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GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
VOI—SOUTH YATTA AREA

DEGREE SHEETS 65, N.E. QUARTER
60, S.E. QUARTER,
AND PARTS OF THE S.W., N.W., AND N.E.
QUARTER OF DEGREE SHEET 60
(With two Coloured Maps)

By

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Geologist

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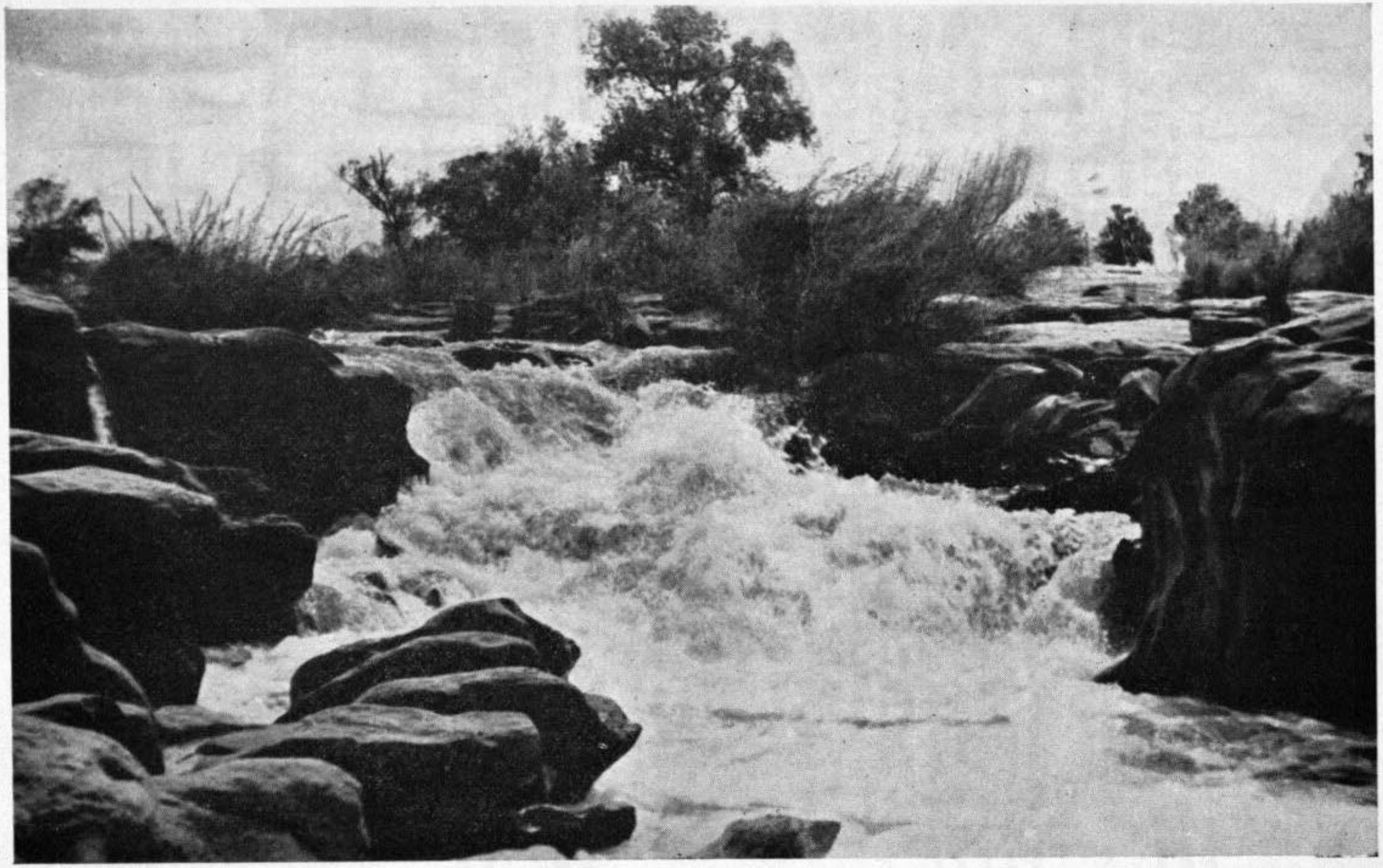

Lugard's Top Falls

FOREWORD

The Voi-South Yatta area is not very satisfactory for surface geological mapping, in so far as apart from various hills near Voi, the Yatta plateau, and the section provided by the R. Galana, exposures are few and scattered. For this reason one of the maps has been extended some miles north of the usual sheet boundary, to bring in the R. Tiva, where some outcrops enable the drawing of geological lines across the generally barren Galana-Tiva strip.

The mapping of the southern part of the Yatta plateau has revealed the presence of a hitherto unsuspected volcanic craterfield at its eastern end, but no additional evidence on the origin of the linear plateau following the R. Athi. Attention is redrawn to a fact discovered by J. W. Gregory many years ago that the slope of the floor of the plateau lava is only about 12 feet per mile to the south-east parallel to the Athi, but about 35 feet per mile to the east in its east-west portion, so that at its eastern end it almost merges into the end-Tertiary erosion surface. The change in slope is explained as due to differential uplift in post-Miocene times, but the possible evidence of faulting is neglected, and the fact that wherever they can be seen in this part of Kenya the sub-Miocene and end-Tertiary erosion surfaces are approximately parallel.

The excellent section in the Sabaki valley was mapped in detail and provides evidence of two series of rocks in the Basement System, separated by a thrust. The reasonably well exposed Sagala hills, south of Voi, were also mapped in detail, and proved to be an excellent example of the effect of parallel faults on folded and dipping sediments.

A detailed account is given of the graphite deposits near Tsavo, and the author expresses his opinion that sporadic copper deposits of the same area may have given rise to secondary deposits at depth that might well be worth while searching for. In view of the fact that the minerals seen, however, are mainly primary, doubt may well arise that any secondary deposits formed, for example during the maturation of the sub-Miocene surface, have escaped erosion. An account is also given in the report of the flow of the rivers in the area, and water-supplies in general.

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Chief Geologist.

Nairobi,
10th September, 1958.

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MAPS

Geological Map of the Voi area (Degree sheet 65, N.E. quarter); Scale 1:125,000 at end
Geological Map of the South Yatta area (Degree sheet 60, S.E. quarter, and parts of Degree sheets 60 S.W., N.W. and N.E. quarters); Scale 1:125,000 .. at end

ABSTRACT

The report describes an area of approximately 2,800 square miles situated in eastern Kenya between Voi and the lower Tiva river. It falls almost entirely within the limits of the Royal Tsavo National Park (East), and is bounded in the west roughly by the railway between Voi and Tsavo (approximate longitude 38° 30′ E.), and by the Athi river north of Tsavo. The northern, southern and eastern boundaries are latitudes 2° 24′ S. and 3° 30′ S. and longitude 39° 00′ E. respectively.

Much of the country considered is of low relief, and except for groups of hills near to Voi, and the narrow Yatta plateau, it consists of a flat or gently undulating bush-covered plain of altitude less than 1,500 feet above sea-level.

Basement System gneisses, schists, migmatites and crystalline limestones which have been variously affected by high-grade metamorphism, granitization and deep shearing exhibit steep foliation dips and a consistent north-north-westerly regional strike throughout the greater part of the area. In the east they are in thrust contact with a series of low-dipping para-gneisses, schists, and crystalline limestones of medium metamorphic grade which occupy a belt some twelve miles in width between the migmatized basement and westernmost outcrops of the Duruma Sandstones. The latter are found in the extreme eastern and north-eastern parts of the area where arkoses of upper Carboniferous or lower Permian age are faulted against the Basement System.

Tertiary phonolite, generally less than 50 feet in thickness, caps the Yatta plateau and adjacent outliers north of the Galana river and was derived in part from numerous scattered vents near the eastern limit of the plateau.

An account is given of the petrography, genesis, and structures of the various rocks, and their economic prospects are assessed with particular reference to copper and graphite.

GEOLOGY OF THE VOI—SOUTH YATTA AREA

I—INTRODUCTION

General.—Between July and December, 1955, a geological survey was made of of the area described in this report. The area comprises:—

(*a*) The north-east quarter of Degree Sheet 65 (Kenya), (Directorate of Colonial Surveys Sheet No. 190), bounded by longitudes 38° 30′ E., and 39° 00′ E., and by latitudes 3° 00′ S. and 3° 30′ S.

(*b*) The south-east quarter of Degree Sheet 60 (Kenya), (Directorate of Colonial Surveys Sheet No. 184), bounded by longitudes 38° 30′ E., and 39° 00′ E., and by latitudes 2° 30′ S. and 3° 00′ S., with extensions to the Athi river in the west (part of the south-west quarter of Degree Sheet 60) and to the Tiva river in the north (parts of the north-west and north-east quarters of Degree Sheet 60).

The area is approximately 2,800 square miles in total extent. For convenience of printing the two sections described above are illustrated by separate maps, one of the Voi area and the second of the South Yatta area, but the two areas are considered together when necessary in the body of the report.

With the exception of Crown Lands about Voi and a small part of the Taita district, which occupies the extreme south-western corner of the area, the area falls entirely within the boundaries of the Royal Tsavo National Park (East), including the Tsavo-Lugard's Falls—Sobo section of the Galana river, and the South Yatta plateau.

Methods of Mapping and Maps.—Existing topographical maps referring to the area are:—

Voi, E.A.F. No. 1,552, 1 : 500,000.

Nairobi-Mombasa, S.A.37, 1 : 1,000,000.

Part of the area in the vicinity of Voi is also covered by Preliminary Plots (Kenya) 190/I, 190/III, and 190/IV on the scale of 1:50,000.

Base maps for the geological sheets were prepared from air-photographs taken under Contract No. 9 (Kenya and Tanganyika) during February 1955, control for the mosaic being obtained in the south from preliminary plots and in the north from plane-table resections on trigonometrical points located near the western margin. Topographic detail was based on barometric spot-heights standardized to sea-level and corrected for diurnal variation. Geological information was plotted directly from air-photographs on kodatrace flight-strips and photostatically reduced to map scale.

The geological symbols and colours representing various rock types on the maps are in some cases different from those denoting the same formations in neighbouring areas, thus at the eastern margin of the Voi sheet Basement System areas appear as Qr (red sandy soil overlying undifferentiated Basement System rocks) whereas on the adjoining Mid-Galana sheet (Sanders, 1959)* equivalent rocks are shown under the symbol *X* (Basement System, undifferentiated).

At the south-western corner of the Voi sheet the symbol *Xga* referring to albite-oligoclase porphyroblast gneisses and garnetiferous biotite gneisses is equivalent to the symbol *Xsg* (biotite-garnet gneisses) of the Kasigau-Kurase area (Saggerson 1962).

* References are quoted on p. 45.

Similarly *Xgc* on the Voi sheet refers to rocks labelled *Xc* on the Kasigau and Kurase sheets. Gneisses containing hornblende are denoted by the symbol *Xhi* on both the Voi and the Kasigau and Kurase sheets, but *Xhg* and *Xgc* have also been used for these rocks on the Voi sheets.

In the north-western corner of the South Yatta sheet the migmatites of the Tiva valley are grouped under the symbol *Xg* (microcline-oligoclase-biotite-hornblende migmatites with biotite amphibolite schlieren, and granitic sheet and vein reticulation). This part of the Tiva valley also appears on the geological maps of the Ikutha area (Walsh, 1963) where equivalent rocks are referred to under a combination of the symbols *Xgc* (hornblende migmatites), and *Xgg* (quartzo-felspathic gneisses and granulites).

Communications.—The south-western part of the area is readily accessible since it is traversed by part of the main road and railway routes between Nairobi and Mombasa, and Taveta and Voi, and in the vicinity of Voi township there are several minor roads that serve the neighbouring sisal estates. A steep track also runs along the western slopes of the Ndara-Sagala ridge, a prominent feature situated some three miles south of Voi, and may be approached either from the Voi-Taveta road where it crosses the Voi river, or from a point on the Voi-Mombasa road about one mile east of Voi.

The remainder of the southern part of the area can be most conveniently entered from the west by the Voi or Manyani entrances to the Royal Tsavo National Park. From the main gate at Voi earth roads run to Kandecha Dam and Aruba Lodge on the Voi river (19 miles), and to Sobo on the Galana river (35 miles), whilst from Manyani one road follows the south bank of the Galana eastwards via Lugard's Falls to Sobo (42 miles) and a second south-south-east roughly parallel to the main road and railway between Tsavo and Voi, linking the Manyani and Voi entrances to the Park via Mudanda Rock, Manga (2,769 feet), and Irima (2,991 feet).

The northern part of the area, lying between the Galana and Tiva rivers, is less accessible. It can be entered by crossing the Galana on a concrete causeway at Lugard's Falls whence routes extend via the Mopea Gap (Yatta plateau) northwards to the Tiva river near Wathoni, and eastwards to the Lali hills. The feasibility of these two routes depends on the level of the Galana at Lugard's Falls; during periods of spate the ford may be unusable for many days or even weeks. Alternatively the north-eastern part of the area may be entered from Mambrui, on the coast, by a road which follows the north bank of the Galana via Matolane and the Lali hills, and thence trends north-west to the Tiva river, approximately 137 miles from Mambrui.

Most of the earth roads within the National Park remain in excellent condition since they carry only light traffic under speed limit. The route that follows the Galana river suffers from having to cross several south-bank tributaries, including the Mbololo and Punda Mlia rivers, and on this account is liable to be interrupted by newly-eroded gullies after heavy rains. Apart from the roads and tracks mentioned above there are numerous elephant trails connecting well frequented watering-places on the Galana and Tiva with water-holes and grazing areas; some of these are sufficiently wide and well-worn to permit the passage of motor-vehicles for many miles, whilst the smaller trails give good access on foot.

Climate and Vegetation.—Most of the area is part of a great tract of semi-arid plainland where the mean annual rainfall is less than twenty inches, lying between the Coast ranges and the uplands of Kitui, Machakos and Taita. Voi and Tsavo are the only two stations recording rainfall in the area, and some representative figures recorded at both are quoted below:—

TABLE I

RAINFALL AT VOI (LAT. 3° 24′ S., LONG. 38° 34′ E.) AND TSAVO (LAT. 2° 59′ S., LONG. 38° 28′ E.)

(*From records of the East African Meteorological Department*)

STATION (Height in ft.)	ANNUAL TOTAL 1953	1954	1955	1956	Average	Number of Years Recorded
Voi, 1,837	19·94	11·88	15·56	24·49	20·98	51
Tsavo, 1,528	17·45	8·55	—	15·92	13·87	26

Temperatures (degrees F.) recorded at Voi during 1955 were as follows:—

Mean	Mean Maximum	Mean Minimum	Highest Maximum	Lowest Minimum
76·9	86·8	66·9	99·1	55·1

High mean temperatures and a low annual rainfall gives rise over the plains to a bush vegetation composed mainly of species of *Acacia* and *Commiphora.* The growth of the trees is generally gnarled and stunted, so that they seldom exceed 25 feet in height. Occasional *Baobab* and rarer *Euphorbia* stand above the level of the smaller thorn-trees. During and after the rains the colours of wild aloes, flowering shrubs and bulbous-rooted plants relieve the monotonous green and brown of the scrub. The bush density varies from place to place; in some areas the trees, secondary shrubs, and *Sanseviera* thickets grow closely enough to be almost impenetrable, whilst in other localities there are expanses of open grassland with only scattered or isolated groups of trees.

The courses of the Galana and Tiva rivers are marked by fringes of tall trees consisting mainly of giant acacias—*Acacia xanthophloae* or the "fever tree"—and *Piptadenia,* reaching a height of from 80 to 100 feet. Palms, of which the commonest is the doum, also grow along the river banks.

Hills in the extreme south-west of the area enjoy a higher local rainfall than that of the plains and in consequence their slopes are densely bush-clad; the summit of Sagala supports a small mist forest with evergreens, parasitic creepers and tree mosses.

Population and Fauna.—The native population is restricted to the south-west and western margins of the area, where there are *Wataita* settlements near to Voi and Ndi; largest of these is the Sagala location where the community is concentrated on the higher parts of the Ndara-Sagala ridge.

The remainder of the area is uninhabited apart from tribesmen who enter it with the object of hunting illegally for ivory, rhino horn, meat and skins. They include *Wakamba, Wataita* and *Wagiriama,* who use the poisoned arrow and a variety of traps to take a considerable annual toll of game, particularly elephant and rhinoceros, in spite of continued preventive efforts on the part of Wardens and Rangers.

In an otherwise arid region the presence of perennial flowing water in the Galana, and permanent water at Aruba and Kandecha on the Voi river, attracts considerable numbers of game to this part of the Tsavo Park. Herds of elephant can be seen watering at these localities particularly during the dry season. The lower Tiva is also well populated with game, but the river bed is often dry for long periods between rains. There are many water-holes in the bushland areas intervening between the main rivers, and these also attract game after the rains until they eventually dry out. Perhaps the best known is the water-hole at Mudanda Rock. Rhinoceros and buffalo are not uncommon throughout the area in addition to elephant. Lion and leopard are less frequently encountered but are seen and heard from time to time. Waterbuck are numerous near the rivers, whilst giraffe, zebra, impala, eland and gazelle graze widely over the bush plainlands. Crocodile infest the Athi and Galana, and hippopotamus are to be seen occasionally at Lugard's Falls and in pools on the Athi.

II—HISTORY AND PREVIOUS GEOLOGICAL WORK

The majority of the early East African explorers followed caravan tracks extending inland to Taveta or Tsavo from the mission station at Rabai near Mombasa. This route, which until the end of the last century was no more than a foot-track, is today roughly followed by the road and railway which skirts Sagala, or Ndara, and the eastern Taita hills. The Rev. J. L. Krapf followed this path in 1849, and 1851 on his journeys to Wakamba country (Krapf, 1860, p. 303) and was followed in 1877 by J. M. Hildebrandt (1879, pp. 241-278). The region was also visited by von der Decken and A. Kersten (von der Decken, 1879) and H. Meyer (1890), who like Hildebrandt collected various rocks including Duruma Sandstones, crystalline limestones, biotite and hornblende gneisses, and pegmatites, some of the latter from near Ndara. Petrographic descriptions of a number of these rocks were given by Beyrich (1878), Hyland Shearson (1889), and Tenne (1890). Later Stromer von Reichenbach (1896) summarized the researches of all the early travellers to this part of Kenya, but without actually visiting East Africa himself. At this time another track leading from the coast into Ukamba followed the Galana river for over seventy miles and was regularly used by ivory and slave traders. In 1890 Capt. F. D. Lugard spent several months in clearing a trade route along the Galana on behalf of the Imperial British East Africa Company (McDermott, 1893, p. 209) and during this reconnaissance at longitude 38° 43′ E. discovered the falls that bear his name. In the following year a survey was started to select the most suitable alignment for a railway from the coast to the interior. Two survey groups were used, the first under Capt. MacDonald, R. E., Lieut. Twining, R. E. and Sgt. Thomas (a surveyor of the Public Works Department of India) investigated the Galana from Makongeni to Tsavo, whilst the second under Capt. Pringle and Lieut. Austin of the Royal Engineers in company with Mr. F. J. Jackson followed the caravan route via Taru to the Tsavo river, which was reached by both parties in mid-January, 1893, (Hill, 1949, pp. 61-62). Construction of the railway on the route followed by the second party started in 1896 and reached Tsavo two years later. During this period lions terrorized the work gangs and are recorded as having killed 28 Indian coolie labourers and scores of Africans, in the vicinity of Tsavo during the latter months of 1898 (Patterson, 1907, p. 106).

The survey party of Pringle and Austin was closely followed by J. W. Gregory who bivouacked in the vicinity of Sagala, the Voi river, and Ndi in March, 1892 on his way to Mt. Kenya and Baringo, and returned later in the year via the Galana (1894; 1896, pp. 68-69, p. 207). Some of the geological specimens collected by Gregory near Lugard's Falls were later described by Prior (1903, p. 230). C. W. Hobley, (1895, pp. 545-561) also travelled to Ndara, Ndi, and Tsavo in 1892 and described prominent rocky ridges of pink gneiss traversing the country in a north-south direction in the Tsavo valley, and limestones and metamorphic rocks west of Voi. E. E. Walker visited the Ndara and Ndi hills in 1902 and briefly described gneisses outcropping there and crystalline limestones which he recorded in the Voi river, at the western margin of the area; later in the same year he spent several days in the Athi valley and described part of the Yatta plateau which he followed for a distance of 25 miles southwards from the Kibwezi-Kitui road (1903, pp. 2-4). Between December, 1905, and September, 1906, H. B. Muff (Maufe) made a geological traverse along the Kenya-Uganda railway from Mombasa to Kisumu and in his report (Maufe, 1908, p. 20) included an account of the hornblendic and garnetiferous gneisses of Voi as part of a general description of the gneisses of the interior. Shortly after Maufe had completed his traverses Capt. L. Aylmer, of the King's African Rifles, journeyed from Ikutha down the Tiva to about longitude 39° 30′ E., exploring the lower reaches of this little known river in an attempt to discover whether it reached the Tana. He discovered that it eventually petered out in the desert before reaching the Tana valley (Aylmer, 1908).

Gregory returned on a second visit to Kenya in 1919, and in company with C. W. Hobley, W. McGregor Ross, and H. L. Sikes made further journeys in the Colony. These included one down the Galana from Voi to Lango Baya, 25 miles west-north-west of Malindi. A geological account of the Galana river section was published two years later (Gregory, 1921, p. 54), and shortly afterwards a summary of the geology of East Africa appeared as part of a descriptive geology of Africa (Krenkel, 1925). The accompanying geological map (p. 342) extends the Duruma Sandstones far to the west of the boundaries determined in both the Voi area and the Kasigau-Kurase area (Saggerson, 1962) to the south.

