REPORT No. 68

GOVERNMENT OF KENYA

MINISTRY OF NATURAL RESOURCES
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE ENYALI–NDIANDAZA AREA

DEGREE SHEETS 53, S.E. QUARTER
AND 60, N.E. QUARTER
(with two coloured geological maps)

by

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FOREWORD

A glance at the two geological maps and sections accompanying this report, is sufficient to show the large region covered by superficial deposits and the relatively small areas of outcropping rock. In an attempt to ascertain more accurately the nature of the underlying rocks, Mr. Rix undertook magnetometer and gravity geophysical work to augment his geological observations. The results of this geophysical work, although indicating strongly that the subsurface extension of a syenite could be considerable, did not provide the additional information hoped for. Obviously other methods, notably seismic, will now have to be tried if a satisfactory knowledge of the subsurface geology of that large part of sediment-covered eastern Kenya is to be acquired.

Nevertheless, the extension into this region of syenitic intrusions and the probable boundary of the Basement System-Duruma Sandstones, help to complete the regional geological map of this part of Kenya.

The recording of the average annual cycle of events of the Thua and Tiva rivers, which corrects the beliefs of the former explorers, together with observations regarding water-supplies, should assist in future water-conservation and any development programmes in this very arid region.

This report has been edited with the approval of Dr. W. Pulfrey, Commissioner (Mines and Geology).

N. J. GUEST,
Chief Geologist.

14th May, 1962.

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ABSTRACT

The report describes an area of approximately 2,400 square miles in eastern Kenya, bounded by latitudes 1° 30′ S. and 2° 30′ S. and by longitudes 38° 30′ E. and 39° 00′ E. The greater part of the region comprises the gently dissected end-Tertiary peneplain, from which two hills rise to 600 ft., representing residuals of the sub-Miocene peneplain. Two large sand-rivers, the Thua and the Tiva, drain eastwards and eventually taper into wide alluvial flats.

The area is almost entirely covered by sand but scattered outcrops of Basement System rocks of Precambrian age occur. They consist of metamorphosed sediments, the commonest being crystalline limestones, granulites, biotite gneisses and quartzites. A syenite presumed to be Upper Mesozoic in age and associated minor intrusions of camptonite, microsyenite and tinguaite, occur as intrusives into the Basement System. Quaternary deposits which mantle the Precambrian rocks consist of concretionary limestones, lateritic ironstones, pebble-sheets and Recent alluvium, sands and soils.

Accounts are given of the petrography, structure, and metamorphism of the rocks. Magnetometric and gravimetric geophysical surveys are also described. Economic possibilities and water-supplies are discussed.

GEOLOGY OF THE ENYALI-NDIANDAZA AREA

I—INTRODUCTION

The area described in this report which deals with degree sheets 53 S.E. and 60 N.E. (Kenya) is covered by the Directorate of Surveys maps 165 and 176 on a scale of 1/100,000. The area is bounded by latitudes 1° 30′ and 2° 30′ S. and by longitudes 38° 30′ and 39° 00′ E., and is approximately 2,400 square miles in extent. The northern half of the area lies almost wholly within the eastern Crown Lands of the Kitui district whereas the southern half, although still in the Kitui district mainly constitutes a part of the Tsavo Royal National Park. In addition, a small portion of the Kitui district special area is included in the northern half of the area and parts of the Tana river district of Coast Province are included on the east.

Maps.—For convenience in printing, the map of the area has been divided along latitude 2° S. and is published as two sheets, one the geological map of the Enyali area (Degree sheet 53 S.E. quarter) and the second the geological map of the Ndiandaza area (Degree sheet 60 N.E. quarter). In the description that follows, however, the two parts of the area are considered as a unit.

The topographical base-maps required for the preparation of the geological maps were made from aerial photographs at a scale of approximately 1:30,000 using kodatrace overlays, some of which were controlled by plane-table survey points. The positions of one triangulation point within the area and of others in adjacent areas necessary for resection were taken from the Survey of Kenya, Ikutha triangulation diagram, 1/250,000, 1956.

Existing maps consulted include the Garissa sheet EAF 680, 1:500,000 published by the army in 1945 and the 1:250,000 Kitui Sheet No. SA. 37/1 published by the War Office in 1912, the latter merely showing approximate outlines of high ground. Place-names and topographical details shown on these maps were found to be approximate and most have been altered in compiling the present maps. Form-lines on the geological maps, controlled by barometric spot-heights observed during the course of the survey, are only approximate. A traverse of accurate levels made by the Survey of Kenya, from Mambrui on the coast to Ikutha in Kitui district (Line 48, Geodetic levels), passed through the present area. Levelling sites 29 to 176 of this traverse formed a convenient series of reference points.

The fixing of the position of the Tiva river at 38° 30′ E. is at variance with the position of the Tiva river mapped during the survey of the area to the south (Sanders, 1963). The position determined during the present survey, however, agrees closely with the fixing of the same point during the survey of the area to the west (Walsh, 1963), and so has been adhered to.

General Information.—The area is a portion of the low-lying, tropical bushland region bounded on the west by the Kitui hill ranges and on the east by the Tana river. The vegetation consists mainly of *Acacia* and *Commiphora* thorn-bush, with in the west, occasional baobab trees that are often useful as land-marks. Dense bush occurs in the western part of the area but thins a little towards the east, while in the valleys of the two main rivers, the Tiva and the Thua, there occur forest fringes, which are more extensive in the case of the latter river. These forest fringes consist chiefly of giant acacia trees and doum palms (*Hyphaene thebaica*) but the candelabra tree *Euphorbia candelabra*, camel thorn and other species of thorn-trees are also present.

The scanty rainfall is confined to short seasons and often comes as violent storms. The river beds are normally dry and sand-filled (*luggas*) and rapidly become raging torrents following storms over the Kitui hills, which are the catchment for the water that flows into the present area. The rainfall occurs during the period of April-May and November-December, corresponding to the long and short rains respectively of other parts of Kenya. No rainfall records are available but a long-term rain gauge has now been set up at Yendoboini, a few miles to the north of the present area, and recordings made at this station suggest an annual rainfall of 10-15 in. for this part of Kenya (Baker, 1964)*.

Roads are non-existent, though a number of motorable sandy tracks were improved and extended where necessary during the survey. The main track leads eastwards from Mutha, a village five miles west of the area mapped, to the first Thua crossing at Enyali (Nyali), and thence E.N.E. to Kakya, a Wagalla encampment on the river at the second crossing. The track continues eastwards to Wayu, a Wagalla village, and then to Galole on the Tana river. This track from Mutha to the Tana river is the old trade route mentioned by A. M. Champion in a description of his journey down the Thua (Thowa) river (Champion, 1912). Another sandy track leads south-eastwards from Mutha to Malindi on the coast, and is one of the old slave routes used by the Arabs on their journeys from the coast to the more populated inland parts of Kenya. A motorable route also exists from the Thua river near Enyali via the Kalikubu river and Yendoboini to Endau 40 miles north of Enyali. Other tracks were cut during the survey, notably that linking Kalalani with the Mukomwe track, and another has been completed by park wardens from the northern administration headquarters of the Tsavo National Park at Ithumba, ten miles west of the present area, to Ndiandaza. There are other tracks, now overgrown, that were orginally cut by the Desert Locust Survey and the Game Department, and there are some that have become completely obliterated in parts and are negotiable only with great difficulty by Land-Rover. Examples include those between the Thua and Tiva rivers via Abasula, and between Endau and Utisi.

Other routes are merely game trails and stock routes which are fairly well marked in the western part of the area where the bush is dense, but are difficult to see in the thinner bush in the east. Extended foot *safaris* were necessary in this more inaccessible eastern part.

No permanent settlements are located in the area because of the lack of adequate permanent water supplies. Nomadic Wakamba herdsmen wander within the Crown lands, their wanderings being dictated by the presence of water. Their main encampments are at Makolongo, Enyali and Kalalani on the Thua river, and at the larger water-holes, chiefly those near the western boundary of the area. If the long rains fail, as happened in 1958, these nomads usually migrate by August or September to the Thua river or into the hillier regions further west, as by that time the area mapped has reverted to a waterless semi-desert.

The region is well stocked with game of various kinds. Elephant are numerous and widespread when water is plentiful, but during dry periods they migrate to the Tana and Galana rivers. Ivory poaching is still carried out by the Wakamba, Wagalla and Waliungulu tribes in spite of extensive anti-poaching activities in recent years. Buffalo and rhinoceros are also found, more particularly in the southern part of the area within the Tsavo Royal National Park. Leopard, cheetah and lion live along the Thua valley and numerous species of buck are widespread, oryx being common. Game birds are abundant, lesser bustard, francolin and guinea-fowl being present in large numbers, as well as many smaller birds.

Acknowledgements are made to P. R. Jenkins, Warden at Ithumba in the Tsavo Royal National Park; to A. Bond and the Administrative Officer at Kitui; and to A. Nieuwenhuizen and P. McLean at Mutomo for their generous hospitality.

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* References are quoted on pp. 26-27.

II—PHYSIOGRAPHY

Relief

The area being described is part of the almost featureless plain situated east of the main Kitui hill-ranges. The two most prominent features are the hills Umbi and Mukomwe, which rise approximately 600 feet above the plain, while the smaller hill features do not rise more than 200 feet above the general plain level. Umbi and the smaller inselbergs occur in the western part of the area in close proximity to the Kitui hill ranges, whereas Mukomwe is an isolated hill situated some 15 miles east of Umbi. East of Mukomwe the horizon is unbroken, the only feature being the small hills at Dakadima, some 55 miles south-east of Mukomwe (Dodson, report in preparation).

Erosion Surfaces

The plain referred to above is composite, part of it being a portion of the slightly dissected end-Tertiary peneplain recognized in north and east Kenya, and part the surface in the region of Kalalani and Kakya region where it is formed by sediments resting on the peneplain. The direction of the maximum gradient of the peneplain surface in this area is E.S.E. and the gradient along this direction is slightly less on the sediments than on the dissected peneplain surface (Fig. 1).

Residuals on the latter surface are degraded remnants of the sub-Miocene peneplain and mostly do not exceed 200 feet in height. Umbi and Mukomwe, however, rise to 600 feet and their summits are presumed to approximate to the level of the sub-Miocene peneplain in this region.

