite which occurs as single crystals or in clusters of radiating prisms, sometimes exhibits typical hour-glass structures and frequently has dark borders, while in other instances there is a suggestion of zoning. In thin section these rocks closely resemble the

Hillhouse and Dalmeny-type olivine basalts of the Midland Valley of Scotland (Tyrrell, 1913, pp. 240-241). The norms of the *aa* basalts from the present area indicate a high felspathoidal content, which in some cases was noted and is probably present in the fine-grained matrices of other specimens.

Only a single specimen (59/338) from one mile east of Ithundu) of *block* lava was examined in thin section. This black, vesicular basalt contains fresh microphenocrysts of olivine in a matrix of pyroxene, black iron ore and labradorite. It differs from the other basalts in containing a preponderance of augite, the labradorite being subordinate.

TABLE III—ANALYSES OF PLEISTOCENE TO RECENT LAVAS FROM THE SIMBA–KIBWEZI AREA

	1	2	3	4	5	6	7
	%	%	%	%	%	%	%
SiO_2	45·57	40·65	47·57	46·13	44·85	43·85	41·87
Al_2O_3 ..	10·50	12·45	11·49	10·22	13·98	12·67	12·89
Fe_2O_3 ..	2·40	3·08	2·43	4·52	3·09	2·41	2·89
FeO	10·15	10·18	9·96	10·18	10·95	12·35	9·81
MgO	10·85	11·78	12·12	10·36	7·47	9·75	13·97
CaO	12·16	11·84	9·12	11·00	9·06	9·64	10·52
Na_2O ..	3·46	2·31	3·45	2·52	3·89	3·25	2·69
K_2O	0·90	0·71	0·79	0·93	1·66	1·07	1·18
H_2O+ ..	0·76	1·58	0·58	0·46	0·56	0·40	0·72
H_2O- ..	0·40	1·60	0·26	0·38	0·08	0·12	0·40
TiO_2	2·72	2·90	1·46	2·72	2·74	3·01	2·56
P_2O_5	0·45	1·16	0·50	0·54	0·87	0·70	0·66
MnO	0·09	0·19	0·19	0·21	0·21	0·21	0·18
CO_2	0·09	0·09	0·09	0·08	0·09	0·11	0·15
BaO	trace	0·14	trace	trace	0·16	0·07	0 ·09
Totals ..	100·50	100·66	100·01	100·25	99·66	99·61	100·58

Analysts: W. P. Horne and Mrs. R. Inamdar.

	NORMS						
or	5·00	4·45	4·45	5·56	10·01	6·12	7·23
ab	11·00	6·81	18·86	20·96	16·77	16·24	3·41
an	10·56	21·41	13·90	13·62	15·57	16·96	19·46
ne	9·94	6·82	5·68	0·28	8·80	5·96	10·37
di	37·44	23·70	24·06	29·54	19·42	20·62	22·04
ol	15·32	21·51	24·54	16·30	17·09	22·40	26·04
mt	3·48	4·41	3·48	6·50	3·71	3·48	4·18
il	5·17	5·47	2·74	5·17	5·17	5·78	4·86
ap	1·01	2·69	1·34	1·34	2·02	1·68	1·68
cc	0·20	0·20	0·20	0·20	0·20	0·30	0·30

1. 59/269 Basanite, Muoni valley.
2. 59/354 Olivine basalt, Ngatatema.
3. 59/294 *Pahoehoe* basalt, Twandu.
4. 59/322 *Pahoehoe* basalt, Kibwezi.
5. 59/327 *Aa* basalt, Umani.
6. 59/363 *Aa* basalt, south-south-west Tindima.
7. 59/325 *Aa* basalt (with augite microphenocrysts), Umani.

An analysis of basalt from Kibwezi made by the East African Industrial Research Organization, in connexion with lavas to be used for ceramic purposes, is quoted on page 61.

Petrogenesis.—All the visible lavas of the Simba-Kibwezi volcanoes are olivine basalts with alkaline tendencies and of similar chemical composition. Analcime in notable amounts has been recognized in the earliest lavas—the basanites of Muoni and Nguu—and small amounts can be seen in some of the later lavas. From inspection of the norms (Table III) it seems probable that felspathoidal material is contained in all the later lavas, although not recognizable microscopically in their very fine-grained groundmasses. The lack of any other lava type and the similarity of the chemical analyses suggests that the parent magma is of olivine basalt composition and may have been derived from the same magma chamber as that from which the neighbouring Rift Valley basalts were derived.

The order of extrusion of the lavas in the area is shown in Table II and the analyses in Table III are also arranged in order of the probable sequence of eruption. The earliest extruded lavas, those near Simba, contain a greater proportion of olivine phenocrysts than do the later lavas of the Kibwezi area. The olivines of the former all show considerable alteration, while those in the Kibwezi area are generally fairly fresh. An intermediate stage in alteration is represented by the olivines of the basalts extruded at Ngatatema, these rocks being older in age than the Kibwezi lavas but younger than those extruded from the Simba vents. This difference in alteration and the abundance of olivine, in basalts of three different ages, suggest that crystallization and separation of olivines began at an early stage with the magma being successively impoverished in this constituent.

Further differentiation in the basalts is suggested by the *pahoehoe* and *aa* lavas. There is a tendency for the *pahoehoe* lavas to develop phenocrysts of plagioclase, while they are generally richer in olivine than the *aa* type. These basalts differ from one another, therefore, in the paucity or abundance of olivine and felspar and are probably derived from one another simply by differentiation. The crystallization of augite phenocrysts is characteristic of the last lavas to be extruded.

The chemical analyses show that variations in composition, though significant, are small. A variation diagram prepared in accordance with the method devised by Larsen gives a better distribution of points than the usual method of plotting the percentages of oxides against that of silica. It is considered, however, that there are insufficient analyses to be able to interpret the diagram with reliability, at least for the present. Similarly, the relationships of the rocks revealed by plotting the von Wolff parameters, calculated from the analyses, are not conclusive. All points fall into a small area which does not suggest a large differentiation of the original magma. Nevertheless, a slight differentiation among the lavas 1, 2 and 3, is shown on the diagram (Fig. 11). It is significant that their arrangement corresponds with the order of extrusion of these lavas as recognized in the field. The later lavas, those of the Kibwezi area, all tend to be less undersaturated than the earlier flows, but a reversal occurs in the final extrusions that took place at various vents such as Umani and other large volcanoes. These latest lavas are of limited extent, having congealed on or close to the volcanoes from which they were extruded. They are generally richer in augite phenocrysts, with a correspondingly lower proportion of olivine phenocrysts. The triangular diagram (Fig. 11), in which the rocks of this area are compared with basalts and more basic rocks from other areas, suggests a straight line variation. The analyses of the other rocks plotted are given in Table IV. The points plotted are all disposed near the straight line joining felspathic basalts of Dunsapie type (Clark, 1956) to the ultra-basic lava of Cyprus (Gass, 1958). An *aa* lava from Umani (No. 5 in Table III) showing the greatest proportion of felspar in the norm is to be found at a point on the line nearest the felspathic basalt of Dunsapie type, while the lavas which were finally extruded are nearer the ultra-basic end of the line. Basalts from other parts of Kenya (e.g. Campbell Smith, 1938) appear to be of similar composition, but with a tendency to be more basic. The Kijabe-type basalt (Shand, 1937), a rock rich in plagioclase, does not fit in with the rocks from this area. The plotted positions of the von Wolff parameters of the Kenya rocks and the positions of these same rocks as shown in Fig. 11 indicate that the Simba-Kibwezi basalts are more basic than the suggested parental magma of the Midland Valley of Scotland (Clark, 1956, p. 59) which is represented by Normal Dunsapie-type basalt (Analysis B in Table IV).

TABLE IV—ANALYSES OF BASALTIC ROCKS FROM KENYA AND OTHER PARTS OF THE WORLD

	A	B	C	D	E	F	G	H
	%	%	%	%	%	%	%	%
SiO_2 ..	45·36	45·10	43·12	45·27	46·25	45·41	46·74	43·00
Al_2O_3 ..	15·52	14·59	12·94	13·91	13·28	13·06	8·19	4·64
Fe_2O_3 ..	12·88	4·59	1·98	3·41	2·55	2·94	2·77	2·42
FeO ..	1·83	7·93	9·52	7·13	7·65	7·64	9·60	6·47
MgO ..	4·14	5·69	8·09	10·76	12·36	12·05	20·47	33·45
CaO ..	8·34	8·10	12·62	12·68	12·62	12·01	7·47	3·99
Na_2O ..	3·33	3·05	2·65	2·14	2·00	2·26	1·74	0·25
K_2O ..	1·75	1·53	1·42	0·97	0·53	0·91	0·35	0·05
H_2O+ ..	2·66	3·13	1·36	1·30	0·04	0·74	—	3·83
H_2O- ..	1·20	1·17	0·32	0·13	0·02	0·10	—	1·22
TiO_2 ..	2·56	3·38	3·45	2·40	1·98	2·72	2·12	0·18
P_2O_5 ..	0·57	0·48	0·44	0·26	0·14	0·36	0·22	—
MnO ..	0·08	0·20	0·26	0·15	0·12	0·28	0·14	0·15
CO_2 ..	Nil	1·22	1·60	Nil	Nil	Nil	—	—
BaO ..	—	trace	Nil	0·03	0·01	0·11	—	—
	100·22	100·31*	99·77	100·68†	99·76‡	100·66§	99·81	100·16‖

*Includes FeS_2 0·15.

†Includes ZrO_2 0·03, Cl′ 0·02, S″ 0·16, SrO 0·02; less 0·09 for S″ and Cl′.

‡Includes ZrO_2 0·02, SO_3 0·05, Cl′ 0·06, SrO 0·04, S″ 0·08, $(Ce\ Y)_2O_3$ 0·01; less 0·05 for S″ and Cl′.

§Includes ZrO_2 0·02, S″ 0·11: less 0·06 for S″.

‖Includes Cr_2O_3 0·51.

A.—Basalt of Felspathic Dunsapie type, G. Arthur's Seat Volcano, Edinburgh. W. H. Herdsman, anal. (R. H. Clark, 1956, p. 51).

B.—Basalt of Normal Dunsapie type, A. Arthur's Seat Volcano, Edinburgh. T. C. Day, anal. (R. H. Clark, 1956, p. 51).

C.—Olivine basalt, Cape Verde Islands. W. H. Herdsman, anal. (G. M. Part, 1950, p. 70, analysis 13).

D.—Olivine basalt with interstitial nepheline, Neangoil river, Kenya. M. H. Hey, anal. (W. Campbell Smith, 1938, p. 530, analysis 5).

E.—Olivine basalt with interstitial nepheline, Likaiyu Volcano, Kenya, M. H. Hey, anal. (W. Campbell Smith, 1938, p. 530, analysis 3).

F.—Lapilli (glassy basalt), north-west of Likaiyu Volcano, Kenya, M. H. Hey, anal. (W. Campbell Smith, 1938, p. 530, analysis 4).

G.—Picrite-basalt, oceanite type; average of nine analyses, Hawaii (G. A. Macdonald, 1949, p. 1571).

H.—Ultra-basic pillow lava, Cyprus. O. von Knorring, anal. (I. G. Gass, 1958, p. 249).

