Report No. 49

COLONY AND PROTECTORATE OF KENYA

MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE AREA SOUTH OF THE TAITA HILLS

DEGREE SHEET 65, S.W. QUARTER AND PARTS OF
DEGREE SHEET 65, N.W. QUARTER AND
DEGREE SHEET 68, N.W. QUARTER
(with coloured geological map)

by

J. WALSH, B.Sc.
Geologist

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ERRATA

GEOLOGICAL REPORT No. 46

(Geological Survey of Kenya—Geology of the Mid-Galana Area)

Page 3, line 3 from bottom, *for* "25" *read* "23".
Page 4, line 21 from bottom, *for* "Plaeau" *read* "Plateau".
Page 8, line 5 of the footnote, *for* "antexis" *read* "anatexis".
Page 14, fourth para., line 1, *for* "comformable" *read* "conformable".
Page 28, fourth para., line 3, *for* "Thomson" *read* "Thompson".
Page 31, line 5, *for* "has" *read* "have".
Page 35, last para., line 2, *for* "desposition" *read* "deposition".
Page 36, second para., last line, *for* "Gandwana" *read* "Gondwana".
Page 42, line 4, *for* "slicken siding" *read* "slickensiding".

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ILLUSTRATIONS

MAP

FOREWORD

Some years ago a reconnaissance geological survey was made of the Taita hills, and published as part of Report No. 13 by Dr. J. Parkinson. The work described in the present report extends that survey southwards to the Tanganyika border, but in a more detailed style. Mapping was begun in 1952 by A. M. Crowther, who, however, soon had to suspend operations on being called to the Services. Before he was able to return to his work he was unfortunately killed on active service during the Emergency, and the mapping of the area had to be taken over by Mr. Walsh.

Much of the area consists of flat country in which exposures of rock are scarce, and Mr. Walsh has had to piece together the geological history from what evidence is afforded by isolated hills. It is only in the northern parts that geological lines can be drawn with reasonable security. The mapping has demonstrated that the predominant rocks in the area are an ancient series in which bands of crystalline limestone are a marked feature. Graphite, sillimanite and kyanite rocks are also present, and together with the limestones suggest correlation with the Turoka Series, established in 1913 by Parkinson in the Kajiado area. At Kajiado recent work has shown that there is strong overfolding to the north, but apparently south of the Taita hills there is only evidence of moderate overfolding to the west. More extensive and more detailed surveys in this part of Kenya may yet prove that here also there is strong overfolding and perhaps produce evidence of more than one period of folding.

Apart from some of the limestones, which might find local uses, it appears that the only mineral of possible economic interest in the area is graphite. Mr. Walsh indicates localities that might repay more detailed investigation.

WILLIAM PULFREY,
Chief Geologist.

Nairobi,
2nd April, 1957.

ABSTRACT

The report describes an area of approximately 1,285 square miles in south-eastern Kenya between meridians 38° 00′ and 38° 30′ East, bounded in the north by the Voi–Taveta–Moshi railway and in the south by the Tanganyika border. Two main topographical divisions are recognized: (1) the almost featureless peneplain covering the western, south-western and southern parts of the area and (2) the hilly area in the north-east. Lesser units are the escarpment running south from Kinjaro hill to the Tanganyika border and the group of hills in the extreme south-east.

The rocks of the area fall into three groups: (1) Metamorphic rocks of the Basement System, mainly paragneisses of psammitic origin, with strongly developed crystalline limestones and local occurrences of graphitic gneisses and schists: (2) a major meta-doleritic intrusive into the Basement System in the south-east: (3) Pleistocene and Recent deposits, mainly sandy soils, with areas of black cotton soils and secondary superficial limestones (*kunkar*). The petrography of the various rock types is described and the metamorphism, granitization and structure of the Basement System are discussed.

Notes are given on the occurrences of garnets, graphite, ilmenite, kyanite and sillimanite, and limestone, and of their economic possibilities. Water-supplies are assessed and suggestions made for siting new bore-holes.

GEOLOGY OF THE AREA SOUTH OF THE TAITA HILLS

I—INTRODUCTION AND GENERAL INFORMATION

General

The area described in the present report is approximately 1,285 square miles in extent and lies between the meridians 38° 00′ and 38° 30′ East, being bounded on the north by the Voi–Taveta–Moshi railway and on the south by the Tanganyika border. The railway between Voi river and Bura marks the southern limit of the Taita hills, a block of country about 150 square miles in area whose peaks rise above 7,000 feet. The area mapped includes the south-west quarter of Degree Sheet 65, parts of the north-west quarter of the same degree sheet and the north-west quarter of Degree Sheet 68.

The whole area lies in Coast Province and, with the exception of a very small part in the extreme south-east which is in Kwale District, lies in the Taita District of the Province. Most of it is Crown Land, the exceptions being two blocks of alienated land in the north, one south and east of Mwatate planted with sisal and a second block south-west of Bura where a cattle ranching project was started early in 1955. A narrow strip of land between these blocks and extending as far as three miles south of the railway is part of the Taita Native Land Unit and is extensively cultivated, the crop being largely maize with a little cassava. Only at Maktau, in the north-west, is there any other settlement. Here some maize is grown near the railway, but the chief occupation of the inhabitants is cattle-herding. Owing to the heavy over-grazing of the land near Maktau, where water for stock is made available by the railway authorities, the District Officer at Taveta has instituted a scheme under which the cattle based on Maktau must be kept to a safe and much lower number, the remainder being moved to the vicinity of the bore-hole at Lualeni, 15 miles south-south-east of Maktau, where excellent grazing is to be had. It is hoped that many of the owners will be persuaded to move their cattle to Kinjaro hill, a further 20 miles, where grazing is again excellent and where natural water-holes will give ample water for several months of the year.

The western, south-western and most of the southern parts of the area lie within the Tsavo Royal National Park, and a control point for the Park is established at Maktau, on the road running south from the station. One of the boundary marks of the Park in the south-east is gazetted as Kavuma hill, but clearly Rumangombe hill is meant. A small hill called Kamuma stands some three miles further to the north-east and possibly accounts for the error in naming the larger hill.

Climate and Vegetation

The only rainfall records are for points on or near the railway, and are as follows:—

Rainfall in the Area South of the Taita Hills
(from records of the East African Meteorological Department)

Locality	Total Rainfall 1953	Total Rainfall 1954	Total Rainfall 1955	Number of rainy days 1955	Yearly average	Number of years recorded
	inches	*inches*	*inches*		*inches*	
Maktau Station ..	17·71	13·96	11·77	29	16·56	19
Mwatate I ..	23·90	21·74	19·22	66	20·19	8
Mwatate II ..	30·61	21·52	25·83	57	23·91	24
Mwatate III ..	25·81	17·47	14·93	38	21·45	10
Mwatate IV ..	17·59	11·41	13·29	35	21·94	24

The rain-gauges at Mwatate are all on the sisal estate of Teita Concessions Ltd. and are located as follows:—

I—Sisal factory; II—Manager's house near Mwatate Station; III—1 mile east of Tasha; IV—1 mile north-east of Sembi.

Rainfall is low and bi-annual, with roughly equal maxima in March/April and November/December. It decreases rapidly with increasing distance from the Taita hills. Thus, while the rain-gauge one hundred yards north of Mwatate Station (Mwatate II) has recorded an annual average of 23·91 inches up to 1955, a gauge only two miles away, north-east of Sembi (Mwatate IV) has recorded an average of 21·94 inches. The annual rainfall figures quoted in the tabulation show a much more striking disparity.

No regular readings have ever been made at Mwangare, eleven miles south of Maktau but intermittent observations made by the writer suggested that no rain fell there between March and May 1955, though rainstorms were frequently seen passing within a few miles to the north and south. This happened at the height of a poor rainy season but the lack of rainfall is mainly attributed to a rain-shadow effect of the Mgama Ridge, which acts as a barrier to the rain-bearing winds from the east and north-east.

The valleys of the Bura and Mwatate rivers are well-marked for their whole length but the actual water-courses are locally poorly defined and during the survey it became clear that these rivers have not flowed at any time in the past few years for more than a few miles south of the railway. In view of the fact that bore-holes on the sisal estate south of Mwatate (recorded on pp. 24–25) indicate alluvial deposits well below the present river bed it is clear that conditions in the recent past were much wetter than today, and the thickness of murram and topsoil now burying the alluvium indicates that a relatively dry phase has been in progress for a fairly long time. Large areas of dead and dying trees, particularly in the extreme north-east, near Mugeno, suggest that the climate is becoming increasingly dry, though there is no indication to show whether the present acutely dry conditions are the culmination of a long-term cycle or the product of a short and geologically insignificant dry phase.

Only two other river systems were mapped, the Voi river in the north-east and that draining the escarpment south and west of Kinjaro hill. In the latter system too no trace was found of water having flowed even after fairly heavy rain. Elsewhere the only surface water seen is in shallow water-holes, none of which is permanent. A large dam has been built across the Mwatate river to supply the heavy demands of the sisal factory.

Gully erosion is active on the hill slopes and sheet erosion on the plains, and the whole area is approaching semi-desert conditions. Denudation by sheet erosion is, however, slow as is shown by the considerably thickness of soil cover, erosion being unable to keep pace with the breakdown of the underlying solid rocks. In places soil-wash from the hilly areas greatly exceeds the amount of soil removed by erosion, so that locally aggradation is in process.

Vegetation is generally of acacia-type scrub, though large areas of open parkland occur to the south of Maktau, indicating a more fertile soil. These areas support vast numbers of game—elephant, giraffe, antelope, gazelle, lion, ostrich, etc., the only common game animal not seen being the wildebeeste. Rhinoceros occur in uncomfortable numbers in the hilly areas, particularly on the steeper slopes and limestone ridges where *Sansevieria* (wild sisal) is abundant. In short stretches of the Bura and Mwatate rivers in the north riverine vegetation occurs, typified by wild fig trees, palms and prolific banana plantations.

Communications

The Voi–Taveta–Moshi branch of the East African Railways system marks the northern boundary of the area surveyed and is closely followed by the telegraph line and the main road. Other good but secondary roads are those from Mwatate to Kasigau and from Maktau to Lualeni, and those traversing the sisal estate at Mwatate. A few other motor tracks, mainly used for hunting or fire-wood collection were mapped, the only important one being that from Lualeni which runs south and east to join the Kasigau road. An old track cut for locust-control purposes can still be followed into the area south-west from Kasigau, but a second locust-control track from the direction of Lake Jipe could only be followed for a very short distance inside the western boundary, before being completely lost.

Maps

The only earlier map of the area that is any way reliable is the military map "Voi" E.A.F. 1748 (1946), which covers the northern half. In using this map form-lines were corrected where necessary and additional heights, which must be considered as only approximate, were obtained by aneroid barometer. Five runs of air photographs cut the area, and the principal points are shown on the map. The remainder of the ground was mapped on compass and cyclometer traverses based on fixed points surveyed by plane-table. Wherever possible local names have been given to features and localities previously unnamed or incorrectly named, though many must necessarily remain unnamed in such an uninhabited region.

The part of the geological map south of parallel 3° 30′ S. is Sheet No. 195 (Kenya) of the Directorate of Colonial Surveys and the part north of 3° 30′ S. falls in D.C.S. Sheet No. 189.