Drainage

The principal drainage systems of the area are the Thua and Tiva rivers which drain eastwards, the watershed between the two systems being formed by the low ridge from Kiothowa to Utisi. The Thua river has a number of small tributary streams, notable ones being the Kalikobo and the Kalikubu. The Tiva, however, has few tributaries, the largest in the present area being the Wakabi.

The two major rivers have a number of features in common. A most important feature is the obvious contrast between the meandering incised channels in the western part of the area, and the wide alluvial flats with anastomosing sand channels in the eastern part. This feature suggests to the writer a former senile valley has been rejuvenated in its upper reaches giving rise to renewed incision, but that its lower reaches became aggraded as a result. Pebble-mounds at Kalalani in the Thua valley are evidence for earlier aggradation. The pebble-mounds protrude through alluvium and are interpreted as the remains of flood-plain gravels of an earlier stage in the history of the valley.*

Two factors that are thought to have been instrumental in producing the aggradation in the eastern part of the area are tilting and climatic change, resulting in rejuvenation of the upper courses of the stream (cf. Dodson, 1955, p. 2; and Baker, 1964, p. 2). A factor that is thought to have been effective in producing the present form of the river Thua is the presence of the sediments resting on the end-Tertiary peneplain in the north-eastern part of the area. The Thua valley is thought to have matured more rapidly on the surface of the sediments than on the peneplain surface, with the development of alluvial flats and a flatter transverse profile on the sediment surface (cf. Wright, at the press). The Tiva river does not flow so far as is known on a surface of post-Tertiary sediments, so the aggradation of the river cannot be attributed even in part to any change of gradient at a sediment boundary. It is in this case considered to be solely due to tilting and climatic change.

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* Alternatively it can be considered that the heavily laden streams draining from the Kitui hills can erode slightly when they reach the bevelled surface, but soon after must drop their load owing to slackening of speed. (W.P.)

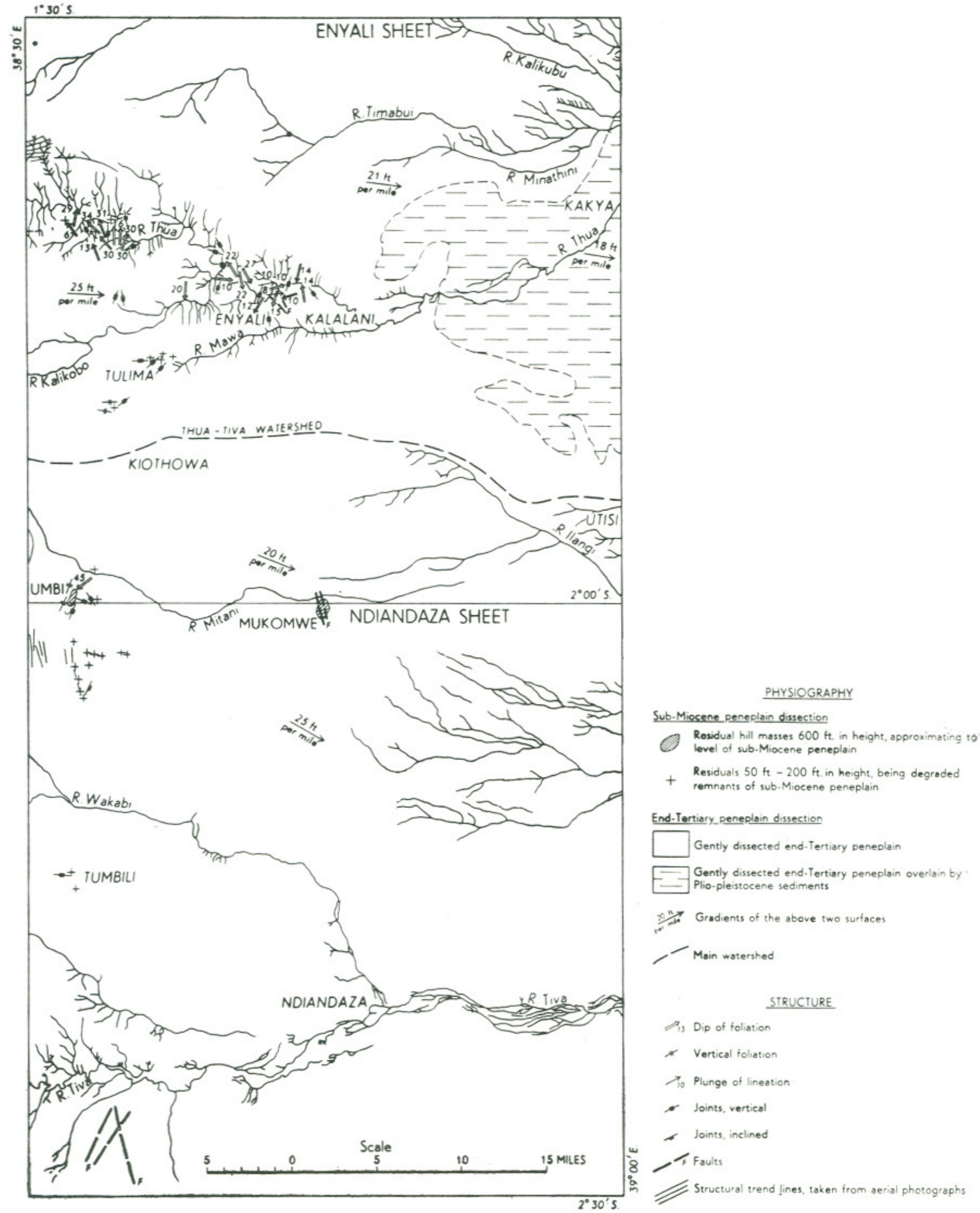

Fig. 1—Physiographical and structural map of the Enyali-Ndiandaza area.

Other contrasting features of the Thua and Tiva valleys are their dissimilar transverse profiles and the longitudes at which the rivers lose their discrete incised sand-channels and disperse into smaller channels on alluvial flats. The valley of the Thua, as can be seen from the map, is relatively deep and narrow when compared with the broad, flat Tiva valley, and in consequence the watershed is much nearer to the Thua. The sand-channel of the Thua is discernible almost as far east as Wayu (approximately 39° 30′ E.), whereas the Tiva disperses into a series of anastomosing channels on alluvial flats near Ndiandaza (38° 45′ E. approximately).

These features are a consequence of the difference in the vigour of the torrential discharges of the two rivers, arising from the difference in altitude and extent of the two catchment areas. The Thua catchment area is situated in some of the higher hills of the Kitui District, whereas the Tiva catchment is lower in altitude and more restricted in lateral extent. This difference results in the Thua having greater erosive powers than the Tiva. It is known that the Thua, which discharges into the Tana river at Galole, does so at far more regular intervals than the Tiva. In fact it is abnormal for the latter river to reach the Tana for periods of several years, whereas the Thua discharges into the Tana at twice-yearly intervals in normal circumstances. Both rivers flow only during the two rainy periods, the discharge being torrential and of short duration. Conjecture about the fate of these two rivers prompted the two explorers, Champion and Aylmer, to journey down their valleys. Their conclusions, mentioned previously, that the rivers terminate on the plain before reaching the Tana river are not correct.

The physiographical evolution of the area is summarized below:—

Mid-Pliocene	1. Mature rivers on end-Tertiary peneplain
Probably pene-contemporaneous (Late Pliocene-Pleistocene)	2. Tilting
	3. Climatic change giving rise to more humid conditions rather than arid conditions with torrential discharge
Probably pene-contemporaneous	4. Initiation of incision of rivers in upper courses and aggradation in lower courses
	5. Pleistocene sediments laid down in lagoons(?) in eastern part of area
Late Pleistocene	6. Continuation of processes of incision and aggradation
	7. Further small uplift or slight climatic change causes rivers to cut their present channels through alluvium.

III—PREVIOUS GEOLOGICAL AND EXPLORATORY WORK

Only two travellers seem to have entered the area with the intention of making exploratory or geological observations. These journeys were undertaken with the object of acquiring more knowledge concerning the two large rivers, Tiva and Thua.

In 1907, Captain Aylmer set out from Ikutha to explore the lower courses of the Tiva river after observing that native reports were of a "very conflicting character, some describing it as a tributary of the Tana, others giving it a separate outlet to the sea near Kipini and others again affirming that it ended abruptly in the desert" (Aylmer, 1908, p. 55). He crossed the old trade and slave route from the Sabaki to Kitui and east of this observed that the river "split into numerous small channels, which disappeared into a patch of very thick forest . . . Native reports represented the Tiva as ending in a lake three days march from the forest". Captain Aylmer set off to verify these rumours, but was obliged to turn back at about longitude 39° 30′ E. after observing that the course of the river at this point was "scarcely recognizable, being merely a series of channels". He then followed the old trade route in a north-westerly direction to Mutha and Kitui, where he heard reports of the existence of a lake called Utisi (presumably temporary, caused by heavy rains) between Mutha and the Tana river. The possible position of this lake is shown on the sketch-map that accompanies his account. He also observed that "quartz abounded everywhere but no shale formation was seen which gave promise of coal".

In 1912, A. M. Champion decided to explore the unknown lower course of the Thua river. As with the Tiva river opinions varied widely, some holding that the Thua flowed into the Tana river while others maintained that it joined the Tiva and flowed into the Sabaki river. Champion set off from Mutha in January, 1912. He reached Tulima, "a little hill composed of granite-gneiss and is the most easterly of the great, north and south dykes that constitute the Kitui district". He first crossed the Thua at Lane's Camp, Enyali, where he noted the existence of a large sandy river bed with exposures of "banded gneisses and other Archaean rocks, all very hard and compact. Owing to the existence of so much bush and the entire flatness of the country exposures of rock were quite insufficient for anything like a geological survey of the country. Judging from the sand and soil I think one may safely say that all the rocks belong to the Archaean Age, and they lie for the most part in a practically horizontal position. Nowhere did we come across sedimentary rocks of any kind except a few very recent river and lake deposits. A few loose fragments of phonolite were found lying about but were not seen *in situ*. These rocks I have also found north-east of Endau".