Busk and Verteuil (1938) also showed the approximate western boundaries of the Duruma Sandstones in a geological map of the Coastal region. In this case the Permo-Triassic formations of the Galana valley are shown to terminate some thirty miles east of the Yatta plateau, whereas in fact the contact is closely adjacent to the eastern extremity of the plateau.

The geology of the areas adjacent to that dealt with in this report is described in Geological Survey reports by Parkinson (1947, Mtito Andei area, on the west), Sanders (1959, Mid-Galana area, on the east), and Saggerson (1962, Kasigau-Kurase area, on the south).

III—PHYSIOGRAPHY

Erosion Surfaces.—The highest points in the area are the summits of Ndara (4,690 feet) in the south-west, and the isolated hills Voi (3,052 feet), Irima (2,991 feet), and Manga (2,769 feet), which rise sharply from plain-level between Manyani and Voi, forming the eastern foothills of the Taita uplands. Sagala (4,982 feet), the highest point on the Sagala-Ndara ridge lies a little south of the southern boundary of the Voi area. The Sagala-Ndara ridge may represent a residual from the Cretaceous peneplain recognized in the Maralal area, north of Mt. Kenya (Shackleton, 1946, p. 44), and known over a considerable part of Africa (Dixey, 1945, p. 243; Dixey in a later paper, 1948, Fig. 1, referred to a surface lower than Shackleton's Cretaceous surface as end-Cretaceous). Both Sagala and the hills north of Voi have probably been lowered several hundreds of feet since the late Mesozoic.

North of the Galana river, plateau phonolites of the south Yatta region rest unconformably on planed-off gneisses of the Basement System. The sub-lava surface slopes gently downwards from a level of 2,500 feet at Wathoni, in the north-west, to about 2,000 feet immediately north of the Tsavo-Athi confluence, a gradient of about 12 feet per mile in a S.S.E. direction. Between Tsavo and Ata at the eastern end of the plateau, however, the slope of the sub-lava floor is steeper, and it is evident that

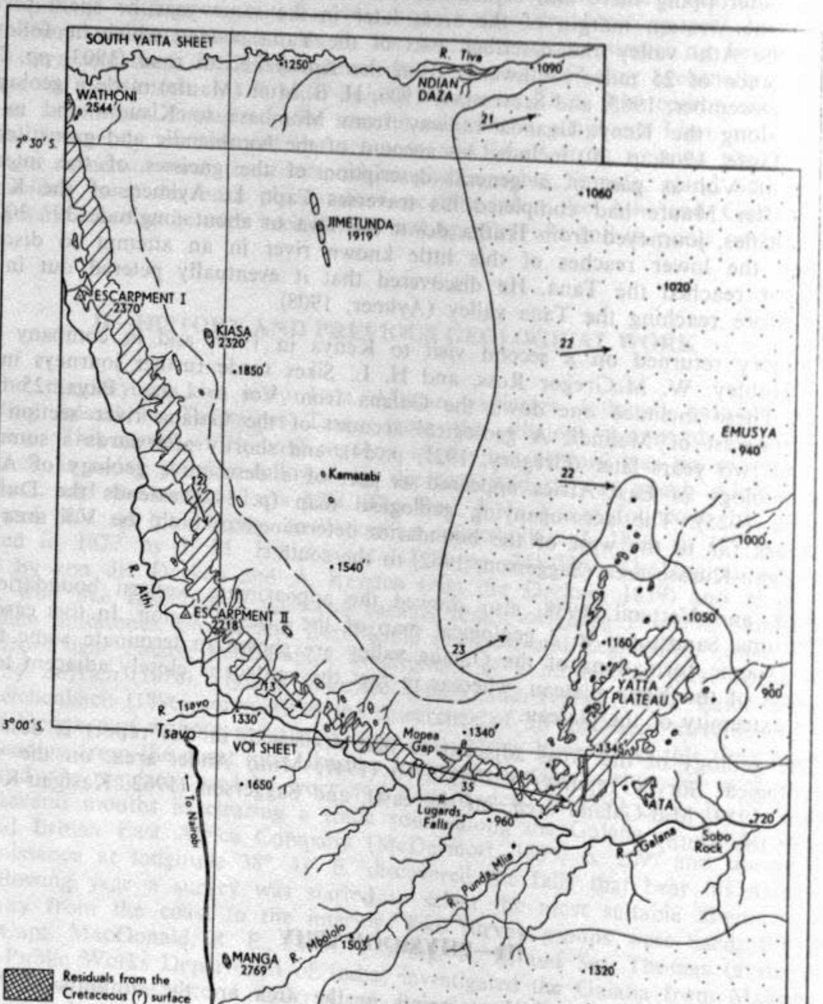

Fig. 1—Physiographical map of the Voi-South Yatta area

the maximum gradient is towards the east or E.S.E. at about 35 feet per mile. The eastward slope is greater than both the inclination of the end-Tertiary peneplain and the indicated slope of the sub-Miocene surface elsewhere in eastern Kenya. To the north, in Kitui (Schoeman, 1948, p. 6; Sanders, 1954, p. 3) and south-east Machakos (Dodson, 1953, p. 3) this surface has been correlated with the sub-Miocene erosion surface of Shackleton (1946, p. 4), which on the eastern fringes of the Laikipia plateau and at the southern foot of the Karissia hills has Miocene sediments preserved on it beneath the overlying lavas. No similar sediments have been found beneath the Yatta phonolites, however, and a correlation of the sub-lava surface with the sub-Miocene surface of north-central Kenya can at present be based only on physiographical and geological similarity. The base of the Yatta phonolite descends almost to a common level with the surrounding plains in the east, giving rise to a topographic feature that is insignificant by comparison with the bold escarpments at the edges of the flow further to the west, for example in the vicinity of Tsavo. In the writer's opinion total uplift during the Miocene and early Pliocene was evidently greater in the western part of the area.

Apart from the few hills in the south-west and the Yatta plateau, the area consists of flat or gently undulating plains of the Nyika, with coastward gradient of about 20 feet per mile. The plains appear to represent an old peneplain surface, possibly of upper Pliocene age (Caswell, 1956, p. 6) and which has subsequently been sculptured by river erosion. It is correlated with the end-Tertiary erosion surface recognized widely in much of eastern Kenya and neighbouring territories.

The Yatta Plateau.—The Yatta plateau provides the main watershed, to the south of which the Galana and its tributaries the Mbololo and Punda Mlia have dissected the end-Tertiary surface to a depth of over two hundred feet. In this region the residual soils are thin and streams have sculptured the underlying metamorphic rocks, exposing ribs of resistant gneiss between the valleys, which have usually been etched in the softer members of the metamorphic series.

The elevated flat summit of the Yatta plateau stretches across the horizon for many miles to the north and east of Tsavo (Plate I, Fig. 2). The plateau has a total length of roughly 170 miles, extending from Ol Doinyo Sapuk near Nairobi to the Galana valley at longitude 38° 55′ E. For the whole of this distance it seldom exceeds three miles in width. The plateau owes its existence to a flow of coarsely porphyritic phonolite, some 25 to 40 feet in thickness, forming a resistant capping to the steeply-dipping gneisses that it overlies. The lava rim forms a vertical cliff at the summit of steep escarpments on both the eastern and western sides of the plateau; the escarpments slope at about 30 degrees and are usually mantled with phonolite talus, including blocks measuring many feet across that have fallen from the edges of the lava outcrop. A series of embayments, intervening spurs, and occasional lava-capped outliers (Plate I, Fig. 1) characterize the western and southern face of the escarpment where it has been incised by tributaries of the Athi and Galana. The western section of the plateau from Wathoni to Tsavo is continuous; although some of the embayments in the edges of the lava are deep, they fail to breach the full width of the plateau. In the south, however, at Thabangunji and Mopea near Lugard's Falls, there are several gaps in the plateau which has been broken into a series of flat-topped hills separated by narrow valleys. The summits of the escarpments overlooking the Athi and Galana valleys stand some 700 feet above river level; those bounding the northern and eastern sides of the plateau seldom reach 500 feet above plain level, and east of the Mopea gap they are much reduced in height.

Drainage and Physiographical Evolution.— The Athi, Tsavo (Plate IV, Fig. 2) and Galana are the only perennial rivers in south-eastern Kenya, apart from a few streams like the Mwachi, at the coast. The direction of flow of the Tsavo and Galana is roughly perpendicular to the regional strike of the metamorphic and sedimentary rocks over which they pass from the region of Kilimanjaro towards the coast. The Athi is a subsequent stream with head-waters on the lavas near Nairobi from where its course follows closely the regional strike of the Basement System to Tsavo, a distance of about 150 miles. The Tiva, which dries out between rainy seasons, enters the area in the north-west and from near Wathoni follows an easterly course until it peters out in the arid plainlands towards the lower Tana. At Wathoni it changes direction through almost a right-angle at an elbow of capture from which the former course of the river extended southwards, closely following the eastern foot of the Yatta plateau. The form of the broad abandoned valley can be clearly seen between Kiasa and the plateau, and from there can be followed towards the Mopea gap for a distance of approximately 30 miles. The bed of the Tiva near the Wathoni elbow of capture stands at 1,470 feet, whilst the old river alluvium is preserved at a height of 1,800 feet near Kiasa, from where the abandoned valley descends to about 1,400 feet at the Mopea gap, a gradient of approximately 13 feet per mile, comparing with the present gradient of the Galana which between Tsavo and Sobo is about 15 feet per mile.

Recognition of capture of the lower Tiva explains the remarkably long and narrow form of the Yatta plateau, and enables an interpretation of post-Miocene erosion events in this region (Fig. 2). They are considered to have been as follows:—

(*a*) In the Miocene period highly mobile phonolitic lava was extruded from a number of centres in the east of the region and flowed over the pre-Miocene surface, the flows being controlled by pre-existing valleys.

(*b*) Subsequent drainage developing in the grain of the Basement System blocks and between them and the lavas progressively reduced the lava area and lowered the metamorphic uplands. Uplift in the west proceeded at a greater rate than that in the east during the late Tertiary, as is shown by the relationship of the sub-Miocene and end-Tertiary surfaces, and was sufficient to impart a tilt to the sub-Miocene surface.

(*c*) By early Pleistocene times the surface of the metamorphic rocks had been reduced well below the level of the Yatta phonolite which stood as the watershed between two parallel consequent streams, the Athi and the Tiva. The bed of the Galana river was probably lower than that of the Tiva, enabling tributaries of the former to incise the southern lava margin and eventually to break through the plateau and capture the lower Tiva via the Mopea gap.

(*d*) As a result of continuing uplift or fall in sea-level a tributary of the Tana captured the middle Tiva, leaving an abandoned valley to the east of the Yatta watershed which by now was reduced to a narrow lava strip; this second capture of the Tiva possibly occurred during one of the Pleistocene pluvial periods.

Recent dissection of the Tiva has carried the present river bed at Wathoni to a level some 300 feet below that of its abandoned course in the vicinity of Kiasa, and the eastern escarpments of the Yatta plateau north of Wathoni are in consequence conspicuously higher than those to the south. Similarly the beds of both the Athi and Galana have been lowered well below the abandoned lower course of the Tiva.

To summarize, the present curious form of the south Yatta plateau is a direct result of erosion processes largely governed by fluctuating river action in geological periods when rainfall and run-off were greater than they are today.

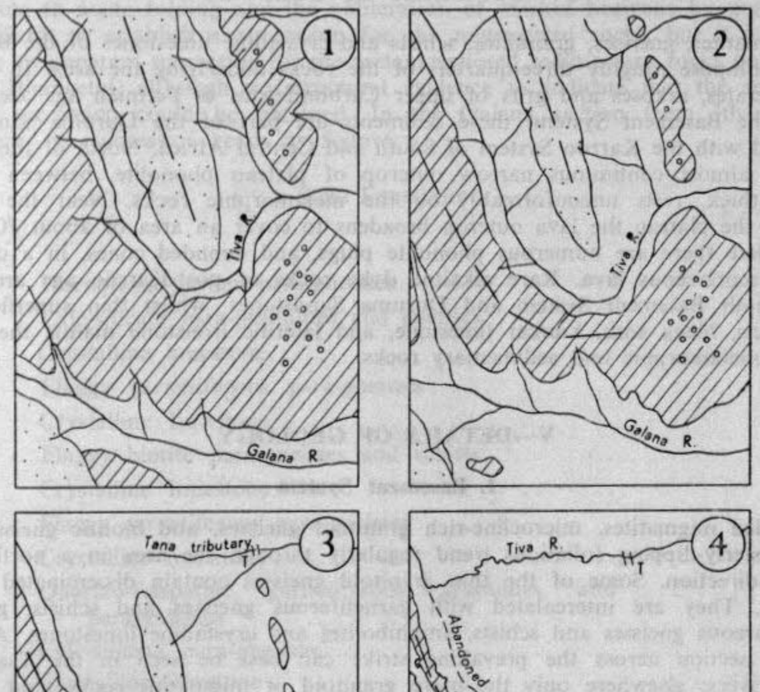

Fig. 2—Physiographical evolution of the Voi-South Yatta area in post-Miocene times:--

Stage 1—Development of subsequent drainage in the grain of the Basement System. Lateral erosion of lava.

Stage 2—Reduction of elevated Basement System areas. Reduction of the lava plateau, and beheading of eastern tributary of the Tiva.

Stage 3—Capture of the lower Tiva river by a tributary of the Galana river via the Mopea gap.

Stage 4—Capture of the middle Tiva river by a tributary of the Tana river.

IV—SUMMARY OF GEOLOGY

Migmatites, gneisses, granulites, schists and crystalline limestones of the Basement System compose roughly three-quarters of the rocks underlying the area. In the east conglomerates, arkoses and grits of upper Carboniferous or Permian age are faulted against the Basement System; these sediments are part of the Duruma Sandstones, correlated with the Karroo System of South and Central Africa. North of the Galana river an almost continuous narrow outcrop of plateau phonolite, between 25 and 40 feet thick, rests unconformably on the metamorphic rocks. Near the eastern limits of the plateau the lava outcrop broadens to cover an area of about 70 square miles where there are numerous phonolite plugs, and denuded cones, in a confused field of scoriaceous lava. Rare alkaline dyke rocks of post-Karroo age are found cutting both Basement System and Duruma Sandstones, whilst thin superficial red sandy soils, black soils, kunkar limestone, and lateritic ironstone mantle the poorly exposed metamorphic and sedimentary rocks.

V—DETAILS OF GEOLOGY

1. Basement System

Banded migmatites, microcline-rich granitoid gneisses, and biotitic gneisses with steep westerly-dipping foliations trend regularly through the area in a north-northwesterly direction. Some of the thin granitoid gneisses contain disseminated copper sulphides. They are intercalated with garnetiferous gneisses and schists, graphitic and calcareous gneisses and schists, amphibolites and crystalline limestones. A representative section across the prevailing strike can best be seen in the Tsavo and Galana rivers; elsewhere only the more granitoid or migmatitic rocks tend to outcrop in isolated tors and whale-back ridges.

Between the Tsavo-Athi confluence and Ithangethi at longitude 38° 47′ E. in the Galana valley, banded and contorted hornblende migmatites are common; they often contain massive pegmatite segregations, dark amphibolite inclusions, and ribs of migmatized garnetiferous or diopsidic gneiss. In this part of the Basement System the rocks have been regionally metamorphosed to a high degree, recrystallized and migmatitized and have been subjected to intense plastic deformation as is evidenced by the flow-folding and "pinch and swell" structures which can be seen in many exposures.

West of the Tsavo-Athi confluence migmatization is somewhat reduced, and original pelitic sediments are represented by isoclinally-folded garnetiferous and graphitic gneisses, which are interstratified with thin hornblendic and hornblende-garnet gneisses. Granitization processes have been active throughout, felspar porphyroblasts and augen being a common feature in the pelitic gneisses and schists. Rocks forming a continuation of this zone are found in Sagala and the hills near Voi where massive hornblende-garnet and hornblende-biotite gneisses are well exposed; the latter often contain diopsidic lenses and *schlieren* indicating an even more calcareous composition for some of the original sediments.

East of Ithangethi steep westerly-dipping migmatites give way abruptly to a non-migmatized assemblage of metamorphosed pelitic, psammitic, and calcareous sediments, here named the Sobo Formation. The bulk of the sediments of the formation are flaggy medium-grade garnetiferous schists and granulites, thin quartzites, abundant crystalline limestones, fissile hornblendic gneisses and dark garnet amphibolites. Foliation dips are generally considerably less than 30 degrees, and although it is affected by faults the formation presents a remarkably stratiform appearance; it occupies a zone some eight or nine miles in width between the Lugard's Falls—Ithangethi migmatites and the western limits of the Duruma Sandstones.

Owing to acute folding and the obliteration of marker horizons by granitization it is difficult to establish a succession for the migmatized rocks, but it is possible to quote an apparent succession for the metamorphosed sedimentary rocks outcropping east of Ithangethi, although no structural evidence to indicate that the series is a straight succession could be obtained. In the Galana section from Ithangethi to near Sobo the succession reads as follows:—

SOBO FORMATION

		Thickness in feet
Upper	Hornblende-garnet para-gneisses	50
	Calc-silicate para-granulites and gneisses	60
	Crystalline limestone	20
	Flaggy garnetiferous para-gneisses	400
	Crystalline limestone	10
	Flaggy biotite para-gneisses and schists	120
	Crystalline limestone	25
	Flaggy garnetiferous para-gneisses	200
	Crystalline limestone	30
	Quartzo-felspathic garnetiferous granulites and para-gneisses	300
	Calc-silicate para-gneisses	3
	Crystalline limestone	2
	Flaggy biotite-garnet para-gneisses	30
	Quartzose para-gneisses	20
	Crystalline limestone	20
	Flaggy biotite para-gneisses	100
	Quartzo-felspathic para-gneisses	400
	Crystalline limestone	30
	Calc-silicate para-gneisses	15
	Flaggy biotite-garnet para-gneisses	200
	Garnet amphibolite	20
	Garnetiferous para-gneisses and granulites ..	150
	Garnet amphibolite	20
	Garnetiferous para-gneiss	2
	Garnet amphibolite	15
	Garnetiferous para-granulites	6
	Garnet amphibolite	5
	Garnetiferous para-granulites	10
	Calcareous para-gneisses	80
	Crystalline limestone	16
	Biotite para-gneisses	180
Lower	Hornblende-biotite para-gneisses	60
	Total thickness ..	2,599

In the Sagala hills measurable sections similar to those in the Galana river are not available, but three main groups can be distinguished and were used as a basis for geological mapping: —

			Approximate thickness (feet)
Upper	3	Hornblende-garnet (andradite) — scapolite para-gneisses—a cliff-forming stratiform group of coarse felspathic gneisses	300-400
	2	Hornblende-biotite banded gneisses with garnet-epidote inclusions—darker and more strongly differentiated into quartzo-felspathic and amphibolitic parts than (3)	at least 500
	1	Felspar porphyroblast and augen gneisses, biotite para-gneisses, and biotite hornblende para-gneisses—contains several contrasting groups, varying from massive to flaggy. The rocks are generally lighter in colour than (2) and (3)	at least 2,000
		Total thickness ..	2,900

For convenience the Basement System rocks together with pre-tectonic intrusive igneous rocks are described under the following headings: —

(1) *Metamorphosed Non-migmatized Sediments*

(*a*) *Calcareous*

Crystalline limestones.
Calc-silicate granulites.

(*b*) *Pelitic and semi-pelitic*

Garnetiferous para-gneisses and granulites.
Sillimanite para-gneisses.
Graphite para-gneisses.
Biotite granulites.
Chlorite schists.

(*c*) *Psammitic*

Quartzites.
Quartz-felspar para-granulites.
Spessartite granulites.

(2) *Metamorphosed Volcanic Rocks* (?)

Hornblende-garnet gneisses.
Plagioclase amphibolites.

(3) *Cataclasites*

Sheared gneisses.
Mylonites.

(4) *Migmatites*

Banded and contorted biotite-hornblende gneisses.

Amphibolites.

(5) *Anatectic or Palingenetic Rocks*

Quartz-microcline-biotite granitoid gneisses.

Pegmatites.

(6) *Metamorphosed Basic and Ultra-basic Intrusive Igneous Rocks*

Garnet amphibolites.

Hornblendites.

Epidiorites.

Serpentines.

(1) METAMORPHOSED SEDIMENTS

(*a*) *Calcareous Rocks*

Crystalline Limestones.—Coarsely crystalline limestones varying from white to pink in colour are found in the eastern half of the area and also in the extreme south-west. The purest varieties were observed in the latter locality where massive outcrops of coarse ash-white limestone (specimens 65/422 *, and 65/430) can be followed from approximately four miles west of Sagala to where they cross the Voi river about four miles west-south-west of Voi and continue northwards. A broad rib of similar limestone, flecked with dusty graphitic inclusions (specimens 65/367 and 65/368) can be traced discontinuously from ten miles south-east of Kiasa on the line of the Mopea gap to beyond the Mbololo river south of Lugard's Falls, a distance of over 30 miles, and further outcrops of parallel trend are well-exposed in the Galana river approximately 1,000 yards below the falls.