Previous Geological Work

The missionary-explorer Charles New (Forbes-Watson, 1951, pp. 31, 32 and 61–63)* in 1871 crossed the area from Kasigau to Lake Jipe and later returned along the approximate course that the railway now follows. He reported the country as being dry and waterless, but except for the rocks near Kasigau made no mention of the geology.

Walcot Gibson (1893, p. 562) mentioned graphite schists and unfossiliferous crystalline limestone near Bura, and noted that quartz veins and quartzites are only feebly developed, a point borne out in the present survey.

E. E. Walker (1903, p. 2) noted the occurrence of crystalline limestone and much younger (*kunkar*) limestone in the Voi river area, and gneisses and schists around Mwatate.

Dr. E. Parsons (1943) reported on the economic aspect of these same limestones, and later (1946) made a geological survey of the country around Mwatate with a view to assessing possible water-supplies, confining his observations to structure rather than lithology.

Acknowledgments

Acknowledgment is made to the late A. F. Crowther, a Geologist of the Mines and Geological Department, who was killed in action against *Mau Mau* terrorists in 1954, and who in early 1953 had spent several weeks in this area mainly on preliminary surveys, and whose work was of the greatest assistance. Thanks are also due to the Manager and staff of Teita Concessions Ltd. for help and hospitality, and to Mr. and Mrs. C. Henderson of Maktau Station for hospitality.

II—PHYSIOGRAPHY

The area can be divided into two major units, the almost featureless plain which extends into the area from the west and south, and the hilly area to the north-east, which is essentially a series of ridges trending just west of north. Plate I gives a view of the valley of the Mwatate river which follows a roughly north-south fault between two such ridges. Other minor units are the marked escarpment running south from Kinjaro towards the Tanganyika border and the group of hills in the extreme south-east.

Much of the southern part of the plain, with an average altitude at the centre of the area of 2,600 ft., is a peneplain (*see* Fig. 1), with an average slope in the south-east of 9 ft. per mile, and in the south-west of 11 ft. per mile, down to the south-south-east. No criterion was found in the field by which this surface could be dated, but extrapolated towards the east it would lie some 500 ft. above the end-Tertiary peneplain in the Mariakani–Mackinnon Road area (Miller, 1952, p. 4). As there is no evidence of disturbance of the surfaces, it is therefore older than the end-Tertiary peneplain, and the writer considers it to be part of the sub-Miocene peneplain. In the north-west the gradient of the plain steepens to 50 ft. per mile, with no marked break of slope. This steepening is considered to be the result of the grading of the sub-Miocene peneplain to a remnant of a higher surface (the Mwangare surface, defined below) which caps an east-west ridge six miles north-east of Maktau. In the south and south-east local steepening of the gradient to the south indicates dissection of the sub-Miocene surface by headstreams of the Umba river, which flows from west to east in Tanganyika about 20 miles south of the most southerly part of the area. In the extreme north-east too the Voi river is actively cutting down into the plain. Evidence of a temporary halt in the downcutting is seen in a discontinuous terrace capped with poorly cemented sand and silt, ten feet above the present river-bed.

*References are quoted on p. 26.

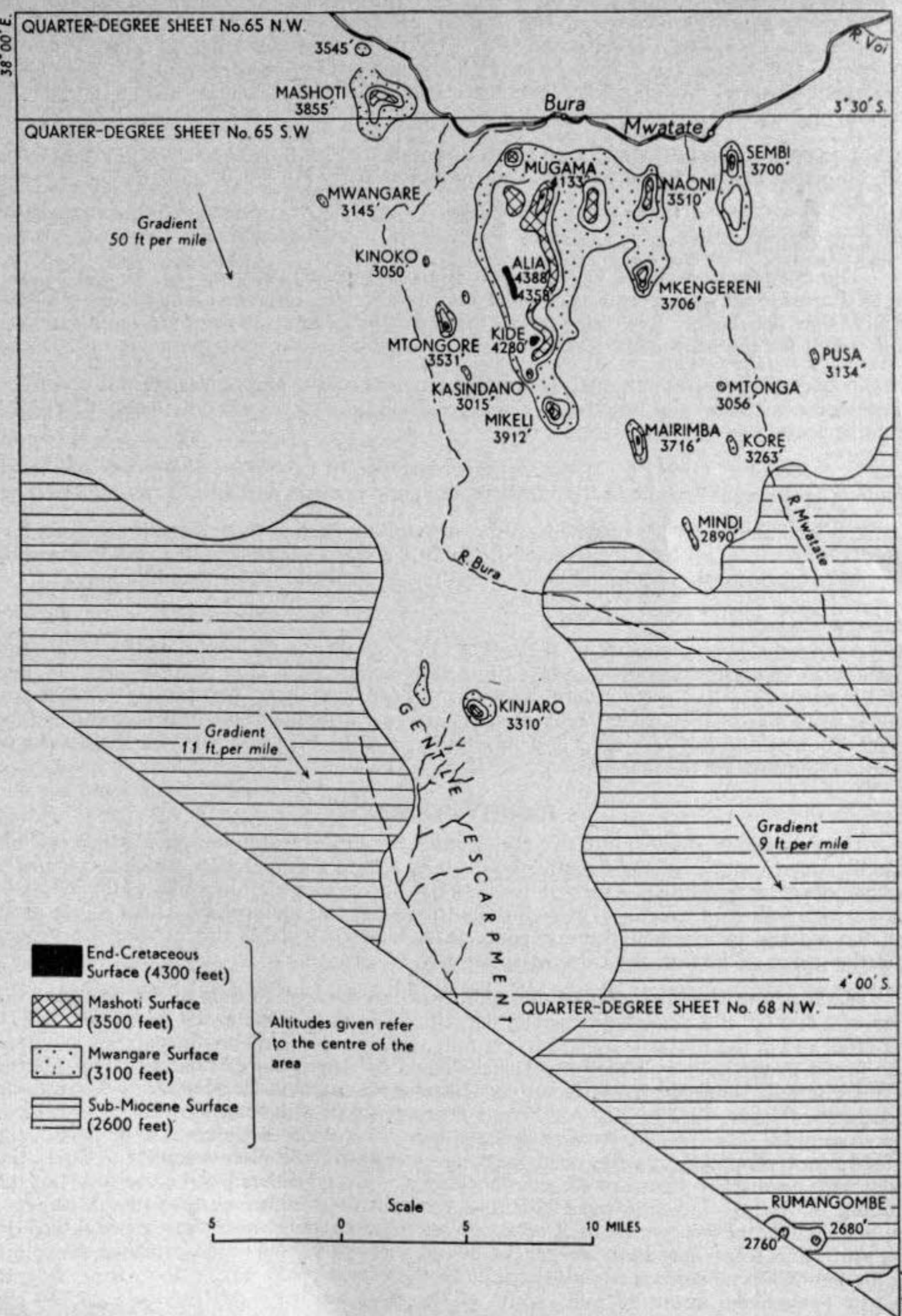


Fig. 1—Phisiographical sketch-map of the area south of the Taita hills.

A concordance of many summit-levels in the hilly region of the north (e.g. Mwangare 3,145 ft., Kasindano 3,015 ft., Mtonga 3,056 ft., Mindi 2,890 ft.) defines an older surface, at an average elevation of 3,100 ft., for which the name Mwangare surface is proposed. Further evidence of the extent of this bevel is given by marked shelves on many of the higher hills and ridges, e.g. at 3,100 ft. on the northern slope of Sembi and at 3,005 ft. on Pusa. The summits of the twin hills of Rumangombe, at 2,760 ft. and 2,680 ft., are thought to be further remnants of the Mwangare surface and, assuming that their summits are still at about the level of the original surface, they indicate that the surface has a slope of 12 ft. to the mile to the south-east.

A third bevel, older than the Mwangare, is indicated by summit-levels around 3,500 ft. and by a broad shelf which runs for several miles along the eastern slopes of Alia and Kide. This feature, which may be called the Mashoti surface as it is well developed on the summit of the hill of that name, marks a still-stand of erosion base-level between the Mwangare and the end-Cretaceous peneplanations. The latter is evident in the present area as flat-topped summits on the Mgama ridge at elevations a little over 4,100 ft.

In all cases it is clear that the peneplains owe their origin to erosion and not to rock structures. A case that illustrates this well is the broad shelf east of Alia and Kide, which is cut into a homogeneous granitoid gneiss.

The explanation of the escarpment south of Kinjaro hill is not clear, but it is possible that it is a fault-line scarp resulting from a strike fault trending west of north. No exposures were found at the foot of the scarp to indicate either the actual position or the nature of any fault.

The drainage of the area is almost wholly by percolation and seepage underground what little storm-water flow there is moving south-east and south towards the coast, the only exceptions being in the south-west (where no water-course exists) where the ground slopes towards Lake Jipe in the west, and in the north-east where the ground slopes north-east to the Voi river which, on leaving Voi, runs due east. Other than the rivers mentioned in Chapter I the only water-courses are mere gullies which flow down the steeper hillsides and are lost immediately they debouch on to the deep soil cover of the plains. Where this soil cover is less deep than usual or more impervious to water percolation shallow water-holes form, often little more than ponds but occasionally, as at Kwamanagadi, up to 500 yards in diameter and holding water for a considerable part of the year.

III—SUMMARY OF GEOLOGY

The consolidated rocks of the area are wholly members of the Basement System, which is assumed to be of Archaean age, together with a doleritic intrusion and other minor intrusions. They are for the most part covered by unconsolidated superficial deposits of Pleistocene to Recent age.

Basement System

The rocks of the Basement System in the area mapped consist of a succession of para-gneisses, some of which are granitoid in composition and appearance and sometimes contain biotite or hornblende, crystalline limestones, graphitic gneisses and lesser amounts of felspathic quartzites, plagioclase amphibolites and calc-silicate rocks. They closely resemble rocks in many other parts of Kenya that are assigned to the Basement System.

The granitoid gneisses, consisting of little more than quartz and felspar, form the most prominent features of the area, Mgama ridge and Mairimba hill south-east of the ridge. They are associated in the Mgama ridge with quartzo-felspathic gneisses of very similar composition but with much finer and more regular grain size, and minor felspathic quartzites. Biotite gneisses form the bulk of the other exposures, and generally give rise to much less prominent features. In a few exposures, e.g. at Sembi and Kambanga, the biotite gneisses are markedly porphyroblastic: elsewhere, as at Pusa and the Naoni–Mkengereni ridge, they contain well-defined bands relatively rich in garnet. The biotite gneisses are frequently well-banded on a small scale.

The crystalline limestones, usually coarse-grained and white or grey in colour, almost always form positive features and can usually be traced for long distances across otherwise featureless country. They usually carry tiny flakes of graphite and more rarely muscovite, diopside, grossularite, actinolite or chlorite, and frequently enclose lenses of quartzo-felspathic gneiss. Their content of magnesium carbonate is high.

The graphite gneisses and subordinate graphite schists occur in several widely separated localities. Pale green mica, sillimanite and kyanite are frequent accessories in those on the Mgama ridge, but in the wide outcrops between Mindi and Karirunga to the south-east of Mgama, where the graphite gneisses are interbedded with crystalline limestone, they consist only of quartz, felspar and graphite, except in the northern part of the outcrops on Kavishoi where sillimanite occurs in addition.

Hornblende gneisses are not common, perhaps owing to the high degree of metamorphism that has prevailed over the whole area, hornblende having been largely changed to biotite. An interesting occurrence is the long ridge formed by Mtonga and Kore, in the east, where a distinctive assemblage is seen of hornblende, diopside and hypersthene in a fairly dark medium-grained gneiss.