He then proceeded to the second crossing of the Thua at Kakya, and followed the alluvial plain of the river to Mutila, Kauti (Wayu?), and eventually Muthungui (Mutiboka?), these localities being approximately 20, 50 and 70 miles respectively east of 39° 00′ E. To the east of Muthungui, 18 miles from the Tana river at an elevation of 360 feet, he observed "the Thua was no more".

The conclusions reached by both explorers were that the waters of both the Tiva and the Thua were absorbed into the Nyika sands before either reached the Tana river (*see* also Gregory, 1894, p. 296).

IV—SUMMARY OF GEOLOGY

Basement System quartzites, granulites, gneisses, migmatites and crystalline limestones of Precambrian age underlie most of the area. These rocks, normally poorly exposed, are best observed in the larger river-beds and on small inselbergs that rise from the end-Tertiary peneplain. It is possible, though not proved, that Paleozoic rocks of the Duruma Sandstones occur in the south-eastern part of the area.

The Basement System is invaded by various intrusions, the major intrusion being a syenite forming Tulima hill. Associated minor intrusive rocks are camptonite, quartz microsyenite and tinguaite dykes. These are considered to be possibly late Mesozoic in age by analogy with alkaline rocks of a more definite age in eastern Kenya and Nyasaland.

Superficial deposits include kunkar limestones, thought to be overlying Plio-Pleistocene sediments in the east, red lateritic ironstone and pebble-sheets, probably Pleistocene in age and alluvium. Recent deposits are represented by red sandy soils and black-cotton soils. All these deposits form a mantle which effectively obscures the underlying metamorphic rocks of the Basement System over most of the area. A large portion of the Tulima syenite is thought to be concealed beneath the light-coloured felspathic sand that occurs in the vicinity of Tulima.

The probable geological history of the area is summarized below:—

Upper Pleistocene to Recent	Superficial sands and alluvium
	Deposition of valley gravels, slight erosion and incision of rivers consequent upon a climatic change
Lower Pleistocene(?)	Concretionary, lateritic ironstones Kunkar limestones
Late Tertiary	Uplift Erosion and Peneplanation
Mid-Tertiary	Uplift Erosion and Peneplanation
Upper Mesozoic (?)	Syenite intrusion with microsyenite, camptonite and tinguaite dykes
	Erosion and peneplanation
Palaeozoic	Deposition of Duruma Sandstones
	Prolonged Erosion Folding and Metamorphism
Precambrian	Basement System

V—DETAILS OF GEOLOGY

1. Basement System

Rocks similar to those exposed in this area have been described in detail from adjacent areas (Sanders, 1954, p. 9; Saggerson, 1957, p. 8; and Walsh, 1963, p. 10), where better exposures enabled syntheses and stratigraphical correlations to be attempted. In the area surveyed, however, exposures are isolated and the relationships between outcrops is obscure, so that the evidence available is inadequate for such correlations to be attempted.

The following rock groups were recognized:—

Psammitic	Quartzites Quartz-felspar granulites and gneisses, with biotite and hornblende granulites
Semi-Pelitic	Banded biotite gneisses Biotite-hornblende gneisses
Calcareous	Crystalline limestones
Migmatitic	Microcline-oligoclase-biotite-hornblende migmatites with amphibolite schlieren and granitic sheet and vein reticulation
Metavolcanic(?)	Plagioclase amphibolite

(1) METAMORPHOSED PSAMMITIC SEDIMENTS

Quartzites

The general trend of the three quartzites encountered is north-south and corresponds to the regional trend in adjacent areas. These quartzites may be the equivalent of beds in the Kitui area, but because of the paucity of outcrops in the Enyali area this suggestion is not capable of proof. The quartzites form pronounced ridges owing to their resistance to erosion and their steeply dipping attitude. Two such ridges are Mwaingi and Mukomwe, both of which show characteristic concave flanks sloping away from the summit formed by the central quartzite rib. The lower slopes are covered with talus derived from the thin band or lens of quartzite, and are probably underlain by gneisses flanking the quartzite, but obscured by the talus. Mukomwe and Mwaingi show these features well but Tumbili is much smaller and less distinctive. Jointing is well displayed in the quartzites and faulting has also occurred at Mukomwe; specimens from the latter locality show pronounced brecciation and recrystallization, with veins of chalcedony. Blocks of muscovite quartzite and quartz-felspar-muscovite gneiss (53/1028)* were found in the talus at Mwaingi suggesting a gradation from the quartzite to muscovite-rich quartzite and gneiss (cf. Sanders 1954, p. 20).

Boulders of quartzite float were found in the Mitani river west of Mukomwe and at the Opemba water-hole, seven miles south of Mukomwe.

In thin section the quartzites are seen to be roughly equigranular, the quartz grains having numerous small inclusions and rather poorly sutured margins. The unbrecciated rock is coarse and has grains reaching 5-10 mms. in size. The Tumbili and Mwaingi quartzites also contain small flakes of muscovite. Typical examples of the quartzites are 53/1080 collected about half a mile N.W. of Enyali, 60/214 from the upper western flank of Mukomwe and 60/218 from a small hill called Tumbili.

Quartz-felspar gneisses and granulites
Quartz-felspar biotite and hornblende granulites

Quartz- and felspar-rich gneisses and granulites generally form the small inselbergs that are residual on the end-Tertiary peneplain and owe their massive character to the lack of well-developed foliation. These rocks weather typically to form yellow and buff-coloured outcrops.

Some difficulty was experienced in deciding the criteria for defining these rocks as compared with granitoid types. They are granitoid in appearance with reference to texture, but the writer prefers to reserve the term "granitoid gneiss" for the medium- to coarse-grained, more homogeneous often porphyritic rocks in migmatite zones. The term quartz-felspar gneiss (or granulite, depending on the structure of the rocks) is then reserved for homogenous, medium- to coarse-grained, non-porphyritic rocks having microcline as the dominant felspar and containing abundant quartz occurring in non-migmatitic associations. The suggestion has been made that such rocks in east Kitui have achieved their constitution by felspathization in the solid state (Sanders, 1954, p. 26). It is notable that they all have a volumetric modal quartz percentage greater than 20 and most rocks contain up to 40 per cent quartz. This is thought to indicate a moderate stage in the felspathization of sandstones and arkoses.

The quartzo-felspathic nature of these rocks is evident in hand-specimens. Hornblende is the predominant ferromagnesian mineral in specimen 53/1025 from the north flank of Umbi hill and 60/217 from the small hill called Nzokani, where other rocks occur in the same limb of a fold. The rocks from other inselbergs show differences, for example biotite is predominant at Ithoku.

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* Numbers prefixed by 53/ refer to specimens in the regional rock collection at the Mines and Geological Department, Nairobi.

Thin sections of the gneisses from the Thua valley are distinctive when compared with the granulitic types from Umbi and Nzokani. Microcline and microcline-perthite are the dominant alkali felspars in the rocks from all these localities, but the Ikandani, Kenze (53/1034) and Kaviuni (53/1027) rocks contain crystals of microcline up to 10 to 20 mms. in length, whereas the Umbi-Nzokani rocks (e.g. 53/1025 from Umbi) contain smaller perthitic plates often displaying albitized rims. Quartz is present in both types as rounded anhedral grains together with small interstitial crystals of plagioclase of composition varying from An_{16} to An_{30} in different rocks. The Umbi-Nzokani rocks contain small hornblende prisms uniformly distributed throughout with occasional flakes of biotite and scattered granules of magnetite. At Ikandani and Kenze in the Thua river valley however, hornblende and biotite are absent but large grains of titano-magnetite up to 5 mm. in diameter are visible. Accessory minerals occurring in these rocks are small flakes of muscovite in specimens 53/1027 and 53/1034 and sphene in 53/1025.

Boulders of granulite float associated with quartzite fragments occur in the Mitani river and near Opemba.

Volumetric modes of quartz-felspar gneisses and granulites are:—

	53/1025	60/217	53/1027	53/1034
	%	%	%	%
Quartz	46	34	41	21
Microcline and perthite ..	26	27	39	65
Plagioclase	14	8	18	13
Orthoclase..	11	24	—	—
Biotite and hornblende	2	5	—	—
Muscovite	—	—	1	1
Accessories	1	2	1	—

53/1025	Quartz-felspar hornblende granulite, Umbi
60/217	Quartz-felspar hornblende granulite, Nzokani
53/1027	Quartz-felspar gneiss, Kaviuni, Thua River
53/1034	Quartz-felspar gneiss, Kenze, Thua River

(2) METAMORPHOSED SEMI-PELITIC SEDIMENTS

Banded Biotite Gneisses

Banded biotite gneisses form a semi-pelitic series outcropping along the Thua river (Plate I). These rocks, in contrast to the quartz-felspar granulites and gneisses, are generally well-foliated and jointed and do not form upstanding residual masses. In appearance the banded biotite rocks vary considerably, but consist essentially of poorly foliated quartz-felspar gneiss bands representing later injections and segregations in biotite-rich gneiss host-rocks. They are essentially semi-pelitic migmatites. There is a gradation from the biotite-rich components to the quartzo-felspathic bands, the latter often becoming coarse and containing occasional development of large biotite crystals. Biotite gneiss float is found along the banks of the Thua river in the vicinity of Masaini and Enyali.

In a thin section of specimen 53/1058 from Masaini, oligoclase and microcline are seen to occur together, the two minerals forming an irregular mosaic with sub-angular quartz grains. Biotite is always present though sometimes in small amounts. An isolated occurrence of biotite-muscovite gneiss float at Mwaingi (53/1028) was found in association with the quartzite and muscovite quartzite talus at this locality.

Biotite-hornblende Gneisses

Biotite-hornblende gneisses occur in the Thua river near Ikandani. They are extremely well-foliated friable rocks and have a mottled appearance in hand-specimen owing to the presence of fine quartzose lenses and laminae.

A thin section of specimen 53/1026 from Masubi shows large flakes of biotite, pleochroic from straw yellow to dark brown, together with pleochroic hornblende crystals. Anhedral quartz grains and a few prisms of oligoclase are other constituents.

(3) METAMORPHOSED CALCAREOUS SEDIMENTS

Crystalline Limestones

Six small isolated outcrops of crystalline limestones occur between the Umbi and Thua rivers but are too small for strike determinations to be made. The limestones are white-grey, fine-grained and homogeneous except that the exposure at Kiothowa exhibits alternating laminae of grey and white calcite.