(2) LIMESTONES AND KUNKAR

Limestones of sedimentary origin occur in the Makindu and Kibwezi areas. They formed in Recent times, by the leaching of carbonate from the lavas, agglomerates and ashes of the volcanic region and by its later deposition by springs and streams at the northern fringe of the lavas.

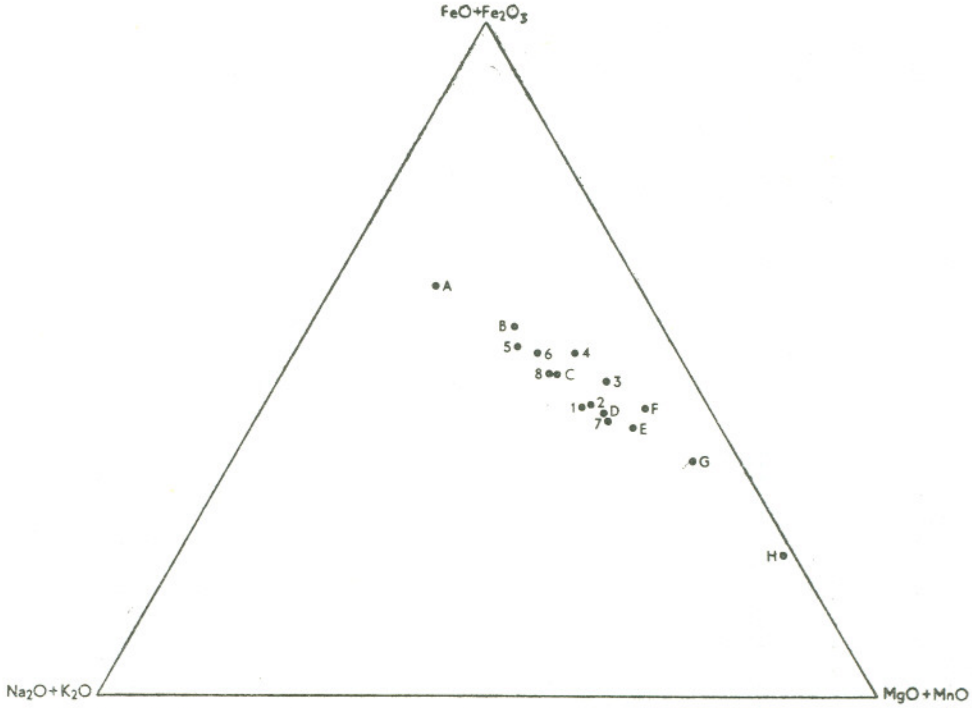


Fig. 11—Triangular diagram to illustrate the chemical relationships of basalts from the Simba-Kibwezi area and similar rocks from other areas. The numbers and letters correspond with those in Tables III and IV. Basalt No. 8 refers to the analysis of basalt from Kibwezi quoted on p. 61

Travertine deposits that accumulated in swampy ground at spring sites, one at Umani and the other at the head of the Kiumbu river at Makindu, are brown, cellular rocks containing fossilized grass, plant and shell remains. The shell remains consist of two distinct genera which the British Museum (Natural History) has identified as *Succinea* and *Planorbis*. Both surface travertines are underlain by white limestone which was probably deposited in deep pools of water forming part of the springs.

Other limestones are the kunkar deposits in the Kiumbu, Kaiona, Kilongoni and Mulilia rivers near Makindu. These rocks are exposed at intervals along the stream-courses, but are never continuous over great distances, their best development being seen near the lava margins. The deposits thin rapidly northwards and at the Kiboko river consist of small nodules of limestone in the soil. These deposits are not found in the Kiangini river north of the Kiumbu-Kiboko confluence indicating that they are younger in age than the Muoni basanite which acted as a dam to north-flowing waters in the Kiumbu river at the time of limestone formation.

Calcareous nodules are frequently found in the volcanic vents especially those of Pleistocene age. These nodules, formed *in situ,* have been derived by weathering of the volcanic ejectamenta forming the cones.

(3) Superficial Deposits

Bright red, sandy soils cover the part of the area underlain by Basement System gneisses. These soils are the products of weathering under semi-arid conditions and are thickest in the north-eastern part of the area where exposures are few. A darker red soil overlies a large part of the volcanic fields, while black-cotton soils are frequently seen near the principal river-courses and along the western margin of the Yatta Plateau. The latter type, which are of restricted occurrence, are a result of poor drainage in soils that are frequently saturated.

Other superficial deposits include alluvials exposed in the principal river-courses and in particular the Muoni river. Here the light-coloured soils are very calcareous and contain nodules of calcium carbonate that has been leached from the volcanic area to the south and deposited during flood periods. Hard encrustations overlie many of the soils seen on the river terraces or highly weathered rock pavements.

The remaining superficial deposits include the Lateritic ironstones developed in thin patches at Mbuinzau and south of Nomau; coarse detritus and boulders of the hill slopes west of Ithumba, which are well-exposed in vertical-sided gullies on the hill flanks, and land-slide deposit. Land-slides have occurred on the northern slopes of the Kimakiu hills and have resulted from saturated volcanic soils sliding on steep slopes during periods of heavy rainfall. The soil accumulations can still be seen at the base of the hills.

VI—STRUCTURE

The rocks of the Basement System in the Simba-Kibwezi area have been intensely folded, metamorphosed, and partly granitized, all of which are thought to have occurred more or less at the same time. The principal structural features of the area are shown in Figs. 12 and 13. Though faulting has affected both Basement System gneisses and volcanic rocks the folding is confined mainly to the Archaean gneisses. Fold axes trend generally north to north-north-east, swinging to a north-north-westerly direction near the northern margin of the area. The folds are overturned to the west in the Merueshi area and elsewhere are normal, frequently with symmetrically disposed limbs. All the folds plunge in a northerly direction. The main faults of the area trend north-west—south-east and north-south, though a few strike nearly due east-west along the Muoni valley. Minor faults and slides have affected the rocks forming the cores of folds and are seen exposed in river-courses. For the sake of convenience the folds and faults are mostly referred to by local names.

Foliation.—The foliation in the Basement System rocks is pronounced and in nearly every instance coincides with the megascopic banding in the gneisses, particularly those rich in biotite, sillimanite and graphite. In the granitoid gneisses, granulites and crystalline limestones foliation is weakly developed and often absent.

Lineations.—The lineations recorded in the present area include the parallel elongation of mineral grains, the axes of micro-folds and linear grooving, all of which occur frequently in rocks of the Kasigau Series. The lineation is a *b* lineation as defined by Weiss (1954, pp. 10-11). The trend of lineation varies from north-east in the area south of Merueshi to north-north-east at Nguu, north at Mbuinzau and north-west along the Athi river. Fig. 13 shows the orientation of lineations within the area, while Fig. 16 includes equal area projections of lineations of a number of sub-areas. In Fig. 17 projections of lineations measured for two sub-areas and the western part of the South Kitui area (situated to the north-east of the Simba-Kibwezi area) are shown.

Folds.—The north-north-easterly-trending folds of the Merueshi-Simba-Nguu area are the most conspicuous structural features of the western half of the area. North of Ol Katetemay, they consist of open synclines and anticlines of which the Simba syncline and Nguu anticline are important. These structures are associated with a number of subsidiary folds all of which have caused severe deformations and are responsible for the complicated sections exposed in the Muoni and Kiangini river valleys. In the north these structures are tight symmetrical folds, but further south at Merueshi the rocks involved in the folding have been overturned to the west, the resulting isoclinal folds having limbs dipping moderately to the east. Overturning of these folds is not attributed to a secondary deformation but to the main period of folding. Three crystalline limestones are involved in the structures in the south-western corner of the area and this type of rock has obviously yielded more easily to compressional forces than the overlying gneisses of the Kasigau Series. Fig. 14 illustrates the type of structure present.