One small outcrop of meta-calcareous rock was found south of Zongoloni.

Strikes in the Basement System rocks are predominantly west of north, and the dip marked to the east. The general structural pattern of the area is that of a series of folds overturned towards the west and plunging northwards.

Pleistocene and Recent Deposits

The Basement System is almost everywhere covered by a great thickness of red soils, with black-cotton soils containing nodules of secondary limestone in poorly drained areas. Wide areas of *kunkar* limestones cover the crystalline limestone outcrops, often extending over a much larger area than the limestones themselves, and are frequently found covering the smaller outcrops of plagioclase amphibolite. The metadolerite outcrop is almost completely masked by superficial limestone and a cellular ferruginous and siliceous deposit, both formed by weathering of the intrusion.

IV—DETAILS OF GEOLOGY

1. The Basement System

The rocks of the Basement System in the area mapped are classified as follows:—

(*a*) Calcareous
- (i) Crystalline limestones
- (ii) Meta-calcareous gneisses
- (iii) Hornblende-diopside-hypersthene gneisses

(*b*) Carbonaceous
- (i) Graphitic gneisses and schists

(*c*) Psammitic
- (i) Biotite gneisses
- (ii) Biotite-garnet gneisses
- (iii) Felspar-porphyroblast gneisses
- (iv) Quartzites and felspathic quartzites
- (v) Quartzo-felspathic gneisses
- (vi) Granitoid gneisses

(*d*) Pelitic and semi-pelitic
- (i) Hornblende and hornblende-garnet gneisses
- (ii) Plagioclase amphibolites

The succession in the north appears to be as follows:—

6. Crystalline limestones
5. { Granitoid and quartzo-felspathic gneisses (Mgama ridge)
Biotite gneisses (Voi river)
4. Crystalline limestones with minor graphitic gneisses

3. Quartzo-felspathic and biotite gneisses

2. Crystalline limestones

1. { Hornblende, biotite and biotite-garnet gneisses (Mwatate area)
   Granitoid gneisses (Mgama ridge)

The total thickness is of the order of 8,000 ft.

In the central part of the area the succession appears to be as follows:—

3. Hornblende and biotite gneisses

2. Crystalline limestones with graphitic gneisses

1. Hornblende and biotite gneisses

The total thickness, as exposed, is of the order of 5,000 ft.

Lack of exposures between the northern and central successions make correlation impossible. It is suggested that the central series is older than that in the north, though it is possible that the three divisions of the central succession represent the three lowest divisions in the northern succession.

(1) Metamorphosed Calcareous Sediments

(a) Crystalline limestones

The crystalline limestones occur in many places in the area, both as thick persistent beds and as small lenticular bodies. They are always dolomitic, though the proportion of calcium carbonate always exceeds that of the calcium-magnesium carbonate, dolomite. The grain size is always medium-coarse to coarse, individual grains being seldom less than 0·3 cm. across, and occasionally exceeding 1 cm. Colours range from off-white to medium-grey, with some varieties showing pale blue or cream tints, the colouring in any bed often varying greatly over a distance of a few yards. Invariably the limestones emit a sulphurous smell on hammering, which is attributed to hydrogen sulphide originally incorporated in the rocks as a result of the decay of organic matter (Hillebrand and Lundell, 1946, p. 823). This contention is supported by the invariable presence of small amounts of graphite disseminated in small flakes throughout the rocks. Silicate minerals and quartz were observed in the limestones at many localities, usually in small amounts except in the case of quartz, which in specimen 65/151* from about 2¾ miles N.N.W. of Mugeno constitutes 40 per cent† of the whole, and meionite which was found only in specimen 65/179 from Mindi where it comprises 15 per cent of the rock together with quartz and plagioclase, each 5 per cent, and pink pleochroic sphene 3 per cent. Cubic crystals of pyrites are also present in this rock. Other minerals recognized were muscovite (65/139 from south of Kambanga, and 65/151), small crystals of diopside and pale green grossularite (65/144 from Voi river) and dark green magnesian mica sometimes in clots but generally as disseminated flakes in specimen 65/224, from the banks of the Voi river. The latter occurrence is interesting since the mica-bearing limestone is a band averaging 5 feet in thickness in limestone which bears the usual tiny graphite flakes. No graphite, however, occurs in the mica-bearing band and *vice versa*. Small lenses of quartz and quartzo-felspathic gneiss are common in all exposures, and south of Mugeno locally make up as much as a fifth of the bulk of the rocks.

(b) Meta-calcareous gneisses

Only one small outcrop of meta-calcareous gneiss was found, in the nose of a plunging fold south of Zongoloni, and is represented by specimen 65/156, a dark green and red medium-grained rock. In thin section this rock shows light pinkish brown sieved garnets, probably grossularite, intergrown with and enclosing plagioclase, epidote, sphene, diopside and iron ore. The epidote often shows good crystal faces, even against garnet. The plagioclase felspars are of andesine/labradorite composition (An_{50}) and are mostly twinned, usually

*Specimens numbered 65/151, etc., are in the regional collection for Degree Sheet 65 of the Mines and Geological Department, Nairobi.

†Unless stated otherwise, all percentages quoted are volumetric and are estimated.

coarsely on the albite law and occasionally on the pericline law. The estimated composition is:—

	per cent
Plagioclase	47
Garnet	26
Epidote	22
Sphene	3
Diopside	1
Iron Ore	1
Apatite	+

(*c*) *Hornblende-diopside-hypersthene gneisses*

Nine miles south of Mwatate a three mile long outcrop of well-banded dark brown medium-grained gneisses forms the conspicuous Mtonga–Kore ridge. There is little variation along the strike, the rocks being composed mainly of plagioclase felspar (oligoclase, An_{20}), much of it untwinned, orthoclase felspar, quartz, and lesser amounts of hornblende, diopside and hypersthene (65/136, 65/137). Specimen 65/137 contains microcline-microperthite in addition to orthoclase. The hypersthene is pleochroic from pink to pale green; the diopside is weakly pleochroic in apple green, and has fine polysynthetic twinning. The hornblende, which is pleochroic from black to medium brownish green, occurs in two distinct modes, as discrete aggregates and as a replacement of both hypersthene and diopside, in the latter case being accompanied by much opaque iron ore. Apatite, while representing a small proportion of the total volume, sometimes forms unusually large crystals, especially when in contact with hypersthene and diopside. Unfortunately this rock is nowhere seen in contact with other rocks, except for a very thin stringer of quartz-felspar-tourmaline pegmatite that cuts its northern end.

A second representative of this rock type is exposed in a gully beside the railway at Mile 15/6* south-west of Mwatate Station. Here the rock (specimen 65/164) is dark grey and relatively schistose due to its biotite content. In thin section the hornblende is seen to be pleochroic from light to dark green, and is intergrown with red-brown biotite. Diopside is present in the same proportion as in the Mtonga–Kore exposures, but hypersthene now makes only one per cent of the whole. Orthoclase felspar is absent, perhaps due to the growth of biotite, and the plagioclase felspar is slightly more calcic, of oligoclase/andesine composition.

Estimated modes are:—

	65/136	65/137	65/164
	per cent	per cent	per cent
Quartz	5	5	10
Orthoclase	15	10	—
Microcline	—	10	—
Plagioclase	60	55	63
Biotite	—	—	10
Hornblende	6	8	10
Diopside	5	4	5
Hypersthene	5	6	1
Apatite	1	1	1
Iron Ores	3	1	+

65/136—Mtonga

65/137—Kore

65/164—Mile 15/6 Voi–Taveta–Moshi railway

*Distances along the railway are marked by metal plates indicating miles and sixteenths measured from Voi station i.e. Mile 15/6 refers to a point 15 miles 660 yards from Voi.

(2) Metamorphosed Carbonaceous Sediments

(a) Graphitic gneisses and schists

The greatest development of graphitic gneisses is in the Mindi–Kandashi ridge and its minor neighbours Kavishoi and Kilima Mbisi, where the gneisses flank a broad band of crystalline limestone and enclose many large and small lenses of limestone. A few small lenses of the gneiss are also found in the limestone. The gneiss, which is locally schistose, at Kavishoi (65/183) is of medium to coarse grain, hard, and consists of an aggregate of quartz and orthoclase felspar with fine acicular crystals of sillimanite intimately associated with grains of corundum, graphite and rounded aggregates up to 0·5 cm. in diameter of very fine granular epidote. The graphite occurs as flakes which average 0·1 cm. in diameter, and seldom exceed 0·3 cm. Rather similar rock occurs in the Mgama Ridge one and a half miles south-east of Alia. Here it is much coarser, and locally contains bladed crystals of blue kyanite that measure as much as 6 cm. in length. Much of the kyanite has been replaced by felted aggregates of sillimanite needles which often enclose tiny crystals of rutile. Corundum was not recognized here, and epidote occurs in trace amounts only. A pale green variety of muscovite was seen in thin section. Estimated modes are as follows:—

	65/183	65/212
	per cent	*per cent*
Quartz..	50	50
Orthoclase	10	10
Graphite	11	10
Sillimanite	10	24
Epidote	17	+
Corundum	2	—
Rutile	+	+
Kyanite	—	5
Muscovite	—	1

65/183—Kavishoi
65/212—South-east of Alia

In two minor occurrences at Tasha and Mkengereni the graphite content of the rock assayed at less than six per cent, but in a similar occurrence at Muguma, at the north end of the Mgama Ridge, the graphite content was found to be over eleven per cent. In none of these occurrences is the graphite of large flake size.

Finally an outcrop of graphitic rock occurs at Lilani, east of the Mgama Ridge where there is a schist (65/210) in the form of a large elongated lens in crystalline limestone. The bulk of the rock consists of quartz, microperthitic orthoclase felspar and microperthitic microcline, with myrmekitic structure often developed between the quartz and felspars, both orthoclase and microcline. The graphite here, which averages five per cent of the whole, is in intimate intergrowth with green mica, sometimes enclosing myrmekitic intergrowths of quartz and felspar. Myrmekitic structure in some of the mica suggests its derivation from the felspar of myrmekitic intergrowths.

(3) Metamorphosed Psammitic Sediments

(a) Biotite gneisses

Under this heading are included all the gneisses in the area carrying more than trace amounts of biotite. Those of the Naoni ridge grade northwards into rocks that are approaching biotite-bearing granitoid gneisses in character, while those south-west of Mwatate and others exposed in the railway-cutting in the extreme north-east of the area might have been mapped as migmatites, containing as they do large and small knots of mafic material. Garnet occurs at many localities but the rocks have only been mapped as biotite-garnet gneisses (*see* section (3) (*b*)) where specific garnetiferous horizons could be traced over fairly wide areas.