Specimen 53/1072, from five miles south of Enyali near Kiothowa, shows in thin section interlocking grains of calcite and numerous rounded antigorite pseudomorphs possibly after forsterite enclosed by the calcite. In addition discrete fibrous flakes of antigorite are locally common.

(4) METAVOLCANIC(?) ROCKS

Plagioclase Amphibolite

Plagioclase amphibolite occurs in the Thua river at Kasiokoni. It is a banded greenish black rock, forming part of the series of semi-pelitic rocks exposed in the valley. The plagioclase amphibolite may represent an original tuff horizon within the sedimentary series. In a thin section of specimen 52/1068, strongly pleochroic green hornblende is found associated with small quartz grains and turbid aggregates of highly sericitized felspar. Accessory minerals include muscovite and iron ore.

(5) MIGMATITES

Rocks of migmatitic origin outcrop in the Tiva river near the western edge of the area and are also sparsely distributed in the bushlands south of the same river. They were investigated previously by Sanders (1963, p. 19) who mapped as far north as the Tiva river and described "heterogeneous veined, banded or contorted biotite-hornblende gneisses . . . and indicate the northward continuation of the broad migmatite zone exposed in the Galana".

(6) METAMORPHISM AND GRANITIZATION

This subject has been discussed at length in earlier reports on adjacent regions (Sanders, 1954, p. 34; Saggerson, 1957, p. 31). In the present area, the major rock types are quartz-felspar gneisses and granulites which have attained their composition by felspathization *in situ*. Semi-pelitic sediments have been transformed to biotite and hornblende gneisses with later quartzo-felspathic injections and auto-segregations, producing migmatites of semi-pelitic origin. The limestones have suffered some change, recrystallization and the development of forsterite having taken place. Only medium-grade metamorphism has taken place in this area, a fact which is compatible with the general decrease in metamorphic grade away from the Kitui anticlinal axis observed to the west (Saggerson, *op. cit.*, p. 31).

The quartzites of this area are considered to be the lateral equivalents of the Nuu hills quartzites of the Kitui area. The extreme composition of the latter rocks has been attributed to progressive residual quartz enrichment during granitization (Sanders, *op. cit.*, p. 37), but the quartzites in the present area are considered to represent original quartz-rich bands, which were resistant to granitizing fluids, so that metamorphism resulted mainly in recrystallization of quartz.

2. Duruma Sandstones—Palaeozoic

Duruma Sandstones is the term applied by later authors to what was originally named the Duruma Formation by Stromer von Reichenbach (1896, p. 22). Rocks of the Duruma Sandstones, Permo-Triassic in age and possibly including Upper Carboniferous rocks, outcrop in south-eastern Kenya. The rocks consist chiefly of sandstones and grits with shale and silt members. Rocks ascribed to the Duruma Sandstones have been mapped in the Mid-Galana and Voi-South Yatta areas to the south of the present area (Sanders, 1959 and 1963). The formation is well exposed in the Galana river area but, further north towards the Tiva river, outcrops are sparse and it becomes increasingly difficult to delimit the boundary of the sandstones. In fact the mapping of the boundary in the area north of the Tiva river is, without aid from drilling or an extensive geophysical programme, almost entirely guess-work.

The contact between the Duruma Sandstones and Basement System metamorphic rocks has been traced as far north as the Tiva river at Ndiandaza (Sanders, 1963), although the exact position of the boundary is conjectural due to the cover of superficial sands. The continuation of this boundary across the Ndiandaza area is uncertain; the boundary must lie between the most easterly outcrop of metamorphic rocks at Mukomwe, and the most north-westerly outcrops of the Duruma Sandstones forming Dakadakatha and Dakadima hills, that is 55 to 60 miles south-east of Mukomwe (Dodson, 1964). The boundary may lie in almost any position between these two limits. Any Permo-Trias rocks in the area mapped are considered likely to belong to the lower Duruma Sandstones owing to the regional easterly dip of the members of the formation on the coast and in its hinterland (Caswell, 1953; Miller, 1952; Sanders, 1959).

The only surface indication that the Duruma Sandstones may underlie the south-eastern corner of the Ndiandaza area was the discovery of a flaggy sandstone fragment at Meakungu on the northern side of the Tiva swamp. A geophysical traverse, details of which are discussed later (p. 18), was completed as far as Ndiandaza, but gave no indication of any pronounced sub-surface change of rock type.

In thin section the flaggy sandstone from Meakungu (60/212) is seen to consist of poorly rounded quartz grains with siliceous cement and is undoubtedly of sedimentary origin. Accessory minerals include shreds of muscovite, occasional sphenes and euhedral zircon(?) prisms. The degree of compaction and cementation suggests that this specimen was derived from the Duruma Sandstones rather than from the more friable Plio-Pleistocene sandstones.

3. Post-Basement System Intrusive Rocks

The small hills at Tulima are composed of syenitic rocks which are considered to be of intrusive origin. Outcrops are restricted to five small hills approximately 100 feet in height, one of which is situated one and a half miles west of the main group formed by the other four hills. The intrusion was shown to be more extensive, however, as a result of magnetometric observations, which indicate the presence of a stock-like body.

The interesting feature of this small syenite intrusion is its obvious association with Endau, Engamba and Kandelongwe syenites in the area to the north (Baker, 1964, p. 4). The two intrusions at Endau and Engamba are much larger than the Tulima syenite. Associated with these syenites are microsyenite, camptonite and

PLATE I

(a) Banded biotite gneisses. Makolongo, Thua river.

(b) Banded biotite gneisses and small fault. Thiunguni, Thua river.

PLATE II

(a) Fine-grained camptonite dyke emplaced in orthoclase-hornblende syenite, Tulima.

(b) Camptonite dyke, Enyali, Thua river.

tinguaite dykes, the first two types being most common. No evidence of ring structures was found in the Tulima syenite and in this respect they resemble the syenite of the Endau area, but differ from the multiple syenite intrusions in Nyasaland (Stringer *et al.*, 1956, pp. 3-18).

The Tulima rock is mainly an orthoclase-hornblende syenite, though boulders of olivine diorite occur on the surface over an unexposed part of the intrusion. The syenitic rocks are similar to syenite intrusives in Nyasaland such as the Chambe plateau ring complex (Stringer *et al., op. cit.,* pp. 11-18) and Zomba and Mlanje syenites (Dixey *et al.,* 1955, pp. 30-31), the last being described as orthoclase-hornblende syenite. The rock varies in grain size, and although the major rock type is a holo-crystalline syenite a portion of the intrusion is microsyenitic.

The Tulima syenite is younger than the Basement System metamorphism and is likely to be pre-Miocene in age (c.f. Baker, 1964, p. 4). Postulation as to age is possible by comparisons with the Jombo alkaline igneous complex of Kenya (Baker, 1953, p. 47) and the Nyasaland complexes forming the Chilwa series (Dixey *et al., op. cit., pp.* 5-6), from which it seems probable that a late Mesozoic to early Tertiary age is appropriate.

(1) ORTHOCLASE-HORNBLENDE SYENITE

Hand-specimens of syenite collected from Tulima are not uniform in composition. The rock has a distinct bluish colour and the texture varies from coarse-grained to microgranular. Ratemeter traverses showed that the syenite is not even slightly radioactive, and no unusual heavy minerals were discovered in the soils.

In thin sections, the rocks from Tulima show a predominance of large crystals of orthoclase perthite, the ferromagnesian minerals having a relatively sparse distribution. One section, of specimen 53/1047 from the westerly peak on Tulima hill, shows large interlocking orthoclase-perthite crystals forming a holocrystalline mosaic. A few crystals of albite, which have not entered into a perthitic relationship with the orthoclase, are discernible. Large ragged hornblende crystals and strongly pleochroic crystals of biotite are also present. The latter are pleochroic from straw yellow to dark brown and the mineral is probably the iron-rich biotite, lepidomelane. Accessory minerals are shreds of muscovite, small prisms of sphene, iron ore and interstitial flakes of calcite (Fig. 2 (*b*)).

Intergrown perthitic felspars are again well displayed in specimen 53/1049, a medium-grained syenite collected close to a water-hole on the south flank of Tulima. Lepidomelane and hornblende are present together with euhedral twinned crystals of augite. Accessories are sphene and iron ore (Fig. 2 (*c*)).

Albitization is a notable feature of the felspars in specimen 53/1051, another syenite from near a track on the north-east side of Tulima; clear albite margins are discernible on a number of the perthitic felspar crystals. Another specimen (53/1041 from the southernmost peak on Tulima) is a microsyenite, consisting largely of elongate, partly seritized orthoclase crystals.

(2) OLIVINE DIORITE

Olivine diorite occurs on the southern and western side of Tulima hills as float blocks amongst the light-coloured felspathic soil that typically overlies the syenitic rocks. Magnetometric work (see p. 20) indicates the presence of concealed rocks, having a greater content of magnetic minerals than the exposed syenite, on the west side of the Tulima hills. The concealed portion may consist of dioritic rocks similar in composition to the olivine diorite float blocks, with the additional possibility that other melanocratic differentiates may also be present.

The olivine diorite is very striking in hand-specimen, being a bluish, coarse-grained rock containing large, bronze plates of biotite, within which are brownish grey patches of other ferromagnesian minerals. In a thin section of specimen 53/1042 an unusual assemblage of minerals is seen which it must be assumed, represents a differentiate more basic than the syenite. The major leucocratic constituent is plagioclase felspar, identified as andesine present in large crystals exhibiting both albite and Carlsbad twinning. Orthoclase is present but forms only a minor constituent of the rock. Large, ferromagnesian aggregates consisting of biotite crystals often replaced by magnetite and replacing clinopyroxene occur, together with euhedral magnesian olivines and magnetite, with brown possibly oxymagnetite rims. Lilac-coloured titanaugites exhibiting zoning are also present and apatite is a prominent accessory mineral (Fig. 2 (*a*)).