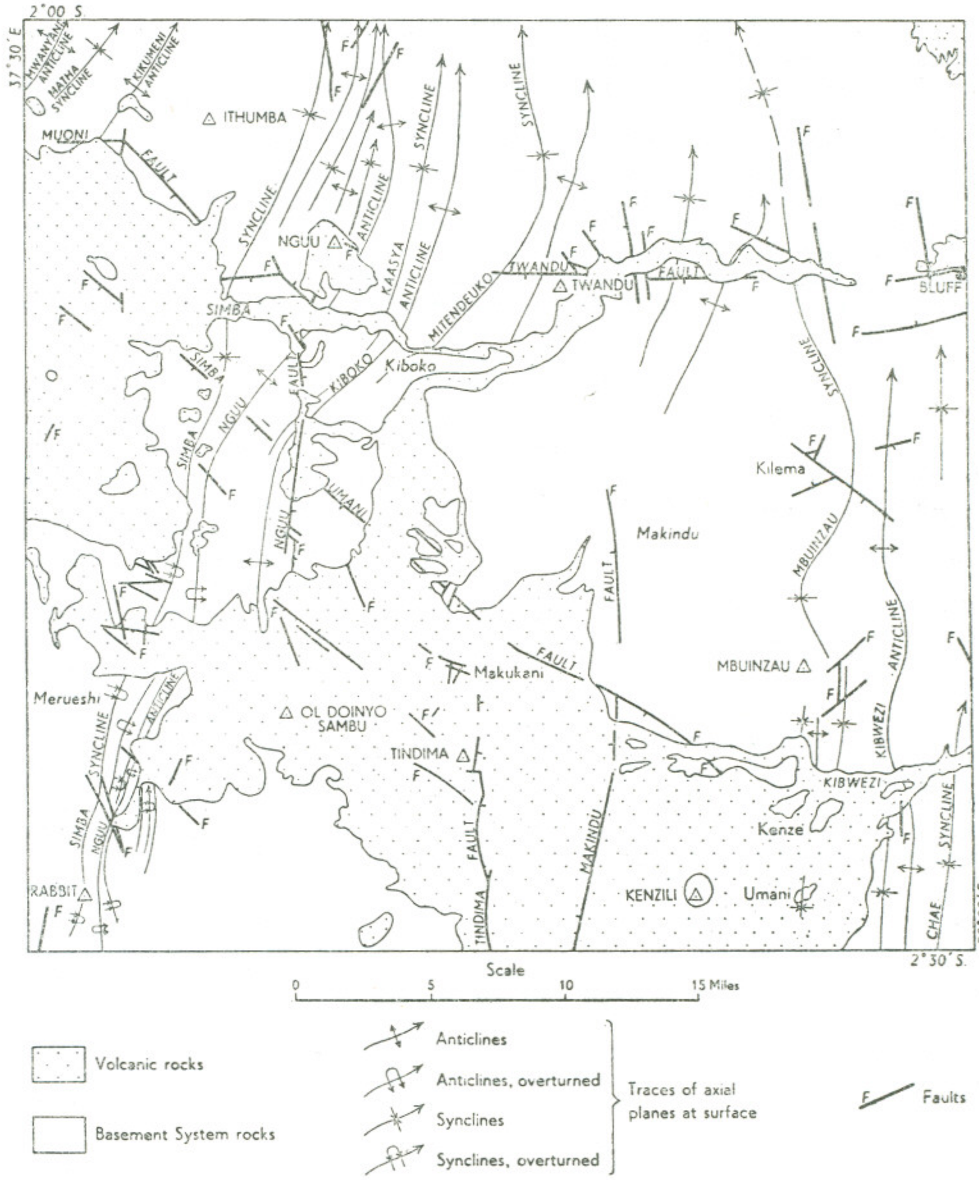


Fig. 12—Structural map of the Simba-Kibwezi area showing faults and fold-axes

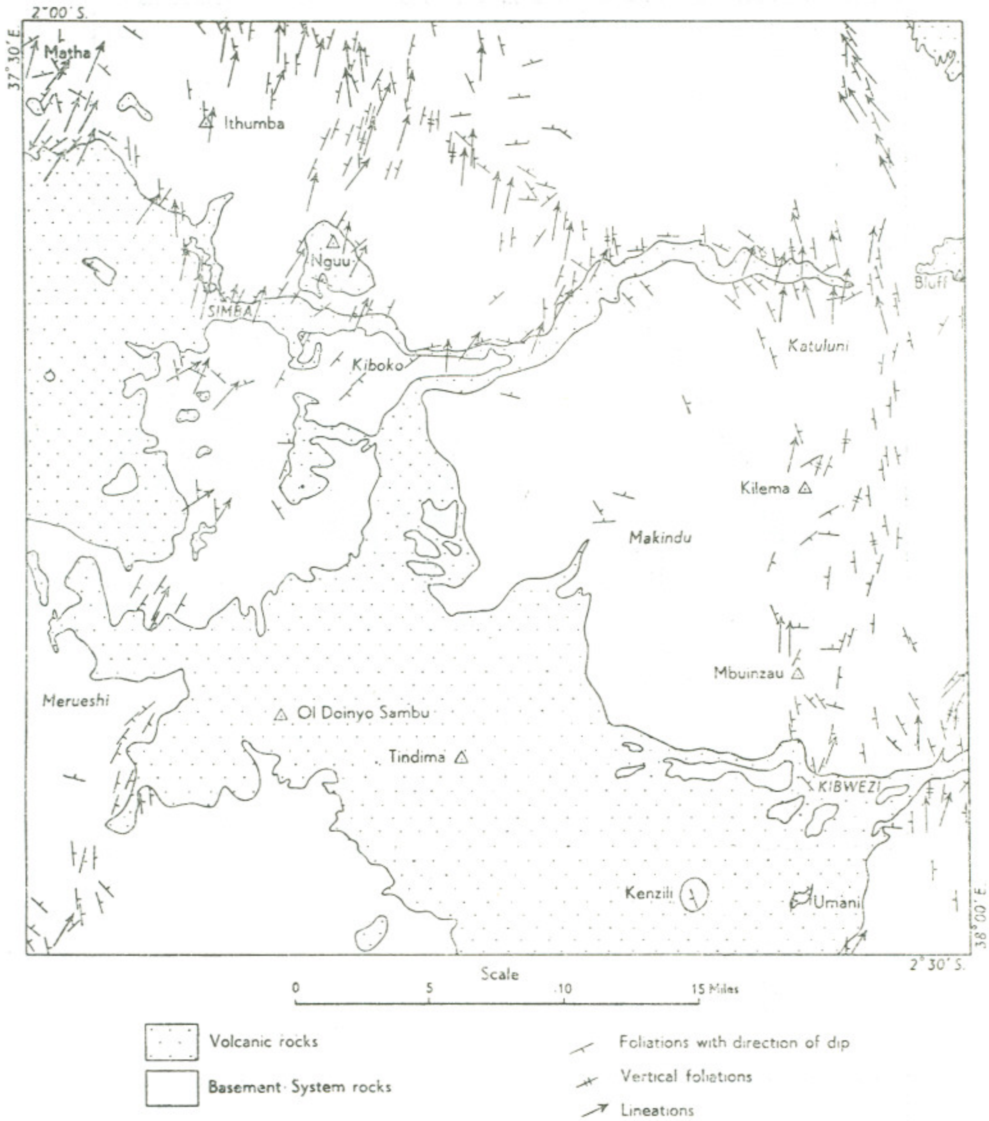


Fig. 13—Structural map of the Simba-Kibwezi area showing foliations and lineations

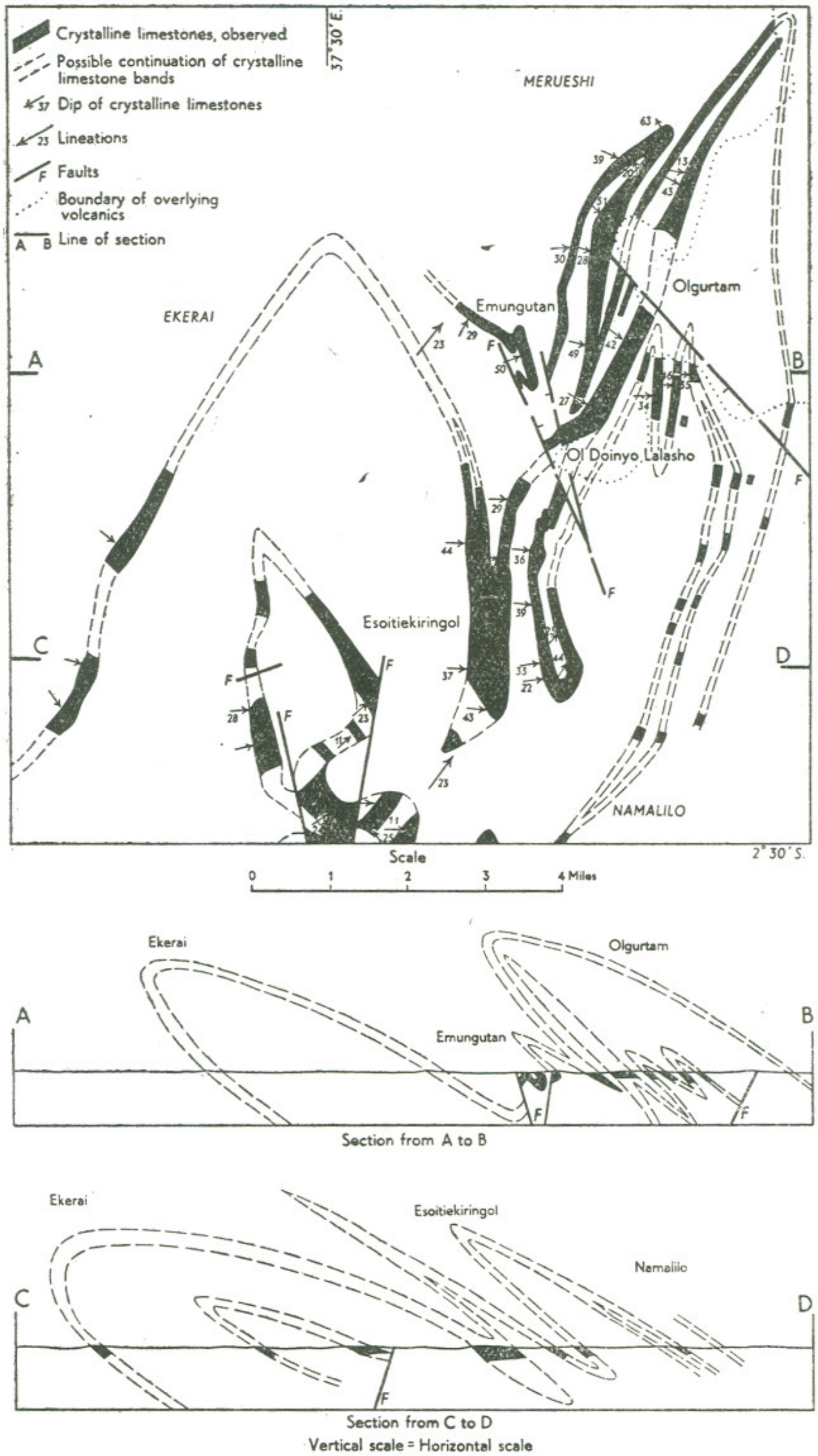


Fig. 14—Geological structures at Merueshi in the Simba-Kibwezi area. For simplicity only crystalline limestone bands are shown

The three limestone bands are those exposed south-west of Esoitiekiringol, south-east of Merueshi and an intervening band at Esoitiekiringol. Unfortunately, exposures of the crystalline limestones are poor and many of the beds are probably lenticular. For clarity the representations of the outcrops of the limestones on the diagram are blacked-in while their probable extensions are shown by broken lines. The broken lines do not indicate, however, that the limestones are necessarily present beneath the soil cover or even at depth.

Another major structure, the Mbuinzau syncline, is located in the eastern part of the area. The structures have been affected by faulting while at Mbuinzau the fold-axis takes a curious bend, which might be a result of doming due to upwelling of granitic material from depth.

An anticline at Mwanyani with flanking subsidiary structures at Matha and Kikumeni (the axes of which are approximately parallel to the Emali-Makueni road) are the principal structural features in the north-western corner of the area. Considerable erosion in the hills has removed the crest of the Mwanyani anticline, the limbs of which are exposed on the hillsides to either side of the roadway.

The southerly extensions of other folds, such as are seen between Twandu and the Athi river, cannot be proved because of lack of suitable exposures.

Joints.—The Basement System gneisses are usually well-jointed rocks, particularly the granitoid gneisses that outcrop between the Athi and Kibwezi rivers as well as the numerous granitoid ribs that are frequently interbanded in the pelitic gneisses in the Kiangini and Muoni rivers. The majority of the joints are sub-vertical fractures (Fig. 15)

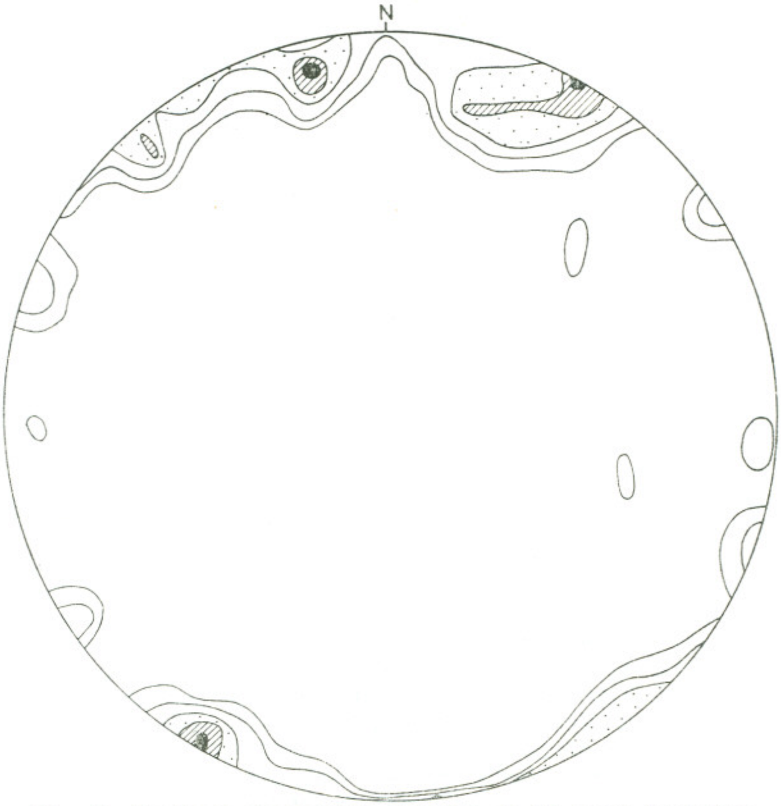


Fig. 15—Equal-area stereographic projection in the lower hemisphere of 142 poles of joint-planes in the Simba-Kibwezi area; contours 2, 3, 4, 5, 6 per cent per 1 per cent area

that formed in response to the folding that affected the rocks. The statistical diagram (Fig. 15) excludes the many longitudinal fractures or *b* joints that are parallel to the north-south axes of the folds. Two sets of major diagonal joints can be recognized, trending at 120° and 230° respectively. These joints are disposed nearly symmetrically about the fold-axes and are probably shear-fractures formed as a result of east-west compression. The third principal joint direction trends nearly due east-west and is marked by strong *ac* or cross-joints perpendicular to the general direction of lineation. Erosion along such joints is responsible for the splitting of rock ribs into small blocks that commonly occur in and near the river-courses. Typical examples can be seen at Twandu, Kakuika and Ngulu. Open, minor joints which were observed during the survey in rocks of all types are considered to be tension fractures. Many of these fractures have been invaded by thin quartz-felspar pegmatites.