Apart from the massive limestones referred to above there are many relatively thin and impure limestones containing abundant siliceous inclusions, which can best be seen in the Galana valley between Lugard's Falls and Sobo. They are often interstratified with calcareous gneisses and show flow-streaming of skarn-like inclusions, indicating that at some stage of their formation they underwent viscous flow whilst their country-rocks were relatively rigid (Plate II, fig. 2). The impure limestones can be divided into two groups, (i) diopside and scapolite limestones, and (ii) ophicalcites.

(i) *The diopside and scapolite limestones* are pink or grey, dappled with scapolite and often contain siliceous, lenticular or distorted inclusions that are more resistant than the enclosing limestone and stand out from weathered surfaces. Specimen 65/481, a pink limestone from four miles south of Ithangethi, is typical, containing granoblasts of scapolite and sphene, occasional grains of quartz and rare brown mica, in a coarsely crystalline calcite matrix. Some specimens, for example 65/382 from two miles south of Lugard's Falls, contain green grossularite in addition to abundant diopside and some scapolite. Siliceous inclusions in the limestones (e.g. specimen 65/478) consist of fine-grained aggregates of quartz and felspar in approximately equal proportions, with granular diopside, sphene and apatite.

(ii) *Ophicalcites.*—Limestones outcropping between Sobo and Ithangethi are conspicuous for their green coloration, which is imparted by an even distribution of serpentine throughout the rocks, the serpentine often weathering out in granular

* Specimen numbers 65/422 etc. refer to material in the regional collections of the Geological Survey, Nairobi.

form on exposed surfaces. In specimens 60/45 from Wathoni, 65/376 from the lower Mbololo river (Fig. 3 (*a*)) and 65/377 from the Punda Mlia river, patches and pools of soft pale green serpentine are seen to make up about one third of the mineral composition of the limestones. Serpentine, olivine relics, phlogopite mica and calcite are usually the only constituents in the specimens, but in some e.g. specimen 65/384 from the Mbololo river, and 65/442 from near the north-west corner of Ata, large olivines are found in the serpentine. Green grossularite and colourless diopside also appears in some specimens. The phlogopite is often colourless, and sometimes occurs as large crystals.

Calc-silicate Granulites and Gneisses.—Dark grey or green rocks of calcareous composition are found in thin ribs among the metamorphosed sedimentary rocks. They are more abundant in the eastern parts of the area and are conspicuous for their resistance to weathering, so that outcrops are typically tough and yield fresh fracture surfaces when broken. The mineral constituents include quartz, felspar, diopside (both colourless and pale green varieties), garnet, sphene, titanomagnetite and occasional epidote, varying widely in their respective proportions. The rocks range from pale-coloured gneissose felspathic varieties like specimen 65/497 from the lower Punda Mlia river, which consists largely of quartz and andesine with granules of garnet, sphene and diopside, to dark diopside granulites similar to specimen 65/373 from a half mile east of Lugard's Falls, and 65/386 from the Galana river west of Sobo rock, which contains abundant scapolite and blue-green granoblastic diopside in approximately equal proportions, together with small granules of sphene, quartz and felspar. Epidote skarns are found as green patches both in the crystalline limestones and the calcareous gneisses; specimens 65/425, and 65/427 taken from typical calc-silicate lenses in hornblende gneisses outcropping on the north-eastern slopes of Sagala consist mainly of a tough homogeneous mass of fine granoblastic green epidote with subsidiary amounts of garnet accompanied by interstitial labradorite, scapolite, sphene and pyrite.

Garnet is a prominent constituent mineral of the calc-silicate granulites and gneisses; specimen 65/370 from near the contact of a crystalline limestone three miles east of Ithangethi is a garnet-diopside granulite. Diopside forms approximately three-quarters of the rock, whilst a pale pink garnet, scapolite and accessory sphene constitute the remainder. In many of the calcareous gneisses there are narrow bands of maroon or purple tough garnetiferous granulite of which specimen 65/365 from the Mbololo river south of Lugard's Falls is typical; in thin section it is seen to contain complex intergrowths of garnet, andesine and sometimes scapolite arranged in folia between garnoblastic aggregates of hedenbergite, garnet and sphene. Pale salmon pink vermicular garnet of this type is a feature of the garnetiferous granulites in the locality and was described and figured by Prior (1903, p. 230; Plate V, Fig. 1) from specimens collected by Gregory from near Lugard's Falls. Specimen 65/488 is a richly garnetiferous granulite from three miles south of Ithangethi. It contains about 50 per cent of garnet in granular intergrowth with highly altered felspar, together with abundant sphene and a small proportion of titanomagnetite. Specimen 65/378 from two miles south-east of Ithangethi is similar, containing large pale golden brown garnets with minor amounts of diopside, apatite and quartz.

Epidote often occurs in lenses, veins and stringers in the hornblendic or diopsidic gneisses and granulites and is readily distinguished by its pale yellow-green colour; specimen 65/511 from three miles east of Voi is typical of this kind of vein, consisting almost entirely of granular epidote with a small proportion of calcic plagioclase, diopside, hornblende, garnet, sphene and iron ore.

A pale grey-green wollastonite gneiss was noted in the Punda Mlia river about one mile from its confluence with the Galana. In thin section (specimen 65/361) it is seen to contain well orientated wollastonite prisms, pale pink garnet, colourless to pale green diopside and quartz.

Some visually estimated volumetric modes of some of the calc-silicate rocks are as follows:—

	65/361	65/511	65/365	65/409
	Per cent	*Per cent*	*Per cent*	*Per cent*
Quartz	5	—	—	15
Felspar	—	6	40	53
Pyroxene	15	5	20	8
Wollastonite	65	—	—	—
Garnet	15	3	30	10
Sphene	—	1	5	4
Epidote	—	80	—	—
Scapolite	—	—	5	5
Apatite	—	—	—	2
Hornblende	—	3	—	—
Iron ore	—	2	—	3

66/361 Wollastonite gneiss. Punda Mlia R., at long. 38° 47′ E.

65/511 Epidote granulite. Three miles E. of Tsavo.

66/365 Garnet-diopside granulite. Mbololo R., at long. 38° 42′ E.

66/409 Garnet-diopside gneiss. Galala R., at long. 38° 38′ E.

(*b*) *Pelitic and Semi-pelitic Rocks*

Flaggy biotitic gneisses, fine-grained granulites, and thin fissile schists derived from the metamorphism of argillaceous sediments are best displayed in the eastern part of the area, particularly in that part of the Galana valley a few miles west of Sobo rock, where the metamorphosed rocks of the Basement System have low dip, are richly garnetiferous, and present a remarkably stratiform appearance. In the central part of the area about Lugard's Falls undoubted argillaceous sediments are less easily recognized owing to powerful migmatization, but in the west near Tsavo there are numerous ribs of gneisses containing garnet, graphite, and albite-oligoclase porphyroblasts, which represent part of a granitized argillaceous formation.

Garnetiferous Para-gneisses and Granulites.—These include dark-coloured biotitic fissile gneisses containing visible garnets. The granulites are generally lighter in colour and less fissile, but also contain abundant garnets. Specimens 65/375 and 65/485 from between Ithangethi and Sobo are typical representatives of the garnetiferous para-gneisses that outcrop in this part of the Galana valley. In thin section they are seen to contain quartz and felspar in irregular folia with liberally distributed biotite, and sparse pink garnet. The bulk of the felspar is andesine with subsidiary perthite or oligoclase. Specimen 65/506 from the western slopes of Sagala, two miles north of Mashanda, is representative of the garnetiferous granulites; it is weakly foliated and pink in colour, showing in thin section an equi-granular mosaic of quartz and albite-oligoclase together with orthoclase and a few shreds of biotite and scattered pink garnets. Specimen 60/37 from one mile west of the Tsavo-Athi confluence is coarser, richly garnetiferous, and contains little biotite.

Sillimanite Para-gneisses.—Sillimanite was rarely observed in the pelitic gneisses, but occurs in some, and is generally accompanied by garnet, for example in specimen 65/379 from one and a half miles west of Sobo Rock; this is a dark well foliated biotitic gneiss containing large red-brown garnets and inconspicuous wisps of sillimanite in the foliation planes. In thin section it is seen to consist mainly of quartz and andesine with garnets and felted masses of fibrolite needles arranged in sheafs both in the foliation and about the periphery of garnets (Fig. 3 (*c*)).

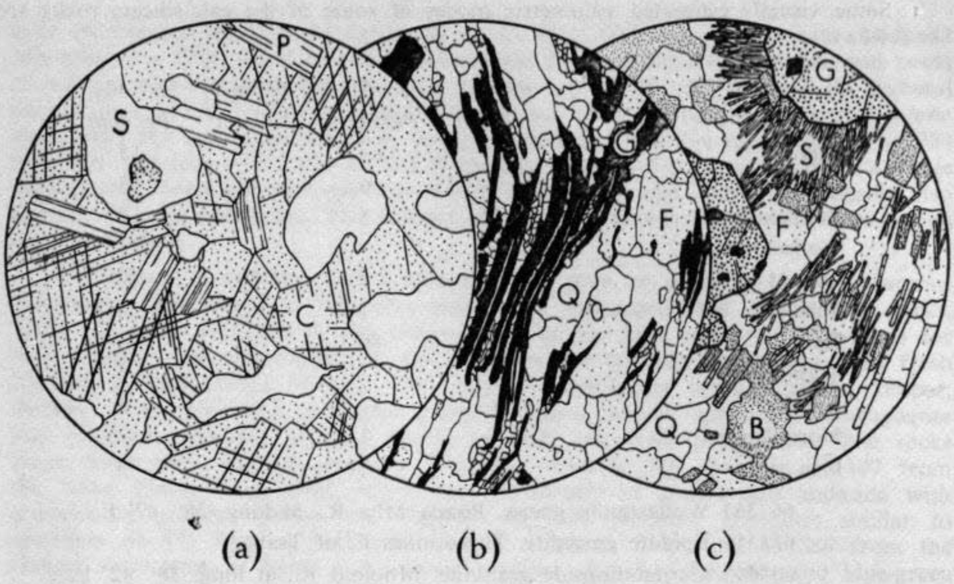

Fig. 3—Drawings of thin sections of metamorphosed sedimentary rocks from the Voi-South Yatta area:—

(a) Ophicalcite, from the Mbololo river. Specimen 65/376. Ordinary light, x 13. Serpentine (S), calcite (C), phlogopite (P).

(b) Graphite para-gneiss, from a mile west of the Tsavo-Athi confluence. Specimen 60/59. Ordinary light, x 13. Quartz (Q), felspar (F), graphite (G).

(c) Sillimanite para-gneiss, from 1½ miles west of Sobo Rock. Specimen 65/379. Ordinary light, x 13. Quartz (Q), felspar (F), garnet (G), sillimanite (S), biotite (B).

Graphitic Para-gneisses.—Grey fissile graphitic gneisses are a feature of the pelitic succession in an area immediately west of the confluence of the Tsavo and Athi rivers, where there are several horizons, each ranging between ten and thirty feet in width. Weathered surfaces of the richer graphitic bands show a wavy foliation with augen of quartz or felspar, and the surfaces often carry a yellow stain possibly caused by the reduction of iron-bearing solutions by carbon. In thin section (e.g. specimen 60/59 from a mile west of the Tsavo-Athi confluence) quartz and oligoclase are seen to make up the bulk of the rocks together with up to about ten per cent of graphite flakes roughly arranged along the foliation. Some of the graphitic gneisses occurring in this zone are garnetiferous, for example specimen 60/46, in which the garnet encloses sillimanite and is accompanied by flakes of graphite in a coarse gneissose matrix of quartz, perthite and oligoclase.

Biotite Para-granulites.—The garnetiferous or graphitic para-gneisses and granulites are interstratified with flaggy biotitic granulites and weakly foliated gneisses that contain no garnet, but are nevertheless of pelitic or semi-pelitic derivation. In thin section (e.g. specimen 65/380, from a mile west of Sobo Rock) they appear as equigranular rocks composed of sodic oligoclase, microcline, microcline-perthite, and quartz which is subsidiary to the total felspar; abundant biotite flakes are scattered throughout the granoblastic matrix.

Chlorite schists.—Some of the easternmost exposures of metamorphosed sediments contain outcrops of blue-grey fissile soapy-feeling chlorite schists. In thin section (specimen 65/451 from one mile east of Ata) these rocks are medium-grained and contain lenticular folia of strain-polarizing quartz in a granoblastic mosaic of highly sericitized plagioclase and microcline; pale green weakly pleochroic chlorite associated with small patches and streaks of leucoxene is liberally distributed throughout.

Some visually estimated modes of the pelitic para-gneisses and granulites are as follows:—

	60/37	60/59	65/379	65/485
	Per cent	*Per cent*	*Per cent*	*Per cent*
Quartz	35	44	25	20
Microcline or orthoclase	—	—	5	15
Plagioclase	45	50	40	50
Biotite	3	—	10	12
Garnet	15	—	15	2
Sillimanite	—	+	5	—
Graphite	—	6	—	—
Apatite	—	—	+	1
Rutile	1	—	—	—
Zircon	—	—	+	—
Iron ore	1	—	+	—

60/37 Garnetiferous para-granulite. Five miles east of Tsavo.

60/59 Graphitic gneiss. One mile west of Tsavo-Athi confluence.

65/379 Sillimanite para-gneiss. 300 yards west of Sobo Rock.

65/485 Biotite-garnet para-gneiss. Sobo.

(*c*) *Psammitic Rocks*

Quartzites.—White or grey pure quartzites are rare, but were observed in the Galana valley near the eastern limits of the Yatta plateau. The most prominent member gives rise to a low discontinuous ridge immediately to the west of the Voi-Sobo road about two miles south of the Galana, where there are outcrops of weakly foliated glassy translucent quartzite carrying only a few flakes of graphite as impurity (specimen 65/461) interstratified with muscovite quartzite. Slabby exposures of impure quartzite were observed near the north-western foot of Ata; in thin section this quartzite (specimen 65/441) is seen to be granulitic and to contain about five per cent of microcline enclosed as blebs and vermicules in the quartz, together with flakes of mica. A coarser iron-stained quartzite of similar composition outcrops in the Tiva some two miles north-north-east of Wathoni, forming the central rib to a series of low hills extending northwards from this point.

Quartz-felspar para-granulites.—Light-coloured massive weakly foliated granulites are interbedded with the metamorphosed pelitic sediments east of Ata and probably represent original sandstones or grits. Their outcrops often form small tors, which are sometimes aligned in the regional strike. In thin section (e.g. specimen 65/505 from between Mzinga and Voi hills) they are granitoid and contain quartz, microcline, and albite-oligoclase. Accessory minerals include flakes of biotite, titanomagnetite, zircon and chlorite after biotite.

Spessartite granulites.—Resistant ribs of maroon siliceous granulites containing visible garnet and abundant iron ore outcrop in the central part of the area, and also in the west, near Tsavo. In the former locality intermittent exposures of this distinctive rock were followed from the Galana valley southwards to the Voi-Sobo road, a distance of ten miles. The granulite is dense and coarse-grained; in thin section (specimen 65/462 from the Voi-Sobo road), half of the rock is seen to consist of quartz, with roughly equal proportions of manganese garnet and iron oxides making up most of the remainder. Apatite is a common accessory in large crystals. It is probable that this rock represents an original manganiferous arenaceous sediment.

(2) Metamorphosed Volcanic Rocks

Hornblende-garnet gneisses.—Dark evenly foliated gneisses are well exposed in the south-western part of the area where they are found in massive outcrops on Sagala and in the hills north of Voi. The most distinctive type is a coarse- to medium-grained resistant gneiss that under the microscope is seen to consist of quartz, plagioclase varying in composition from calcic oligoclase to sodic labradorite, hornblende, garnet and accessory iron oxides and sphene. The optical characters of the constituent minerals remain similar throughout the extent of outcrop, but the relative proportions vary from band to band as is illustrated below:—

	65/421	65/503	65/419
	Per cent	*Per cent*	*Per cent*
Quartz	10	35	45
Plagioclase (An_{25}-An_{65}) ..	37	40	39
Hornblende	25	15	9
Garnet	25	7	2
Sphene	3	1	2
Apatite	+	+	+
Iron ore	—	2	3

65/421 Hornblende-garnet gneiss. South-west of Sagala summit.
65/503 Hornblende-garnet gneiss. Two miles E.N.E. of Voi.
65/419 Hornblende-garnet gneiss. One mile south-east of Ndara.

These rocks show a uniformity of texture throughout a thickness of several hundreds of feet and are tentatively considered to be the metamorphic equivalents of lavas.

Epidote-diopside granulites.—Green epidote granulites are found in the hornblendic gneisses of the Voi-Sagala region; in hand-specimen they present an unusual dappled appearance due to an uneven distribution of dark diopsidic glomeroporphyroblasts. Epidote is often segregated into lenses or veins. In thin section (specimen 65/504, from the Mzima springs—Mombasa pipeline immediately north of the Voi river) it is found that large and small crystals of green diopside are accompanied by abundant small idiomorphic granules of pale epidote, and hornblende. Quartz and andesine are interstitial to the dark minerals. A visually estimated composition for this rock is diopside 35 per cent, epidote 25 per cent, hornblende 15 per cent, andesine 15 per cent, quartz 10 per cent. The rock was possibly derived from a tuff.

(3) Cataclasites

Crushed and mylonitic gneisses are found in a tectonic zone which crosses the Galana valley at longitude 38° 47′ E.; its continuations can be followed for many miles north of the Yatta plateau where indurated flinty blocks of sheared gneiss are scattered over the surface. The rocks vary from coarse visibly brecciated types bearing a superficial resemblance to porphyritic lavas owing to the inclusion of light-coloured cataclastic grains in dark vitreous matrices, to fine-grained siliceous mylonites. Black biotite-rich porphyroblastic schists represent rocks that have suffered mechanical deformation intermediate in severity between the brecciated and mylonitized types.

Sheared gneisses.—Specimen 65/456 from three miles west of Sangayaya in the South Yatta area is typical of the coarser crush-gneisses; in thin section it is seen to contain severely fractured angular cataclastic grains of strain-polarizing quartz and felspar in a dusty and granulitized sub-microscopic base (Fig. 4 (*a*)). Shear-planes within the metamorphosed sedimentary rocks are often defined by thin black schistose layers similar to specimen 65/381, from two miles south of Ithangethi, which contains ovoid strain-polarizing quartz and quartz-felspar porphyroblasts enclosed in a fine-grained granulitized schistose base of quartz, felspar and biotite (Fig. 4 (*b*)). Nearly all the quartz granules have ragged margins interlocking with those of their neighbours.

Mylonites.—Specimen 65/489 (Fig. 4 (*c*)) from eight miles north-east of Mopea is more completely mylonitized than either of the foregoing examples; it is fine-grained throughout, consisting entirely of comminuted quartz and felspar with a few micaceous and graphitic interfoliations.

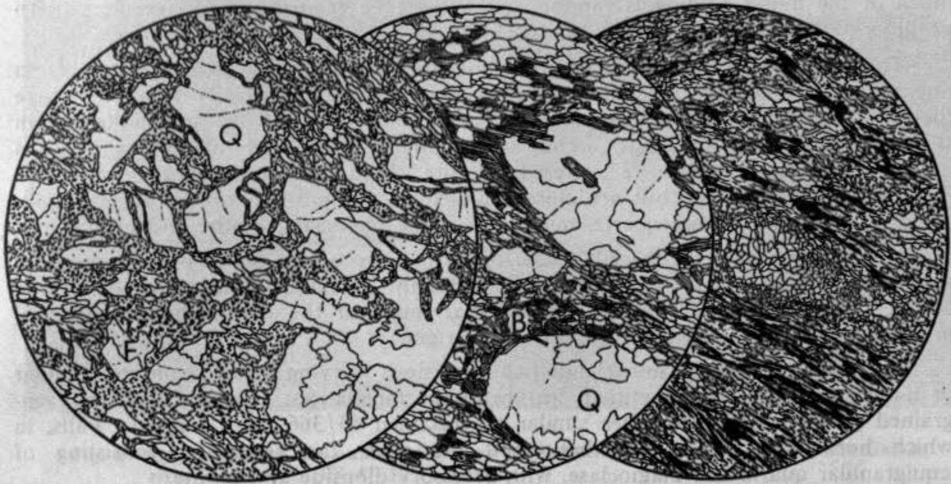

Fig. 4—Drawings of thin sections of sheared gneisses and mylonite from the Voi-South Yatta area:—

(a) Crushed gneiss, from three miles west of Sangayaya. Specimen 65/456. Crossed nicols, x 13. Quartz (Q), felspar (F).

(b) Sheared biotite-gneiss, from two miles south of Ithangethi. Specimen 65/381. Crossed nicols, x 13. Quartz (Q), felspar (F), biotite (B).

(c) Mylonite from eight miles south of Mopea. Specimen 65/489. Crossed nicols, x 13,

(4) Migmatites

Banded and contorted biotite-hornblende gneisses.— Heterogeneous, veined, banded or contorted biotite-hornblende gneisses are of wide extent in the central part of the Voi-South Yatta area. They are particularly well exposed at various points in the Galana river between the Tsavo confluence and Ithangethi, and in the Athi about a mile north of the Tsavo confluence. For many miles east of Wathoni outcrops in the Tiva river are similar and indicate the northward continuation of the broad migmatite zone exposed in the Galana. In the bush-lands isolated outcrops of migmatite are often the only rock type to be seen, and appear as broad whale-backs or rock pavements stripped of their top-soil. Some of the finest exposures are to be seen in the gorge below Lugard's Falls (Plate II, Fig. 1).