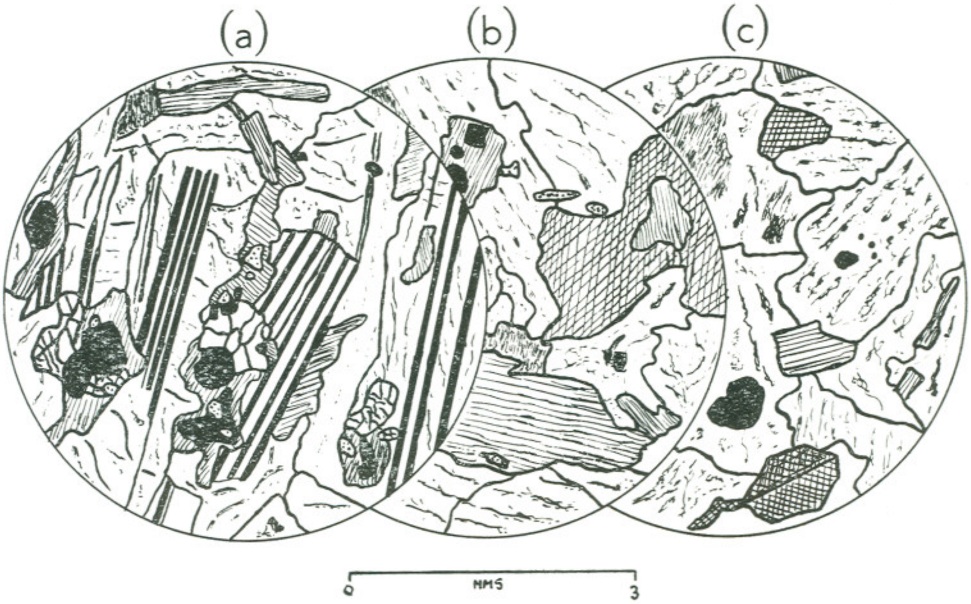

Fig. 2—Microscope drawings of thin sections of intrusive rocks from Tulima. Crossed nicols, × 12.

(a) 53/1042, Olivine diorite. Large plates of andesine, biotite (shaded), magnesian olivines, magnetite and apatite (dotted).

(b) 53/1047, Orthoclase-hornblende syenite. A large crystal of hornblende (cross-hatched), with lepidomelane, sphene (dotted) and perthitic felspars.

(c) 53/1049, Syenite. Perthitic felspars with lepidomelane, magnetite and twinned crystals of augite.

Volumetric modes of the syenites and olivine diorite are:—

	53/1047	53/1049	53/1042
	%	%	%
Alkali felspar (including perthite)	86	83	5
Plagioclase felspar (sodic)	6	12	76
Biotite	2	3	9
Hornblende	5	+	—
Augite (titaniferous)	—	1	2
Olivine	—	—	4
Apatite (+sphene)	+	+	1
Ores	+	+	3

53/1047, Orthoclase-hornblende syenite, Tulima
53/1049, Orthoclase syenite, Tulima
53/1042, Olivine diorite, Tulima

(3) QUARTZ MICROSYENITE AND TRACHYTE DYKES

Microsyenite and trachyte dykes emplaced in Basement System rocks, occur in considerable numbers in the vicinity of the Tulima syenite but also outcrop up to a distance of ten miles from the intrusive centre. In hand-specimen they are pink rocks, a few exhibiting a pophyritic texture with occasional phenocrysts of felspar up to 10 mms. in length.

In thin sections, the mineral assemblage in these dykes is similar. In some sections the dominant mineral, orthoclase, occurs in short stout prisms closely packed together producing an orthophyric texture. In other sections the orthoclase crystals have a distinct orientation. The former type are classified as microsyenites, examples being specimen 53/1032 from 3 miles north-west of Tulima and 53/1055 from 2½ miles south of Tulima: 53/1032 is rather fine-grained but is classified in this group owing to its lack of orientation of orthoclase prisms. The types with orientated felspar crystals are classified as intrusive trachytes on textural considerations in addition to their fineness of grain. Examples of this type are specimen 53/1036 from six miles west of Tulima, 53/1038 from five miles north-west of Tulima and 53/1039 from five miles west of Tulima. Other minerals seen in thin sections are interstitial quartz granules, small flakes of biotite, iron ore and sphene.

Similar rocks have been described from the Kitui area as porphyritic trachytes (Sanders 1954, p. 33) and identical rocks occur in association with the Endau and Engamba syenites. It has been suggested (Baker, 1964, p. 7) that these dykes are comparable with the sölvsbergite dykes associated with the Chilwa Series of Nyasaland (Dixey *et al.,* 1955, p. 22).

A dyke considered to have been emplaced along a pre-existing fault-plane was mapped at Mukomwe. In hand-specimen the rock is light grey and has a speckled appearance due to the presence of white porcellaneous material. In thin sections of specimens 53/1095 and 60/215B, the rock is difficult to recognize as a microsyenite owing to shearing and alteration. It consists of anhedral quartz grains in a turbid groundmass in which quartz has recrystallized as chalcedonic silica. Occasional felspar outlines are seen and there is much opaque iron ore.

(4) CAMPTONITE DYKES

A number of camptonite dykes were discovered in the Thua river and near Tulima. Direct evidence of their association with the alkaline centre at Tulima is gained from the presence of a small, fine-grained camptonite dyke intruding orthoclase-hornblende syenite on the westernmost hill at Tulima (Plate II (*a*)).

The dykes are observed in the Thua river jutting out from the banks and forming lines of large rounded boulders wherever the dyke has been subjected to erosion by flood waters. (Plate II (*b*)). In hand-specimen the rocks consist of a mass of greenish black prismatic crystals with a number of rounded pink crystalline aggregates up to 10 mms. in diameter.

In thin sections the rocks are found to contain abundant crystals of a brown amphibole identified as barkevikite. This mineral is often difficult to distinguish from lamprobolite but its low birefringence and association with sodic plagioclase in these rocks are confirmation of its identification.

Specimen 53/1076, from a dyke crossing the track ½ mile east of Enyali, is one of the best examples of a camptonite dyke from this area. Numerous euhedral barkevikite crystals are present, exhibiting zoning and marked pleochroism from light yellow to dark brown. Basal sections are common. Augite, sometimes the lilac-coloured titaniferous variety, is an important constituent and numerous octahedra of magnetite are scattered throughout the slide. Oligoclase is discernible as large crystals in a turbid groundmass that contains much calcite and some zeolite (Fig. 3 (*b*)).

In specimen 53/1089 from Endawa, a dense scattering of barkevikite crystals, octahedra of magnetite and occasional crystals of augite are seen. The felspars are poikilitic and mostly untwinned although a few show albite twinning. The untwinned felspars have positive optical sign and are also plagioclase, probably oligoclase. There are groups of plagioclase cystals devoid of barkevikite and magnetite corresponding to the rounded pink crystalline patches seen in the hand-specimen. Calcite is common in this thin section. Another specimen 53/1048 from Tulima, was collected from the fine-grained camptonite dyke that has invaded the syenite. In this case oligoclase is distinctly orientated and the barkevikite and magnetite are present in small often interstitial anhedral crystals. Small granules of a light green mineral are also discernible and are thought to be aegirine-augite.

One specimen, 53/1096 from the Thua river, shows the contact between camptonite and a xenolith of quartz-felspar gneiss. A narrow rim of black crystalline rock up to 5 mms. thick surrounds the xenolith. In thin section the rim is seen to consist of fine-grained, dense concentrations of magnetite, barkevikite and some augite crystals. Adjacent to the contact, but in the xenolith, acicular crystals of barkevikite and magnetite have developed within quartz and felspar crystals, and calcite has replaced quartz and possibly felspar. Additional veins of camptonitic material extend along grain interstices into the xenolith as far as 20-30 mms. away from the contact (Fig. 3). Large calcite-filled vesicles are present in the camptonite.

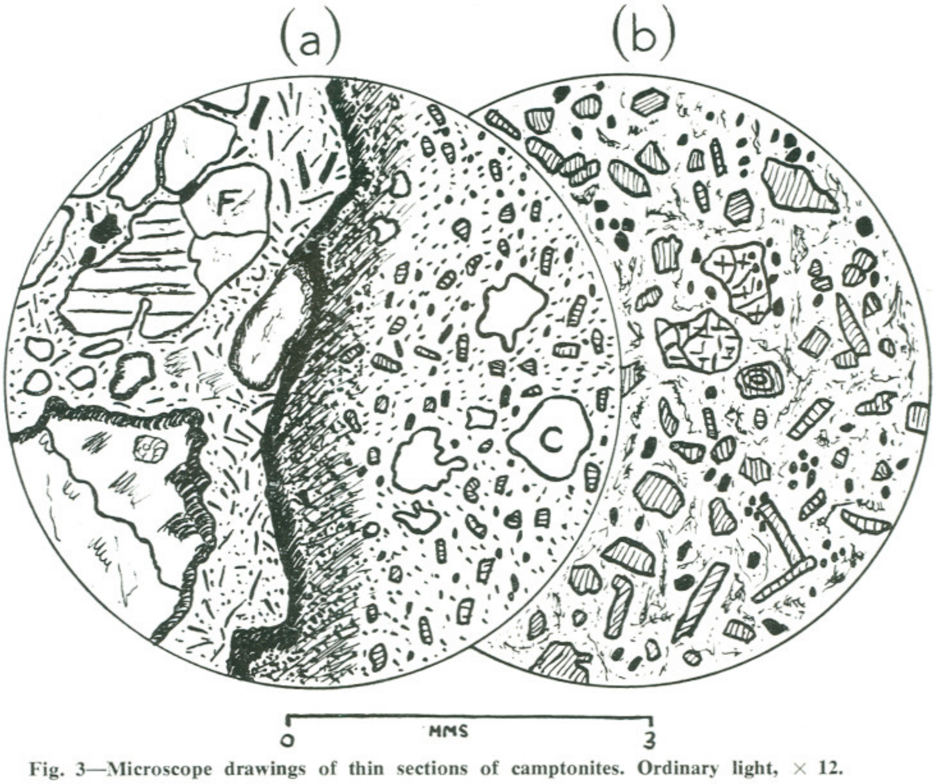

Fig. 3—Microscope drawings of thin sections of camptonites. Ordinary light, × 12.

(a) Contact between camptonite dyke and gneiss xenolith. 53/1096, Thua river. The camptonite has a narrow chilled zone and contains calcite (c): felspar crystals (f) in the gneiss are surrounded by channels containing acicular crystals of barkevikite and magnetite.