Faulting.—It is assumed that there have been at least three main periods of faulting. The first affected the gneisses of the Basement System at the time of their folding, the second occurred in late Tertiary times and the third is of Recent age and is probably still continuing at the present day.

Many of the faults in the Basement System rocks are fractures with small throws, but others are considered to be major disturbances and considerable movement has occurred along them. One such fault is that which has displaced beds in the northerly extension of the Mbuinzau syncline west of the Athi river. Other faults associated with this syncline have displaced the granitoid bands at Mbuinzau and at Kilema. Two miles east of Kilema, in the Mukokoni valley, movement has occurred along what was originally a joint in sillimanite gneisses. The vertical joint-face is covered by a thin skin formed of quartz and closely-packed sillimanite needles (specimen 59/334). The sillimanite is lineated in a vertical plane and represents a linear structure parallel to the direction of movement. This, together with the field evidence suggests that the major N.W.-S.E. fault at Kilema is a high-angle fault, with downthrow to the south. Near-vertical, slickensided rock surfaces and numerous displacements of bands occur along the east-west Twandu fault. About two and a half miles north-north-west of Kilawa in the Kiboko valley corrugations on a slickensided surface reveal that the downthrow on this fault was also to the south. The fault was not seen east of this point because of poor exposures, but it is likely that the east-west fault at Bluff is an easterly extension of it. Small faults have displaced the crystalline limestones of the Kurase Series, but during the period of folding the limestones were more liable to flow than rupture.

In the neighbourhood of Bluff, the Yatta plateau phonolite has been faulted along N.N.W.-S.S.E. and E.-W. fractures. These are considered to be late Tertiary faults that are probably a result of movement along old established faults of Basement System age during Tertiary times. The northward-trending faults parallel similar fractures mapped in the adjacent area by Walsh (1963), who has shown that displacement of the phonolite has occurred in numerous places. In the present area the most westerly of these faults has not, however, displaced the Muoni lava, indicating that the faulting occurred before the beginning of Pleistocene times. The east-west fault at Bluff has a throw to the north of about 300 ft.

The volcanic cones, the products of Pleistocene to Recent eruptions, are concentrated along north-west—south-east and north-south lines that correspond with the major fault-trends of the area. It is probable that rejuvenation of movement along old-established fault-lines in Basement System rocks has taken place from Pleistocene times to the present day. The principal north-west—south-east and north-south zones of fracture, one represented by the Simba-Umani fault and the other by a series of parallel faults between Esteti and Tindima and the north-south faults of Makindu and the Nguu, are bounding fractures of a downthrown block of country in which occurs the greatest concentration of volcanic cones. The Simba-Umani fault can be traced through the lava and south of Makindu it is actually represented by a small scarp feature now partly mantled by soil. Near Kibwezi this fault has a more southerly trend and the extinct volcanoes of Kenze and Umani probably lie along it. The other faults in the volcanic area, many of which form steep-sided depressions where they cut volcanic cones and scarp features in lavas, are never continuous over long distances, but the lines of cones such as those at Mangwa probably indicate hidden faults. Movement along faults has occurred in historical times and at intervals reports are received that small earthquake shocks have been felt in the region of Kibwezi.

Minor Structures.—Boudinage structure is seen frequently throughout the area and particularly fine examples can be seen in the pegmatites and amphibolites exposed in the upper reaches of the Kiangini river (Plate IV (*a*)). Another excellent example of minor structures is that in the Muoni river at Tutini, where mullions developed in biotite-hornblende gneisses are elongated parallel to the local lineation (Plate V (*b*)). In the latter case rolling has probably occurred in response to compressional forces that acted in a direction at right-angles to the length of the mullions.

Detailed mapping of the Basement System rocks of Kenya has revealed a number of structures that as yet are not fully explained. These structures are formed of gneisses cross-cutting other gneisses, and a tectonic origin has been suggested for some (Saggerson, 1963, p. 48). Similar occurrences were seen at Tutini in an area of highly complicated structures. The cross-cutting gneisses are sharply defined features, against which in some instances the foliation in the host-rock has been deflected. Both host gneiss and cross-cutting gneisses are similar and have been derived from the same rock. It is probable that these represent, therefore, parametamorphic dislocations developed while the rocks were on the verge of the plastic state. Associated with them but of probably later origin is another structure, in which steeply dipping rocks are overlain by nearly horizontal gneisses (Plate V (*a*)). These apparently unconformable gneisses are separated by a three-inch band of epidote-rich rock. The junction between the beds may represent a slide or thrust zone in which high shearing stresses have resulted in a localized zone of retrogressive metamorphism.

Minor recumbent folds and associated thrusts are not common in the area but a number were observed in the Muoni valley east of Tutini and south of Nguu. These folds occur in the cores of major structures, the fractures being stretch thrusts (Billings, 1942, p. 175) along which movement took place parallel to the axial planes of the folds. It is unlikely that such structural breaks have any regional significance.

Banded, fine- to medium-grained granulites, exposed east of Twandu are of local occurrence. Their field relationship suggests that they have been derived in part by crushing of rocks along the margin of a fault-zone.

Tectonic Synthesis.—Geometrical analysis of the attitude of foliation and lineation in the Basement System rocks of the area indicates that the structure as a whole is fairly simple. Stereograms prepared for sections of the area show that in five out of eight cases the poles to foliation planes fall along a single great circle, while in the remaining three areas (Nos. 5, 6 and 7) the poles to foliation planes fall along two great circles π_1 and π_2 (Fig. 16). The position of the β poles to the great circles are plotted on each stereogram. Equal area projections of lineations for each sub-area are also included in the stereograms, the concentrations of lineations being contoured for convenience. In all but the three sub-areas mentioned the β maxima coincides with the B maxima, the statistical maxima of *b* lineations within separate areas. In addition all diagrams show a tendency for the B maxima to be dispersed along an arc trending north-east in the western part of the area to north-west in the eastern part of the area. Stereograms for the two sub-areas numbers 1 and 5 and for the western portion of the South Kitui area (situated to the north-east of the present area, Saggerson, 1957) are shown in Fig. 17. The western part of the Kitui district is characterized by a zone of north-south to north-west—south-east-trending rocks in which few closures have been mapped (Sanders 1954; Saggerson 1957; Walsh 1963). The stereogram of the South Kitui area is a typical example for the whole Kitui zone. Another is given by Walsh (1963, p. 27) for the area immediately east of the present one.

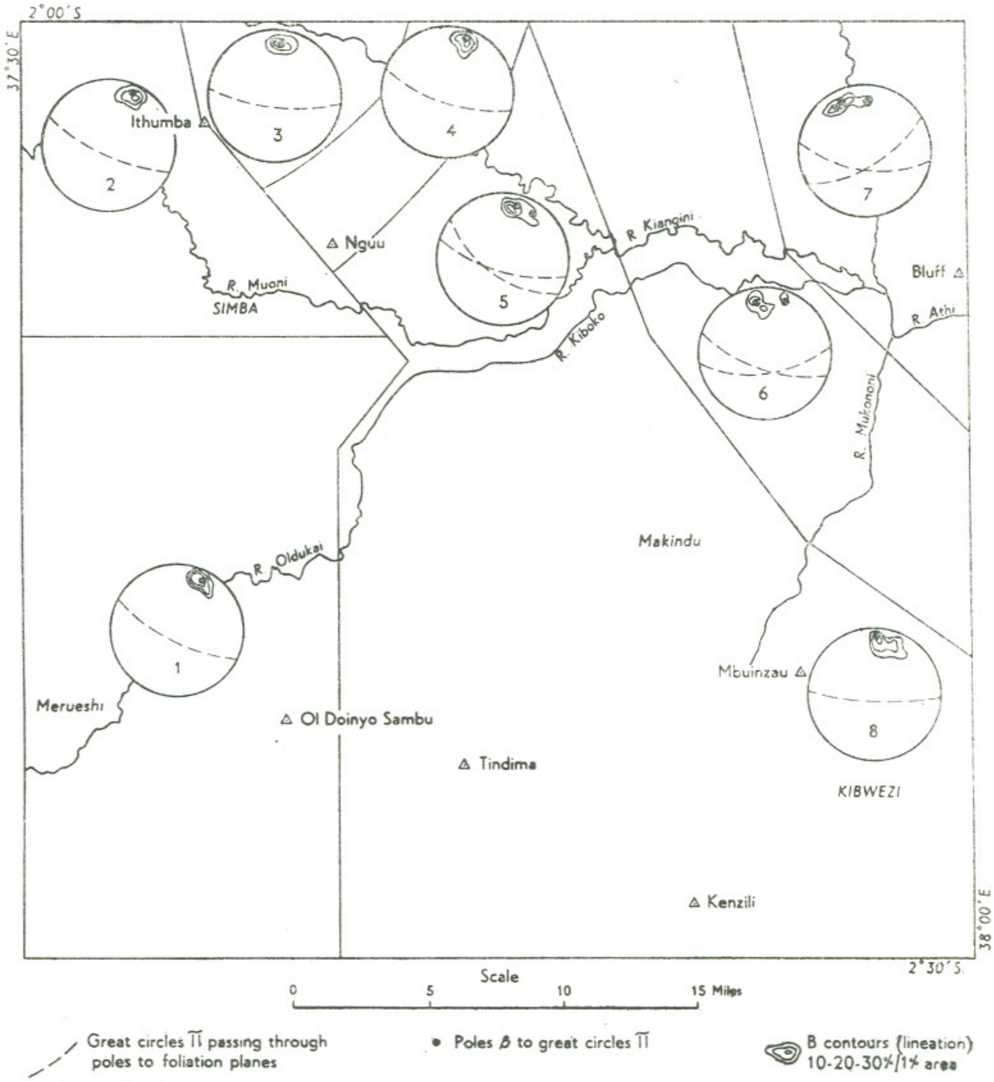


Fig. 16—Stereograms of poles to foliations, and lineations, of eight sub-areas in the Simba-Kibwezi area. The position of the β poles to the great circles and the B maxima (the statistical maxima of *b* lineation poles) are also shown

The stereograms suggest that during folding generally east-west compression was dominant. Initial south-east—north-west compressive forces created north-east—south-west folds and the early implantation of north-east regional lineations. Continued compression was accompanied by rotation in an anti-clockwise direction of the direction of applied force and the development of north-west—south-east folds with north-west lineations. The lack of many closures in the Kitui region suggests that the final stages of compression resulted in regional strike-slip and the production of marked north-west—south-east bands. It is interesting to note that Baker (1954, p.22) dealing with the area north-west of the Simba-Kibwezi area, postulated east-west compression aided by rotation around centres of granitization to account for concentric structures around granitoid domes. It is possible that the deflection in the trends of the fold-axes in the present area is a development of the same movement.