In the migmatites uniformity of composition or texture is seldom found over more than a few inches. Hornblende, biotite, quartz, plagioclase and microcline are the typical constituent minerals; the hornblende is usually a dark green pleochroic variety and is more abundant than biotite, with which it is arranged in interfoliations in a granoblastic mosaic of quartz and felspar, as in specimen 65/374 from the Mbololo river. Gneisses of this composition are of a green-grey colour, and generally contain more quartz and felspar than ferromagnesian minerals; they are traversed by quartzo-felspathic veins varying from thin stringers conforming to the foliation of the enclosing gneiss to veins containing augen, and massive pink or white felspathic dykes that pinch and swell and sometimes cut across the foliation or banding of the host gneiss. In some exposures foliation and veining are sub-parallel and contrasting bands are evenly preserved along the strike, whilst in others the gneisses have evidently undergone acute deformation exhibited by flexural-slip folds, *boudinage* structures (Plate II, Fig. 1) and the drawing out of hornblendic bands into *schlieren*, or their rupture into rounded or sub-angular fragments. In the type of complex so produced much of the minor folding is random and cannot be related to any specific pattern of deformation.

The light-coloured veins are of granodioritic composition, varying in texture from fine-grained to coarsely crystalline; the coarsest material is usually localized where there has been a reduction in pressure during movement of the migmatite i.e. in shear-zones, at local swellings, arches of ptygmatic folds, and intervening between amphibolite bands that have suffered rupture. In these instances the veins are pegmatitic in appearance but are closely similar in composition to the normal light-coloured bands containing quartz, microcline, sodic oligoclase, biotite and hornblende.

Nodules, which are either diopsidic or garnetiferous, are sometimes arranged in zones enclosed in the migmatite and probably represent calcareous or pelitic sedimentary relics; their presence implies that much of the biotitic banded material in the migmatites is of original sedimentary origin.

Amphibolites.—Dark hornblende-rich inclusions varying from ovoid to angular or tabular in shape are a common feature of the migmatites; generally they are even-grained plagioclase amphibolites similar to specimen 65/366 from Lugard's Falls, in which hornblende constitutes about half the rock, the remainder consisting of equigranular quartz and plagioclase, with accessory diopside and biotite.

(5) Anatectic or Palingenetic Rocks

(a) Granitoid Gneisses

Coarse-grained massive granitoid gneisses outcrop in the Galana valley and in bush country to the north and south of Tsavo where their rib-like exposures can be followed for several miles. They are usually pink in colour and resistant to erosion, forming narrow ridges, bold tors, or inselbergs. Some of the best examples can be seen immediately east of the "Tree house", a game observation platform at Maji ya Chumvi about two miles east of Tsavo. East of Tsavo railway station the Tsavo river cuts its way through a series of steep-sided ridges composed of well jointed granitoid gneiss of which specimens 60/52 and 60/53 are typical. In thin section they are seen to be granoblastic in texture and to contain quartz, microcline, vein perthite, and albite-oligoclase, with scattered biotite and chloritized biotite, rare hornblende, and crystals of apatite, zircon and iron ore. Microcline is the dominant mineral, replacing plagioclase extensively and imparting a strong pink coloration to the rocks, of which felspar forms more than two-thirds. Tors of a similar granitoid gneiss are a prominent feature on the south bank of the Galana river between Lugard's Falls and Tsavo. In thin section (specimen 65/372) coarse folia of quartz are seen to be tongued and embayed by the enclosing felspar which is mainly microcline with some oligoclase.

Granitoid gneisses also outcrop near the railway two miles north-west of Ndara station (specimen 65/396), and are often the only rocks exposed in the inselbergs and whale-backs situated between the Tiva river and the Yatta plateau; most conspicuous of these is Kiasa (2,320 feet) which rises sharply to a height of 500 feet above the surrounding plain. The smooth exfoliation surfaces show numerous thin biotitic streaks in a gneiss which in thin section (specimen 60/28) resembles the examples described above. The massive granitoid gneisses forming the central ribs to these features merge at their margins into banded biotite-hornblende gneisses, the whole being shown by the symbol *Xg* on the map.

PLATE I

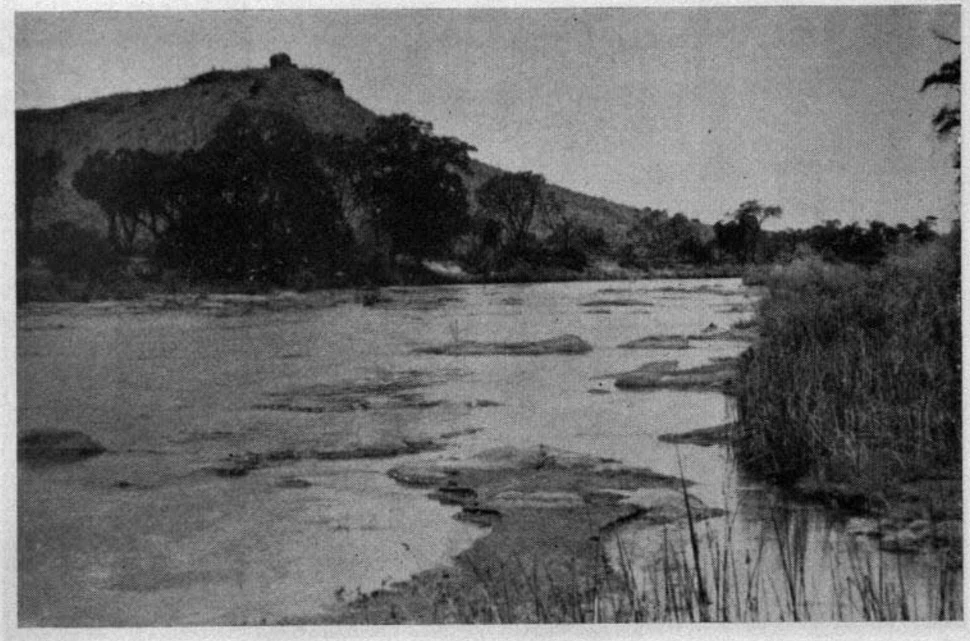

Fig. 1—Epiya Chapeyu, an outlier of plateau phonolite near the north bank of the Galana river at longitude 38° 47′ E.

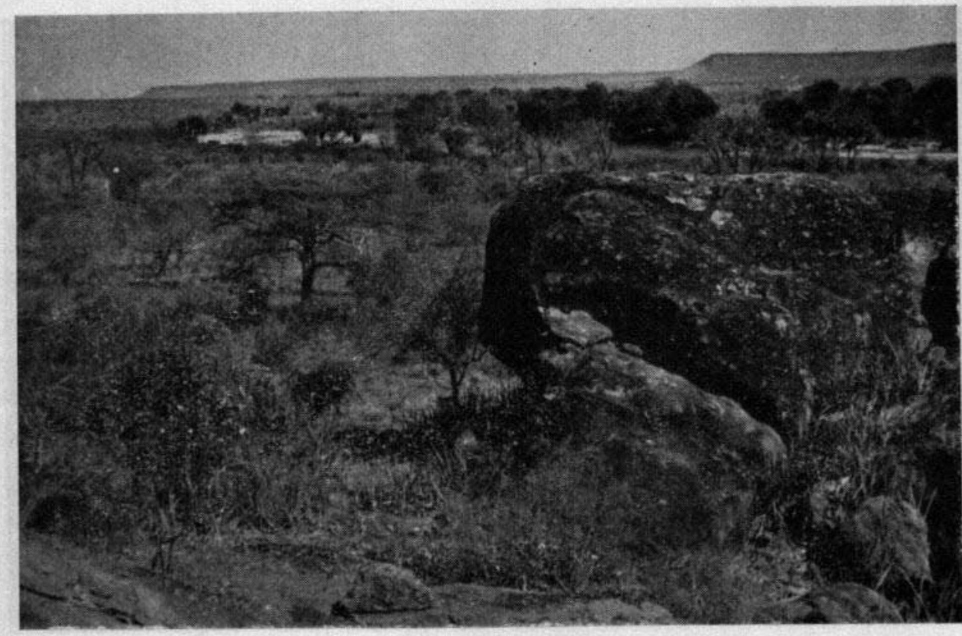

Fig. 2—Sobo Rock, an outcrop of conglomeratic grits in the Duruma Sandstones. The Galana valley and Yatta plateau are seen in the distance.

PLATE II

Fig. 1—Pegmatite with boudinage structure in banded migmatite near Lugard's Falls.

Fig. 2—Mobilized crystalline limestone with xenoliths of hornblendic gneiss and diopside skarn, near Ithangethi.

PLATE III

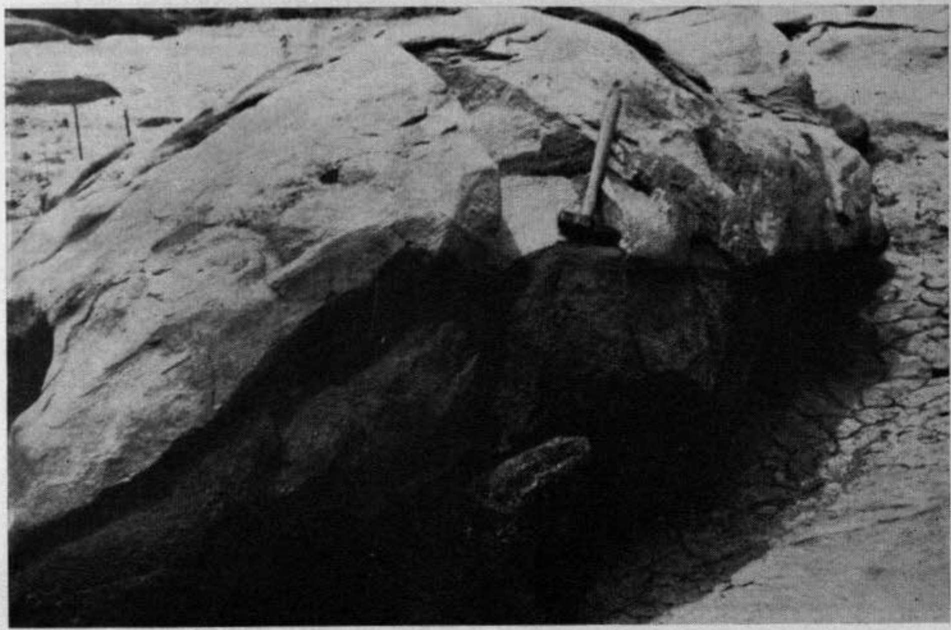

Fig. 1—Massive graded beds in the lower Duruma Sandstones. The hammer rests on an eroded surface between dark mudstone and light-coloured coarse grit. Galana river, near Sobo Rock.

Fig. 2—Thin bedded sandstones and calcareous flags in the lower Duruma Sandstones. Galana river, near longitude 39° 00′ E.

Fig. 1—Panorama from Sagala summit looking north. Teri valley in left foreground, Ndara (4,690 feet) in middle distance, eastern Taita hills in left background.

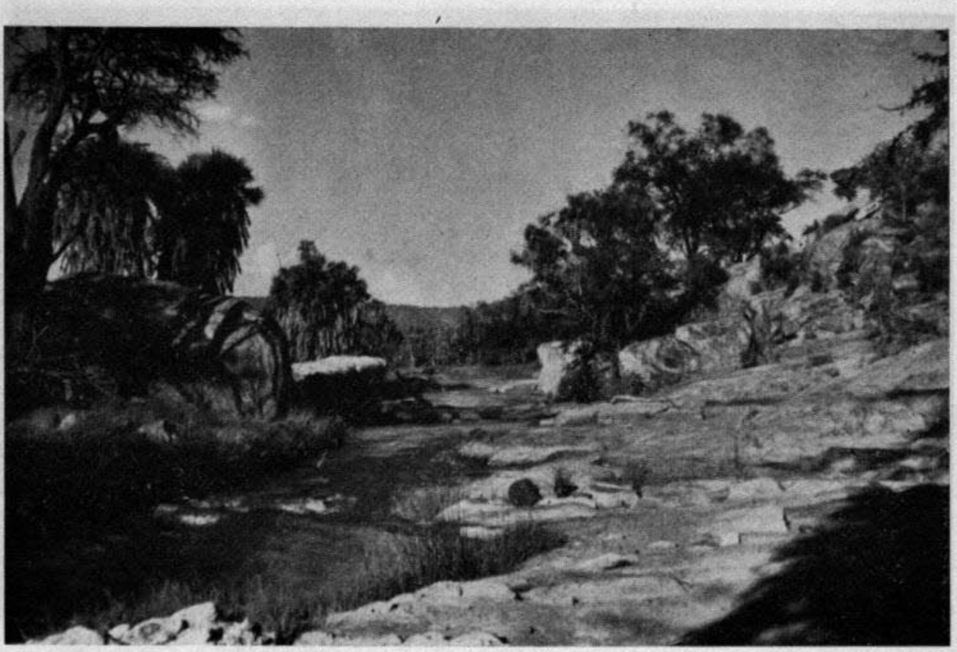

Fig. 2—The Tsavo valley two miles east of Tsavo.

Some five miles south-east of Voi a granitoid gneiss is quarried at Gutuni, near the railway, for ballast and concrete aggregate; the rock exposed in the quarry is white and is evenly dappled with black biotite glomeroporphyroblasts. An equigranular texture is revealed in thin section (specimen 65/512), granoblasts of quartz, microcline, and oligoclase making up the bulk of the rock, whilst large sub-idiomorphic flakes of biotite with accessory zircon, apatite, iron ore and rare white mica complete the mineral assemblage. The gneiss is traversed by narrow dark grey microgranitoid veins (specimen 65/513) containing abundant biotite and some muscovite in a fine-grained equi-granular mosaic of quartz and oligoclase with large apatite crystals. Microcline is comparatively rare.

(*b*) *Pegmatites*

Pegmatites are common both in granitoid gneisses and migmatites of the central part of the area, but are less frequently encountered in the gently-dipping metasediments in the east, and in the hornblendic gneisses of Voi and Sagala. They can be classified into two compositional types:—

(i) Soda pegmatites.

(ii) Potash pegmatites.

(i) *Soda pegmatites* are less abundant than the potash variety and are generally found as conformable veins or sheets in biotite gneisses, or as lenticular swellings and veins in migmatite, but occasionally are seen to cut across banding or foliation without producing displacement so that they are demonstrably non-dilational and have evidently grown by replacement. In composition they resemble the host-rocks. They are usually barren of ore minerals and contain no potash mica.

(ii) *Potash Pegmatites.*—Pink potash pegmatites vary from small auto-segregations in rocks that have reached an advanced stage of granitization, to massive coarsely crystalline bodies with clear margins cross-cutting their host-rocks. The auto-segregations are often lenticular, with augen structure, and rich in microcline. In the darker biotitic host-rocks a mafic aureole sometimes surrounds the coarse segregations, indicating depletion of quartzo-felspathic material to form the pegmatite. Larger dyke-like pegmatites sometimes contain felspar up to six inches in size; the felspar is generally a pink or flesh-coloured visibly perthitic microcline, but a pegmatite outcropping approximately a mile to the west of Ata was found to contain abundant green microcline, or amazonite (specimen 65/434). Graphic intergrowths of quartz and felspar are not uncommon in the pegmatites and one large body that was followed intermittently in a south-south-easterly direction from the Galana at longitude 38° 50′ E. was found to contain perfect graphic intergrowths of quartz and microcline over a distance of many miles (specimen 65/469). Most of these pegmatites are barren of traces of mineralizing volatiles, but black tourmaline was noted in a pegmatite between Manyani and Tsavo, and again in massive pegmatites in the Athi river approximately four miles north-west of the Tsavo-Athi confluence; the latter outcrops also contain amethystine quartz. Potash mica occurs in some pegmatites of the Tsavo area, but is generally of small size. Rose quartz is also occasionally found.

Argon-potassium ratios determined by Shillibeer and Watson at the University of Toronto give an age of 560 $\pm$ 50 million years for potash felspars from a pegmatite outcropping one mile south of Tsavo (Holmes and Cahen, 1955, p. 12).

(6) METAMORPHOSED BASIC AND ULTRA-BASIC INTRUSIVE IGNEOUS ROCKS

Rocks believed to have been derived from pre-metamorphic basic dykes or sills are difficult to distinguish from the metamorphosed volcanic rocks described in the previous section; both are essentially hornblende gneisses and have been shown on the map under the same colour and symbol *(Xhg)*. Generally the metamorphosed apparently intrusive basic igneous rocks are limited in extent and do not constitute large stratiform units like the metamorphosed volcanic rocks. They occur as lenses and contain only minor amounts of quartz and felspar.

Garnet Amphibolites.—Dark green or black dense amphibolites containing red garnets up to a few millimetres in size occur as lenticular or dyke-like masses in the Galana valley near the Punda Mlia confluence. In specimen 65/449 from this locality prisms of hornblende and large idiomorphic garnets constitute some 80 per cent of the rock, the remainder consisting of interstitial quartz and highly sericitized felspar (Fig. 5 (*a*)).

Hornblendites.—Coarse heavy hornblendites outcrop in a similar manner to the garnet amphibolites and were observed in the Punda Mlia and Galana rivers. In thin section (specimen 65/364, from the Punda Mlia at 38° 47′ E.) they are found to consist almost entirely of interlocking blades of hornblende, with minor amounts of diopside and interstitial quartz and sericitized plagioclase.

Epidiorites.—A distinctive rock, not found elsewhere in the area, outcrops on the western slopes of the Ndara-Sagala ridge immediately above the village of Vuria Sagala; here the steep hillsides are underlain by a dense coarsely crystalline rock containing large pink garnets and interlocking prisms of pyroxene and amphibole. In thin section (specimen 65/420, Fig. 5 (*b*)) the rock is seen to contain garnet, hypersthene

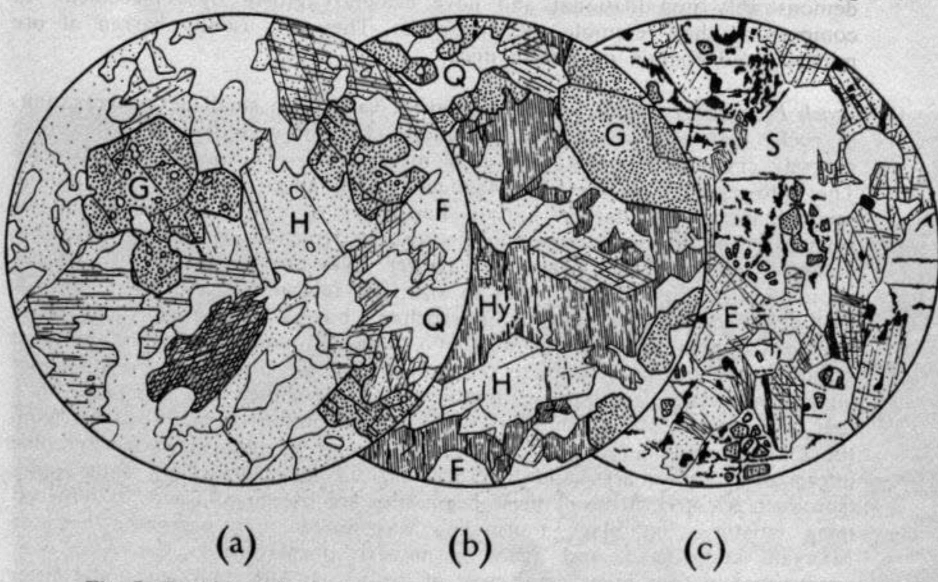

Fig. 5—Drawings of thin sections of metamorphosed basic and ultra-basic igneous rocks from the Voi-South Yatta area:—

(a) Garnet-amphibolite from near the Galana-Punda Mlia confluence. Specimen 65/449. Ordinary light, x 13. Quartz (Q), felspar (F), hornblende (H), garnet (G).

(b) Epidiorite from near Vuria Sagala. Specimen 65/420. Ordinary light, x 13. Quartz (Q), felspar (F), hypersthene (Hy), hornblende (H), garnet (G).

(c) Serpentine, from Pundia Mlia river, two miles from confluence with R. Galana. Specimen 65/362. Ordinary light, x 13. Serpentine (S), enstatite (E), olivine (O).

exhibiting a strong pink to green pleochroism, hornblende, and quartz, in approximately equal proportions. Plagioclase and accessory rutile and iron ore are the accompanying minerals. Garnet is sometimes developed as coronas about quartz and felspar segregations and between quartz or felspar, and pyroxene; this distribution may have been brought about by the liberation of quartz from felspar during garnet formation in an original dolerite (Temperley, 1938, p. 33). Specimen 65/426 from Vuria Sagala is similar in composition but is more gneissose than specimen 65/420; granulitization of garnet and hypersthene is conspicuous and is attributed to the strong shearing to which the Sagala block has been subjected.

Serpentines.—Green to black vitreous serpentine was observed in small outcrops close to the contact between the low-dipping meta-sediments near Sobo and the Lugard's Falls—Ithangethi zone. In thin section (specimen 65/362, Fig. 5 (*c*)) more than half the rock is seen to consist of a pale yellow serpentine reticulated with the cleavage patterns of olivine from which it was derived. Streaks and aggregates of iron ore are abundant in the serpentine together with relics of olivine and the remainder of the rock is composed of strongly cleaved pale green enstatite. The present composition was probably brought about by the serpentinization of a peridotite saxonite).