(b) Camptonite. 53/1076, Enyali. Prismatic, zoned crystals of barkevikite, granules of magnetite and plates of titanaugite.

On the south flank of Mukomwe a second dyke-rock was discovered along a fault-plane. It is a red-brown rock with quartz segregations and yellowish brown areas of extreme alteration. In a thin section of specimen 60/220 iron ore pseudomorphs after amphibole preserve good crystal shape and indicate the original nature of the rock. Magnetite granules and laths are ubiquitous and red-brown oxidation products of iron ore are present. Much introduced cryptocrystalline silica with turbid material and calcite form the groundmass.

(5) TINGUAITE DYKES

Three occurrences of this rock type were mapped, two dykes occur near Tulima, and another on the south bank of the Tiva river eight miles west of Ndiandaza, where the dyke has a damming effect during flood periods, forming a large water- hole. Similar but fine-grained rocks have been described from the Endau area (Baker, 1964, p. 7).

The Ndiandaza occurrence lies in the area south of the Tiva river previously investigated during the survey of the Voi-South Yatta area. The rock was described as a "dense grey or green dyke with pin point vesicularity". In a thin section of specimen 60/30 the rock is seen to contain "abundant needles and microlites of aegirine with strong green to brown pleochroic effects, enmeshed in a zeolite base with occasional pools of quartz" (Sanders 1963, p. 27 and Fig. 6 c).

The other dykes, from the vicinity of Tulima, are green-grey fine-grained rocks flecked with small, white vesicle infillings up to a few millimetres across. A thin section of specimen 53/1037 from 5 miles north-west of Tulima, shows abundant acicular aegirine crystals and laths of turbid alkali felspar possibly sanidine, set in an isotropic base of primary analcite; interstitial calcite is also present.

Scattered fragments of fine-grained grey phonolitic trachyte are found as float north of Kenzongoi. A thin section of specimen 60/213 found about two miles north-west of the Kenzongoi water-hole, shows turbid phenocrysts of sanidine set in a groundmass composed of sanidine and aegirine microlites with strong flow orientation. Interstitial nepheline and isotropic analcite are subsidiary.

Trachyte and vogesite fragments were noted by Sanders (1963, p. 27) three miles south of Tiva, at a point six miles west of Ndiandaza, during the survey of the Voi-South Yatta area.

(6) FELSITE DYKE

An extremely fine-grained homogeneous pink rock (60/216) was obtained from a poor exposure near Nzokani. In thin section it was found to consist of a fine-grained mosaic of quartz and altered felspar crystals; numerous black grains of iron ore with brown oxidation products and many tiny vesicles, some of which are infilled with zeolite, are also present. The rock is a felsite and is most likely a dyke.

4. Superficial Deposits of Pleistocene to Recent Age, and Plio-Pleistocene (?) Sandy Sediments

Pebble-Sheets

Pebble-sheets are found on the valley slopes of the Thua river and in one instance on a small hillock forming an inlier on the Thua alluvial plain. They consist chiefly of sub-angular quartz and felspar fragments with gneiss pebbles, and are considered to be the remains of flood-plain gravels of an earlier valley than that seen today. No pebble-sheets were encountered in the Tiva valley, although the presence of gravels beneath the alluvium at Ndiandaza has been confirmed from shallow borings carried out by the Ministry of Works during a water-supply investigation in Tsavo Royal National Park.

Kunkar Limestones

Calcareous crustal deposits are present as small surface patches scattered between the Thua and Wakabi rivers and as hard compact deposits filling fissures in the rocks exposed in the Thua river at Makolongo and Thiunguni. In addition, such deposits form a sheet of considerable size through which the present channel of the Thua river has eroded, in the eastern part of the area. These kunkars often have a nodular, concretionary structure and consist of quartz and felspar fragments with accessory sphene and hornblende cemented by a highly calcareous matrix. Such limestones are considered to be formed as a result of leaching alternating with desiccation and upward capillary motion under seasonal rainfall conditions, producing a residual deposit rich in calcium and sometimes magnesium carbonates.

The evidence for the large sheet of concretionary limestone in the eastern part of the area is two-fold. Firstly, east of Maliluni, the banks of the Thua sand-river are composed of gritty kunkar limestone or calcrete, whereas west of this locality the banks are composed of red sands, both types of deposits being overlain by a veneer of alluvium. Secondly, evidence for a change in the nature of the surface deposits can be seen on aerial photographs. Photographs of a large area in the Maliluni-Kakya region show a water-hole pattern that is quite distinct from that on photographs of areas further west. This pattern, which borders the Thua river east of Maliluni, is probably developed on a large sheet of gritty kunkar limestone. The base of this residual deposit is not seen, although a thickness of 20 ft. is exposed in the banks of the river at Kakya. The soil developed on these kunkars is generally whiter in colour than the red soils found on the metamorphic rocks.

The reasons for the development of a considerable thickness of kunkar limestone in the east compared with relatively insignificant patches further west, is likely to be due to different underlying rocks. The presence of scattered exposures of Basement System metamorphic rocks in the western part of the area indicates that these rocks probably underlie most of that region. In the eastern part no similar exposures occur and the identity of the underlying rock is unknown, but comparison with other areas provides some pointers. For instance in the Koreh Wells area (Wright, report in preparation), a similar type of gritty kunkar is developed on Plio-Pleistocene sandy and marly sediments, the kunkar crust reaching a thickness of 10 ft. or more. In view of this, it is considered probable that sandy sediments of a similar age to those in the Koreh Wells area underlie the gritty kunkar in the Enyali area. These deposits and comparable beds found in the Ndeyini area (Wright, at the press) form part of the western margin of the Plio-Pleistocene sediments which cover a large region of eastern Kenya.

Concretionary Lateritic Ironstones

Concretionary lateritic ironstones occur in small patches near the Thua river, at Opemba water-hole 7 miles south of Mukomwe, and as a crust four to six feet thick along the Mitani river. They are bright red conglomeratic rocks mostly fine in grain but containing some coarse-grained patches of quartz and gneiss pebbles, particularly in the exposures in the Mitani river. In a thin section of specimen 60/221 from the Mitani river, sub-angular quartz and felspar fragments are seen cemented by a highly ferruginous matrix consisting of red haematitic material.

The lateritic ironstones are residual rocks resulting from leaching during wet seasons, followed by upward capillary motion, during periods of desiccation, but deposition of colloidal hydroxides of iron takes place instead of the deposition of calcium and magnesium carbonates, as happens under similar processes during the formation of kunkar limestone. Lateritic earths are not produced under semi-arid climatic conditions such as prevail in the area mapped, being typical of more humid regions.

Recent Alluvium, Sands and Soils

Recent banks composed of loosely cemented pebbles are found at Makolongo in the Thua river and rest on a surface of Basement System gneisses. The fragments forming the pebble banks consist of gneiss, magnetite, quartzite and granulite.

Alluvial deposits are found chiefly in the valleys of the two large rivers Thua and Tiva, which have formed large alluvial flats and swamps in the eastern part of the area. These deposits generally consist of fine silt and form mud-flats adjacent to the larger river beds which themselves consist of sand and occasionally, as in the Tiva river, black alluvial mud.

Most of the region is covered by a reddish sandy soil with small magnetite and ilmenite concentrations in places. Whiter, sandy soil occurs in the eastern part of the area. Black-cotton soil has a patchy distribution resulting from areas of bad drainage along some of the smaller river depressions, e.g. Timabui and Mitani river-courses, the latter being almost lost in a large area of black-cotton soil. This soil contains numerous calcareous concretionary nodules and when dry becomes dark to light grey with numerous deep cracks. Dark alluvial muds similar to black-cotton soils are being deposited at present in the Wakabi and Tiva valleys.

The Quaternary evolution of the drainage pattern has already been briefly discussed (pp. 3-5) but additional information on the relationship between the different types of superficial deposits follows.

Consequent on the end-Tertiary peneplanation, residual formations developed, possibly as fairly widespread sheet-deposits covering a large part of the erosion surface. Lateritic ironstones and kunkar limestones, the latter developed extensively on pene-contemporaneous sediments, were deposited in this way probably in late Pliocene or early Pleistocene times. Later climatic changes resulted in the incision by the rivers into these sheets until the deposits became fragmentary. Accompanying the climatic change was the deposition of river gravels which possibly took place in the Middle Pleistocene. A return to more normal climatic conditions resulted in the development of the present-day soil cover and the deposition of alluvium in the broad river valleys during Upper Pleistocene and Recent times. It is possible that there may have been oscillation of climatic changes during the Quaternary period and alternating deposits of gravel and alluvium may therefore be present beneath the blanket of alluvium in the present river-courses.

VI—GEOPHYSICAL INVESTIGATIONS

Traverses using a Hilger and Watts vertical force magnetic variometer and a Worden gravimeter were undertaken (Fig. 4). The purpose of these geophysical investigations was primarily to try to delineate the Basement System-Duruma Sandstones boundary beneath the superficial cover, and to discover whether it was feasible to correlate disconnected outcrops of Basement System rocks. The results were not particularly successful though one or two interesting anomalies resulted from the work.