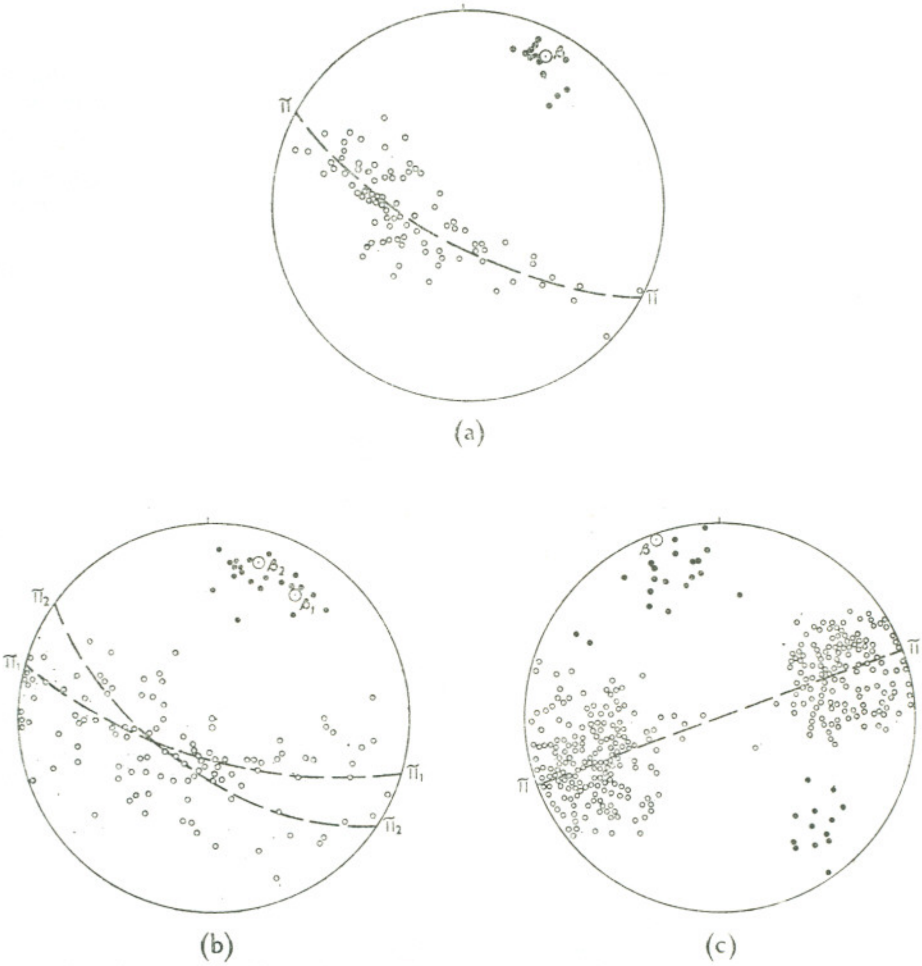


Fig. 17—Stereographic projections of poles to foliation planes, and lineations, in two sub-areas of the Simba-Kibwezi area and in the western part of the South Kitui area. The great circles π, π_1, and π_2 passing through the poles and the poles to the great circles are also shown:—

(a) Sub-area number 1 (Merueshi).

(b) Sub-area number 5 (Mid-Kiangini).

(c) South-Kitui area.

A small area along the course of the Muoni river on the western border near Tutini has been excluded from the tectonic synthesis. The area is highly complex and much detailed work is required before a clear structural picture can be obtained. The many foliations and lineations recorded in it appear to bear little relationship to the remainder of the area.

VII—MINERAL DEPOSITS

A large proportion of the area is covered by sandy soils and lava flows, which makes prospecting by ordinary methods difficult. Exposed economic deposits if present will be mainly confined to the part of the area north of the railway. Here outcrops are few and confined to the scattered hills and principal river-courses. Except for the examination of limestone and ballast deposits no systematic prospecting has been previously carried out in the area. No evidence of major intrusions was found during the geological reconnaissance.

1. Limestones

Crystalline Limestones.—Crystalline limestones occur at two places in the Simba-Kibwezi area. Two miles south of Simba station a small hill is composed of partly iron-stained limestones interbanded with thin biotite gneisses. Outcrops of this limestone occur in the Engejuolongonjine river, while to the east of it the limestone forms small exposures often concealed by kunkar. South of Merueshi the main limestone occurrences form a number of low hills near the Emali-Loitokitok road, of which Esoitiekiringol (Rabbit) is the most prominent.

The crystalline limestones are medium-grained, fresh rocks containing disseminated graphite flakes and less commonly other mineral impurities. Analyses made on the hand-specimens collected from the two localities gave the following results:—

	1	2
	%	%
R_2O_3	0·32	0·52
CaO	33·29	30·64
MgO	19·41	20·99
Insoluble	0·82	2·32
Loss on ignition	46·17	45·82
Total	100·01	100·29

1. Specimen 53/349, Simba.
2. Specimen 53/357, Emungutan (Merueshi).

Analyst: W. P. Horne.

Both limestones have a high magnesia content and would be of no use in cement manufacture. It is unlikely that deposits of magnesium-free limestone will be found associated with these deposits. They could be used for domestic and industrial purposes but their distance from the railway and the presence of more accessible deposits nearer the centres of population will prevent their economic exploitation.

Superficial Limestones.—Two deposits, at Makindu and Umani, have been visited by geologists on more than one occasion and their findings are embodied in unpublished departmental reports. The author considers that the limestones have been formed mainly in Recent times, the carbonate having been leached from the lavas, agglomerates and ashes of the Kiboko-Kibwezi area and deposited by springs and streams at the northern fringe of the lavas.

Makindu Limestones.—Kunkar deposits are exposed at intervals along both banks and in the bed of the Kiumbi (Makindu) river (Fig. 20, at end). The deposits are rarely continuous over great lengths, the most extensive being those near the railway. Here the width of the deposits is about 70 yd. but further north it is considerably less, occasionally only a few tens of feet. The thickness of individual deposits is very variable, a maximum of 5 ft. being measured on a terrace south of the railway, while to the north of the Makueni road the combined thickness of limestone exposed in the river bank and in pits sunk in the river bed is over 20 ft. At the head of the Kiumbi river a trench and pit dug in the kunkar reveals a thickness of 30 ft. of white limestone overlying Basement System gneiss detritus. This thick, bedded deposit is probably of limited extent and is considered to have formed in a deep pool into which poured waters highly charged with carbonate. It is likely that other similar deposits exist in this locality.

The presence of limestone is indicated by pavements of white limestone and by white carbonate nodules in black-cotton soils. The former generally indicate the presence of solid limestone while the latter occur around the margins of the solid deposits and as detritus derived from clays containing nodular limestone.

The surface limestones are hard, white, massive types. often iron-stained. They overlie a less compact type that is rubbly in appearance and variable from deposit to deposit. Gneiss and clay fragments are often contained in it. It is rarely possible to obtain an accurate estimate of thickness or of lateral extent, for the margins of the deposit are concealed beneath red soils which flank the black cotton soils along the river-course. The deposits are considered to be of limited extent and to evaluate the tonnage available would take several months' pitting.

Travertine deposits are generally confined to the head of the Kiumbi river (Fig. 20). The surface travertine is a pale brown cellular rock containing fossilized grass and other plant stems. The rock is a much purer limestone than the kunkar deposits downstream and is composed almost entirely of large blocks of iron-stained travertine measuring up to 4 ft. in length and 2 ft. in thickness.

A number of analyses of samples of the limestones of this part of the area collected by Muff (in 1903) and by Wayland (in 1926), are available, namely:—

	A	B	C	D	E
	%	%	%	%	%
SiO_2	7·63	11·54	4·87	6·08	3·34
Al_2O_3	3·00	0·44	0·27	2·67	0·23
Fe_2O_3	2·58	0·17	0·98	1·47	0·61
MgO	2·90	n.d.*	0·53	1·07	0·72
CaO	47·50	48·72	50·74	48·28	52·16
H_2O	2·42	—	—	—	—
TiO_2	nil	nil	trace	0·18	0·08
P_2O_5	0·59	trace	0·05	0·02	0·01
SO_3	nil	nil	0·10	0·13	0·17
CO_2	33·63	—	—	—	—
Loss on ignition	—	39·08	41·95	39·96	42·33
Total	100·25	99·95	99·49	99·86	99·65

*n.d. = not determined.

A.—Kunkar. H. B. Muff (1908, p. 24).
B.—White kunkar. Bull. Imp. Inst. 1924.
C.—Soft white kunkar. Bull. Imp. Inst. 1927, p. 377.
D.—Brown compact limestone. Bull. Imp. Inst. 1927, p. 377.
E.—Grey compact limestone. Bull. Imp. Inst. 1927, p. 377.

Anal.: Imperial Institute, London.

During the present survey samples of white kunkar from the pit at the head of the Kiumbi river and of travertine from the same locality were collected, and later analysed. The results are as follows:—

	1	2
	%	%
R_2O_3	2·34	0·19
CaO	38·07	52·58
MgO	2·53	2·02
Insoluble	19·14	0·16
Loss on ignition	37·16	44·70
Total	99·24	99·65

1. Specimen 59/333, Kunkar, Makindu.
2. Specimen 59/332, Travertine, Makindu.

Anal.: W. P. Horne.