2. The Duruma Sandstones

The Duruma Sandstones underlie a great part of the Taru desert situated to the east and south-east of the area considered here (Miller, 1952; Sanders, 1959); their western contact with the Basement System enters the Voi-South Yatta area some miles south of the Galana river and trends in a north-north-westerly direction to the lower Tiva river. Much of this country is a monotonous plain over which there are no outcrops, so that on the surface it is difficult to distinguish between areas underlain by the Basement System and the Duruma Sandstones.

The Duruma Sandstones are the Kenya equivalents of the Karroo System of South and Central Africa and show close similarities to the Permo-Triassic successions of Madagascar and Tanganyika. Three major lithological divisions are distinguishable, with coarse grits and sandstones at the top and bottom of the sequence and finer sandstones and shales in the middle:—

Duruma Sandstones ..	Upper ..	4. Mazeras Sandstone and Shimba Grit.
	Middle ..	3. Mariakani Sandstones.
		2. Maji ya Chumvi Beds.
	Lower ..	1. Taru Grits.

Only the Taru Grits are seen in the present area.

(1) The Taru Grits

The Taru Grits in the area mapped are best exposed in the Galana valley near Sobo rock at longitude 38° 56′ E. (Plate I, Fig. 2), where massive green, red and pink arkoses and conglomerates dip eastwards at about 30 degrees. The conglomerates which can be seen in the western faces of Sobo rock and neighbouring tors, contain pebbles of granitoid gneiss and other varieties of quartzose gneiss derived from the Basement System. The pebbles are sub-angular and range to over six inches in size, although the average diameter is about one inch.

Coarse thick bedded grits outcrop between here and the eastern margin of the area; they are essentially arkosic, the proportion of clastic felspar in some specimens (e.g. 65/394 from two miles east of Sobo rock) reaching more than fifty per cent. The constituents are angular and poorly sorted throughout, and the cementing matrix is either ferruginous as in specimen 65/438 from the Galana at longitude 38° 57′ E., or calcareous as in specimen 65/439 from a point three miles north of the Galana at longitude 38° 58′ E. Some of the massive grits are cross-bedded but east of Sobo rock they are seen to be graded (Plate III, Fig. 1); the lower coarse part of each bed is light in colour and approaches gravel-grade whilst the upper more fine-grained part is a dark red gritty mudstone.

The easterly dip of approximately 30 degrees is maintained for distances of three to four miles from the Basement System contact, but near to the eastern margins of the area the dip in the Galana valley reduces to ten or fifteen degrees and an increasing proportion of thin gritty sandstone and shales with nodular limestones appear (Plate III, Fig. 2). Dips probably reduce in depth with an attendant thinning of beds away from the Basement System contact and a conservative estimate for the total thickness of the Taru Grits is believed to be in the range 3,600-7,700 feet (Sanders, 1959, p. 15). Thin-bedded black limestones and oolites (specimen 65/387, from three miles east of Sobo Rock), are intercalated in thin bedded sequences in the upper part of the succession; they are typically fresh and give a clean conchoidal fracture. Angular grains of clastic quartz and felspar are sometimes abundant and impart a gritty appearance to the dark weathered surfaces of the limestones.

Age and Conditions of Deposition of the Taru Grits.—In the Mid-Galana area (Sanders, 1959) the Taru Grits are overlain by beds containing the fresh-water bivalve *Palaeanodonta fischeri* Amal. of Upper Permian age (Gregory 1921, p. 54) so that it is likely that the bulk of the grits outcropping in the present area were deposited during the lower and middle Permian Period, and the lowermost beds may be of upper Carboniferous age.

In eastern Kenya the end-Tertiary peneplain bevels the Basement System and Lower Duruma Sandstones alike, and in consequence there are few hills in which a representative thickness of the Taru Grits can be seen; in the Galana river section, however, a great thickness of coarse arkosic beds is banked against the metamorphic foundation, representing rapidly deposited and ill-sorted debris derived from the neighbouring Basement System terrain. A considerable thickness is also indicated for the Lower Duruma Sandstones outcropping in the vicinity of Taru on the Kenya-Uganda railway where a marked negative gravity anomaly of about 17 milligals has been recorded on passing from the Basement System to the Taru grits (information supplied by courtesy of the B.P.-Shell Exploration Parties).

The arkoses and conglomerates appear to form a series of coelescing wedges and are essentially piedmont deposits. The tectonic factors influencing this type of sedimentation have been emphasized by Krynine (1941, p. 1918), who attributed the rapid accumulations of arkoses at the fringes of granitic or metamorphic terrains to steep youthful topography resulting from uplift and block-faulting at the end of orogenic cycles. It is likely that some graded beds in the Taru Grits were deposited in lakes of tectonic origin by turbidity currents released during slumping under the trigger of contemporaneous tectonic movements (Sanders, 1957, p. 369).

3. Tertiary Lavas—Yatta Phonolite

The Yatta plateau phonolite is dense and microcrystalline, and exhibits a conchoidal fracture and dark green to grey colours. Fresh surfaces frequently have a greasy lustre due to the waxy nepheline content of the groundmass. A porphyritic texture is conspicuous throughout the extent of the flow; the phenocrysts are predominantly of anorthoclase felspar in euhedral plates ranging up to four or five inches in length, and are frequently flow-orientated, their sub-parallel alignment being particularly apparent in vertical sections of the lava seen in the cliffs bounding the plateau. Cruciform twins of anorthoclase are common. Nepheline phenocrysts are less abundant than anorthoclase, and are distinguished by their stout rectangular or rounded shape and green lustrous appearance.

In thin section (specimens 60/25, 60/26 from Sangayaya, 65/431 from the Mopea gap, and 65/444 from Epiya Chapeyu) a groundmass of trachytic texture is seen to be composed of prisms of anorthoclase, together with amphibole and pyroxene and interstitial nepheline. The soda amphibole cossyrite occurs as small grains pleochroic in dark brown to black and is accompanied by needles of brown barkevikite and kataphorite. Soda pyroxene is represented by aegirine-augite and is sometimes accompanied by a pale green diopsidic pyroxene, apatite is a common accessory, and zeolitic material is a conspicuous alteration product replacing both phenocrysts and groundmass. Analcime is present interstitially and is sometimes abundant.

Marked vesicularity of the flow is absent to the west of the Mopea gap, but in the eastern parts of the plateau amygdales become abundant in the lava and often contain white zeolites. Some outcrops are scoriaceous, the lava being riddled with ovoid or lenticular vesicles which occupy as much as fifty per cent of the rock. In this region the lava outcrop broadens to cover an area measuring approximately ten miles from north to south, and seven miles from east to west; the lava surface which elsewhere forms an almost flat capping to the Yatta plateau (Plate I, Fig. 2) is here chaotically broken by a multitude of craters, some of which have small phonolite plugs at their centres. The majority of the craters range between two and four hundred yards in diameter, and are floored by red sandy soils surrounded by low amphitheatres of vesicular phonolite. Centres of neighbouring craters are generally separated by no more than a few hundred yards; sometimes they are mutually interfering, producing doublets or clover-shaped triads in plan, and several groups show a linear arrangement about north-north-easterly-trending axes. The central plugs rise sharply to heights of thirty or forty feet above the crater floors; they are of dense unvesiculated and coarsely porphyritic phonolite in which subvertical flow-streaming of anorthoclase phenocrysts is sometimes distinguishable. Approximately two hundred craters and a smaller number of plugs are found on the eastern Yatta plateau, representing the eroded remnants of a series of centres from which a phonolitic lava flood was almost simultaneously extruded. The distribution of the plugs suggests that lava was poured out from points on several *en echelon* fissures in the Basement System foundation and this view is suggested by the occurrence of a tinguaitic dyke in the lower Tiva river. The alignment of the supposed feeder fissures is unrelated to the direction of the linear outcrop of the western part of the South Yatta phonolite, which was explained on an earlier page as an erosion feature.

Lava fields exhibiting a multitude of small craters formed on closely spaced fissures have been described from Iceland by Rittmann (1939), and Barth (1950, p. 132). The East Yatta lava field is possibly of similar origin, although due to its advanced state of erosion pyroclastic products of the eruptions are lacking.

4. Superficial Deposits

Red sandy soils evenly mantle much of the bed-rock over the Voi and South Yatta plains; the accumulations are shallow in the Galana, Tsavo and Athi valleys where the underlying rocks are generally exposed in platforms or narrow ribs, and thickest about the bases of hills like Sagala, Irima and Manga and near to the foot of the Yatta plateau. Over the plains the superficial soils contain layers of kunkar limestone and lateritic ironstone, and thicken into talus accumulations and alluvial fans near to hills. As a result of small rainfall and slight run-off the minerals derived from the disintegrating metamorphic rocks suffer little transportation, and garnet, titanomagnetite, or mica are often localized in the soils over their source rocks. Lava surfaces on the Yatta plateau are almost devoid of soil apart from thin accumulations in pans, which collect fine-grained detritus and form seasonal water-holes.

Black clay soils are restricted to regions of poor drainage and are not extensive. They occupy an area of several square miles between Irima and Mzinga hills and east of Irima, and have also formed in a narrow strip between Kiasa and the Yatta plateau in the old Tiva valley; these localities support little or no thorn scrub in contrast to the surrounding red soil areas which are densely covered by vegetation.

Red, brown and dark grey alluvial earths mark the course of the lower Tiva river east of longitude 38° 35′ E. They are flood deposits which spread for distances of over a mile on either side of the indefinite river bed and are exposed in a multitude of narrow ramifying gullies. Pleistocene to Recent scrolls of cross-bedded sand and gravel containing pebbles of gneiss and lava margin the course of the Galana.

5. Unmetamorphosed Intrusive Igneous Rocks

Unmetamorphosed igneous rocks are represented in the area by a pyroxenite, and dark lamprophyric and alkaline dykes of post-Permian age, which cut both the Basement System and Duruma Sandstones.

Biotite Pyroxenite.—A dark very coarse biotite pyroxenite invades gneisses forming a group of hills approximately two miles south-east of Wathoni. The outcrop is of some extent; it may represent a plug-shaped plutonite. Exposed surfaces of the rock are lustrous with dark mica, and in thin section (specimen 60/47, Fig. 6 (*a*))

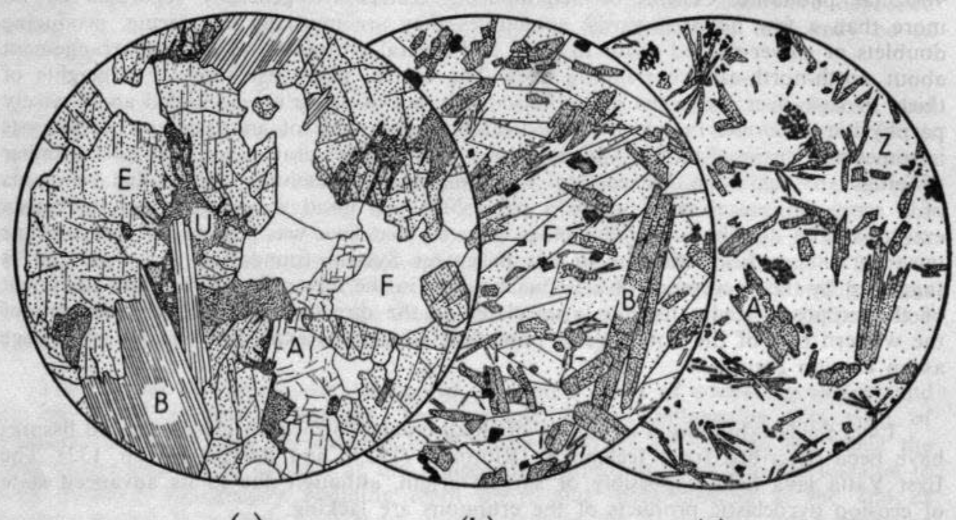

Fig. 6—Drawings of thin sections of intrusive rocks from the Voi-South Yatta area:—

(a) Biotite pyroxenite, from two miles south-east of Wathoni. Specimen 60/47. Ordinary light, x 13. Enstatite (E), augite (A), hornblende and uralite (U), biotite (B), felspar (F).

(b) Vogesite, from the Galana valley near the eastern border of the area. Specimen 65/360. Crossed nicols, x 33. Felspar (F), barkevikite (B).

(c) "Tinguaite", from the lower Tiva valley. Specimen 60/30. Ordinary light, x 13. Aegirine-augite (A), zeolite and felspathoid (Z).

it is seen to contain large sub-idiomorphic biotite crystals, xenomorphic pyroxene consisting of enstatite and diopsidic augite, and hornblende. The enstatite exhibits weak pink to green pleochroism, and both the pyroxenes are partly uralitized along cleavage partings. Interstitial oligoclase forms less than ten per cent of the rock; a little interstitial carbonate is also present, together with a small amount of cummingtonite.

Vogesite.—Dark green nodular-weathering dykes cut grits of the Lower Duruma Sandstones in the Galana valley near the eastern margins of the area. A thin section (specimen 65/360, Fig. 6 (*b*)) is seen to contain abundant slender crystals of brown pleochroic barkevikite and green augite in a matrix of stout soda orthoclase crystals with secondary calcite and chlorite, iron ore granules and needles of apatite being scattered throughout. Some analcime is present as infrequent interstitial patches. The texture of this rock is similar to that of a lamprophyre dyke outcropping a few miles further east in the Mid-Galana area, and scattered blocks of vogesite were also found in the vicinity of the lower Tiva river, near Ndian Daza (specimen 60/31).

Trachytes.—A trachytic dyke has invaded coarse garnetiferous para-gneisses approximately two miles west of Sobo Rock, where it can be seen in the bed of the Galana river; it has a width of about eighteen inches and strikes almost due north. In composition it compares with the vogesite dykes but the dark minerals (barkevikite and iron ore) are less abundant and a trachytic texture is pronounced. Fragments of dark grey fine-grained trachyte (specimens 60/32 and 60/33) were also found near Ndian Daza. Large barkevikite phenocrysts are a feature in the former specimen, and the latter contains a small amount of analcime.

Amphibole Monchiquite.—A narrow porphyritic dyke of basaltic appearance cuts hornblendic migmatites at a point where the Galana river takes a sharp northward sweep mid-way between the Athi-Tsavo confluence and Lugard's Falls. It is about eighteen inches in width, has an easterly dip of 70 degrees and strikes north-north-east. Fine-grained chilled margins are developed at the dyke walls. In thin section (specimen 65/399) the rock is seen to contain abundant phenocrysts of olivine and long prisms of augite in a dense pilotaxitic matrix of barkevikite augite, iron ore granules, and apatite; the base is colourless and isotropic or zeolitic.

This dyke is of interest since it is probably that referred to by Gregory (1921, pp. 185-186) as "a dyke of phonolite cutting through the gneiss of the plain east of Tsavo". Gregory's view that the Yatta phonolite represents a lava flow originally confined by the walls of a valley, rather than a fissure eruption fed by underlying dykes, is hence supported since although this particular dyke lies near to the axis of the present phonolite outcrop it is non-phonolitic and strikes across rather than parallel to the Yatta plateau.

"Tinguaite".—A dense grey or green dyke with pin-point vesicularity outcrops in the lower Tiva approximately seven miles west of the Kitui-Mambrui road. Exposure is poor but the intrusion appears to be relatively large, and the resistant dyke apparently has a local damming effect during flooding of the river, so that a large water-hole some acres in extent (Ndian Daza) has formed on the upstream side of the outcrop. In thin section (specimen 60/30, Fig. 6 (*c*)) the rock is seen to contain abundant needles and microlites of aegirine, exhibiting strong green to brown pleochroism, enmeshed in a zeolitic base with occasional pools of quartz.

Dyke rocks similar to those described above are probably more common in the Voi-South Yatta area, and also the Mid-Galana area in the east (Sanders, 1959), than the number of specimens collected would suggest. The examples cited are, however, instructive since they are often lamprophyric and commonly contain alkaline pyroxene and amphibole; they compare with dyke rocks recorded from a wide area in eastern Kenya extending from Jombo hill in the Coast Province some 100 miles to the south-east (Caswell, 1953, p. 45), to Kitui in the north (Sanders, 1954, p. 34). Dyke rocks of this type are generally associated with highly alkaline deep-seated rocks, for example foyaite and other sodic syenites, such as are found at Jombo hill (Baker, in Caswell 1953, p. 35). The occurrence of a rock that may have been derived from a tinguaite in the lower Tiva, and the presence of phonolite extrusive centres in the east of the area serve further to emphasise the alkaline character of this petrographic province, since tinguaite is the hypabyssal equivalent of phonolite and occurs as marginal facies of nepheline syenite and, like the vogesites and monchiquites, in dykes. It seems likely therefore that alkaline plutonic rocks must underlie parts of the area between the Galana and Tana valleys but are either concealed or have yet to be located at surface.

VI—METAMORPHISM AND GRANITIZATION

A large part of the area is underlain by crystalline schists and gneisses derived from sediments that have suffered intense regional metamorphism; before metamorphism the sediments ranged from coarse arkoses, greywackes and sandstones to fine-grained shales and mudstones. Marls and limestones, together with volcanic rocks and basic or ultra-basic injections, were intercalated in the clastic accumulations. Subsequent to their deposition these rocks were subjected to powerful stresses and were folded and sheared, whilst some, it is believed, were thrust deep into the earth and under the influence of high pressures and temperatures were recrystallized and underwent compositional changes effected largely by the slow migration or exchange of elements in an ionic state (Ramberg, 1952, p. 248) at the same time the incompetent rocks yielded by plastic flow. Relaxation of compressive forces and a slow return to isostatic equilibrium accompanied by deep erosion over a long period of geological time eventually completed the cycle and revealed a metamorphic assemblage of great complexity.

In the present area two groups of crystalline rocks can be distinguished in the Basement System. They are (i) medium- to high-grade metamorphosed sediments, the Sobo Formation, which although metasomatized have not suffered strong granitization and are only moderately deformed, and (ii) the migmatites of the Lugard's Falls area, a fundament of original sedimentary, volcanic and basic igneous rocks which has been intensely granitized and deformed, so that the original sedimentary pattern is almost obliterated. Both are of great regional extent and continue into neighbouring areas.

(i) *The Sobo Formation.*—This is a stratiform series of para-gneisses and granulites containing thin serpentinized dolomitic limestones and abundant intercalations of hornblende gneiss. It is probably equivalent to the Kurase Series which has been mapped some 60 miles further south (Saggerson, 1962, p. 11), but the two series cannot be traced into each other. The intensity of metamorphism impressed on the Sobo rocks is shown by the pelitic gneisses and schists, and by the calc-silicate granulites, which formed from rocks sensitive to mineralogical changes during regional metamorphism, when characteristic stable mineral assemblages were developed. The pelitic rocks commonly contain almandine garnet, often accompanied by brown biotite, and the rare aluminous beds carry thin folia of sillimanite. Interstratified calc-silicate gneisses contain a pale green diopsidic pyroxene, scapolite, plagioclase, and garnet.

Some typical mineral assemblages include—

- sillimanite-garnet-plagioclase-biotite-quartz;
- garnet-biotite-plagioclase-quartz;
- diopside-scapolite-garnet-plagioclase;
- epidote-garnet-sphene-plagioclase;
- calcite-diopside-scapolite-sphene;
- calcite-grossularite-wollastonite-sphene.

These assemblages may be correlated with rocks of the amphibolite facies of Eskola (1920, p. 146), the pelitic rocks falling within the sillimanite-almandine sub-facies (Turner, 1948, p. 85).

The high grade of regional metamorphism exhibited by the sillimanite-bearing pelitic schists is possibly not sustained throughout the whole of the formation. Assemblages indicative of intermediate grades of metamorphism i.e. kyanite-staurolite were not observed, but it is evident that some parts of the formation are of a comparatively low grade, characterized by floggy garnetiferous schists and thin phyllites containing chlorite and green biotite. These low-grade metamorphic rocks are possibly localized in post- or late-orogenic zones of shearing found in the easternmost exposed parts of the Basement System.

The metamorphosed sediments have been widely reconstituted; crystalloblastic textures are almost universal throughout and some of the schists contain porphyroblastic felspar, much of which is sodic plagioclase. Quartzo-felspathic veining and pegmatitization are comparatively rare, however, and apart from the crystalline limestones the series shows little evidence of plastic deformation. For the most part the various metamorphic rock types appear to represent originally stratified sediments which have remained comparatively competent during folding and shearing.

(ii) *Migmatites of the Lugard's Falls Area.*—In the central part of the area the exposed Basement System is of heterogeneous migmatites, granitoid gneisses, and banded or veined gneisses which occupy a broad zone between the Tiva and Galana valleys. This complex contrasts with the Sobo Formation, to which it evidently forms an older granitoid fundament. Elements contributing to its heterogeneous character are (i) dark amphibolites, generally felspathic, containing variable amounts of biotite and more rarely garnet, (ii) pink or white quartzo-felspathic gneisses either granoblastic or with augen, and (iii) microcline pegmatites. In some exposures alternating bands of amphibolite and quartzo-felspathic gneiss strike evenly along the outcrops, though more often the veins and bands pinch and swell, or are discontinuous and contorted, whilst in extreme cases the migmatites are intensely deformed, hornblendic inclusions being ruptured or drawn out into *schlieren*, and it is apparent that these parts of the complex reached a plastic condition. The composition and texture of the rocks implies that powerful metasomatism has tended towards the production of granitic material—even the most tenuous quartzo-felspathic veins are knotted with porphyroblasts or augen of microcline, and perthitic microcline is ubiquitous in the pegmatitic segregations. The texture of the rocks demonstrates that replacement of original constituents by migratory material has contributed to their present composition, thus oligoclase is sometimes enclosed in, and has embayed margins against porphyroblastic microcline. The oligoclase sometimes shows albitic margins and myrmekite is commonly developed between microcline and oligoclase. Although granitization processes have converted this migmatitized basement into an essentially granitoid shield it would appear that, like the Sobo Formation, it consisted originally of a suite of sedimentary rocks intercalated with volcanic accumulations and basaltic intrusions, since in some localities coarse gneissose garnetiferous bands and massive microcline-rich granitoid gneisses are enclosed in the complex and probably represent pelitic and psammitic sediments respectively. Lenticular diopsidic skarns may mark the relics of former calcareous sediments. Some of these metamorphosed sediments perhaps represent infolded parts of the superincumbent Sobo Formation.