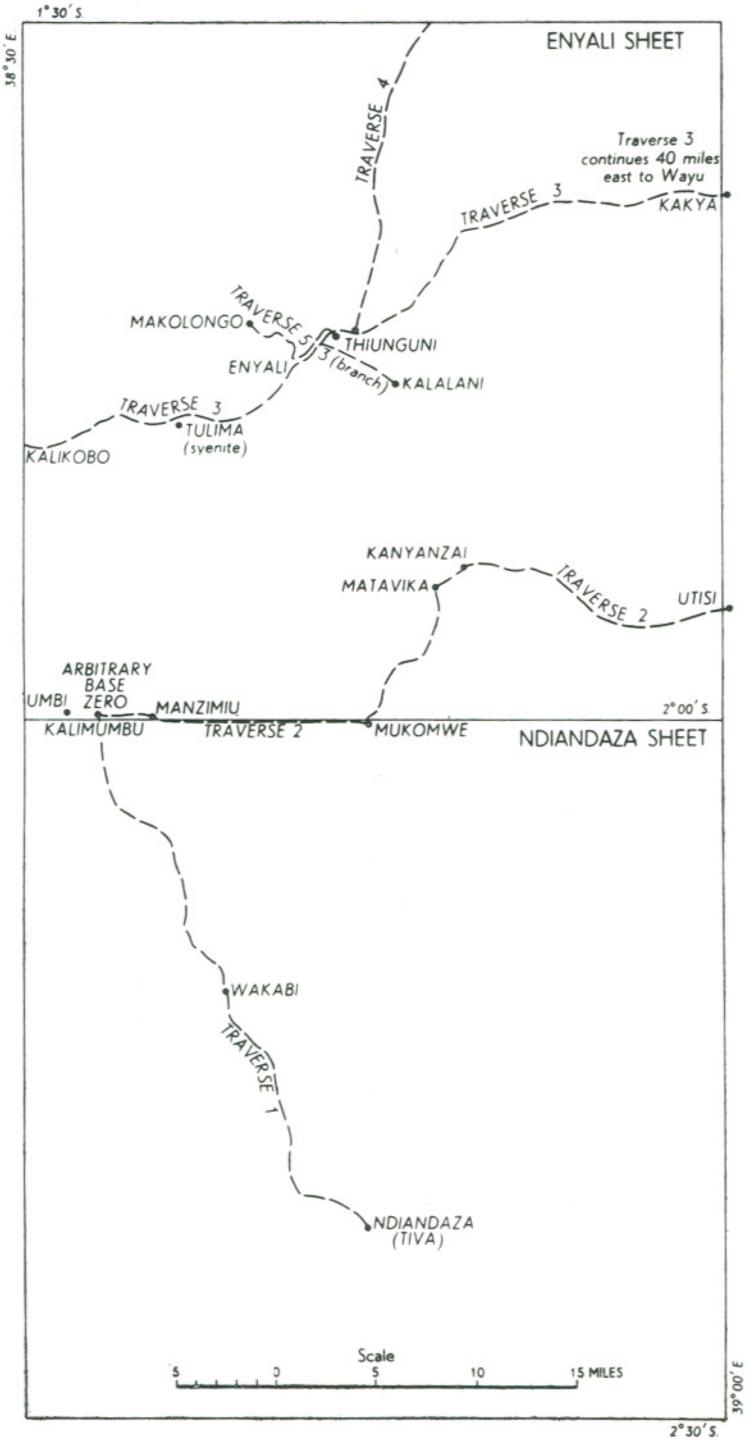

Fig. 4—Geophysical traverses—location map.

1. Magnetometric Observations

The vertical force magnetic variometer measures variations in the vertical component of the earth's magnetic field. These variations are produced by rock formations of different magnetic susceptibilities occurring in the area under survey. Normally traverses are either completed in a direction at right angles to the structure which is being investigated or a complete network of traverses is undertaken. In the area concerned, it was found impracticable to attempt a network and traverses were completed in a direction as near east-west as possible. An arbitrary base station was chosen, and all readings were related to value giving a series of negative and positive anomalies relative to this base.

Field Observations

Kalimumbu rock, composed of quartz-felspar granulite, was chosen as a base that was likely to have a normal magnetic variometer reading. Five traverses were completed across this area, one of which extended a considerable distance east of 39° E. Readings were taken every mile, or more often where larger variations of the vertical magnetic component were encountered, and any additional observations such as nature of terrain and rock formations exposed were noted. Readings were repeated each day at a given base before and after the completion of a traverse so that the diurnal variations could be calculated.

Calculations and Corrections

The standard corrections were applied to the field readings and values in gamma (γ) obtained for the various stations. The value obtained for the arbitrary base station was deducted from all other values so that the anomalies represent positive or negative variations in the vertical component of the earth's magnetic field relative to this base zero. The results obtained are plotted as vertical component magnetic anomaly profiles (Fig. 5 at end).

A curve of diurnal variation of magnetic intensity was drawn, but it was found that the variations of magnetic intensity due to changes in the rock formations were large enough for the diurnal variations to be considered insignificant. Similarly the temperature correction was found to be negligible relative to the variations measured. A correction was applied where necessary in connexion with the use of an auxiliary magnet at large anomalies viz. over the Tulima syenite intrusion. Variations are present in the earth's magnetic field due to latitude but are difficult to predict. The effect is detectable on traverse profiles 1 and 4 (Fig. 5, at end) which run north-south and show a gentle rise and fall respectively in the mean position of the curve. This has not been corrected for, but it is normally only necessary to tilt the whole profile to eliminate the overall gradient due to latitude.

Geological Interpretation of Magnetic Anomalies

The largest anomaly within the area was obtained over the Tulima syenite intrusion, the subsurface extent of which was found to be considerably greater than was evident from exposures. The intrusion proves to be a steep-sided, stock-like body with a considerable portion, particularly on the western side, concealed beneath a thin cover of felspathic soils. The anomaly over this concealed portion was of greater intensity than that experienced over exposed orthoclase-hornblende syenite, suggesting the presence of a rock type or types having a greater magnetite content. The only surface indication of such a rock was the presence of float boulders of olivine diorite west of the hills, and it is postulated that the large anomaly may be due to a concealed portion of the intrusion consisting of olivine diorite.

The position of the Basement System—Duruma Sandstones boundary was not revealed. The lack of any indication of such a boundary along the lines of the traverses suggests that the edge of the Duruma Sandstones basin probably does not extend as far north as 2° S. nor as far west as the Mutha-Ndiandaza track. Thus any occurrence of Duruma Sandstones beneath the superficial sands can only be situated in the south-eastern part of the Enyali-Ndiandaza area. The depth of superficial deposits overlying a homogeneous rock type can often be interpreted from magnetic profiles, but anomalies over the sand-covered Basement System metamorphic rocks are difficult to interpret. This arises because of the heterogeneity of the Basement System, for example, an anomaly produced by a magnetic band at a considerable depth could also be interpreted as a less magnetic band nearer the surface. Thus no correlation has been attempted between anomalies of a given magnitude and the rock type that they might indicate.

The only traverses from which inferences can be drawn concerning underlying rock type, are those having stations sited on exposed rocks in addition to those on sand-covered terrain. Positive anomalies obtained over concealed areas and having greater values than those over exposed rocks, represent bands or zones in the metamorphic rocks with greater magnetic susceptibility than the exposed types. Such instances occur on traverses 1 and 2. Both these traverses begin at the base station at Kilimumbu on quartz-felspar granulite. On traverse 1 all the anomalies are positive and indicate that the underlying rocks are all more magnetic than the granulite at Kalimumbu. On traverse 2 positive anomalies in the Manzimiu and Misi regions indicate zones of rocks more magnetic than the Kalimumbu granulite. The negative anomaly at Kanyanzai, however, is less easy to interpret; it could indicate bedrock of a greater or lesser magnetic susceptibility than the granulite at Kalimumbu, depending on the depth of overlying sand. The size of the negative anomaly however, makes it unlikely that the rock is more magnetic than the granulite at the base station. A more reasonable interpretation is to infer the presence of rocks having a magnetic susceptibility similar to that of granulite but overlain by a thick layer of sands.

A number of sharp anomalies are recorded, particularly on the Thua river profile, which are doubtfully interpreted as indicating faults. If these are such faults a possible explanation of the anomalies may be that chemical changes have taken place along the fault-zones resulting in alteration to, and deposition of, iron-bearing minerals, analogous to the processes of chemical magnetization described by Blackett (1954, p. 12). The fault would then possibly act in a manner comparable with a weakly magnetic dyke (Bristow, 1961). Haematitic veins were indeed noticed along the Mukomwe faults where however, no magnetometric station was sited.

2. Gravimetric Observations

A portable Worden gravimeter was used for the gravimetric work, the stations occupied being the same as for the magnetic variometer. Generally, the gravimeter provides information on structural features and relatively deep sub-surface variations in rock density. The survey was not tied in to an absolute gravity station and the same arbitrary base was used as for the magnetic work.

Field Observations

Readings of the gravimeter were carried out in a manner similar to that described for the variometer. Readings on the instrument increase with decrease in altitude irrespective of any other anomalies that may be present. To obviate the necessity for re-setting the instrument too often, it is set to one end of its range near to one margin of the area to be surveyed, preferably in the higher part of the area. In the case of the Enyali-Ndiandaza area the base station was chosen near to the western margin, the part with the highest average altitude. The instrument was set to zero at this base and required re-setting only near the eastern margin of the area. This was done at a station where the reading approached the end of the scale, so the amount of the re-setting was known.

Calculations and Corrections

To compensate for the superimposed tidal and temperature effects which together constitute the observed diurnal variation of the instrument, a station was re-occupied every two hours as during this period the drift can be regarded as linear. Cumulative drift inherent in the mechanism of the instrument was taken into account by reading the gravimeter night and morning, noting the change and correcting for it by interpolation from a graph.

An elevation correction, combining the free air and Bouguer effects, was applied to reduce all readings to sea-level and two profiles were drawn using different rock density constants. For the purpose of these computations the importance of knowing the accurate height of the station (to within one foot at least for most areas) cannot be over emphasized. The aneroid heights determined during the survey are not sufficiently accurate for the construction of reliable anomaly curves, and observed instances of correlation with topography are probably due to relatively inaccurate heights. Owing to the flat nature of the country a terrain correction was found to be unnecessary for most stations, the exceptions being those in the vicinity of Mukomwe hill. This correction, naturally a very important one in mountainous terrain, is applied by means of a zone chart, the construction and use of which is explained by Jakosky (1950, p. 404). A small latitude correction was applied using a reference graph constructed from the formula for variation of gravity with latitude, but isostatic correction, applicable in certain areas of high mountains and elevated plateaux, was not applied. Full details of the computations and corrections to be applied will be found in Jakosky (1950, pp. 402-411). A succinct account of these computations has been prepared for departmental use (Rix and Wright, 1959).

Geological Interpretation of Gravity Anomalies

Reliable interpretation of the results obtained is difficult owing to the possible inaccuracy of station heights, except on traverse 1 (Fig. 6, at end), where accurate levels forming part of a line of geodetic levels along the track from Mutha in the Kitui district to Mambrui on the coast are available. Two profiles using two different elevation correction factors were constructed for all traverses. The difference between the two correction factors arises from the use of two density constants, which in this case were those for sand (1.6) and gneiss (2.7) (Gutenberg, 1951, p. 42). The two profiles are almost parallel in all cases, the only difference being a slight convergence towards the east on traverse 3. The parallelism of the curves reflects the flatness of the region and it is of doubtful value to construct profiles for different rock-densities in an area such as this. In a region of rugged terrain however, the various density profiles may show considerable differences, the one showing the least correlation with topography being the most accurate.