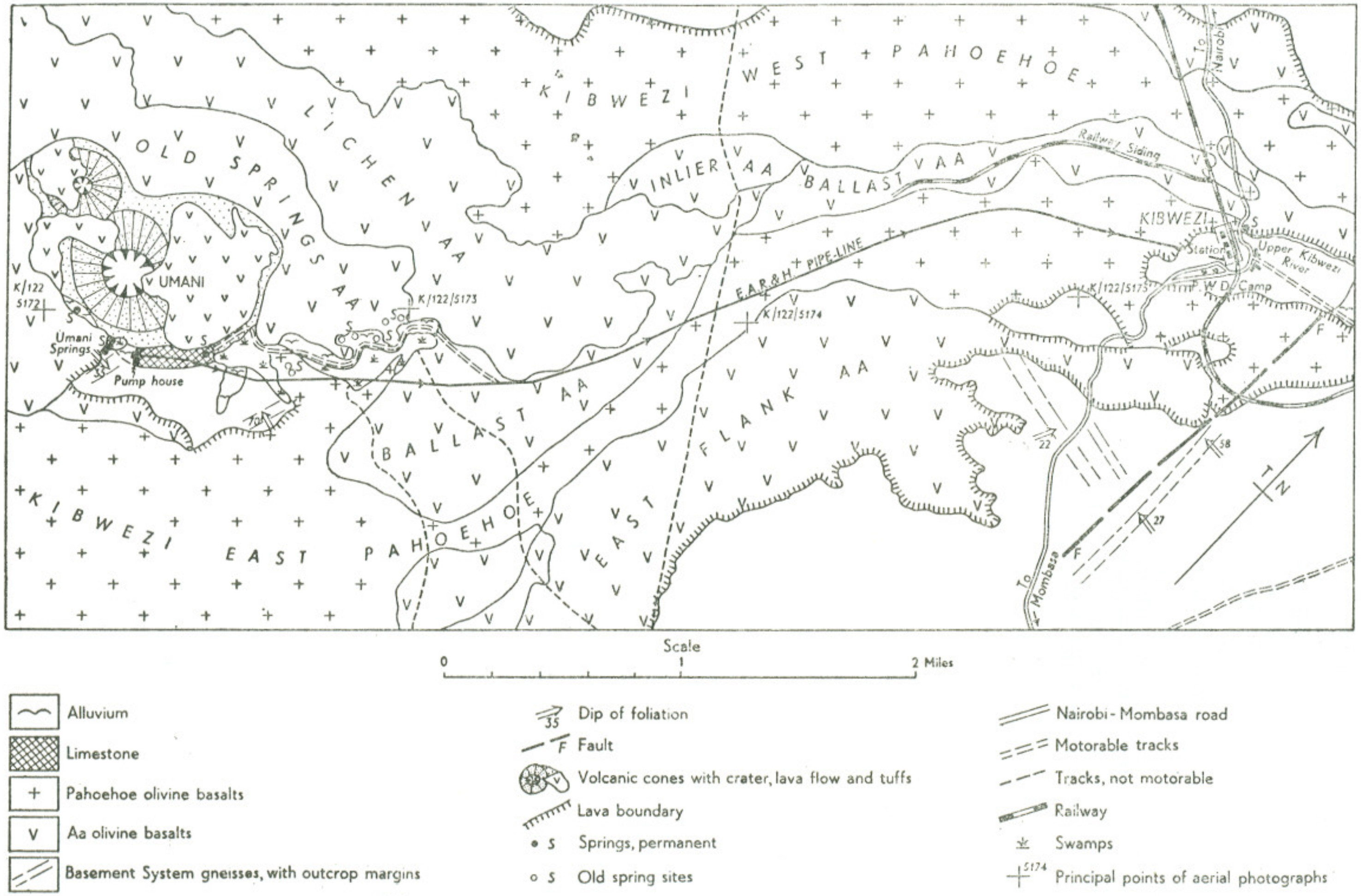


Fig. 18—Travertine, ballast deposits and springs at Umani

The analyses indicate that the travertine is a much purer limestone and better suited for economic use such as burning to produce agricultural or building limes. Selected portions of the kunkar and travertine may be suitable for chemical lime, but careful examination and sampling of each deposit would have to be made, as superficial kunkar (which is usually purer than the underlying material) is no indication of the type of deposit as a whole.

Other kunkar deposits occur in the black-cotton soils of the rivers Kaiona, Kilongoni and Mulilia, all of which are tributaries of the Kiumbi river. The occurrences, which are similar to those already described, are not considered to be extensive, though small tonnages of limestone are available.

The Makindu deposits have been worked since 1926, but only three companies and a few Africans were producing lime at the time of the survey. The three companies were Lime and Cement Company (E.A.), The Bharat Lime Company and Mr. Punna Ram. All the producers burn the limestone at Makindu, the resulting lime being slaked, bagged and transported to various parts of Kenya, where it is sold for building purposes. The building limes were sold f.o.r. Makindu at about Sh. 190 per ton in November, 1955. The Lime and Cement Company (E.A.) sold 1,100 tons during the period 1954-1957, but figures for other producers are not available.

Umani Limestone.—The limestones at Umani are similar to the fossiliferous travertine at Makindu and were formed under identical conditions. They are exposed to depths of approximately 7 ft. over a total length of about 500 yd. between the Umani Springs and the swamp further north (Fig. 18). The visible part of the deposit is over 180 ft. in width. About 500,000 cu. ft., or between 35,000 and 50,000 tons, of material is available. Exposures are poor, consisting of small blocks in black-cotton soil and it is unlikely that great thicknesses of limestone exist.

The following analyses have been made of the limestone:—

	1	2	3	4
	%	%	%	%
R_2O_3	0·16	0·22	0·32	0·40
CaO	52·43	52·09	52·05	52·17
MgO	1·66	1·93	1·78	1·75
Insoluble	0·62	0·72	0·84	0·90
Loss on ignition ..	44·19	44·38	44·28	44·18
Total	99·06	99·34	99·27	99·40

Aanlyst: W. P. Horne.

Markham and Company were given a licence in December, 1955, to extract the limestone from Umani, but at the time of the survey only a track from Kibwezi to the deposit and labour lines had been constructed, and a few small pits dug in the limestone.

2. Graphite

Graphite is commonly distributed in the schistose gneisses of the area and is often associated with biotite. Some bands, such as those that outcrop in the Kiangini river north of Masumba and in the Mkambwambeo river five miles N.N.E. of Nguu hill, are very rich in graphite flakes and are highly weathered rocks. These and other graphite bands are considered to be repeatedly folded and reappear further downstream in the Kiangini river. When thoroughly prospected the thick overburden could be removed by mechanical excavators, while labour and timber supplies are obtainable locally. Exploitation of graphite deposits in other parts of Kenya has been hindered through lack of water and the heavy transport costs to the railway. The proximity of the deposits in this area to a main line of communication and to adequate water-supplies at Simba and Kiboko is important, and they may prove to have economic significance.

Samples of graphite ore were taken by a Government prospector in 1958 from outcrops in the river Kiangini north of Masumba and from the river Mkambwambeo. These samples were treated in the ore-dressing laboratory of the department, the graphite from the ore being recovered by flotation and then screened and where necessary polished. The following results were obtained:—

	R. Mkambwambeo		R. Kiangini	
	380/1	380/2	380/5	380/6
	%	%	%	%
Crucible grade content of ore	3·2	3·6	0·8	0·15
Estimated graphite content of ore ..	8	12	10	7

The samples from the river Kiangini are considered to be too poor in coarse graphite flakes to be suitable as a source of crucible-grade flake though the fine flake would probably be useful for lubricants and other purposes. The presence of 3 to 3½ per cent crucible-grade flake in the ore from the river Mkambwambeo and the fact that the graphite from this locality has a good surface coefficient of 53.7 (60 is acceptable in industry) is encouraging. Screen distribution tests carried out on the combined Mkambwambeo samples gave the following results:—

B.S.S. mesh	*R. Mkambwambeo Sample Percentage recovery*	*Specification*
+ 22	10·4	
− 22 + 25	12·9	+ 25 minimum 20%
− 25 + 44	56·8	
− 44 + 60	18·8	+ 60 minimum 80%
− 60	1·1	− 60 minimum 5%

The tests indicate that at least one of the graphite deposits is of potential importance though further prospecting will be necessary to prove whether it has economic possibilities.

3. Copper

A single copper occurrence was seen, in graphitic gneisses in the lower reaches of the Mkambwambeo river. The copper mineral present is fine-grained malachite, associated with veins of chalcedonic quartz parallel to the foliation of the country rock. A number of copper deposits have been reported from the Tsavo-Voi area, where they outcrop over a distance of 50 miles. It is possible that the Mkambwambeo occurrence is a northerly extension of that mineralization.

4. Pyrite

A single pyritiferous calc-silicate gneiss outcrops on the upper slopes of Matha hill. No economic significance is attached to the occurrence.

5. Sillimanite

Sillimanite mainly occurs north of the railway in garnetiferous and muscovite gneisses similar to sillimanite-rich gneisses in many other parts of Kenya. No economic concentrations were seen during the survey.

6. Garnet

Garnets are a common mineral in the Basement System gneisses and are particularly abundant in the rocks north of the railway. They are concentrated in many of the sillimanite gneisses, in which they often measure up to two inches across. Although present in other gneisses they do not then attain such large sizes. Many bands contain sufficient garnet to be considered as economic prospects, but sampling would have to be carefully undertaken to determine where garnets free from silicate impurities could be obtained. Samples taken from rocks in the Kiangini river have recently been tested in the United Kingdom by abrasive manufacturers who state that the quality is good.

7. Magnetite

Few occurrences of iron ores were seen in the area. The Mbuinzau granitoid gneiss, however, contains small nodules of magnetite, measuring up to two inches in diameter, that are frequently scattered throughout the rock.

8. Gypsum

Small crystals of gypsum in soil have been reported from a well at Simba, though none were seen during the survey.

9. Ballast

The lava at Kibwezi station has been worked for a period of years for railway ballast. An *aa* basalt (Fig. 18) is being quarried here because of its suitability. The surface of such a basalt consists of small fragments of lava of a size that requires little breaking before use. Large reserves exist at Kibwezi and any of the *aa* lavas would be suitable for railway-ballast purposes. Over the period 1950-1957 nearly 1,000,000 cu. ft. of ballast were removed for use by the railway.

10. Sand

Although no sand is taken from the area large quantities exist in the three main river-courses—the Athi, Kiangini and Muoni. All the rivers are accessible by motorable tracks, and in particular, the Muoni, which also is dry in the inter-monsoon periods. The sands are clean deposits and could be used in the building trade.

11. Lapilli

The unconsolidated lapilli deposits of Nguu are being quarried locally and used for minor road repairs and as a cheap aggregate for building purposes. Unlimited quantities of such deposits exist in the volcanic part of the area.

12. Brick-earths

A number of red soils are used in the trading-centres for the making of rough bricks. These are only used by local Africans for building of houses and shops. Wayland (1926, p. 2) considered the red earths at Makindu could be used in the cement industry, but it is unlikely that manufacturers would accept this highly siliceous earth when better materials can be obtained elsewhere. An analysis of the red earth from

Makindu made by the Imperial Institute in London (1927, p. 376) gave the following result:—

	%
SiO_2	59·37
Al_2O_3	21·37
Fe_2O_3	5·21
MgO	0·41
CaO	0·34
Na_2O	0·04
K_2O	0·56
H_2O+	2·95
H_2O-	8·75
TiO_2	1·48
P_2O_5	0·02
MnO	trace
CO_2	nil
BaO	nil
Total	100·50

Anal.: Imperial Institute, London.

Elutriation tests carried out by the staff of the Geological Survey in Uganda on the the red earth gave:—

Sand	*Silt*	*Clay*
%	%	%
60	20	20

The analyses and tests show that the earth can only make a rough brick; in order to obtain a good-quality product it would need an admixture of clay.

13. Lateritic ironstone

Small deposits of lateritic ironstone occur at Kabolole north of Mbuinzau. Other deposits up to 2 ft. in thickness are exposed on the grassy plains to the west of the Nomau volcanic cones. Here the laterite is an excellent cellular iron ore similar to deposits in many parts of Kenya that are used for surfacing earth-roads. Unfortunately its distance to the main road is likely to preclude its economic extraction for use as road-metal.

14. Lavas for ceramic uses

Samples of basalt collected from between Kibwezi and Mtito Andei by B. H. Baker in 1950 were analysed and tested by the East African Industrial Research Organization in connexion with the establishment of a factory for the production of agricultural pipes. The lava was to be used as a glaze.