VII—STRUCTURE

The rocks of the area comprise three groups of widely differing age and with different structures. They are:—

1. Metamorphic rocks of the Basement System.
2. Duruma Sandstones.
3. Yatta plateau phonolite.

Structures in the Basement System are more complex than in either of the remaining groups.

1. Basement System

The metamorphic rocks exhibit a north-north-westerly regional trend which is expressed by a ribbed topography readily distinguishable on air-photographs taken over areas where the soil cover is thin. In the east foliation dips are generally less than 20 degrees, and well-foliated flaggy gneisses occupy a gently folded belt some eight miles in width west of the contact between the Basement System gneisses and the Duruma Sandstones. Here the major structural feature is an open syncline which occupies the area between Sobo Rock and the Voi-Sobo road (Fig. 7).

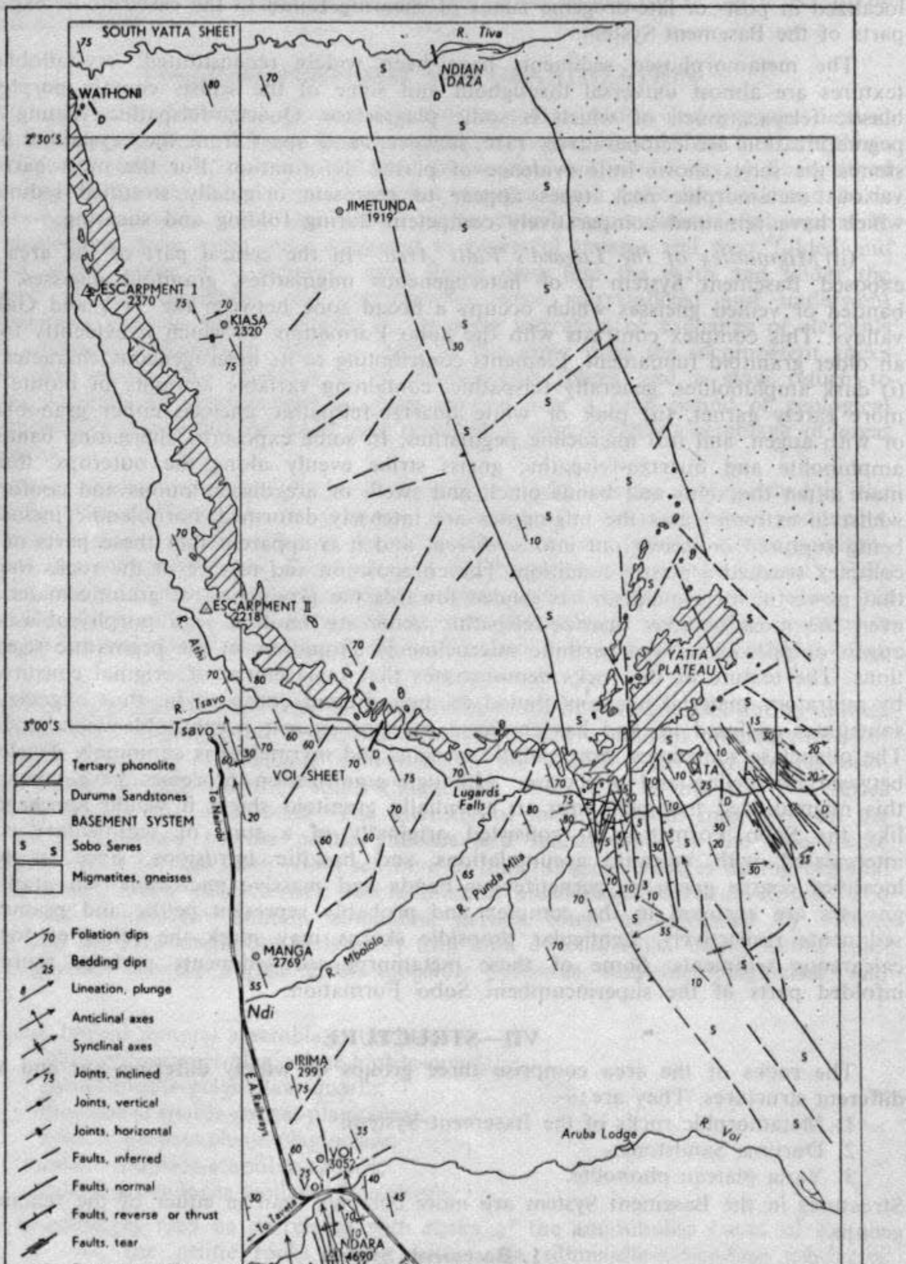

Fig. 7—Structural map of the Voi-South Yatta area

Near the confluence of the Punda Mlia and the Galana there is an abrupt change in both structure and petrography; the low eastward dips of the Sobo belt give way to steep westerly dips which are maintained in a broad zone for some eleven miles across the strike. It is unlikely that the migmatites of this section represent a straight succession, and they are thought rather to represent migmatitized sediments that have been folded isoclinally about steep westerly-dipping axial planes. Further west, in the vicinity of Tsavo, foliation dips are high but show fluctuations from east to west across the strike; folding is evidently more open here than in the Lugard's Falls belt to the east, and in some cases the noses of plunging folds can be seen on the ground and are well shown on air-photographs. These large structures are obscured by soil cover over much of the area, but a complete, well-defined northward-plunging syncline can be seen immediately north-north-west of Ndovu na Lala (1,804 feet) near Tsavo, and open folding of northerly pitch is evident on Sagala and the hills north of Voi.

A linear fabric is often seen in the well foliated gneisses and schists, but is rare in the banded migmatites. The lineation * generally plunges towards the north-north-west at an angle of between five and ten degrees in the western part of the region. Southerly pitch is more frequent in the Sobo Formation to the east.

Major faulting in the Basement System earlier than post-Miocene is inconspicuous, but crushing and granulitization of many gneiss horizons suggest that strike faults replace the limbs of some of the tight folds. The contact between the nearly horizontally disposed Sobo Formation and the steeply dipping migmatites near Ithangethi is one of thrusting; crushed and mylonitized gneisses of westerly dip can be seen in the Galana valley and continuations of this tectonic zone can be followed to the north and south where there are outcrops of mylonitized gneisses. Near the south bank of the Galana the dip of the thrust contact is shown by quartz veins which are grooved and fluted with great regularity. The flutings dip at 35 degrees in a west-south-westerly direction.

Post-Permian faults are conspicuous in the Duruma Sandstones and faults of similar trend in the Basement System are possibly of the same age. They are well seen in the lower reaches of the Punda Mlia river, and in other tributaries which enter the Galana south-west of Ata, the prominent outlier of phonolite standing near the eastern end of the Yatta plateau. In this locality minor tributaries of the Galana often follow fault-lines in which drag effects and cleavage or shattering of the wall rocks can be seen in the comparatively flat-lying gneisses and granulites. Outcrops of the granitoid gneisses and para-granulites are generally strongly jointed throughout the area. The principal joint directions are determined by bedding-plane partings which generally strike north-north-west, and by dip joints which are either vertical or of steep northerly dip and strike in an east-north-easterly direction (a true bearing of 260 degrees was frequently recorded). A flat or near-horizontal jointing which often causes the more resistant outcrops to form groups of tors consisting of large cuboid blocks is also common.

Over the greater part of the Voi-South Yatta area the relief is low, so that it is difficult to observe entirely any structure in three dimensions. An approach to three-dimensional exposure is, however, seen in the Ndara-Sagala ridge the highest parts of which stand some 3,000 feet above the surrounding Voi plains (Plate IV, Fig. 1). This feature is instructive from a structural point of view since it is the only part of the Basement System sufficiently well exposed to permit satisfactory boundary mapping of the contrasting metamorphic formations. The hills stretch for a distance of about ten miles immediately south of Voi, and are about four miles in width from east to west. The hill-slopes are steep on the north, south and west, and precipitous on the east, where in places there are cliffs and sheer rock faces several hundreds of feet in height. When viewed from the north or north-north-east (Fig. 8) the rock groups are

* A descriptive and non-genetic term for any kind of linear structure within or on a rock (Cloos, E., 1946, p. 1).

Fig. 8—Sketch drawing of the Sagala massif viewed from the north-north-east

seen to dip towards the west at about 30 degrees, and a westerly dip is sustained over the higher western slopes of both Sagala and Ndara so that whether viewed from the north or south the dominant physiographic features are a series of dip-slopes inclined to the west at approximately 25 degrees, broken by several steeper, step-like, eastward-facing escarpments. When viewed from the east and north-east cliff-forming horizons are seen to plunge gently northwards at between five and ten degrees, the section seen in the eastern face of the hills being almost in the axial-plane of a great anticlinal fold. A "lineation" on the grand scale is produced by the intersection of the folded series of contrasting rocks with north-south-trending steeply inclined major shear-planes.

The succession in the Sagala hills has been quoted on a previous page (p. 12). The three units distinguished—

3. Hornblende-garnet para-gneisses
2. Banded hornblende-biotite gneisses
1. Felspar prophyroblast and augen gneisses, biotite para-gneisses, and biotite-hornblende gneisses

enable the structural mapping of the hills. The uppermost group is stratiform and cliff-forming and is a marker horizon responsible for the bold topographic features of Sagala. On the western flanks it forms the subsidiary Mashanda ridge (4,050 feet), where at the summit dips are about 30 degrees to the west increasing to almost vertical on the lower slopes, for example near Vuria Sagala (Fig. 9). The north-south-trending Teri valley, about one mile in width, intervenes between Mashanda and Sagala; here group (3) with the underlying groups (2) and (1) in stratigraphic order, are repeated by a series of fractures that follow the valley axis. The cumulative effect is one of downthrow to the east, and if the fault-planes were assumed to be vertical the total indicated throw would be 3,500 feet. A uniform westerly foliation dip of between 30 and 40 degrees is maintained in this section. The major dislocations can be followed through zones of deep decomposition where the intensely disturbed rocks, stained in browns, reds and greens, contain mylonites.

Group (3) again forms a dip-slope between the Teri valley and Sagala summit. The westerly dip here is less than in the Mashanda ridge and reduces from about 30 degrees at the westernmost foot of the slope to 10 degrees at the summit, where a fault of similar trend to those of the Teri valley passes immediately east of the trigonometrical beacon and extends northwards through Kimbasi and across the foot of the precipitous eastern face of Ndara; this fault almost follows the axial plane of the Sagala anticline, the steep east-facing cliffs below the summit ridge revealing an almost vertical section in the core of the fold. Dips measured high on the face are low to the west, as at the summit, but at intermediate levels they pass through horizontal to become easterly, and at the foot of the eastern slopes of Makiboro they are about 55 degrees to the east.

It is evident therefore that the Sagala structure although complicated in detail is essentially simple; it comprises an open anticlinal fold of gentle northerly pitch broken into a series of slices by faults downthrowing to the east. Similar high-angle faults of appreciable throw have also been mapped to the south at Kasigau, and also in the southern part of the Sagala hills by Saggerson (1962, p. 48). The Sagala fractures although large in themselves are probably subsidiary to a fault zone of steep or vertical dip which determines the straight eastern margin of the Taita hills and the Mbololo ridge immediately outside the western boundaries of the area.

2. The Duruma Sandstones

The western limits of the Lower Duruma Sandstones in the Galana valley are marked by massive grits dipping at more than 30 degrees to the east; they are strongly cleaved, veined, and jointed parallel to the Basement System contact, so that the junction between the two is evidently faulted. The contact continues in a north-south to north-north-westerly direction across the Galana and passes near to the eastern limits of the Yatta plateau. It is shifted for a distance of approximately two miles by a large dextral tear-fault of north-westerly trend which traverses the grits immediately to the north of Sobo Rock. The wall-rocks of the fracture show horizontal or gently inclined slickensides.

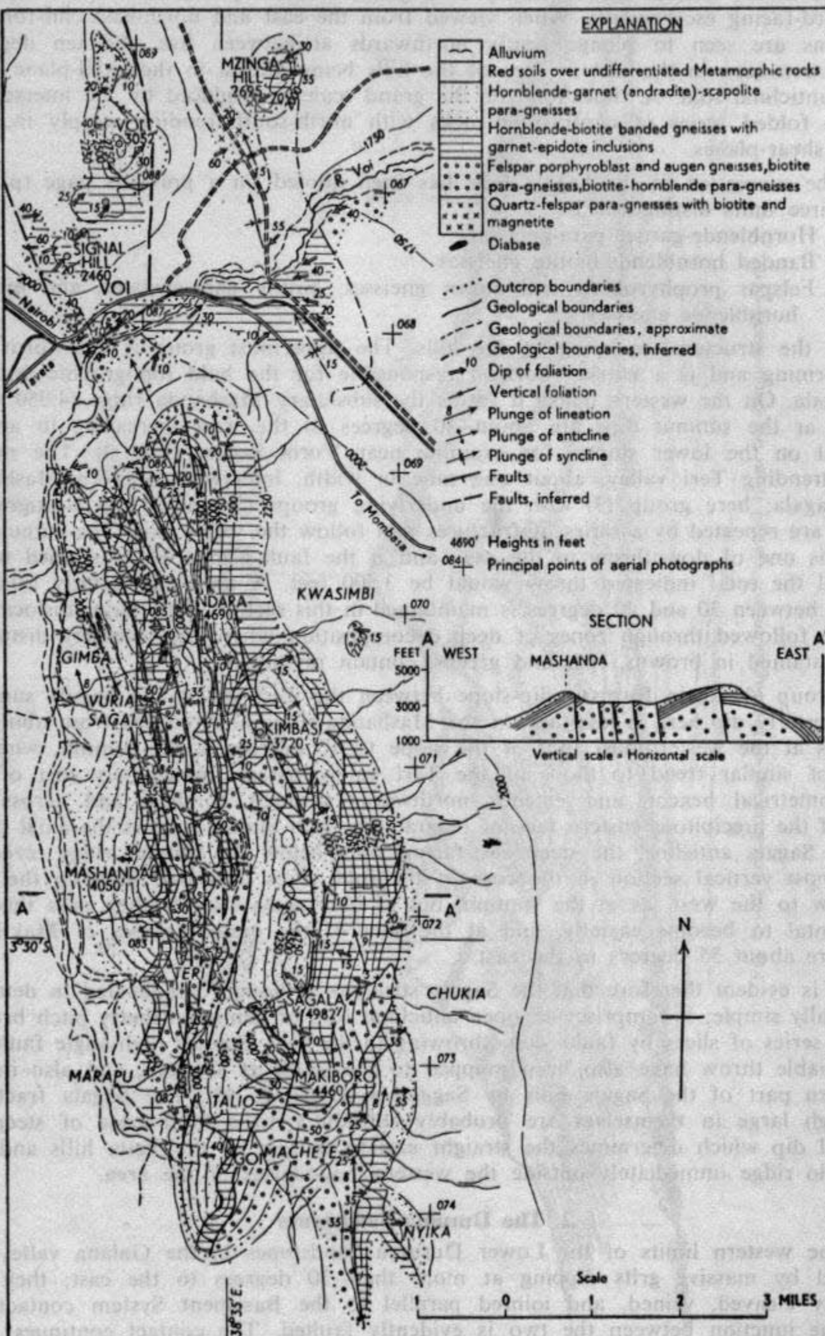

Fig. 9—Geological map of the Sagala-Ndara massif

3. The Yatta Phonolite

Flow-streaming in the Yatta lava is displayed by a preferred orientation of anorthoclase phenocrysts. In vertical sections the phenocrysts are conspicuously aligned with their long axis parallel to the floor and upper surface of the flow; on horizontal surfaces of the lava their alignment is less clearly defined but is often sufficient to indicate an approximate direction of movement. In the southern and eastern parts of the plateau statistical orientation is roughly from east to west, whilst north of Tsavo it swings towards the north-west. The directions of flow-streaming seen in the phonolite at various points are shown on the geological map.

VIII—MINERAL DEPOSITS

1. Copper

Prior to the present investigation copper staining had been recorded from several places north and south of the river Tsavo, and during the survey similar secondary copper stains and films were noted in localities between Tsavo and Lugard's Falls, near the western banks of the Athi river north of Tsavo, near Voi hill, and on the eastern slopes of Sagala, and are indicated on the geological map.

As long ago as 1893-94 C. W. Hobley discovered indications of copper in the gneisses near the junction of the Athi and Tsavo rivers (*see* Annual Report, Mining and Geological Department for 1937, pp. 28-29). No prospecting was however carried out until April, 1936, when N. E. Fraser applied for an exclusive prospecting licence over an area of approximately 60 square miles embracing both banks of the Galana south-east of the Tsavo-Athi confluence and extending to the vicinity of Lugard's Falls (Official Gazette, April 28th. 1936, Government Notice No. 272). An application for a reduced area of 20 square miles was accepted in December, 1936, (Official Gazette, January 5th, 1937, Government Notice No. 8), and an exclusive prospecting licence valid for a period of three months was granted on 11th February, 1937, but was subsequently allowed to lapse and the area was reopened to prospecting on 17th February, 1938. During this period a vertical prospect shaft was sunk to a depth of about 15 feet in copper impregnated rock outcropping on the south bank of the Galana at longitude 38° 38′ E. The shaft exposes a quartzo-felspathic granulite containing disseminated chalcopyrite ($CuFeS_2$) and bornite (Cu_5FeS_4) in minute visible granules. Carbonate stains are abundant. A chip sample taken over a width of a foot in the walls of the shaft during the present survey assayed 1.8 per cent copper (analysis No. 25205, W.P. Horne). Sampling during the earlier prospecting had yielded values ranging between 0.2 and 5 per cent of copper.

Elsewhere copper disseminations in the gneisses, particularly near the Tsavo-Athi confluence, give rise to surface stains of green malachite ($CuCO_3\ Cu(OH)_2$) with smaller amounts of blue azurite ($2CuCO_3\ Cu(OH)_2$) and rare pale blue chrysocolla ($CuSiO_3\ 2H_2O$). Primary copper ore is finely disseminated in pink microcline-rich granitoid gneisses and also in coarse amphibolitic migmatites; the granules of ore have a blue iridescent sheen, are visible to the unaided eye and range up to the size of a pin-head. Visual estimations of the proportions of copper in thin sections (specimens 60/57, 60/58, 60/68) vary from one to four per cent. The primary ore is bornite in most specimens, occurring in blue-grey shagreened granules interstitial to quartz, felspar and amphibole. The copper sulphide is almost invariably enclosed in and replaced by a brownish red limonite (Fig. 10) which contains subsidiary cuprite (Cu_2O). The limonite often displays a triangular grid probably pseudomorphosing the crystalline structure of the copper sulphide from which it has been

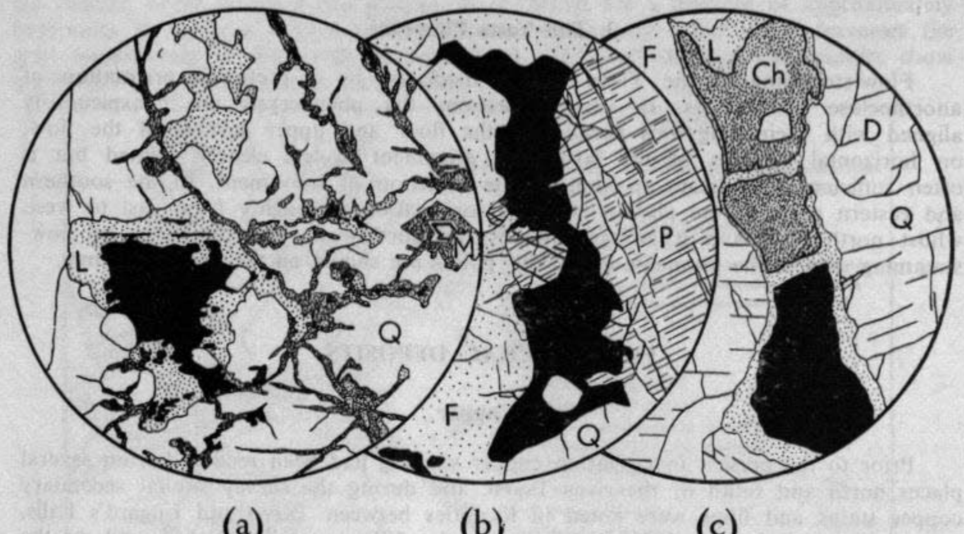

Fig. 10—Drawings of thin sections of copper-bearing rocks from the Tsavo-Lugard's Falls area :—

(a) Oxidized bornite in sheared granitoid gneiss. Specimen 60/56. Reflected light, x 13. Bornite black, limonite (L), malachite (M), gangue (Q). The left-hand side of the drawing represents the edges of the thin section.