The biotite content is nowhere high, the maximum percentage measured being fifteen, in specimen 65/155 from Zongoloni. Quartz and orthoclase felspar are always important constituents, but plagioclase (always of the composition of oligoclase) never exceeds ten per cent of the whole and is often absent. In every thin section but two microcline felspar constitutes about half of the total, exceptions being specimen 65/216 from Mwatate hill where it only reaches fifteen per cent, and 68/1 from Rumangombe where it is absent. This points to a high degree of alkali metasomatism, which has led to a well-defined banding in most exposures, the banding being on a small, almost microscopic scale, and consisting of alternations of biotite-bearing layers and quartz-felspar layers. Contacts between the layers are usually sharply defined but never show chilling or similar contact phenomena. Microscopic examination shows the leucocratic layers to consist always of relatively unaltered felspar and quartz, while the felspar associated with biotite is often cloudy and altered. The quartz in the leucocratic layers tends to be flattened and elongated parallel to the layering, and seldom shows strain effects. Typical estimated modes, arranged in decreasing order of biotite content are as follows:—

	65/155	65/216	68/1	65/188	65/150b	65/142b	65/215
	per cent	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*	*per cent*
Quartz..	20	30	50	25	25	35	25
Orthoclase	10	40	35	25	20	3	25
Plagioclase	—	10	10	10	5	10	—
Microcline	55	15	—	35	45	50	48
Biotite	15	5	5	4	4	2	2
Muscovite	—	—	+	—	—	—	+
Other minerals ..	—	+	—	1	1	—	—

65/155 —West of Zongoloni.
65/216 —Mwatate hill, south of Mwatate.
68/1 —Rumangombe.
65/188 —Kamshari plain.
65/150b—North of Mugeno.
65/142b—Railway section, 1½ miles west of Voi river.
65/215 —Mwatate hill.

In specimen 65/216 a small amount of the biotite has been chloritized, but was the only occurrence of chlorite in all the biotite gneisses examined. The "other minerals" include opaque iron ores, and apatite, and occasional garnet.

(*b*) *Biotite-garnet gneisses*

The biotite-garnet gneisses generally have a higher proportion of biotite than the biotite gneisses, and therefore are more melanocratic. Banding is usually fairly well marked, though on a very fine scale, and is due to segregation of felsic material. The garnets are usually small, seldom attaining a diameter of 0·5 cm. and in only one specimen, 65/220, was any suggestion of augen structure seen. In the thin section of this specimen it can be seen that biotite flakes sometimes bend around the garnets and the frequent intimate association of garnet and biotite indicates replacement of biotite by garnet. The garnets are usually subhedral, and commonly fractured and deeply embayed.

Typical estimated modes are:—

	65/159	65/133	65/220	65/217
	per cent	*per cent*	*per cent*	*per cent*
Quartz	15	35	15	35
Orthoclase	30	40	40	40
Plagioclase	20	10	25	15
Biotite	20	10	10	9
Garnet	15	5	10	1
Other minerals	+	—	+	—

65/159—Sembi.
65/133—Pusa.
65/220—Naoni.
65/217—Mwatate hill.

In striking contrast to the biotite gneisses there is a complete absence of microcline. The orthoclase content tends to be higher and the plagioclase is rather less sodic, being positive andesine in specimen 65/133, and otherwise oligoclase-andesine. The location of the garnet-bearing gneisses makes it obvious that, like the biotite gneisses, they must have been exposed to attack by alkali metasomatizing fluids. It is suggested that the biotite gneisses have been derived from felspathic sandstones with little ferromagnesian mineral content, and the biotite-garnet gneisses from chloritic sandstones. Under a comparable degree of metasomatism the higher alkali content of the original felspathic sandstones would lead to the greater emphasis of minerals containing alkalis in the biotite gneisses as compared with the biotite-garnet gneisses.

(*c*) *Felspar-porphyroblast gneisses*

The felspar-porphyroblast gneisses are generally similar to the biotite gneisses already described, and the porphyroblasts of alkali felspar are nowhere strongly developed. Their greatest development is in the northern half of the Sembi-Zongoloni ridge, where they merge southwards into normal biotite gneisses. The biotite content never exceeds ten per cent of the whole and garnet occurs only in small patches, never exceeding trace amounts overall. Banding occurs on a fine scale and is little disturbed by the growth of the felspar porphyroblasts, no true augen structure resulting. This indicates that the porphyroblastic felspars have grown by absorbing existing rock materials from within a small radius.

(*d*) *Quartzites and felspathic quartzites*

In contrast with some Basement System areas of Kenya few exposures of quartzite were found. The largest occurrence is in the nose of a plunging synclinal fold west of Mugama where the quartzite (specimen 65/168) makes a prominent feature in quartzo-felspathic gneisses. It is a fine-grained, hard, well-banded rock, the bands varying in colour from white to deep red. It is markedly fissile due to the occurrence of muscovite in discrete layers parallel to the banding. Under the microscope it appears as an even-grained mesh of interlocking anhedral crystals. Other minerals besides quartz are orthoclase felspar, microperthitic microcline, minor amounts of plagioclase (oligoclase-andesine) and muscovite. No mafic minerals are present. Specimen 65/211 from a point four miles further south in the Mgama ridge, was taken from a very small outcrop whose relation to the adjacent granitoid gneiss was not clearly determined. The rock is very similar in appearance to specimen 65/168 except that the banding is on a finer scale. A higher proportion of muscovite and the presence of graphite make for an even higher degree of fissility. Marked iron-staining along cracks and crystal junctions gives a red colour to the rock. Quartz here makes 75 per cent of the whole, and the only felspar present is orthoclase. Often accompanying the graphite, and occurring as discrete blebs and veins, is a very fine granular aggregate of a bright yellow weakly pleochroic mineral, a weathering product believed to be copiapite.

Float blocks of quartzite were found at various scattered localities in the south-east, over a large area between Kinjaro hill and Rumangombe, but no exposures were seen.

(*e*) *Quartzo-felspathic gneisses*

The quartzo-felspathic gneisses are mostly of medium grain with well-marked gneissose structure, sometimes cream in colour but usually reddish due to iron-staining. Quartz, potash felspar and usually small amounts of plagioclase felspar (oligoclase) make up the bulk of the rocks with mica, mainly muscovite, as a common accessory, and occasionally garnets. In specimen 65/161 from Zongoloni sillimanite occurs as silky aggregates of fibrolite which amount to about ten per cent of the whole. Where metamorphism has locally attained a higher degree the gneissose layering tends to disappear and the grain size becomes much coarser, so that in hand-specimen the rock might be termed a granitoid gneiss. Cases in point are in the northern end of the Mgama Ridge and further west, at Mwanakindi and Mtongore. Distinction between quartzo-felspathic gneiss and granitoid gneiss was made on the aspect of the outcrop in the field, the term granitoid gneiss being reserved for those outcrops which show a typical granitic appearance, with craggy tors giving a broken and rugged topography as compared with the much more even outlines and smooth rock pavements typically developed by the quartzo-felspathic gneisses.

Some estimated modes of the quartzo-felspathic gneisses are as follows:—

	65/197	65/196	65/172	65/161	65/169
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Quartz	50	50	40	30	20
Orthoclase	35	30	45	55	50
Plagioclase	4	5	5	—	—
Microcline	10	15	10	—	—
Micas	—	+	+	5	8
Other minerals	1	+	—	10*	22†

*Mainly sillimanite. †Mainly hydrated iron oxides.

65/197 and 65/196—Kamshari plain.
65/172—North Mgama ridge.
65/161—Zongoloni.
65/169—North Mgama ridge.

(*f*) *Granitoid gneisses*

Granitoid gneisses form the bulk of the Mgama ridge and the two hills to the south-east, Mairimba and Kavisago, giving rise to conspicuous features that rise steeply from the surrounding country. In the Mgama ridge they form the core of a tight synclinal fold and it is probable that Mairimba has a similar structure, though this could not be determined with certainty. In hand-specimen the granitoid gneisses are coarsely crystalline and of a patchy pink and white colour, seldom showing more than a vague indication of gneissose structure. Under the microscope the main constituent minerals are seen to be quartz, potash felspar and plagioclase felspar. Microcline, usually coarsely perthitic, is always later in origin than the orthoclase felspar, and in specimen 65/165 from Mugama clear glassy crystals of microcline can be seen to have grown at the expense of a cloudy orthoclase crystal. The plagioclase is always sodic, near oligoclase, and myrmekite is not uncommon between quartz and felspar. Mica, which is seen in only small amounts, is mainly muscovite in thin filmy flakes resembling talc, and in specimen 65/214 from Kide the place of much of the mica is taken by apple-green sericite. The only other accessory mineral identified is rutile, which appears as minute crystals in specimen 65/182 from Kavisago.

The coarseness of grain and lack of foliation in these gneisses suggests that when metamorphism was taking place the rocks must have been fairly plastic, but contacts, particularly with the crystalline limestone of Muguma hill, are always sharp and unchilled, with none of the intertonguing that would be expected had the rock material been mobilized to any great extent. By the same criterion it is certain that the granitoid gneisses are granitized sediments and not intrusive granites derived from a deep-seated source.

True pegmatites were nowhere seen in the granitoid gneisses, though a few thin stringers and veins of quartz sometimes cut across the strike, or more commonly form lenticles whose disposition bears no relation to the strike. It is considered that these quartz veins are segregations from the rock in their immediate vicinity.

Some estimated modes of granitoid gneisses are quoted below:—

	65/213	65/165	65/180	65/182	65/185
	per cent	*per cent*	*per cent*	*per cent*	*per cent*
Quartz	60	30	25	20	10
Orthoclase	40	14	50	55	15
Microcline	—	55	10	4	70
Plagioclase	+	—	13	20	4
Mica	—	1	2	1	1
Other minerals	—	—	—	+	—

65/213—West of Lilani.
65/165—Mugama.
65/180—Mairimba.
65/182—Kavisago.
65/185—Mikeli.

(4) Metamorphosed Pelitic and Semi-Pelitic Sediments

(a) Hornblende and hornblende-garnet gneisses

Hornblende gneisses are not well-developed in the area, though two fairly wide exposures at Campi ya Bibi and Kisorini, both west of Maktau and both only patchily exposed in railway drainage channels, suggest that they may be far more widespread than the map shows, and that their poor resistance to erosion has led to their planation and covering by detrital soil. Further, it is possible that some original hornblende gneisses may have been converted to biotite gneisses under the high grade of metamorphism which has been proved over most of the area.

The hornblende gneisses are always dark brown or grey, relatively coarse in grain and markedly gneissose, often with banding well-marked by alternating layers of yellow leucocratic material and mafic hornblende-bearing layers. The hornblende, which makes as much as thirty per cent of the rocks, is always strongly pleochroic from pale to dark green and is usually associated with opaque iron ores. Other minerals always present are quartz and plagioclase felspar of oligoclase-andesine composition. Orthoclase felspar was recognized in all thin sections except 68/2 from Rumangombe, where its presence is doubtful. Microcline was not seen in any section. Garnets are pale pink to almost colourless in thin section, subhedral or irregular in outline and generally much fractured, with heavy iron-staining picking out the fractures. Formation of the garnets has nowhere given rise to augen structure. Accessory minerals are rare, only apatite, muscovite and graphite (all in trace amounts) being recognized in addition to the opaque iron ore mentioned above. Typical estimated modes are:—

	68/2	65/186	65/202	65/199
	per cent	*per cent*	*per cent*	*per cent*
Quartz	8	5	40	40
Orthoclase..	?	25	25	30
Plagioclase	60	60	25	10
Hornblende	30	10	9	5
Garnet	+	+	1	15
Other minerals	2	+	+	—

68/2 —Rumangombe.
65/186—Kisorini.
65/202—Nine miles south of Kinjaro hill.
65/199—Three miles west of Kinjaro hill.