A trial frit (B/3 new) was prepared using 26.5 parts borax glass and 50 parts Kibwezi lava. This was built up into a new frit (B/3/6 new) with a composition of 60 parts B/3 new and 40 parts of Kibwezi lava to which was added glue. The product fused to a black glass containing some crystals. An analysis of the lava and the glaze produced gave:—

	1	2
	%	%
SiO_2	43·73	28·50
Al_2O_3	13·40	8·73
Fe_2O_3	15·07	9·78
MgO	10·21	6·64
CaO	9·58	6·24
Na_2O	3·70	13·00
K_2O	1·80	1·17
TiO_2	3·01	1·95
MnO	0·20	—
B_2O_3	—	23·90
Total	100·70	99·91

1. Basalt, Kibwezi.
2. Glaze produced from Kibwezi basalt.

Anal.: East African Industrial Research Organization.

The high magnesia content was considered to give the glaze a certain resistance to crazing. The frit after standing in water for one week did not absorb any water. This frit compared favourably with one produced from the same type of basalt from Masongaleni, six miles south-east of Kibwezi. The latter product when compared with frits produced from some other Kenya lavas had the smoothest finish and gave the least trouble in manufacture. On the other hand the cost of the Masongaleni product may be too high and its resistance to crazing too low. It is concluded that lavas from Kenya including those from the Kibwezi area would make glazes suitable for earthenware pipes that could be used in the Colony.

15. Water supplies

For purposes of description the water-supplies of the Basement System rocks and the volcanic area are dealt with separately.

(1) Basement System Area

The only permanent river that drains the rocks of the Basement System is the Athi, which maintains a fairly constant flow throughout the year except during periods of flood. In 1956, the average flow measured at a point about 20 miles to the north of the present area was 375 cusecs, except during January when 15,000 cusecs were recorded. All other rivers and streams flow for only a short period of the year following the rains. Water can be obtained, however, by digging in the sandy river beds and a number of African settlements are thus able to maintain themselves and their herds of cattle and goats. The larger locations are situated near the hills in the north-west of the area where rock-bars across the rivers are common and where the soils are capable of growing better crops. Water was seen at the surface at various places along the sandy courses of the Muoni and Kiangini rivers, but it quickly disappears again a few hundreds of feet downstream. Many of these localities are usually to be found along the flanks of the Muoni lava where water flows in the aquifier formed by the old land surface over which the lava flowed (Plate VI (*c*)). A single spring was seen at Kathioni in the Kiangini river north of Nguu (Fig. 19). Here the water bubbles up a small longitudinal joint in gneisses at the side of the river, but the flow of water is small and is unlikely to provide adequate supplies for settlement purposes.

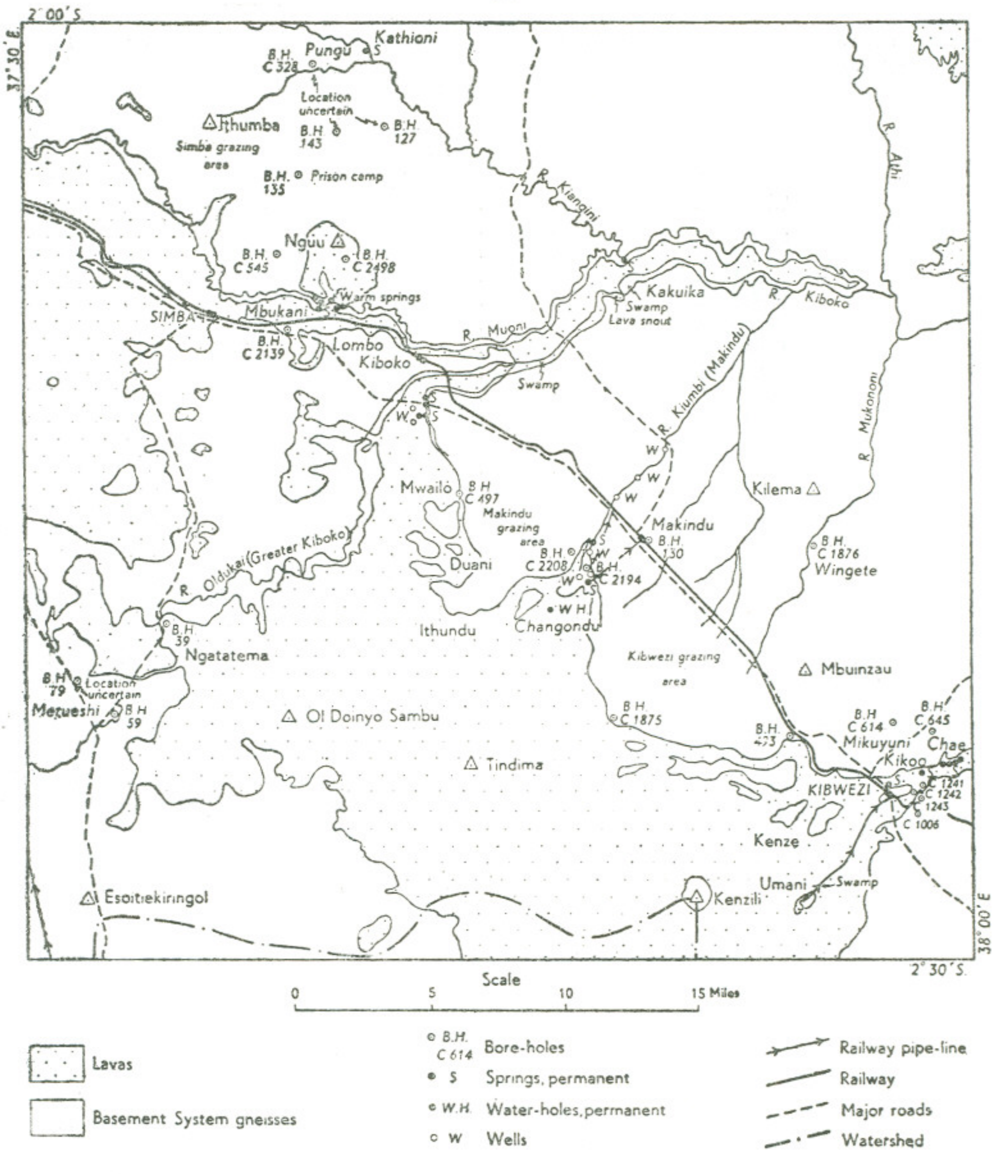


Fig. 19—Water-supplies of the Simba-Kibwezi area

During the rains water-holes in the soil cover provide water for game animals for short periods. At these times it is usual to find the animals widely dispersed and only when the water-holes have dried up do they return to the perennial supply in the Athi river.

A number of bore-holes have been drilled in rocks of the Basement System and these supply the needs of the inhabitants and their cattle between Nguu and Mikuyuni and at Merueshi where the Masai water their cattle. Bore-holes have also been constructed for use by the African District Council ranch at Nguu. Details of the bore-holes, supplied by the Ministry of Works, are as follows:—

Bore-hole Number	Locality	Depth in feet	Depth at which water struck	Yield in galls. per day
135	Prisons Camp, Kaasya	281	343	24,000
C545	West of Nguu	271	65 and 250	29,184
C328	North of Nguu	250	157	25,440
C143	North of Nguu	143	—	nil
C127	North-east of Nguu	110	—	nil
130	Makindu Station	565	38–40	33,000
C2194	Makindu	110	28	72,000
C2208	Makindu	122	20–120	
C493	Mbuinzau	183	50 and 145	43,200
C1876	Wingete	167	100	3,000
C614	Mikuyuni	500	125 and 248	2,400
C1006	Dwa	484	200	12,000
39	Ngatatema	374	343	67,200
76	Merueshi	66	Abandoned	
59*	Merueshi	402	368 and 385	70,000

*A geological section of this bore-hole is given by H. L. Sikes in "The Underground Water Resources of Kenya Colony" published in 1934.

Analyses of the water from various bore-holes and wells gave the results shown in Table V.

The analyses indicate that only borehole 135, at the prison camp west of Nguu, is eminently fit for human consumption. This bore-hole is situated at least two miles from any volcanic rock, which suggests that the waters of at least a number of the remainder have increased their content of dissolved salts by percolation through the volcanics. The bore-hole C545, west of Nguu, and the Kiumbi river south of the railway are used daily for watering cattle, while wells sunk in the same river further north are also used by cattle in the wettest months. The remaining bore-holes and wells are not now in use.

(2) Volcanic Region

Surface water is present in three main streams that drain the volcanic region, the Kiboko, the Kiumbi and the Kibwezi. Apart from these rivers no other main water-courses cross this part of the Chyulu-Kiboko lava field and it is evident that most of the rain that falls on the lavas disappears rapidly underground. The water infiltrates through the lavas and is sufficiently retarded so that a constant flow of water is present at the Simba, Kiboko, Makindu and Umani springs, which are situated along the northern margin of the lava-fields (Fig. 19). Small rivers such as the Engejuolon-gonjine near Simba and tributaries of the Oldukai near Merueshi drain parts of the Simba and Ngatatema lavas, but these contain water only during the wettest periods,

TABLE V—ANALYSES OF WATER FROM BORE-HOLES AND WELLS IN BASEMENT SYSTEM ROCKS IN THE SIMBA–KIBWEZI AREA

	Bore-hole 135 (Parts per 100,000)	Bore-hole C545 (Parts per (100,000	Bore-hole C328 (Parts per 100,000)	Bore-hole 130 (Parts per 100,000)	Bore-hole C614 (Parts per 100,000)	Bore-hole C645 (Parts per 100,000)	Bore-hole C1006 (Parts per 100,000)	Simba Well (Parts per 100,000)	Makindu Rly. Well (Parts per 100,000)	Makindu Rly. Cattle Well (Parts per 100,000)
Alkalinity (as $CaCO_3$)—										
Carbonate	nil	nil	nil	—	nil	nil	nil	nil	nil	nil
Bi-carbonate	8·1	30·7	19·2	—	28·0	57·0	58·5	33·6	41·2	54·8
Ammonia—										
Saline	0·004	trace	—	0·051	trace	0·007	—	trace	trace	trace
Albuminoid	trace	0·006	—	0·032	trace	0·014	—	trace	trace	trace
Chlorides (as Cl)	1·6	21·00	23·2	8·00	185·0	298·0	260·0	4·9	2·0	4·7
Sulphates (as SO_4)..	trace	127·6	86·5	—	72·2	507·0	128·0	55·4	12·8	38·7
Nitrites (as NO_2)	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Nitrates (as NO_3)	present	nil	nil	nil	nil	nil	nil	nil	nil	nil
Calcium (as Ca)	—	34·3	23·93	—	—	53·0	68·3	—	4·6	—
Magnesium (as Mg)	—	11·4	8·63	—	—	46·5	45·8	—	4·4	—
Iron (as Fe)	trace	—	0·56	—	—	—	0·66	—	trace	trace
Silica (as SiO_2)	1·4	—	—	—	—	—	—	—	2·4	3·2
Total hardness	3·0	132·6	95·33	18·0	—	323·8	359·2	60·0	29·6	9·0
Permanent hardness	—	—	—	8·0	—	—	—	32	—	—
Temporary hardness	—	—	—	10·0	—	—	—	28	29·6	—
Free CO_2	present	—	present	—	—	—	present	—	—	—
Total solids..	not stated	275·7	196·0	120	382·6	703·8	640·0	142·8	70·0	127·0
Fluorides (as F) p.p.m.	0·3	5·6	—	—	—	—	8·4	—	2·6	4·7
pH	6·7	7·1	6·9	—	7·6	7·2	6·9	7·1	7·5	7·8

Anal.: Government Chemist, Kenya.

generally for a few days of the year. The watershed between north-easterly-flowing streams feeding the Simba-Kibwezi region and southerly-flowing tributaries of the Ol Turesh passes through the area between Kenzili and Esoitiekiringol.