(b) Primary bornite in meta-gabbro. Specimen 60/58. Ordinary light, x 13. Bornite black, pyroxene (P), felspar (F), quartz (Q).

(c) Oxidized chalcopyrite and bornite in calc-silicate granulite. Specimen 65/401. Reflected light, x 33. Bornite black, chalcopyrite (Ch), limonite (L), diopside (D), felspar (F), quartz (Q).

derived. Chalcocite is present in specimen 60/67. Crystal interstices and cleavages in the silicate parts of specimens are conspicuously veined by malachite, as in specimen 60/56.

This kind of mineralization occurs at scattered localities ranging over a width of about seven miles, but was best observed immediately north of the Tsavo river in a zone parallel to, and about 1,000 feet west of the Athi river. Here several granitoid ribs with steep westerly dip show copper mineralization. One of these was pitted to a depth of ten feet and was found to be a dyke of weakly foliated microcline granulite with sharply defined walls dipping at 75 degrees to the west. The contacts are slightly discordant with the foliation of the surrounding biotite-hornblende gneisses. The width is 40 inches, and the maximum concentration of sulphides found occurred equidistant between the walls. A channel sample taken over a ten inch width in a central part of the dyke assayed 2.21 per cent copper *, and since copper sulphides were visibly distributed across the full width of the body an average copper content between 0.5 to 1.0 per cent for the 40 inch width is likely. Microscopically the host-rock is granulitized throughout, containing ragged granoblasts of perthite, and strain-polarizing quartz; it is evidently a crush-gneiss occupying a broad shear-zone which facilitated alkaline metasomatism leading to the formation of a dyke-like granitoid body and also assisted the entry of hypogene sulphide solutions. It is likely that other primary copper sulphide disseminations in this area are due to the same cause. They include impregnations in coarse

* Analyst—J. Furst.

plagioclase amphibolite from which malachite stains have been leached from the exterior of the rock and are often only to be seen on interior surfaces; as in the granitoid shear-gneisses the primary mineral is bornite, scattered in blue and purple iridescent granules. A chip sample taken at random assayed 2.49 per cent copper *.

The texture and composition of the copper impregnations in the Tsavo area are typically those of an oxidization zone. Primary copper-iron sulphide is decomposing under the influence of air and moisture into ferrous sulphate and copper sulphate. The former has been further hydrolized to limonite or goethite which replaces the primary sulphide in varying degrees, whilst some of the copper sulphate solutions have reacted with alkali carbonate solutions derived from the host-rock and deposited the green and blue copper carbonates, malachite and azurite. It is probable, however, that not all the copper removed in solution has been precipitated as carbonate in the oxidized zone; some is likely to have been leached to greater depths where it may have been reduced at ground-water level and precipitated as secondary sulphides such as chalcocite (Cu_2S), or covellite (CuS). This process tends to produce a zone of supergene enrichment in many copper-bearing ore-bodies, the position of the zone often being determined by the level of the water-table, although in some deposits no enrichment can be detected and in others an enriched zone is related to earlier rather than present day water-tables. In the present case the outcrops of copper-impregnated gneisses in the Tsavo valley have elevations above sea-level of 1,400 to 1,600 feet, whereas the level of the nearby Athi river is about 1,330 feet, so that the water-table possibly stands at depths of between 70 and 200 feet below the surface. To the east the sub-Miocene surface has an altitude of 2,100 feet so that the fall of the water-table since Miocene times has been about 700 feet. The metamorphic rocks through which the water-table has moved are of steep or vertical dip, so that their foliation planes, lithological discontinuities, and strike shears might be expected to facilitate the slow downward movement of metalliferous solutions.

It appears therefore that conditions necessary for the formation of a zone of supergene enrichment are favourable in this area. At the surface the primary copper ore is in small scattered grains unaccompanied as a whole by introduced gangue minerals such as quartz or carbonates, and spread over considerable widths. Such disseminated deposits do not have well defined walls, and the margins of impregnation can often only be detected by assay. The maximum tenor of copper rises to four per cent over widths of a few inches, and in some localities an average copper content of one per cent over widths of 36 inches can be expected, a figure that is too low to warrant extraction from narrow and steeply inclined stopes. If, however, enrichment has taken place a "blanket" type of secondary deposition due to lateral spreading of solutions during their downward movement may have increased both the tenor of copper and the effective width of the impregnation zones. This can only be tested by drilling or shaft sinking to the water-table.

2. Graphite

Graphitic gneisses were first discovered near Tsavo by Parkinson (1947, p. 24) and prospecting by B. A. Brannstrom in the north-western angle of the Athi-Tsavo confluence revealed at least eight bands of graphitic gneiss varying between 20 and 50 feet in width, striking at about 335 degrees roughly parallel to the Athi river. A total of fifteen trenches was excavated in the graphitic bands (Fig. 11) and samples taken in horizontal cuts over lengths of ten feet, were obtained from ten of them. The samples were crushed, the graphite floated off and the approximate percentage of carbon in the concentrate determined. The results were as follows:—

* Analyst—J. Furst.

TABLE II—PERCENTAGES OF EXTRACTABLE GRAPHITE

East end of Trench | West end of Trench

Trench No.	0–10 ft.	10–20 ft.	20–30 ft.	30–40 ft.	40–50 ft.	Average for Trench
A. I ..	6·26	3·83	2·85	3·70	3·47	4·0
A. III ..	5·50	4·87	1·87	5·14	—	4·3
A. IV ..	6·97	9·03	7·77	—	—	7·9
B. I ..	5·83	—	—	—	—	5·8
C. I ..	6·24	7·68	—	—	—	6·9
C. II ..	4·75	4·19	—	—	—	4·4
D. I ..	6·93	5·70	—	—	—	6·3
D. II ..	5·66	9·47	6·72	5·15	0·54	6·7
D. III ..	8·12	8·94	5·84	6·64	—	7·4
E. II ..	6·62	4·67	—	—	—	5·6

Weighted overall average value = 5.8 per cent.

As the deposit appeared worthy of serious consideration applications were invited from the public in May, 1942, to work a concession in the area, and in January, 1943, a special licence was issued to Kitmag Ltd. covering an area of 160 square miles and including all the known deposits. When work was begun on the concession a pilot plant capable of dealing with one ton of ore per day was erected. Subsequently a further special licence was granted to Kitmag Ltd., for a period of two years over an area of 44 square miles, covering the deposits north of the Tsavo river.

Plant was erected including a two-head stamp battery, flotation cells, rolls, vibrating screens and driers. Provision was also made for obtaining an air-floated fraction during screening. The stamps proved unsatisfactory and it was realized that rolls would give a more satisfactory comminution of the ore. Full-scale rolls were not obtained, however, and the mine continued to operate as best it could with the inefficient plant already installed. Production ceased in April, 1945, and the company went into liquidation at the end of 1946.

According to returns in the files of the Mines and Geological Department, production from the mine was as follows:—

TABLE III—GRAPHITE PRODUCTION—KITMAG LTD. 1944-45

Month	Ore Treated (Tons)	Crucible Grade in lbs.	Foundry Grade in lbs.	Lubricant Grade in lbs.	Stove Polish in Number of Blocks
1944					
June	No record	336	—	—	—
July	No record	145	564	—	—
August	No record	3,360	8,960	—	—
September ..	No record	—	8,960	2,390	—
October	220	—	—	2,630*	—
November ..	390	—	11,300*	—	576*
December ..	432	6,319	—	—	—
1945					
January	none	—	11,200	—	800*
February ..	230	20,160 (lb. concentrates)			—
March	none	3,920	1,120	1,120	2,960 (1,730)*
May	none	—	—	1,120	—

* Denotes Sales.

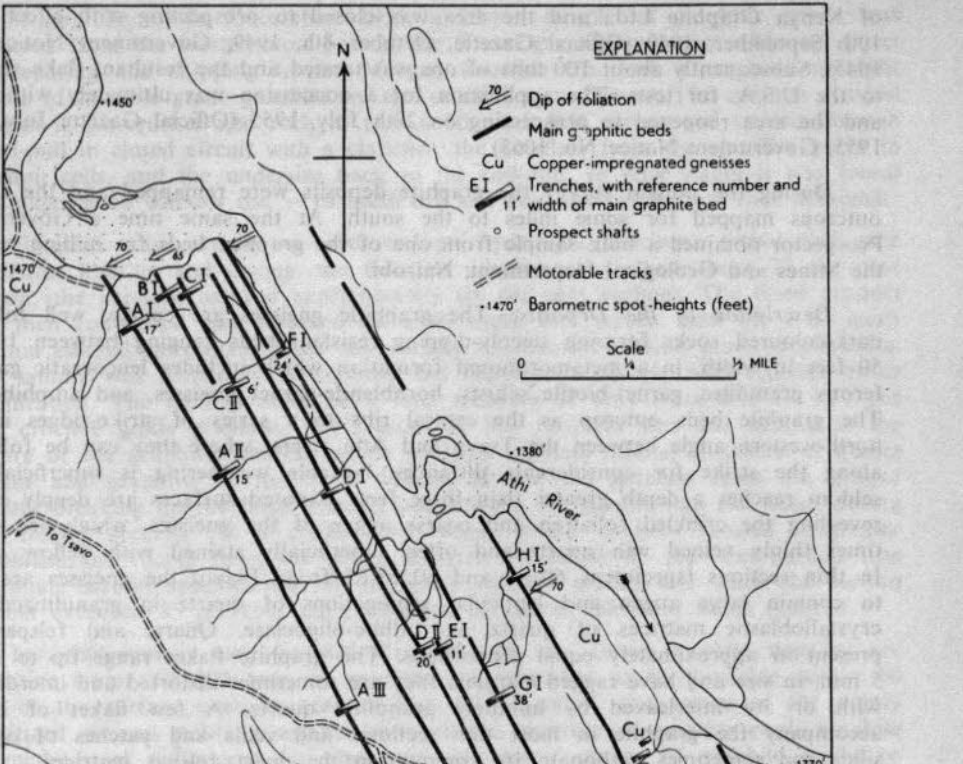

Fig. 11—Map of Tsavo graphite and copper deposits

In July, 1949, an application for an exclusive prospecting licence over an area of approximately 66 square miles situated between the Athi river and the Kenya-Uganda railway between Kyulu and Manyani was made by Dr. E. Parsons on behalf of Kenya Graphite Ltd., and the area was closed to prospecting with effect from 19th September, 1949 (Official Gazette, October 8th, 1949, Government Notice No. 1045). Subsequently about 100 tons of ore was treated and the resultant flake shipped to the U.S.A. for tests. The application for a concession was ultimately withdrawn and the area reopened to prospecting on 20th July, 1955 (Official Gazette July, 26th 1955, Government Notice No. 1063).

During the present survey the graphite deposits were remapped and the known outcrops mapped for some miles to the south. At the same time a Government Prospector obtained a bulk sample from one of the graphite beds for milling tests at the Mines and Geological Department, Nairobi.

Description of the Deposits.—The graphitic gneisses are coarse, well foliated, dark-coloured rocks forming steeply-dipping resistant beds ranging between 10 and 50 feet in width, in a metamorphosed formation which includes leucocratic garnetiferous granulites, garnet-biotite schists, hornblende-garnet gneisses, and amphibolites. The graphite beds outcrop as the central ribs to a series of strike-ridges in the north-western angle between the Tsavo and Athi rivers, where they can be followed along the strike for considerable distances. Notable weathering is superficial and seldom reaches a depth greater than three feet. Exposed surfaces are deeply etched revealing the crinkled foliation and coarse augen of the gneisses, which are sometimes thinly veined wth quartz and often superficially stained with yellow ochre. In thin sections (specimens 60/49 and 60/59-65 from Tsavo) the gneisses are seen to contain large augen and lenticular segregations of quartz in granulitized and crystalloblastic matrices of quartz and albite-oligoclase. Quartz and felspar are present in approximately equal proportions. The graphite flakes range up to about 5 mm. in size and have ragged margins; they are sometimes distorted and interdigitate with or are interleaved by minutely granulitic quartz. A few flakes of biotite accompany the graphite in most thin sections, and veins and patches of opaline silica and sometimes carbonate are common in the quartz-felspar matrices.

North of the Tsavo river the resistant graphitic beds are well exposed owing to the relatively thin soil cover in the dissection areas of the Tsavo and Athi rivers. At the Tsavo the gneisses are obscured by a narrow strip of river sands and alluvium, but graphitic gneisses again appear within 400 yards of the south bank of the river and can be followed to the south-south-east. They are seen in tributary streams of the Tsavo and Galana about four miles north-east of Manyani. In the northern part of this belt continuations of all the horizons found to the north of the Tsavo river have been identified, but exposure becomes increasingly poor southwards so that at a distance of ten miles south of the river only two bands could be located. It is likely, however, that trenching in this region would reveal the remaining parallel beds. Graphitic gneiss was also located between Voi hill and Mzinga hill some 28 miles south-south-east of the Tsavo graphite deposits; here the beds are of finer grain and do not lie in the strike of the Tsavo occurrences.

The proportions of graphite contained in chip-samples representative of indicated widths of some outcrops of graphitic gneiss noted south of the Tsavo river are as follows:—

TABLE IV—GRAPHITE CONTENT OF SAMPLES FROM THE TSAVO AND VOI AREAS

Assay No.	Locality	Width (ft.)	Graphite (%)	Analyst
25204	100 yds. S.S.W. of Observation hill	15	8·6	W. P. Horne.
25214	Two miles east of Ndovu na Lala . .	15	5·5	Mrs. R. A. Inamdar.
25215	Three miles E.N.E. of Ndovu na Lala	18	4·9	Mrs. R. A. Inamdar.
25437	Midway between Voi and Mzinga hills	40	1·85	J. Furst.

Milling Tests.—In December, 1955, a 23-ton sample of graphitic gneiss was extracted from the westernmost bed of the Tsavo graphite prospect with the object of preparing and shipping to the Morgan Crucible Co. Ltd. a ten-hundredweight sample of crucible grade graphite for test crucible manufacture. The ore was crushed through a jaw-crusher and rolls to pass a 10 mesh B.S. screen and treated through a rod-mill in closed circuit with a classifier, the overflow from the classifier going to flotation cells, and the undersize back to the rod-mill. In later stages it was found advantageous to winnow the − 10 mesh ore and float the concentrate thus obtained.

Flotation was carried out with sodium hydroxide, kerosene, teepol and pine oil. After filtering and drying, the flotation concentrate assayed about 72 per cent carbon (the ore-feed assayed approximately six per cent carbon). The dried product was then rod-milled and screened on a 60 mesh B.S. screen until the + 60 mesh fraction assayed more than 85 per cent carbon, to meet the crucible grade specification. The sample was ultimately re-screened and blended to comply with crucible grade specification. The method achieved a final recovery of only from 0.78 to 1.14 per cent crucible grade graphite. The reason for low recovery was due mainly to the texture of the graphitic gneisses which involves intimate mutual enclosure of quartz gangue and graphite, so that it is difficult to free the graphite from the gangue without breaking up the flake graphite and driving the gangue into the flakes during the milling process. As a consequence when screen analysis showed a greater proportion of coarse flake the grade analysis fell below 85 per cent carbon (the minimum carbon specification for Morgan's crucible grade), and when the carbon content exceeded 85 per cent the proportion of coarse flake was much reduced.

In conclusion it may be said that although the Tsavo graphite deposits are extensive (some 500,000 tons of graphite are estimated to be available within 50 feet of the surface over an area of five square miles), the nature of the highly granitized gneisses militates against an economic recovery of *crucible grade* graphite by methods of milling so far attempted, but lower grades of graphite might be produced satisfactorily for a guaranteed market.

3. Limestone

Three types of limestone are found in the area:—

(*a*) Crystalline limestones in the Basement System.

(*b*) Sedimentary limestones in the Duruma Sandstones.

(*c*) Surface limestones, or kunkar.

(*a*) *Crystalline Limestones.*—The most extensive and accessible outcrops of crystalline limestone are located in the south-west of the area, where a series of massive horizons are crossed by the Voi-Taveta road about five miles south-west of Voi. They can be seen near the bridge crossing the Voi river in this area, and form a series of hills at the western margins of the Voi sisal estates. Some of the beds are over fifty feet in thickness and consist of coarsely crystalline blue-grey magnesian limestone comparatively free from siliceous inclusions. Samples taken from the outcrops by Dr. E. Parsons in 1943 showed a magnesia content varying between six and twenty per cent (*Mines and Geological Department file* M/1992/50d).

Further bands of crystalline limestone occur in the Sobo region and extend for many miles to the north and south of the Galana. They are generally impure, containing numerous siliceous inclusions as well as olivine and serpentine, and were evidently originally dolomitic.

(*b*) *Sedimentary Limestones.*—Limestones outcropping in the Duruma Sandstones exposed in the Galana valley seldom exceed a few feet in thickness; they are dark and contain visible siliceous impurities in the form of sand and felspar granules. A partial analysis * of a Lower Karroo limestone from the Mid-Galana area immediately to the east contained 12.29 per cent silica and 0.76 per cent magnesia (Sanders, 1959, p. 45).

(c) *Surface Limestones, Travertine or Kunkar.*—Calcareous deposits are often found as sheeted or nodular encrustations over the crystalline limestones in the Basement System. Samples taken by Dr. Parsons from five miles south-west of Voi are less dolomitic than the crystalline limestones but contain more siliceous impurity.

4. Wollastonite

Outcrops of a massive grey-white wollastonite ($CaSiO_3$) rock were observed at the contacts of a crystalline limestone below the slopes of the Yatta escarpment about 2 miles east of Epiya Chapeyu. The rock consists almost entirely of large fibrous or columnar prisms of wollastonite and is patchily exposed over an area of approximately half an acre.

5. Mica

Few pegmatites containing mica of any size were noted in the area. Most of the mica is biotite, segregated in books and lenticular aggregates at the pegmatite margins. Muscovite occurs in quartzose pegmatites outcropping in the Athi river north of Tsavo, where the size and quality are too poor to warrant extraction.

6. Sands and Clays

Sands free of earthy material are absent over much of the area, and apart from quartz gravels and sands surrounding a quartzite outcrop approximately seven miles west of Sobo rock the only sources of quartz sands are in the Athi-Galana, Tsavo and Tiva rivers where there are deep sand levees, especially in the course of the former†. Impurities in these sands include iron, which occurs both as oxide coating the grains and as heavy particles of ore, felspar, hornblende, micas, garnet and rutile, so that although they are fit for building purposes they are unsuitable for glass manufacture. Beneficiation, including separation from the heavy minerals and acid leaching, might render them of use for the manufacture of coloured glass.

Fine-grained grey or brown alluvial earths containing some clay and a higher proportion of fine sand are extracted from the banks of the Voi river and used for local brick manufacture.

7. Ballast and Concrete Aggregate

Ballast for use on the Voi section of the East African Railways is quarried at Gutuni, a small hillock adjacent to the railway approximately five miles south-east of Voi. Some 53,000 tons of rock were taken from this quarry during 1954-55 for use as concrete aggregate in the manufacture of spun pre-stressed concrete pipes at the Voi factory of the *Société des Tuyaux Bonna.* The pipes, which were 21 feet in length and varied from 30 to 21 inches in diameter, were employed in the construction of the water pipeline from Mzima Springs to Mombasa. The rock is a compact medium-grained quartzose para-granulite having a granitoid texture, and in the absence of suitable lava for road-metal in the vicinity of Voi it may prove a good local substitute.

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* Analyst—Mrs. R. A. Inamdar.

† The Development Committee (Sub-committee on building materials) reported in 1946 that at that time about 45,000 cu. ft. of good quality sand were being moved per month from Voi into the Mombasa area (Report of the Development Committee, Government Printer, Nairobi, 1956, vol. II, p. 60). It was stated (p. 63) that the sand was river sand, but no further details were given.

8. Water

A large part of the area receives a mean annual rainfall of rather less than 20 inches, the whole of which is often concentrated into short wet seasons during the months of May and November. Apart from the Tsavo and Galana, which are fed from catchments outside the area, most of the rivers are insignificant sand-choked channels carrying running water for only short periods. The discharge of the Tsavo river fluctuates less than that of the Galana, as throughout the year it is supplied by a relatively steady escape of waters from the lavas of the Chyulu range and Kilimanjaro. Records taken at Tsavo between 1951 and 1955 are as follows:—

TABLE V—DISCHARGE OF THE TSAVO RIVER 1951-55

(From records of the Ministry of Works, Nairobi)

Discharge	1951 Cusecs*	1952 Cusecs	1953 Cusecs	1954 Cusecs	1955 Cusecs
Maximum ..	2,959†	307	319	995	995
Minimum ..	80	123	113	117	123
Mean	181	141	137	196	179

* Cusecs—volume of water passing a given point measured in cubic feet per second.

† 1951 was an exceptionally rainy year throughout Kenya.

No continuous register of the flow of the Galana river is available; it is, however, liable to wide variations in discharge between the dry and wet seasons—during the former the rate is often between 100 and 400 cusecs, but this figure increases rapidly to several thousand cusecs for short periods, and 105,000 cusecs have been recorded during seasonal spate.