(b) Plagioclase amphibolites

Plagioclase amphibolites occur in two forms, as continuous bands concordant with the strike of the neighbouring rocks and as inclusions in the biotite gneisses where, with the host, they form agmatite (when they are present as angular blocks) or boudinage bodies, with ovoid or lenticular outlines (*see* Figs. 2 and 3).

A typical specimen is 65/195, from an isolated outcrop five miles south of Kwamanagadi. In hand-specimen it is a compact, medium-grained rock, with whitish translucent felspars, speckling a jet black background. Under the microscope it shows an equigranular mosaic of subhedral hornblende, pleochroic from yellow-green to dark green, intergrown with blue-green faintly pleochroic diopside. The felspar crystals are interstitial to the mafic minerals and are andesine. Most of the felspars are albite-twinned. The volumetric mode of 65/195 was estimated as plagioclase 40 per cent, hornblende 45 per cent and diopside 15 per cent. Common accessories in the plagioclase amphibolites are garnet and epidote in trace amounts.

Exposures of the plagioclase amphibolites are poor due to their lack of resistance to weathering, and are usually heavily masked by secondary limestone formed during weathering, which has led to the leaching-out of calcium carbonate and its redeposition at the surface.

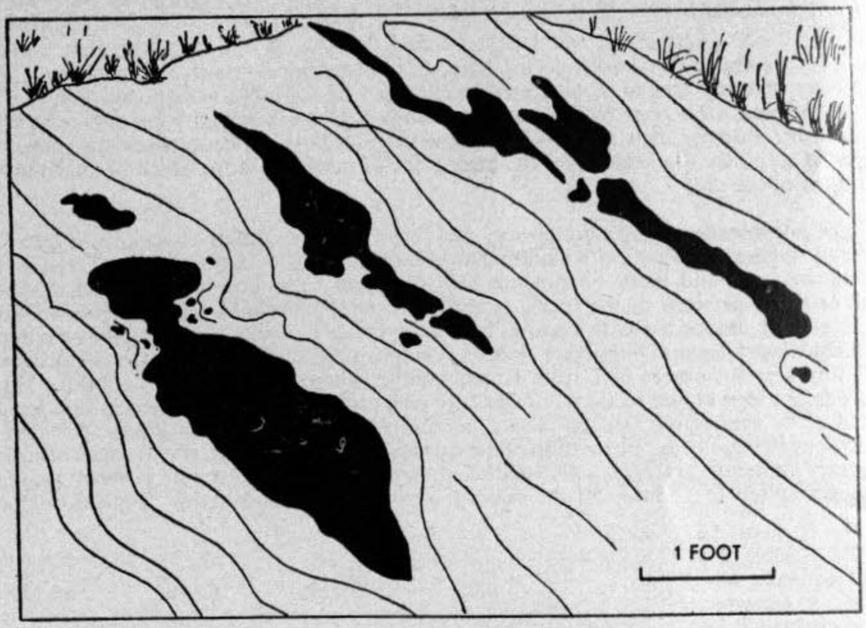


Fig. 2.—Boudinage structure in biotite gneiss. North of Naoni.

Fig. 3.—Agmatite structure in biotite gneiss. Railway cutting east of Voi river bridge.

The origin of the plagioclase amphibolites is not clear. They might possibly represent metamorphosed basic igneous intrusions or lavas, when the latter would be more likely in view of their general concordance with the strike of adjacent rocks. The writer prefers to think, however, that here they had their origin in fairly calcareous clays or siltstones, the boudinage structures resulting from local segregation in sandy sediments of calcareous material which has to some extent resisted metasomatism or has not been completely assimilated into the surrounding migmatized gneiss. Sanders (1954, pp. 11–12) describes similar occurrences in the Kitui area which he classifies as hornblendic migmatites, and in describing the adjoining North Kitui area Dodson (1955, pp. 11–12) has referred to the sedimentary origin of plagioclase amphibolites occurring as lenses in biotite gneiss.

The plagioclase amphibolites of the present area are typical of those of the amphibolite facies of Eskola (Turner, 1948, pp. 76–88) and are in good accordance with the grade of metamorphism of the whole area (*see* p. 17).

2. Intrusives into the Basement System

(1) Metadolerites

Only one occurrence of metadolerite was found, represented by outcrops in the extreme south-east that have been cut and displaced by a strong north-west to south-east fault. The rock is poorly exposed and is found mainly as float fragments, but the outcrop can be traced as a marked ridge almost denuded of topsoil and exposing surface concretions of *kunkar* limestone and a reddish brown cellular siliceous ironstone (specimen 68/4) both of which have formed from the breakdown of the solid rock under weathering. In hand-specimen (68/3) the metadolerite is a medium- to fine-grained admixture of black pyroxene and whitish translucent felspar, and locally has a vague banded appearance. The banding appears to bear no relationship to the strike of the body as a whole. Garnets are rare, sometimes occurring in thin streaks whose individual crystals seldom attain a diameter of 1 mm. Its mode was estimated as:—

	per cent
Plagioclase	42
Diopside	53
Epidote	3
Sphene	2
Garnet	+
Apatite	+

The diopside occurs in an interlocking mosaic with felspar and has subangular grains showing a fairly strong pleochroism from yellow-green to medium olive-green and occasionally fine polysynthetic twinning. The plagioclase felspar, labradorite-bytownite in composition, is roughly equigranular with the diopside and interstitial to it. It shows coarse albite twinning and rare individuals have pericline twinning in addition. The sphene seldom shows crystal form and occurs as small rounded grains in contact with and sometimes enclosed by diopside. Epidote occurs as zoned crystals, the cores being pleochroic from yellow to pale olive-green, and sometimes simply twinned, the rims being almost colourless.

The concordance of the strike of this rock with nearby gneisses suggests that it may possibly be a sill or a metamorphosed basalt flow, but the only contact seen was with a small outcrop of crystalline limestone, the junction being largely obscured by surface crustal deposits, and it was not possible to deduce whether the two rocks are still concordant at depth. The age of the intrusion is similarly a matter of conjecture, but it is tentatively regarded as being of Basement System or immediate post-Basement System age.

(2) Giant Quartz Veins

Although not intrusive rocks in the strict sense of the words the giant quartz veins are considered here for convenience. Two were mapped, one forming the hill of Kinjaro and the other three miles to the south. Both are of a brilliant white colour and are extremely pure, no other mineral than quartz being seen, and there is no discoloration except by organic growths at the surface of the outcrop. The rock weathers to huge sub-angular boulders, but no preferred orientation of jointing was noted. The vein forming Kinjaro hill is remarkable in that, while little more than 150 feet in width of outcrop, it forms a steep ridge standing three to four hundred feet above the surrounding country, the surface of the flanks of the hill being composed of fallen blocks of quartz in sandy soil. Both veins are conformable with the general strike of the rocks in their vicinity.

(3) Minor Acid Pegmatites

Intrusive pegmatites are few and small in the area. South of Mwatate hill a small amount of float shows a coarse aggregate of quartz and felspar with rare clusters of black tourmaline, and a stringer of similar rock only a few inches in thickness cuts the summit of Mtonga. Fragments of ilmenite and quartz over a small area of the *kunkar* limestone and siliceous ironstone capping the metadolerite near Rumangombe indicate a small pegmatite there. A small excavation at Maktau Station is cut in a very coarse pegmatite (specimen 65/190) of quartz and felspar with small amounts of black and white mica, whose individual flakes never exceed the size of a postage stamp. Owing to the thick cover of red soil here and the lack of float fragments no indication was found of its extent.

In the metasomatized gneisses discordant pegmatites composed of quartz and large semi-rounded microcline felspars are common but their lateral extent is always small and mineralization completely lacking. In most cases they can be traced back to, and grade imperceptibly into the country-rock and they are clearly replacive segregations derived partly from the country-rock and partly resulting from local concentrations of metasomatizing fluids.

3. Pleistocene and Recent Deposits

Over much of the area the solid geology is completely masked by varying thickness of red-brown sandy soils consisting of angular fragments of quartz and felspar with small amounts of mica, hornblende, garnet and iron ores, mainly haematite and magnetite, with some ilmenite. Gullies in the Mwatate valley prove these soils to exceed 20 ft. in thickness locally. Lateritic ironstone is rarely seen, probably due to the low rainfall and consequent slow rate of chemical leaching. Where seen, e.g. in railway drainage ditches west of Maktau, it consists of a layer averaging 18 inches in thickness under up to three feet of apparently unaltered soil.

Poor drainage over large areas of the sub-Miocene peneplain has led to the formation of black-cotton soils with a thin and discontinuous layer of nodular *kunkar* limestone just below the surface. The surface of this black soil is frequently covered with a thin (up to six inches) deposit of light grey sand, which is almost free of vegetation and results from the loss of clay minerals and humus at the surface. This is thought to be due to the periodic drying out and shrinkage of the top surface, resulting in the formation of deep, open cracks and the breaking down of the soil into a crumb structure. At this stage some of the fine clay material and humus can be removed by wind action, and later rain will wash out more of the fine material and carry it downwards, leaving at the surface only the coarser sandy constituents of the original soil.

Sandy river alluvium is almost lacking, being confined to the Voi river and to narrow and discontinuous bands along the Bura and Mwatate rivers. Panning showed the only heavy minerals present to be magnetite, haematite and a small amount of ilmenite.

Over outcrops of crystalline limestones and other lime-rich rocks *kunkar* limestones are widely developed, generally extending laterally well beyond the outcrop which gave rise to them. They are cream or pink in colour, the latter due to iron oxide staining, and frequently include angular fragments of quartz and felspar.

V—GRANITIZATION AND METAMORPHISM

The widespread granitization found throughout the area, which shows itself in the development of microcline, arose as a result of alkali metasomatism. The earliest stage of metasomatism that is clearly recognizable is the fine-scale banding in the biotite gneisses, where melanocratic layers are separated by leucocratic quartz-felspar layers. The freshness of the felspars in the leucocratic layers against the turbid and often altered felspars in the melanocratic layers demonstrates the subsequent origin of the clear felspars.

There is no marginal chilling between adjacent layers such as would occur with the injection of a magma into the foliation planes of the original gneiss (provided that the gneiss was at a lower temperature than the invading magma), but a sounder argument against injection is the absence of any true granitic mass or even pegmatite in the neighbourhood of the banded gneisses.

A higher degree of metasomatism is shown by the development of felspar porphyroblasts in the banded gneisses, the porphyroblasts growing through the melanocratic layers without noticeably displacing them or giving rise to augen structures. This can be explained only by postulating the growth of the felspar porphyroblasts at the expense of the existing rock minerals, promoted by diffusion of fluids through the rock, with no significant addition to its mass.

The third and ultimate stage is the development of granitoid gneiss with little or no remnants of the original gneissic foliation and generally a very marked coarsening of grain. At this stage the rock attained a degree of plasticity if not of true mobility.

The field relationship of the banded gneisses and felspar porphyroblast gneisses, particularly in the Sembi-Zongoloni ridge, suggests that the original rock was fairly homogeneous, and that the higher degree of granitization in the north is a result of more intense metasomatism there. The granitoid gneisses of the Mgama ridge are nowhere in contact with or adjacent to the banded or porphyroblastic gneisses, and whether the higher degree of granitization is due to the degree of metasomatism or rather to the susceptibility of the original rock could not be determined.