Two main varieties of lava are recognized in the area, *pahoehoe* and *aa*. Both lava types on cooling split into columns (sometimes hexagonal) that have numerous fractures sub-parallel to the surface of the flow. The permeability of such lavas is, therefore, extremely high. The Muoni lava is typical and some exposures in the Muoni river are seen to be saturated, water issuing from the numerous cracks and joints and from the base of the flow. Other examples are the lavas occupying the Kiboko, Makindu and Kibwezi valleys. *Aa* lava, however, is compact beneath the surface clinker with few cooling cracks, and is less permeable. Lavas occupy all the old valleys and water flowing down the original channel gives rise to springs at the snouts of the flows, as can be seen one mile west of Kakuika. After consolidation of the lavas, lateral streams developed and some of these now contain perennial streams, though others like the Oldukai carry only flood waters.

The volcanic area can be divided into a number of small catchments and includes those of Simba, Kiboko, Makindu and Kibwezi. All but the first have been described in detail by Temperley (1956).

Simba.—Springs at Simba issue from beneath the lavas on the north side of the main road approximately one mile west of the station. These springs, which have a constant discharge of about 0.16 cusecs (86,000 gallons per day), are fed by underground water draining from the volcanic area due west of Simba township. This catchment area is small and is never likely to yield greater supplies except after the seasonal rains. The Masai tribesmen use this water-supply daily and move their herds of cattle as much as nine or ten miles from the south near Esteti because of lack of water in that region.

South of Nguu hill in the river Muoni are a number of hot-springs that discharge at the base of the lava. The water, which is fresh and warm, is used by a few local Africans. These springs are fed by waters flowing down the original Muoni river channel and which overflow against a rock bar outcropping at Lombo on the main road.

Kiboko.—The Kiboko area is drained by two rivers, the Oldukai and Kiboko (Lesser Kiboko), which are lateral streams along the Kiboko lava. The Oldukai river, which rises in the Kajiado area and flows along the northern margin of the lavas, is dry for the greater part of the year except during flood periods. A permanent flow of water, however, is maintained in the easterly Kiboko river, which rises at two springs in the lava 600 yd. above the road-bridge. The discharge from these springs is 0.52 cusecs and is augmented by two springs with a total discharge of 0.94 cusecs in the west bank of the river just below the road-bridge. These springs are fed by waters from the mid-lava channels. A total flow of 4 cusecs was measured by the Ministry of Works at the railway bridge and 2 cusecs at the Makueni-Makindu road drift. This suggests further discharge to the river below the lower springs and a loss of 2 cusecs between railway and drift that can be accounted for by evapo-transpiration from the swamps midway between the two. At the Kiboko lava snout, downstream, further loss by evapo-transpiration occurs from the terminal swamp. The waters are ponded in the swamp behind the Kakuika rock-bar, and overflow northwards through the Muoni lava, discharging in springs just below the Muoni-Kiangini confluence.

A bore-hole at Mwailo yields 66,000 gallons per day and it is likely that it is partly supplied by water in an unexposed north-south fault-zone which can be traced further south in the region of Tindima.

Makindu.—The Kiumbi river flows along the eastern margin of the Ukatu lava-triangle and the flow of water in the bore-hole C1875 suggests that the river-course, although concealed by lavas, is probably situated a few hundred yards to the south. The catchment includes the hills between Ithundu and south of Tindima, but excludes the northern end of the Chyulu range. Surface water, which is seen only in one small portion of the river south of the road-bridge, is rapidly lost underground. Springs and wells are present in the river near its source where it issues from beneath the lavas and numerous wells downstream (north of the railway) provide ample water-supplies for cattle. One spring which is utilized by the railway maintains a steady flow of about 0.185 cusecs and this with the discharge at the cattle-spring yields a perennial discharge of 0.3 cusecs. Two bore-holes, C2194 and C2208, drilled between these two localities and to the west of the river are also capable of yielding 0.3 cusecs. The calcareous alluvium and sub-limestone surface in the Kiumbu valley provides an excellent aquifer and wells and bore-holes sited along the river in the future should give an adequate and permanent supply.

A number of old spring-sites, the water from which once supplied a now dried-up swamp, are situated along the fringe of the lava at the limestone workings (Fig. 20). These probably ceased to flow owing to earth-movements and to decreasing rainfall over a number of years. Any increase in the annual rainfall would probably result in their flowing once more. To the south-west of the springs, at Changondu, is a permanent water-hole fed by underground water draining from the area to the west. Here lava has collapsed so that the water-table now stands above the lava-surface in the water-hole.

Kibwezi.—A number of sub-lava drainage-courses converge on the Kibwezi valley and drain the heavily forested lava area of the northern end of the Chyulu range. Surface water emerges at Umani springs where a discharge of about 3.5 cusecs has been recorded. The water quickly disappears underground in the Umani swamp to reappear at the Kikoo and Chae springs two miles north-west of Kibwezi township. Here the total maximum discharge is approximately 6 to 7 cusecs, indicating that the Umani flow is supplemented from another source. This increase is supplied by the flow from the area to the west and south-west of Umani where the water-table is probably close to the lava surface, which here supports a dense luxuriant forest. The sub-lava channels cross the strike of the Basement System gneisses and numerous rock bars are considered responsible for the emergence of dammed waters at the Kikoo and Chae springs, while some of the water continues to flow downstream to emerge at Manoni springs five miles to the north-east.

The Umani springs and the underground water-flow between Kenze and Umani are probably augmented by water accumulating along a north-west—south-east fault-zone along which the two volcanoes are considered to have erupted (*see* p. 50). Another small spring situated on the north side of the road at the Kibwezi railway station yielded only .025 cusecs in 1954. North-east of this, three successful bore-holes, the property of Dwa plantations, are situated near the snout of the Kibwezi west lava. Two of these penetrated lava before entering Basement System rocks.

Improvement of water-supplies in all the valleys could be effected by the elimination of the swamps and the tapping of the springs at their points of discharge. In valleys such as the Kiboko the construction of dams would be impracticable due to lack of good dam-sites. Any boreholes or wells sunk through the lava or in the calcareous alluvium of the valleys would yield water. Other bore-holes should be sited along the western margins of the Makindu and Kibwezi grazing areas near the main rivers. Two bore-holes C497 and C1875 have already proved very successful. Perhaps the best bore-hole sites lie in the lava-covered country, but the highly irregular and bouldery surfaces would prevent drilling equipment being taken into such areas except

TABLE VI—ANALYSIS OF WATER FROM BORE-HOLES AND RIVERS ASSOCIATED WITH THE VOLCANIC ROCKS IN THE SIMBA–KIBWEZI AREA

	Bore-hole C2139, Mbukani (Parts per 100,000)	Oldukai River (Road Bridge) (Parts per 100,000)	Kiboko River (Parts per 100,000)	Kiboko River 30 ft. above Road Bridge (Parts per 100,000)	Kiboko River 200 ft. below Road Bridge (Parts per 100,000)	Kiumbi (Makindu) River Cattle Watering Place (Parts per 100,000)	Kiumbi (Makindu) River Railway Well (Parts per 100,000)	Kibwezi River Chae Dam (Parts per 100,000)	Kibwezi River 500 ft. above Chae Dam (Parts per 100,000)	Kibwezi Railway Station Water (Umani Swamp) (Parts per 100,000)	Makindu Railway Station Water (Dam) (Parts per 100,000)
Alkalinity (as $CaCO_3$)—											
Carbonate	nil	nil	n il	nil	nil	nil	nil	nil	5·0	1·4	3·4
Bi-carbonate	33·6	31·3	20·7	23·4	20·4	54·8	41·2	33·2	40·6	28·5	30·5
Ammonia—											
Saline	trace	trace	trace	trace	trace	trace	trace	trace	trace	—	—
Albuminoid	trace	0·008	nil	0·002	trace	trace	trace	0·001	0·005	—	—
Chlorides (as Cl)	17·9	31·6	9·0	11·6	9·2	4·7	2·0	1·2	8·0	1·2	2·4
Sulphates (as SO_4)	120·0	153·0	66·7	85·6	69·0	38·7	12·8	3·2	3·2	3·8	15·2
Nitrites (as NO_2)	present	nil	trace	nil	present	nil	nil	nil	nil	nil	present
Nitrates (as NO_3)	nil	nil	present	nil	nil	nil	nil	nil	nil	nil	nil
Calcium (as Ca)	27·2	31·1	15·1	17·5	15·1	—	4·6	4·4	—	3·8	3·5
Magnesium (as Mg)	10·2	14·9	5·2	6·4	5·3	—	4·4	2·9	—	2·6	3·6
Iron (as Fe)	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace	trace
Silica (as SiO_2)	3·6	3·0	2·7	4·0	4·0	3·2	2·4	3·0	3·0	3·5	2·9
Total hardness	110·0	158·9	59·1	70·0	59·5	9·0	29·6	22·9	12·0	20·2	23·55
Permanent hardness	76·4	127·6	38·4	46·6	39·1	—	—	—	—	nil	nil
Temporary hardness ..	33·6	31·3	20·7	23·4	20·4	—	29·6	22·9	12·0	20·2	23·55
Free CO_2 p.p.m.	nil	—	—	—	—	—	—	present	—	2·8	—
Total solids	276·0	254·0	136·0	176·0	144·0	127·0	70·0	45·0	78·0	44·0	63·0
Fluorides (as F) p.p.m. ..	0·8	2·0	5·6	1·8	1·8	4·7	2·6	1·0	2·0	—	—
pH	7·3	7·5	7·3	7·7	7·5	7·8	7·5	6·9	8·3	8·1	8·3

Anal.: Government Chemist, Kenya.

at great cost. Other promising localities for bore-holes are along the fault-zones, particularly within the Makindu and Kibwezi grazing areas. Details of bore-holes in the volcanic region are as follows:—

Bore-hole Number	Locality	Depth in feet	Depth at which water struck	Yield in galls. per day	Depth of lava base (feet)
C2498	Nguu	Abandoned		nil	—
C2139	Mbukani	250	100 and 185	69,120	20
C497	Mwailo (Makindu grazing area).	330	320	60,000	20
C1875	Maimu (Kibwezi grazing area)	146	80	56,000	10
C1241	Kibwezi	130	35–50	60,000	29
C1242	Kibwezi	91	32–50	28,800	32
C1243	Kibwezi	115	50	16,800	—

Analyses of the water from various bore-holes and rivers are given in Table VI. The analyses indicate that the water from the Kibwezi river at Chae (and therefore the water from Umani springs) is suitable for human consumption. The Kibwezi railway station water is piped from Umani spings and the analysis confirms the excellent quality of the water.

A water pipe-line has been constructed by the railway authorities from Loitokitok on Mount Kilimanjaro to Sultan Hamud. The pipe-line, which passes through the south-western corner of the area, is capable of supplying about 480,000 gallons per day. The water is stored in a reservoir at Sultan Hamud, from where it is piped alongside the railway as far as Simba. The pipe-line between Sultan Hamud and Simba has a maximum capacity of 100,000 gallons of water per day. This drinkable water, an analysis of which is quoted in Table VI (Makindu station), is used by Masai and Wakamba herdsmen for watering their cattle and also for railway purposes.

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