Water is pumped from the Tsavo river for the railway watering-point at Tsavo station, and is also piped by nine-inch water-main to Voi and Mackinnon road. It is likely that this small pipeline will become obsolete, with the completion of the pipeline from Mzima springs to Mombasa. Water is also piped to Voi from the Kigombo reservoir in the Taita hills approximately seven miles to the west of the town, and this supply has been supplemented by bore-holes drilled in the vicinity of Voi. The majority are sited in alluvial beds of the Voi river (Fig. 12) and reach a decomposed zone in the underlying gneiss from which a fair yield of good quality water is obtained. Particulars of these bore-holes are given below:—

TABLE VI—BORE-HOLES IN THE VICINITY OF VOI

(From records of the Ministry of Works, Nairobi)

Bore-hole (M.O.W. No.)	Location and Date of Completion	Depth (ft.)	Depth to Water Table (ft.)	Yield (Galls. per 24 Hours)	Quality
32	Voi Rly. station 19–2–29 ..	121	25	60,480	Good.
C. 188	Voi airstrip, 17–12–42 ..	502	148	24,080	Bitter.
C. 619	Mzinga Sisal Estate, 1–9–47	77	7	39,624	Good.
C. 620	Mzinga Sisal Estate, 5–9–47	85	7	54,000	Good.
C. 621	Mzinga Sisal Estate, 14–10–47	193	7	25,920	Good.
C. 636	Voi Sisal Estate, 11–12–47 ..	400	27	14,400	Good.

For details of the bore-hole logs see Appendix (pp. 47-48).

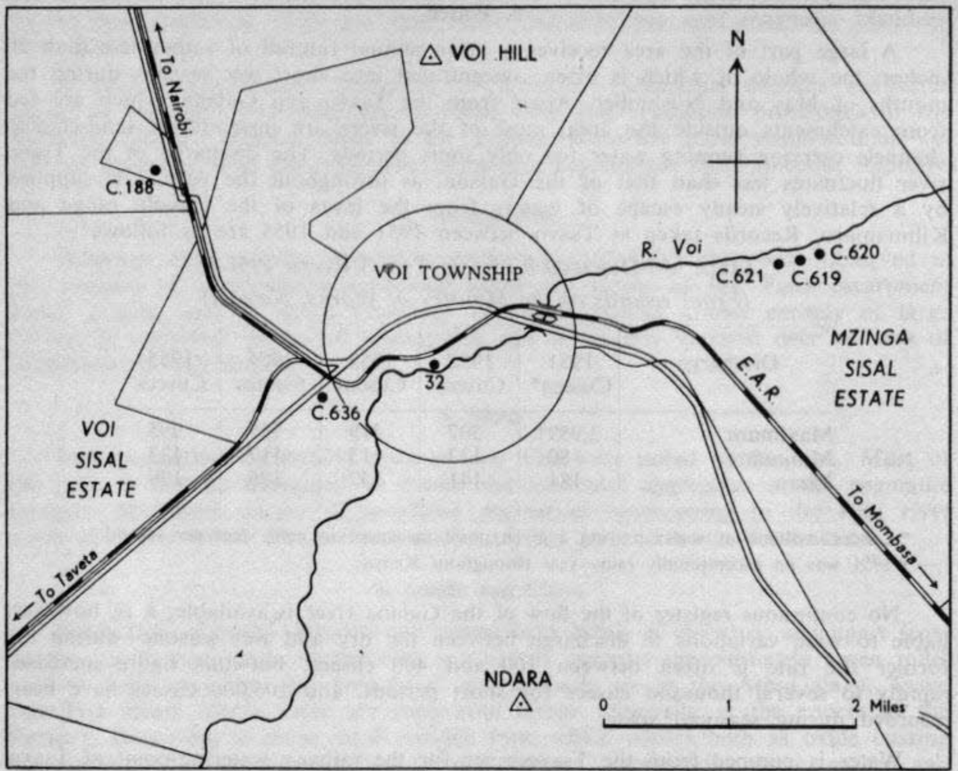

Fig. 12—Location of bore-holes in the vicinity of Voi

The flow of the Voi river is intermittent; it sometimes discharges at over 100 cusecs for short periods during the rains but is liable to dry out in the intervening dry seasons. Bore-hole records indicate, however, that the water-table remains near surface in the alluvial sands of the valley.

The present demand for water in the area as a whole is small, as there is little human settlement apart from that in the south-west, where the population is centred about Voi township and the Sagala Native Location. Sagala is of sufficient altitude to attract a higher rainfall than the surrounding plains and much of the run-off can be conserved by the construction of small earth dams on the upper slopes and valleys. The western foot of the hills is likely to provide favourable sites for bore-holes designed to tap the zone of weathered gneisses underlying deep detrital fans that flank the hills.

Elsewhere the cheapest method of water conservation is by the construction of earth dams such as those on the Voi river at Kandecha and Aruba, approximately nine miles east of Voi. Each of these provides a large artificial pool attracting considerable numbers of game during dry seasons.

Hydro-electricity .—The Galana is the only river in the area with a sufficient flow to provide hydro-electric possibilities. A suitable dam-site for small-scale generation could possibly be found about a mile below Lugard's Falls where the river is confined to a narrow steep-sided channel with rock walls on either side. The head obtainable here is not more than 70 feet however, and the site is remote from areas having an immediate demand for electricity.

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APPENDIX—BORE-HOLE LOGS

(Adapted from records of the Ministry of Works, Nairobi)

Bore-hole No. 32—Voi Railway Station

Total depth 121 feet. Depth from surface at which water was struck—40, 70 and 110 feet. Estimated yield per 24 hours—60,480 gallons.

Depth in feet	*Lithology*
0— 10	Soil
10— 42	Gravel
42— 79	Decomposed gneiss
79—121	Gneiss

Bore-hole No. C. 188—Voi Airstrip

Total depth 502 feet. Depth from surface at which water was struck—178, 265 and 315 feet. Estimated yield per 24 hours—24,080 gallons.

Depth in feet	*Lithology*
0— 10	Sand
10— 29	Murram
29— 47	Decomposed gneiss
47—502	Gneiss

Bore-hole No. C. 619—Mzinga Sisal Estate

Total depth 77 feet. Depth from surface at which water was struck—58 feet. Estimated yield per 24 hours—39,624 gallons.

Depth in feet	*Lithology*
0— 4	Drab micaceous clay
4— 34	Brown sandy clay
34— 37	Yellow coarse quartzose sand
37— 40	Yellow sand with garnet
40— 43	White sand with mica, hornblende and garnet
43— 46	Coarse sand
46— 58	Fine sand with mica and garnet
58— 62	Pebble bed
62— 71	Grey felspathic sand
71— 75	Khaki clays and decomposed gneiss
75— 77	Sand with gneiss fragments

Bore-hole No. C. 620—Mzinga Sisal Estate

Total depth 85 feet. Depth from surface at which water was struck—22 and 49 feet. Estimated yield per 24 hours—54,000 gallons.

Depth in feet	*Lithology*
0— 12	Red-brown sandy alluvium
12— 20	Brown micaceous soil, decomposed gneiss
20— 41	Weathered hornblendic gneiss
41— 49	Quartz-biotite-muscovite schist
49— 85	Quartz-biotite gneiss

Bore-hole No. C. 621—Mzinga Sisal Estate

Total depth 193 feet. Depth from surface at which water was struck—45, 102 and 172 feet. Estimated yield per 24 hours—25,920 gallons.

Depth in feet	*Lithology*
0— 14	Sandy alluvium
14— 18	Red subsoil over gneiss
18— 31	Weathered granitoid gneiss
31— 36	Granitoid gneiss
36—193	Quartzose biotite gneiss with mica schist bands between 65 and 102 feet

Bore-hole No. C. 636—Voi Sisal Estate

Total depth 400 feet. Depth from surface at which water was struck—33, 68, 116, 192 and 355 feet. Estimated yield per 24 hours—14,400 gallons.

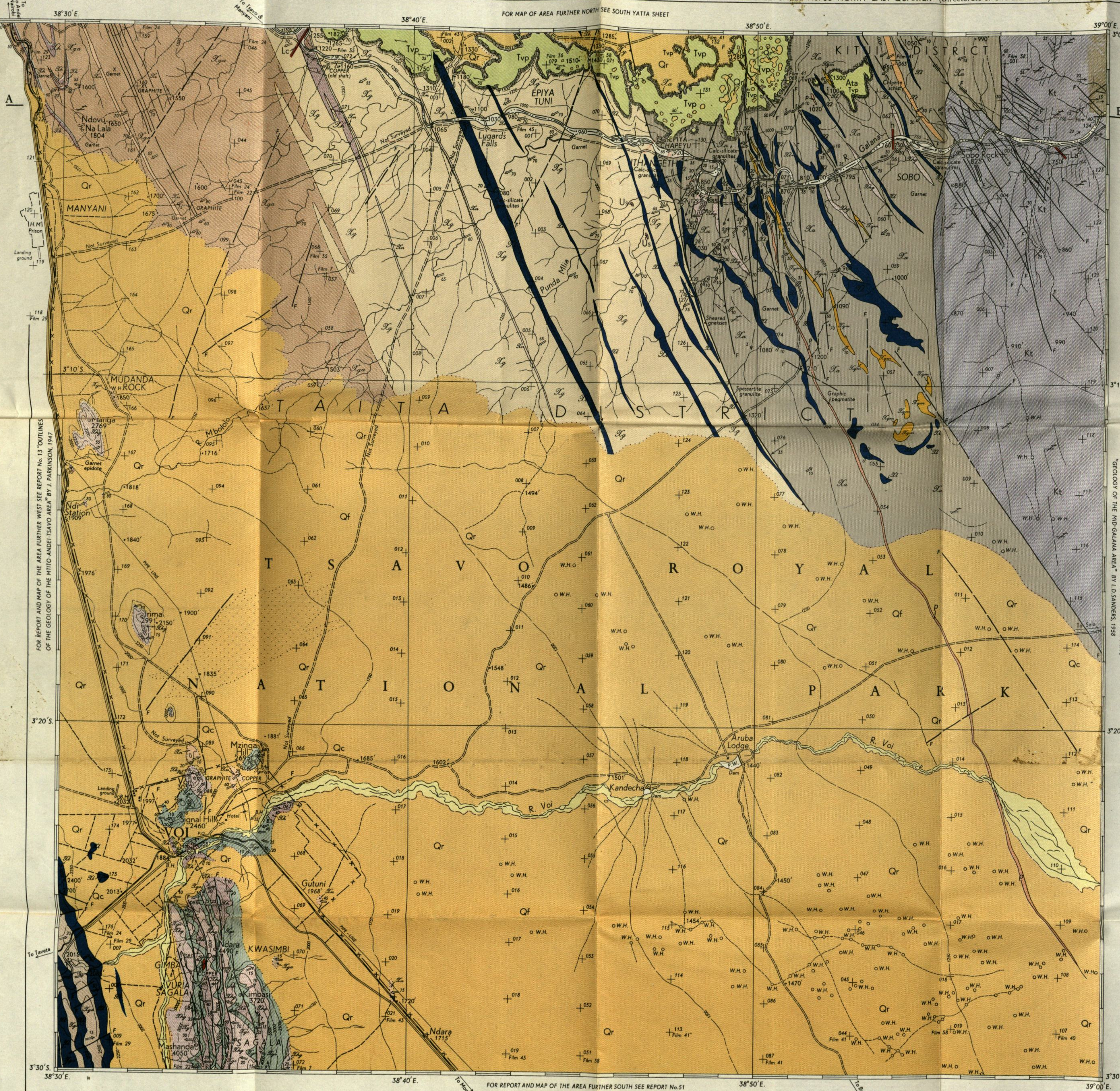
Depth in feet	*Lithology*
0— 6	Red clayey soil
6— 10	Pink soil
10— 18	Coarse sands and clays
18— 31	Yellow weathered gneiss
31— 46	Grey gneiss
46— 68	Yellow quartzo-felspathic gneiss
68—109	Grey hornblende-garnet gneiss
109—113	Quartzo-felspathic gneiss
113—116	Coarse quartzo-felspathic gneiss
116—164	Fine-grained quartzo-felspathic gneiss
164—185	Biotite-garnet schist
185—192	Hornblende-garnet schist
192—204	Grey hornblende-garnet gneiss
204—235	Quartz-biotite gneiss
235—355	Quartzo-felspathic gneiss
355—359	Hornblende-garnet gneiss
359—400	Yellow felspathic hornblende-garnet gneiss

G.P.K. 369—1m—2/60

To accompany Report No. 54

GEOLOGICAL MAP OF THE VOI AREA

DEGREE SHEET No. 65 NORTH-EAST QUARTER (Directorate of Overseas Surveys Sheet No. 190)



MINISTRY OF COMMERCE & INDUSTRY
MINES & GEOLOGICAL DEPARTMENT
KENYA COLONY

Scale 1:125,000

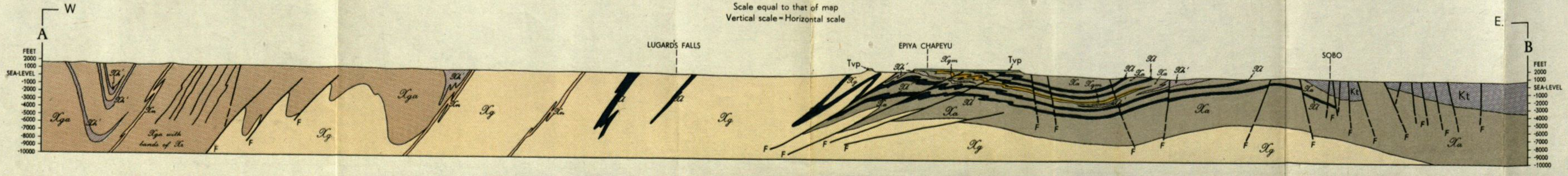
1 inch=1·972 miles or 1·014 inches=2 miles

GEOLOGICALLY SURVEYED BY L. D. SANDERS, GEOLOGIST
Between July and December 1955

Printed by Survey of Kenya 1962.

SECTION FROM A to B

Scale equal to that of map
Vertical scale=Horizontal scale



EXPLANATION

QUATERNARY
- Sandy alluvium
- Qr — Red sandy soils over-lying undifferentiated Basement System rocks. Black soil, stippled. Crustal deposits {Qc calcareous, Qf ferruginous}

TERTIARY — Miocene
- Tvp — Phonolite

U.PALAEOZOIC — Permo-Carboniferous

DURUMA SANDSTONES
TARU GRITS
- Kt — Arkoses, with locally, sandstones, conglomerates, shales and thin limestones

BASEMENT SYSTEM

ARCHAEAN

Psammitic
- Quartzites and muscovite quartzites
- Quartz-felspar para-granulites

Pelitic
- Garnetiferous para-gneisses and granulites
- Albite-oligoclase porphyroblast gneisses Garnetiferous biotite-gneisses

Calcareous
- Crystalline limestones
- Hornblende biotite gneisses with garnet, diopside, sphene, epidote, talc, actinolite. Calc-silicate granulites
- Hornblende-garnet gneisses

- Microcline-oligoclase-biotite-hornblende migmatites with biotite amphibolite schlieren, and granitic sheet and vein reticulation
- Granitoid gneisses
- Hornblende-biotite gneisses
- Graphitic gneiss bands

INTRUSIVES
- p — Pegmatites
- Vs — Serpentine
- Alkaline, basic and other dykes. Lc Monchiquite, La Vogesite, h Trachyte, De Epidiorite

Geological boundaries, observable
Geological boundaries, approximate
Boundaries of outcrops
Dip of bedding
Horizontal bedding
Dip of foliation
Vertical foliation
Plunge of lineation and minor folds
Joints, inclined
Anticlinal axes
Synclinal axes
Faults, nature unknown
Faults, inferred
Faults, normal, with dip and downthrow
Faults, reverse or thrust with direction of dip
Faults, tear, or strike-slip
Orientation of phenocrysts in lavas, with thickness of flow
X COPPER Mineral locality

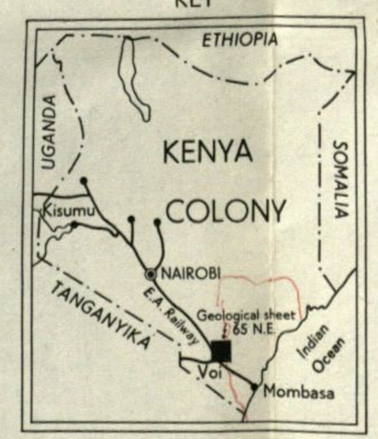
Railway
Main roads (earth)
Secondary roads
Motorable tracks
Game-trails
Form-lines at 250-ft. vertical intervals
Resected points
•1310′ Spot-heights in feet
Principal points of aerial photographs
Lines taken from aerial photographs
Lava escarpment
Bridges
P.W. Permanent water
W.H. Water-holes, seasonal
B.H. Bore-holes
Church, ▪P.S. Police station, ▪P.O. Post office
District boundary
National Park boundary
A — B Line of section

Secondary roads completed after 1955 and inserted from a map prepared by the staff of the Royal Tsavo National Park are denoted "Not Surveyed"

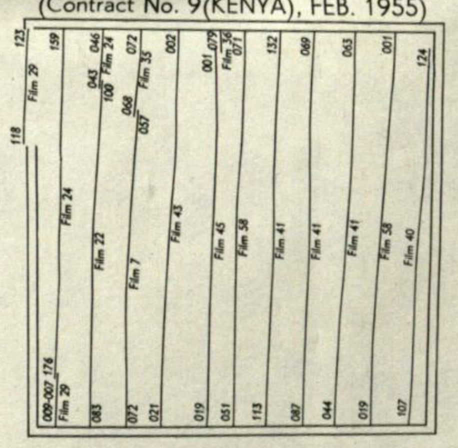
Topography based on 1:500,000 VOI E.A.F. No. 1714 and preliminary plots (KENYA) D.O.S. sheet Nos. 190/I, 190/II, and 190/III

Magnetic declination 3°25′ West

KEY



AIR PHOTO. FLIGHT DIAGRAM
(Contract No. 9(KENYA), FEB. 1955)



To accompany Report No.
GEOLOGICAL MAP OF THE SOUTH YATTA AREA
Scale 1:125,000
1 inch=1·972 miles or 1·014 inches=2 miles
SECTION FROM X to Y
Scale equal to that of map
Vertical scale = Horizontal scale
DEGREE SHEET No.60, SOUTH-EAST QUARTER (Directorate of Overseas Surveys Sheet No. 184)
WITH PARTS OF DEGREE SHEET No.60, SOUTH-WEST, NORTH-WEST AND NORTH-EAST QUARTERS (D.O.S. Sheet Nos. 183, 175, and 176)
EXPLANATION
QUATERNARY
Sandy alluvium
Qr Red sandy soils over-lying undifferentiated Basement System rocks
TERTIARY Miocene
Tvp Phonolites
DURUMA SANDSTONES
TARU GRITS
U.PALAEOZOIC Permo-Carboniferous
Kt Arkoses, with locally, sandstones, conglomerates, shales and thin limestones
BASEMENT SYSTEM
ARCHAEAN
Psammitic
Quartzites and muscovite quartzites
Quartz-felspar para-granulites
Pelitic
Garnetiferous para-gneisses and granulites
Albite-oligoclase porphyroblast gneisses
Garnetiferous biotite-gneisses
Calcareous
Crystalline limestones
Microcline-oligoclase-biotite-hornblende migmatites with biotite amphibolite schlieren, and granitic sheet and vein reticulation
Granitoid gneisses
Hornblende-biotite gneisses
Graphitic gneiss bands
INTRUSIVES
Up Biotite pyroxenite
Tinguaite
Geological boundaries, observable
Geological boundaries, approximate
Boundaries of outcrops
Dip of foliation
Vertical foliation
Joints, inclined
Joints, vertical
Faults, inferred
Faults, normal, with tick on downthrow side
Faults, reverse or thrust, with direction of dip
Faults, tear, or strike-slip
Orientation of phenocrysts in lavas, with thickness of flow
X COPPER Mineral locality
Prospect, derelict
Railway
Main roads (earth)
Secondary roads
Motorable tracks
Game-trails
Form-lines at 250-ft. vertical intervals
Trigonometrical stations, altitude in feet
Resected points
Spot-heights in feet
Principal points of aerial photographs
Lines taken from aerial photographs
Lava escarpment
B.M. Bench-mark
Bridges
P.W. Permanent water
O W.H. Water-holes, seasonal
Abandoned river valleys
District boundaries
National Park boundary
X—Y Line of section
Secondary roads completed after 1955 and inserted from a map prepared by the staff of the Royal Tsavo National Park are denoted "Not Surveyed"
Magnetic declination 3°25′ West
KEY
ETHIOPIA
KENYA
COLONY
SOMALIA
UGANDA
TANGANYIKA
NAIROBI
Mombasa
AIR PHOTO. FLIGHT DIAGRAM
(Contract No.9(KENYA), FEB. 1955 and R.A.F., 82D, 1950)
FOR REPORT AND MAP OF THE AREA FURTHER NORTH SEE "GEOLOGY OF THE IKUTHA AREA" BY J. WALSH
FOR REPORT AND MAP OF THE AREA FURTHER NORTH SEE "GEOLOGY OF THE NYALI-NDIANDAZA AREA" BY P. RIX
FOR REPORT AND MAP OF THE AREA FURTHER EAST SEE "GEOLOGY OF THE LALI HILLS AREA" BY R.G. DODSON
FOR MAP OF AREA FURTHER SOUTH SEE VOI SHEET
TSAVO ROYAL NATIONAL PARK
TAITA DISTRICT
MACHAKOS DISTRICT
SOUTH YATTA PLATEAU
ATHI RIVER
NDIANDAZA
MASIBO
SANGAYAYA
EMUSYA
MINISTRY OF COMMERCE & INDUSTRY
MINES & GEOLOGICAL DEPARTMENT
KENYA COLONY
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