The crystalline limestones have not been affected by metasomatic agents, being chemically much less susceptible to alteration and, due to their ability to flow plastically rather than fracture under pressure, may have proved a barrier to activating fluids. Some evidence of their ability to hold back granitizing agencies is shown at the northern end of the Mgama ridge where two bands of crystalline limestone enclose quartzo-felspathic gneiss, whereas north and south of the limestone bands the rock is true granitoid gneiss.

The metamorphic grade of the rocks of the area indicates that they fall into the amphibolite facies, reaching the sillimanite-almandine sub-facies, equivalent to the sillimanite zone of the Scottish Highlands. In the Mgama ridge kyanite and sillimanite are present in the same rock (specimen 65/212) suggesting that that part of the area may be marginal to the kyanite and sillimanite zones. Sanders (1954 B, p. 147) has sketched the approximate boundary between the two zones in Kenya, and tentatively places it about 20 miles east of Mgama, the higher (sillimanite) grade occurring to the eastward. The fact that sillimanite is not more plentiful in the area is explained by the lack of sufficient alumina in the original sediments to have allowed it to develop. The great majority of the original sediments which gave rise to the rock types now exposed apart from limestones, were sandstones and arkoses, and clays (rich in aluminium) were insignificant or absent.

In the crystalline limestones the only minerals recognized indicative of metamorphic grade are tremolite (actinolite) and diopside which indicate a lower grade than that attained in the other rocks. Wollastonite, which frequently occurs in marbles in Kenya, was not found, although the silica percentage of the limestones is generally sufficient to allow its formation. Turner (1948, p. 102) explains its absence from metamorphosed limestones by its instability in the presence of excess CO_2 under extreme pressure.

The sequence of events in the history of the area was: first deposition of the original sediments, secondly intense folding and metamorphism, and lastly metasomatism and granitization, which are thought to have commenced after the completion of the second stage.

VI—STRUCTURES

The main structural features of the area are shown in Fig. 4. As in so many other areas of Basement System rocks in Kenya the strikes are generally parallel and trend west-north-west to east-south-east.

Lineation is well-marked in most of the micaceous rocks and can frequently be determined in the crystalline limestones. It is recognized by parallel orientation of mineral grains and fine-scale puckering in the micaceous layers of banded gneisses. Foliation is marked by orientation of mica and graphite flakes and by alternation of leucocratic and melanocratic layers in banded gneisses. It is invariably parallel to the junctions of rocks of differing composition. Two hundred and fifty four poles to foliation planes were plotted on a Schmidt equal area stereographic net and a contoured diagram produced (Fig. 5). The maximum indicates that the majority of the observed foliation planes dip to the east-

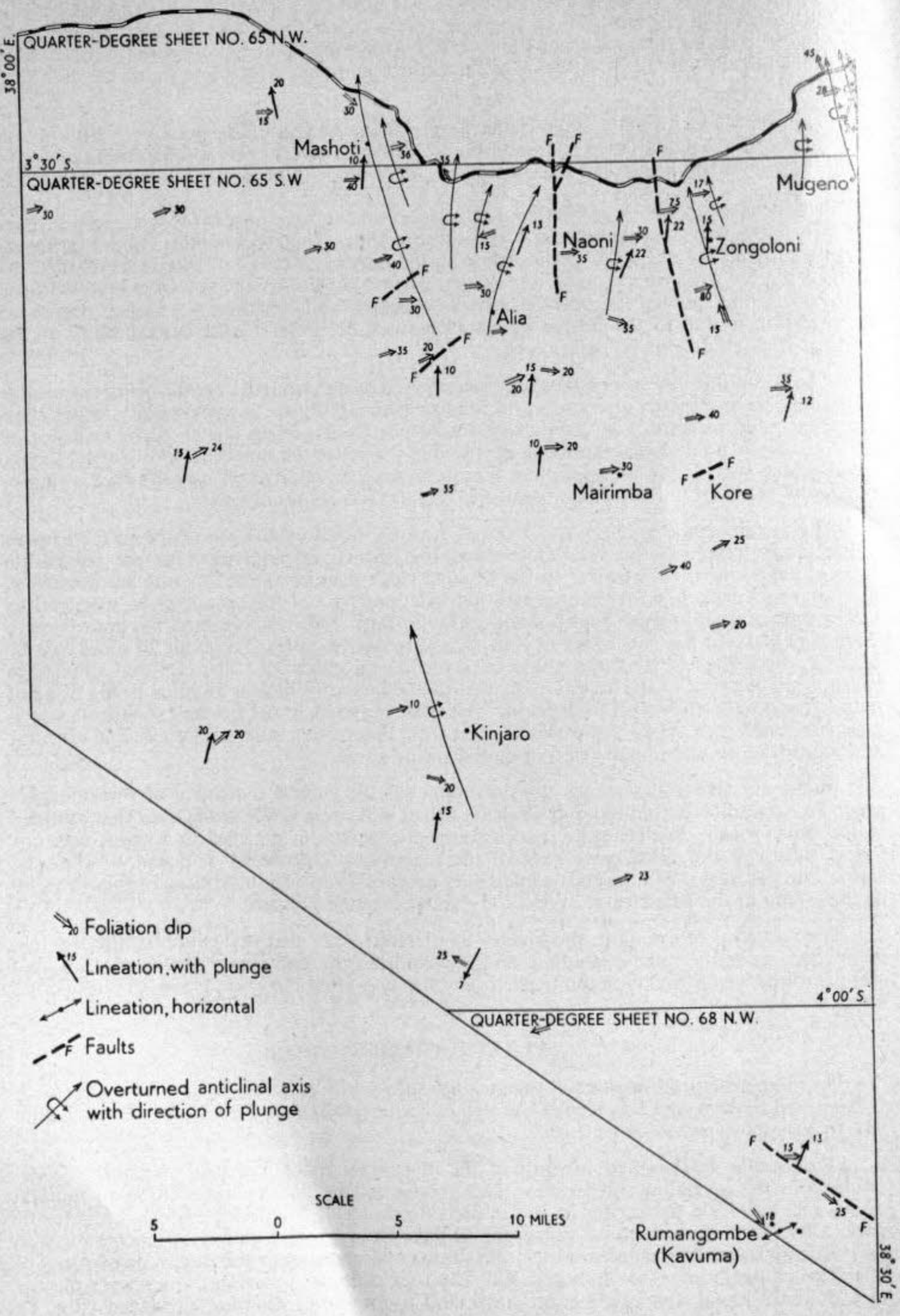
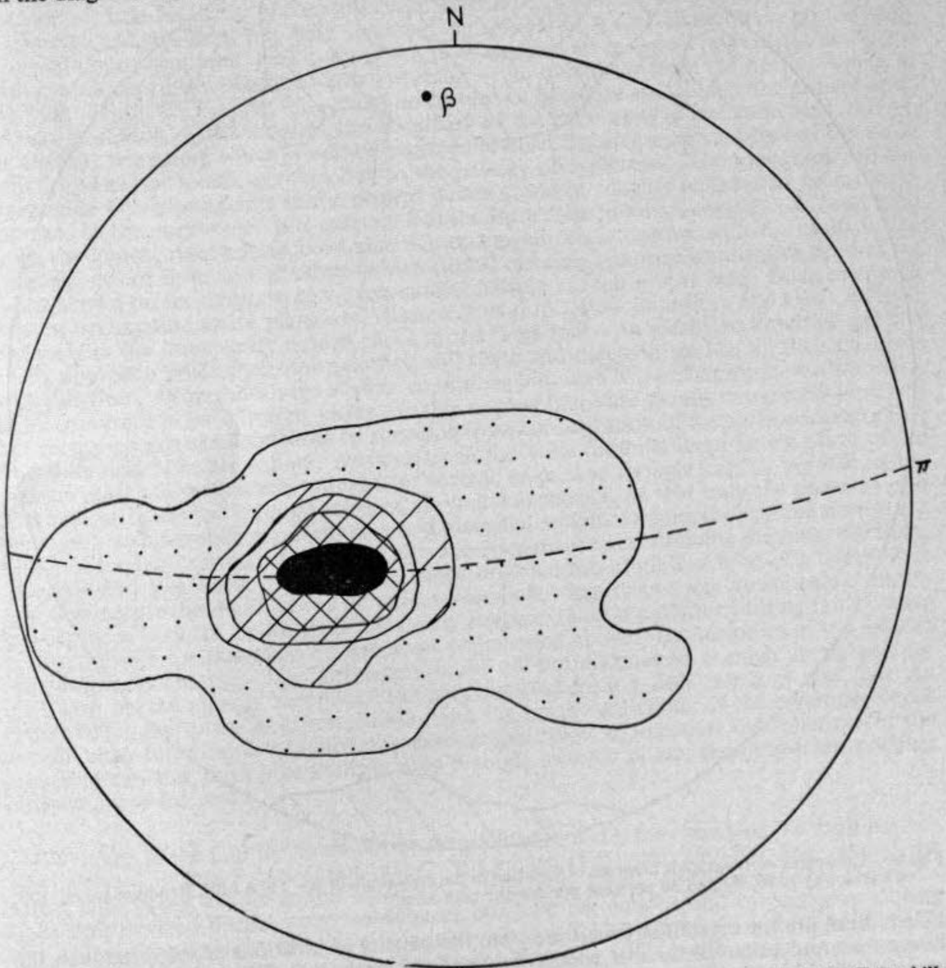


Fig. 4.—Structural sketch map of the area south of the Taita hills.

north-east at angles of between 15 and 35 degrees. Weiss (1954, p. 6) points out that such a single sharp maximum shows either that the intensity of the folding is relatively slight, so that the rocks in effect form a uniformly dipping sheet, or that the area is over-folded. In the present area the latter is the case. The concentration of poles along the great circle on the diagram indicates a single system of folding, with B as fold axis.



Fi . 5.—Contoured stereographic diagram of poles of foliation plans in the area south of the Taita hills Readings taken, 254. Contours at 1, 5, 9, 13 and 17 per cent for one per cent area.

The lineations measured almost invariably trend north-south, with a marked plunge to the north. One hundred lineations were plotted to give the contoured diagram of Fig. 6 (the faulted block in the extreme south-east was ignored in this construction and in the preparation of Fig. 5). The excellent accord of the maximum here with the fold axis B of Fig. 5 is a clear indication that the rock structure is of monoclinic symmetry and that the lineation is a true B lineation marking the axis of folding. In other words the foliation and lineation are the result of a single tectonic phase or, if of repeated phases, later pressures always followed a similar direction. No microscope investigations of mineral grain orientations were made but these too would be expected to show a similar pattern.

Twelve anticlinal folds were recognized in the northern part of the area, all plunging northwards and overfolded towards the west, and it is certain that more such folds occur but are not seen due to lack of exposures. The best marker horizons for deciphering the

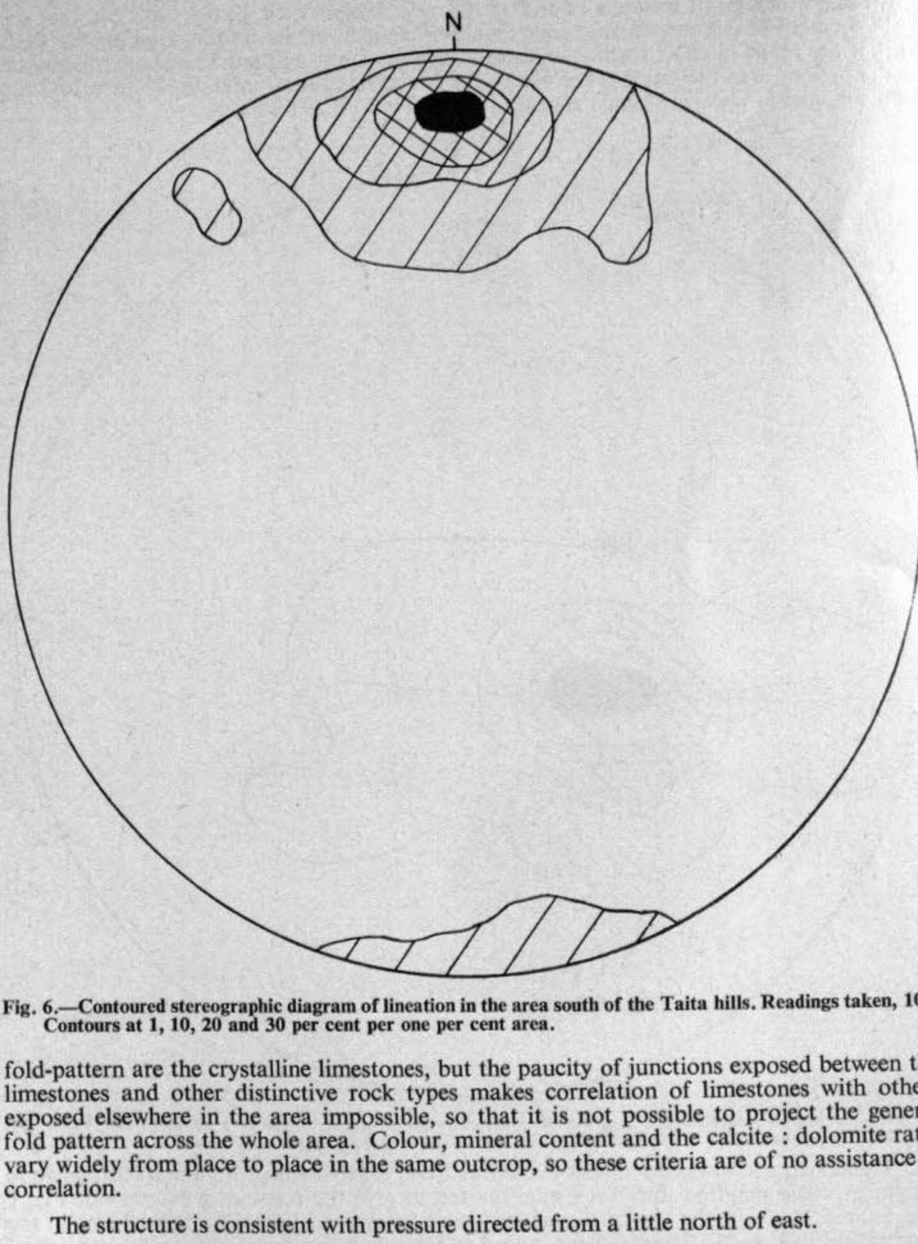


Fig. 6.—Contoured stereographic diagram of lineation in the area south of the Taita hills. Readings taken, 100. Contours at 1, 10, 20 and 30 per cent per one per cent area.

fold-pattern are the crystalline limestones, but the paucity of junctions exposed between the limestones and other distinctive rock types makes correlation of limestones with others exposed elsewhere in the area impossible, so that it is not possible to project the general fold pattern across the whole area. Colour, mineral content and the calcite : dolomite ratio vary widely from place to place in the same outcrop, so these criteria are of no assistance in correlation.

The structure is consistent with pressure directed from a little north of east.

The general northwards plunge of lineation has been noted in many areas of Basement System rocks in Kenya, viz.—in south-east Machakos (Dodson, 1953, p. 16), south Machakos in part (Baker, 1954, p. 21), west of Kitui (Schoeman, 1948, p. 40), north Kitui (Dodson, 1955, p. 24), Embu-Meru (Schoeman, 1951, p. 52), south-east Embu (Bear, 1952, p. 35), Nanyuki–Maralal (Shackleton, 1946, pp. 25–26) and Taveta (Bear, 1955, p. 37). In all these areas the directions of the lineations are almost parallel to the traces of the axial planes of the folds. Such a northerly plunge of fold axes, continuing with only minor variations over a distance of some 300 miles with an average plunge of 10°, would indicate a vertical thickness of the fold-complex of above 50 miles. This would not only require a very great thickness of original sediments but, making the reasonable assumption that crustal shortening throughout the 300 miles is fairly constant (it is of the order of two and a half miles compressed to one mile, south-west of Bura) would indicate that the complex in the south had been eroded to a depth greater by 50 miles than that in the north. This is so unlikely that other explanations must be looked for. It is possible that plunge depressions occur which have not been recognized, but the writer prefers to believe that the explanation lies in a series of east-west faults which again have not been mapped. In the Mtito-Andei–Tsavo area, immediately north of the present area, Parkinson (1947, p. 4) mapped an east-west fault along the Tsavo valley, and tentatively described it as the result of an overthrust from the north. Again, at the foot of Bura Bluff, some three miles north-west of Mwatate and outside the present area, an east-west fault marks the southern boundary of the main mass of the Taita hills, though its westerly extension, which would be expected to enter the area mapped between Bura and Maktau, was not found, perhaps due to the paucity of exposures. The topography of the Taita hills strongly suggests to the present writer a grid of roughly rectangular fault blocks all tilted to the north-east. It is possible that the Bura river follows a roughly east-west fault from the almost right-angled bend near Kwamanagadi and, together with the faults in the valleys south of Bura and Mwatate (which almost certainly continue southwards beyond the limits shown on the map), would give a similar pattern of fault-blocks here. In an area such as this, undergoing active planation, rivers will tend to follow fault-lines and excavate their channels in the more easily eroded rocks of the fault-zone. As planation develops and the rivers approach grade their down-cutting will cease and they will tend to fill their channels with alluvium. With the advent of drier conditions hill-wash will perhaps bury the alluvium, as has occurred in the Mwatate valley. In this manner faults are usually completely obscured but their presence can sometimes be surmised from consideration of the surface topography. The Bura and Mwatate valleys, particularly in the Taita foothills immediately north of the present area, are remarkably straight for several miles, and though roughly parallel to the strike nevertheless cut through rocks of varying competence, so that only the presence of a fault could explain such regularity in a non-glaciated region. Despite the marked northward tilting of the land surface of the Taita hills the three main rivers draining the hills, the Bura, Mwatate and Voi, all flow southwards, suggesting that the tilting has been of a continuous and slow nature that has allowed the original south-flowing rivers to cut down their channels to keep pace with the uplift. It is tentatively suggested that a pattern of tilting fault blocks occurs through the Basement System areas enumerated above. The tectonics of the pattern are admittedly obscure. The north-south faults are not uncommon in other areas, and are explained by the already mentioned pressure directed from a little north of east, but the forces which led to the east-west faulting and the northward tilting of the resulting blocks are not clear for, as already stated, the stereographic plots of lineation and foliation for the area south of the Taita hills indicate only a single tectonic phase, resulting from pressure directed from the east.

The age of the faulting could not be determined, but it is assumed that the fault pattern was initiated in late Precambrian times. McConnell (1951, pp. 199–200) has related the Great Rift Valley to this ancient system of north-south faults, and suggests that the faults have been revived during many subsequent orogenic revolutions and in particular during the Alpine diastrophism and its posthumous phases, which formed the East African rift valleys as we know them today. That movement along the faults is still continuing is evident from the fairly frequent earth tremors that are known to occur in the area. In June, 1955, a tremor felt in the Mwatate valley was carefully investigated by the writer and it was concluded that movement had occurred at depth from south to north along the Mwatate valley fault.

No preferred direction of jointing was noted in the area as a whole. Over very small areas, in the order of a square mile, a definite pattern could sometimes be determined but no obvious connexion could be seen between the patterns of nearby areas.

VII—ECONOMIC GEOLOGY

No written records exist indicating that this area has ever been prospected for economic minerals, though it is known that E. Blood and E. Parsons examined it. Both kyanite and graphite have been prospected and worked in nearby areas to the north.

1. Garnets

Garnets occur in many of the rocks and in one specimen from south of Zongoloni (65/156) garnet was estimated as 26 per cent of the whole. The outcrop, however, is small and isolated and the garnets too small to command a ready sale. In other outcrops the garnet content seldom reaches ten per cent and is not regarded as suitable for economic exploitation, while again their small size as well as erratic distribution makes profitable working most unlikely.

2. Graphite

Occurrences of graphite are fairly widespread, the more important localities being—

(1) The Mindi area
(2) The Mgama ridge
(3) The Mkengereni–Tasha block.

Mindi.—Sample 65/178x from Mindi showed a graphite content of 6·98 per cent on assay, and sample 65/183x from Kavishoi assayed 10·92 per cent. The latter, while of fairly small flake size, occurs in friable rock and could be easily worked. The same rock carries an estimated 10 per cent of sillimanite. A serious disadvantage to economic working is the lack of water in the area, though bore-holes in the valleys of the Mwatate or Bura rivers (both several miles distant) would almost certainly provide a steady and adequate supply.

Mgama Ridge.—Three important graphite localities were mapped on or near the Mgama ridge. Sample 65/166x from the outcrop immediately west of Mugama trigonometrical point contains 11·08 per cent of graphite in a fairly hard rock that could not be easily worked. Sample 65/210x from Lilani, east of the ridge, contains 7·76 per cent of graphite in a coarse rock matrix which is in part friable, and separation would not be difficult. Flake size reaches 0·3 cm. in diameter and it is expected that a saleable product could be extracted. The deposit occurs as a fairly narrow band flanked by crystalline limestones, the whole forming a steep elongated hill, and the removal of any great quantity of ore would necessitate underground working or the removal of a great deal of limestone to expose an adequate working face. The last occurrence, in the central part of the ridge (specimen 65/212) contains an estimated 10 per cent of graphite, generally in good-sized flakes. They were set in a coarse, hard matrix and would not be easily extracted. An average content of 30 per cent of kyanite and sillimanite in the same rock, however, would provide a by-product which might make the whole a payable proposition. No water occurs anywhere near, but might be obtained from bore-holes sited on either side of the ridge.

Mkengereni-Tasha.—Representative samples from Mkengereni showed a total graphite content of 5·13 per cent (sample 65/162x) and from Tasha 3·91 per cent (sample 65/163x). The former has a fairly large flake and might repay closer prospecting but the smaller flakes of the Tasha graphite would not be readily saleable on the present market.

It is considered that further prospecting in the Mindi and Mgama areas would be justified to prove the quantity and concentration of the available graphite. Careful laboratory tests on truly representative samples would have to be made to determine whether the mineral can be readily extracted and refined to meet the specifications of buyers, and to compete with the product of such major producers as Madagascar.

3. Ilmenite

Ilmenite was found as float in the extreme south-east of the area, but the small quantity seen and the remoteness of the occurrence from any form of communication makes it of no economic value. Very small quantities occur in the alluvium of the Voi and Bura rivers, but are of no commercial importance.

4. Kyanite and Sillimanite

Kyanite, in blue bladed crystals reaching a length of 6 cm. occurs in the graphitic gneiss of the central Mgama ridge (specimen 65/212, discussed above under "Graphite") and is associated with sillimanite which has replaced much of the crystalline kyanite. The proportions of kyanite and sillimanite vary widely from place to place in the outcrop, but it is estimated that they nowhere reach 50 per cent by volume of the country-rock. Sillimanite occurs in quartzo-felspathic gneisses between Sembi and Zongoloni (specimen 65/161) but the alumino-silicate makes up only 10 per cent of the rocks. Finally, in specimen 65/183 from Kavishoi (also discussed under "Graphite") the sillimanite also averages only 10 per cent.

None of these occurrences would repay further investigation at present for the sake of kyanite and sillimanite alone.

5. Limestones

The existence of the various limestones that outcrop along the northern margin of the area has long been known, and an investigation of their commercial possibilities was made by Parsons (1943) who, as part of a widespread search for local materials to replace imports cut off by war-time conditions, made a traverse from Voi to Taveta. The only limestone he sampled here was from the extensive outcrop near the Voi river in the north-east of the area, whose magnesia content proved to be 18·6 per cent. As the primary object of his search was to find limestones suitable for the production of cement no further work was done on the outcrop since the maximum allowable content of magnesia in British Standard Portland Cement is 4 per cent, which means that the raw limestone should preferably contain not more than 2 per cent.

Since the magnesia content of limestone is the overriding criterion in determining its commercial value samples from the various outcrops were tested to determine their calcite dolomite ratios. Results were as follows:—

Specimen Number	Ratio Calcite ($CaCO_3$) : Dolomite ($CaMg(CO_3)2$)*
65/135	55 : 45
65/139	95 : 5
65/141	65 : 35
65/157	55 : 45
65/167	65 : 35
65/170	65 : 35
65/173	55 : 45
65/198	65 : 35
65/224	65 : 35
65/218	95 : 5
65/223	95 : 5

Analyst: Mrs. R. Inamdar.

*The method used for these determinations was colorimetric. Samples ground to −200 mesh were treated with $AgNO_3$ (silver nitrate) and K_2CrO_4 (potassium chromate) under standardized conditions and comparison of the shade of powder with that of 11 standards prepared from pure calcite and pure dolomite varying in ten steps from 100 per cent calcite to 100 per cent dolomite. A colour range was obtained from very dusky red for calcite to light grey for dolomite.

Crystalline limestones:—

65/135—South-west of Pusa
65/139—South of Kambanga
65/141—Two miles west of Pusa
65/137—Three miles south of Mugeno
65/167—Three miles north of Mugeno
65/170—Mashoti
65/173—Mwanakindi
65/198—Two and a half miles west of Kinjaro hill
65/224—Two miles south-south-east of Voi river landie.

Secondary limestones (*kunkar*):—

65/218—Mkameni
65/223—Two miles south-south-east of Voi river landie.

Of the crystalline limestones only 65/139 shows a low ratio of dolomite to calcite, equivalent to magnesia (MgO) content of about one per cent, but the small size of the outcrop makes it unlikely to prove of importance, even if more detailed prospecting should prove the magnesia content to remain constantly low throughout the whole deposit.

The two deposits of surface limestone are both easily accessible to the railway and may warrant further investigation. The thickness of the deposit at Voi river was not determined, but that at Mkameni is above six feet where sampled, in a pit dug for road-metal. The *kunkar* limestones are cream or pink in colour, the latter denoting a small content of iron oxide, and usually contain angular fragments of quartz and felspar where they transgress the crystalline limestones which gave rise to them and overlie gneisses. The volume of such inclusions in places reaches ten per cent of the whole.

No evidence was found of the limestones being utilized except as road metal, though the availability of almost unlimited supplies of brushwood in the neighbourhood of all the deposits would make the burning of small quantities of lime for local use a cheap and simple matter.

6. Water

For the greater part of the year no surface water occurs anywhere in the area except that impounded by the dam at Mwatate, built a few years ago to supply the sisal factory of Teita Concessions Ltd. Only the Voi river flows for more than a few days in the year, and springs are unknown. The Voi, Bura and Mwatate rivers all drain from the Taita hills, where the annual rainfall in places averages nearly 60 inches per year, and flow strongly all year round in their upper courses. The flow diminishes rapidly to nothing, however, within a few miles of their leaving the hills, the water being lost by downward seepage.

Four bore-holes, C.301, C.302, C.347 and C.350 have been sunk in the Mwatate valley and have proved daily yields of from nearly 5,000 to 48,000 gallons. Bore-hole C.505 at Lualeni in the Bura valley gives a daily average of nearly 20,000 gallons of good though fairly hard water, and bore-hole C.520, close to the railway, halfway between Bura and Mwatate stations, yielded on test a daily output of over 26,000 gallons. The last two bores were sunk mainly to supply water for cattle.

Further supplies could be expected from bore-holes sited anywhere along the Mwatate valley, in small quantities from buried alluvium and in larger quantities from the fault-zone which probably extends along the whole length of the valley and which provides a passage for the underground flow of water draining from the Taita hills. Similarly, as mentioned earlier, the writer thinks the Bura river may follow the line of a buried fault or faults, and if so may similarly provide good bore-hole sites.

In the open plains in the west and south of the area there is virtually no run-off, the proportion of rainfall not held in surface water-holes being lost by evaporation and downward percolation, the latter accounting for the greater part. Resistivity surveys would probably indicate good sites for bore-holes, both where waterlogged strata lie in or under deep soil cover, and in hidden fault-zones in the underlying solid rocks.

VIII—BORE-HOLE LOGS

The following information was derived from the records of the Public Works Department, Nairobi:—

Depth (feet) From	Depth (feet) To	Thickness (feet)	Lithology
			C.301 TEITA CONCESSIONS LTD. SISAL ESTATE, MWATATE
0	5	5	Top soil
5	38	35	Clay and sand
38	312	274	Gneiss
			Water struck at 93, 150 and 250 feet; rest-level 64 feet. Yield on 24-hour test, 4,656 gallons.

Depth (feet) From	To	Thickness (feet)	Lithology
			C.302 TEITA CONCESSIONS LTD. SISAL ESTATE, MWATATE
0	2	2	Top soil
2	23	21	Murram
23	96	73	Quartz sand*
96	440	344	Gneiss
			Water struck at 103, 168 and 350 feet; rest-level 38 feet. Yield on 24-hour test, 21,600 gallons.
			C.347 TEITA CONCESSIONS LTD. SISAL ESTATE, MWATATE
0	15	15	Soil
15	34	19	Clay and sand
34	495	461	Gneiss
			Water struck at 33, 87, 294, 365 and 435 feet; rest-level 20 feet. Yield on 24-hour test, 48,000 gallons.
			C.350 TEITA CONCESSIONS LTD. SISAL ESTATE, MWATATE
0	15	15	Soil
15	23	8	Clay and sand
23	38	15	Decomposed gneiss
38	200	162	Gneiss, hard and soft layers
			Water struck at 35, 70 and 183 feet layers; rest-level 21 feet. Yield on 24-hour test, 25,080 gallons.
			C.505 LUALENI
0	6	6	Red soil and sand
6	42	36	Buff quartz-biotite gneiss
42	53	11	Pinky white fine quartz gneiss with a little biotite
53	80	27	Dark grey quartz-biotite schist
80	116	36	Pinky white quartz schist
116	200	84	Dark grey quartz-biotite schist
200	247	47	Pinky white quartz gneiss with a little biotite.
			Water struck at 148 and 200 to 222 feet; rest-level 69 feet. Yield on 24-hour test, 19,440 gallons.
			C.520 TEITA RESERVE, BURA
0	6	6	Sandy clay
6	28	22	Sandy clay with large quartz-felspar fragments
28	40	12	Weathered gneiss detritus
40	72	32	Pale brown quartz-biotite gneiss
72	100	28	Grey biotite schist
100	160	60	Dirty white quartz-felspar gneiss with biotite
160	240	80	Light grey biotite gneiss
240	253	13	White quartz-felspar gneiss with biotite
253	281	28	Pink quartz-felspar gneiss or pegmatite
281	295	14	Grey quartz-felspar-biotite schist
295	311	16	White-mottled grey biotite gneiss
311	326	15	Light grey-mottled white quartz-felspar-biotite gneiss
326	349	23	As above, slightly schistose
349	363	14	Dirty white quartz-felspar gneiss with small amount of biotite
363	378	15	Dark grey biotite schist and quartz-felspar-gneiss
378	400	22	As above, with less biotite
			Water struck at 208, 240 to 250 feet, main supply at 378 feet; rest-level 131 feet. Yield on 24-hour test, 26,400 gallons.

*It is considered that the top few feet of this stratum represents alluvium and that the major part is decomposed gneiss.

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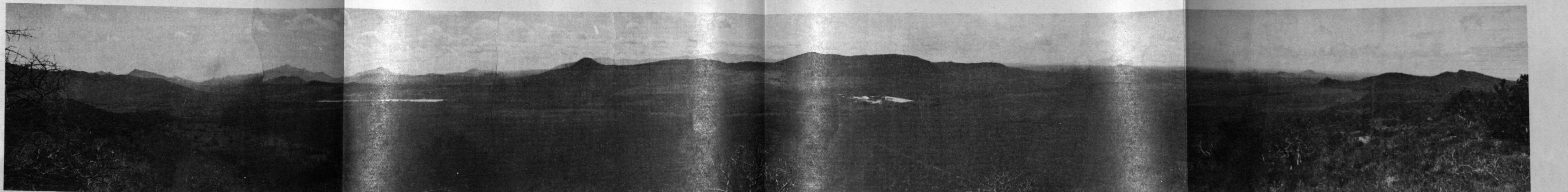

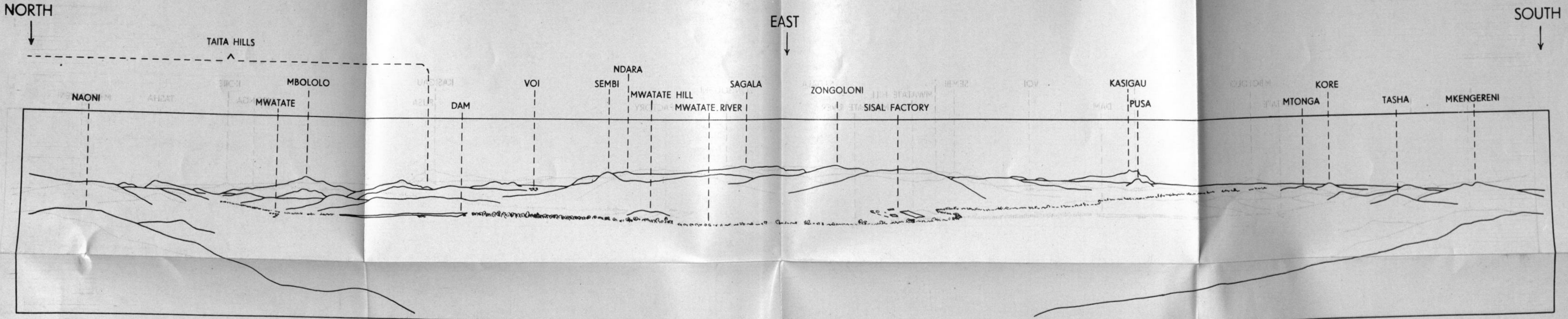

Plate I.—Panorama of the Mwatate valley. The photograph covers 180° from north (left) to south (right), the distance from Naoni to Mkengereni being $4\frac{1}{4}$ miles. Ndara is 15 miles from the camera.

GEOLOGICAL MAP OF THE KURASE AREA