The profiles produced from east-west traverses 2 and 3 across the strike of the metamorphic rocks, indicate a considerable "high" across the central part of the region. This is probably due to the presence of rocks of greater density than the quartz-felspar gneisses in the Kalikobo river, the starting points of traverses 2 and 3 respectively. (The Kalikobo river is crossed by the Mutha-Enyali track; this site was chosen as the starting point for traverse 3.) Similarly, traverse 3 shows a "low" near 39° 00′ E. and another "high" towards Wayu, indicating the presence of zones of rocks of different densities, possibly associated with major structural zones.

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VII—STRUCTURE

Folds

Folding is indicated by opposing dips of foliation in the Thua river at Makolongo and Enyali (Fig. 1.); the direction of the fold-axis is not known although vertical foliations have been observed striking between N.N.E.-S.S.W. and east-west. This probably indicates that the direction of the fold axes lies within the above limits but the vertical foliation observations are too scattered and too few to be statistically useful. Two lineations plunging to the E.N.E. were measured near Thunguni in the Thua valley. When plotted on a stereogram, the measurements of foliation and lineation suggest an east or E.N.E. fold-axis plunging at a shallow angle. Vertical foliation at Ihoko may indicate a local W.N.W.-E.S.E. axis.

In addition to the folds exposed in the Thua valley, a large fold is present in the western part of the area near Umbi and Nzokani. The structural trend-lines are clearly seen on aerial photographs and suggest that the group of inselbergs at Nzokani and Umbi are part of one large fold. Foliation measurements in the Umbi region point to the existence of an asymmetrical syncline plunging northwards.

Faults and Joints

A few faults were mapped, and most are thought to be normal with small throws. Two small faults occur at Thiunguni in the Thua valley (Plate 1 b) and two others are mapped at Mukomwe. The presence of the latter faults is indicated by brecciation of the quartzite and introduction of chalcedonic veins. Thin quartz microsyenite and camptonite dykes have been emplaced along the fault-planes at Mukomwe and show the effects of shearing. Faults also occur south of the Tiva river (Sanders, 1963, p. 30).

The fault mapped as forming the Basement System—Duruma Sandstones boundary in the South Yatta area (Sanders, *op. cit.*) is considered to be of doubtful validity in the extreme northern part of that area near Ndiandaza, on the Tiva river. Although the edge of the Duruma Sandstones basin may be faulted near Ndiandaza, no surface evidence of the fault was seen, and it is considered preferable not to indicate the fault as far north as the Tiva river.

The predominant joint-direction in different rock types appears to vary from N.N.W.-S.S.E. to N.N.E.-S.S.W. but as with other structural information, the number of readings obtained is too meagre for a useful analysis of joint-patterns to be made.

VIII—MINERAL DEPOSITS

1. General

No economic mineral deposits were discovered in the area. The syenite would form good *road-metal,* and in the event of any development in the eastern part it would be necessary to use calcrete for *concrete aggregate,* as at Hola, on the Tana river 90 miles east of 39° E.

Sands are abundant and there are patches that contain streaky concentrations of ilmenite and magnetite. Panning of the Thua river sands was carried out to obtain heavy concentrates, but the latter consisted mostly of magnetite and pyrite.

Radiometric monitoring was carried out throughout the area but no radio-active minerals were found and no anomalies discovered, the variation over the whole area being little more than 0.03 m.R/hr.

2. Water

Existing Supplies

Water-supplies in semi-arid areas are most important and worthy of considerable attention, as the possibility of any settlement depends ultimately on the presence of permanent water. No water in this area other than limited supplies at certain localities along the Thua river can be regarded as permanent, and consequently the region is not settled, being inhabited only by nomadic herdsmen.

Water is mainly obtainable from seasonal water-holes and from diggings in the beds of the Thua and Tiva sand-rivers. In years of exceptional rains, some of the larger water-holes probably hold water for most of the year and selected places along the sand-rivers, particularly the Thua, retain water at depth all the year round. In the event of a dry year, when perhaps the short rains fail, water is non-existent apart from that retained at depth in the sand-rivers.

After the rains nomadic Wakamba herdsmen wander throughout the area utilizing the larger seasonal water-holes, such as Manzimbu, Tulima and others nearer to Mutha, five miles west of the present area. Rival claims to water-holes in the eastern part of the area were formerly the cause of considerable trouble between the Wakamba of the Southern Province, and Wagalla tribesmen of the Coast Province. This problem was solved only when Adminstrative Officers from the Kitui and Tana River districts allocated water-holes to the respective tribes.

In the Tsavo Royal National Park water-holes are numerous along the western boundary of the area but further east are sparsely distributed and only a few large ones exist, for example at Kenzongoi and Opemba.

After good rains, water is easily obtainable by digging to shallow depths along most of the course of the Thua river. During the period of prolonged drought following the rains, the water-level in the sand drops fairly rapidly but not uniformly throughout the length of the river, owing to rock outcrops in the river-bed forming effective dams that retain considerable quantities of water in the sand upstream from the barriers. This is particularly true at Makolongo where there are extensive gneiss outcrops across the river-course. The deep sand pockets between the rock barriers retain a good supply of water, which can be regarded as permanent, although obtainable only at depth during the dry season. Smaller "rock dams" occur at Masubi, Enyali and Thiunguni; these together with another dam at Makolongo, constitute the best watering places along the Thua river, although rocks probably form sub-surface dams in the river at other places.

The water-supply situation in the Tiva river is worse than in the Thua river, owing to the loss by the Tiva of its discrete sand channel up-stream from Ndiandaza, whereas the Thua retains a definite channel as far as 39° E. and probably for some distance further downstream. The Tiva diverges into a series of anastomosing small, sandy channels on wide alluvial flats at Hidilathi, approximately 10 miles up-stream from Ndiandaza; thus downstream from Hidilathi there is no sand reservoir large enough to retain significant quantities of water. The best watering places in the Tiva valley are sand-channels near the western margin of the area and the large water-hole, on the south bank of the Tiva up-stream from Ndiandaza, that apparently owes its existence to the damming effects of a tinguaite dyke (Sanders, 1963, p. 27).

Water Development

During 1952-57 wells were sunk with a hand-boring rig alongside the Thua sand-river at Enyali and Kalalani for the African Land Development Board. The results of these borings are tabulated below:—

SUMMARY OF TEST DRILLING WITH HAND-BORING RIG IN KITUI EASTERN CROWN LANDS
(*Localities are shown on the geological map*)

Bore-hole	Site	Water struck		Water rest level		Total depth		Remarks
		ft.	*in.*	*ft.*	*in.*	*ft.*	*in.*	
Enyali No. 1.	Approx. 100 yds. W. of Enyali camp-site on S. bank of Thua and 60 yds. from river.	24	6	21	6	25	6	Water in river sand, Cased
Enyali No. 2	Approx. 100 yds. W. of camp-site and 60 yds. from river.	—		—		—		Abandoned at 10 ft. owing to loose sand
Enyali No. 3	N. bank of Thua opposite to No. 1 and 50 yds. from river.	31	0	26	6	32	0	Water in river sand. Cased
Kalalani No. 1	6·5 miles E. of Enyali approx. 600 yds. from S. bank of Thua in fringing forest.	60	0	57	6	64	0	Water in river sand. Cased
Kalalani No. 2	Site as above approx. 300 yds. from S. bank of river.	—		—		46	0	Abandoned owing to lack of casing

Future water development in the area is practicable only along the Thua and Tiva rivers. Water-holes away from these rivers could be deepened to enable seasonal water to be retained for a larger portion of the dry season, but any significant development away from the valleys would probably require deep bore-holes in an attempt to tap water in fracture zones in the metamorphic rocks.

Additional shallow permanent wells could probably be sited alongside the Thua river at selected places up-stream of rock barriers, for example at Masuli, Makalongo and Thiunguni in addition to Enyali. In time it may prove desirable to construct sub-surface dams at such geologically advantageous localities along the river. Even low surface dams with provision to channel-off flood waters to irrigate adjacent areas may prove feasible.

In the Tsavo Royal National Park some deepening of water-holes is contemplated for the benefit of wild animals, but the only prospect of obtaining good water-supplies in the northern part of the Park is to sink holes in the Tiva river bed. The Tiva valley profile may be composite, former valley gravels having been blanketed by alluvium (*see* p. 18), and thus a drill-hole through the alluvial cover may tap water in the underlying gravels, but test-holes would be required to prove this. Electrical resistivity traverses across the valley alluvium may confirm the presence of a buried gravel-filled channel.

A shallow bore-hole financed from the "Water for Wild Animals" fund, and known as Ndiandaza No. 1, was drilled in the Tiva river bed at Ndiandaza by the Mowlem Construction Company after the hole had been sited by the Ministry of Works Hydraulic Branch. The position of the bore-hole is indicated on the geological map.

The log of this bore-hole is as follows:—

	Feet	
River deposits	0–20	Fine alluvial silt
	20–100	River sand
	100–175	Sands with calcareous lacustrine deposits
	175–200	Clean washed sand, water-bearing
Plio-Pleistocene (?)	200–280	Gritty, calcareous sandstone.

The yield of water at 175-200ft. was insufficient and drilling was subsequently continued to 320 feet through river sands and clays with calcareous pebbles in the sand. A yield of 400 gallons per hour was obtained.

A second bore-hole, Ndiandaza No. 2 sited some four miles to the west of the first bore-hole, was cased to the bottom of the hole at 400 ft. The Mowlem Construction Company report that the samples are similar to those in the first bore-hole and no solid rock was encountered. Water was again struck at 175 ft. and a yield of 400 gallons per hour was obtained.

The quantity of water obtainable from these bore-holes is sufficient for present purposes and no deepening is contemplated. The bore-holes appear to indicate a depth of at least 200 feet of Plio-Pleistocene (?) sediments.

No surface indication of the Plio-Pleistocene sandstones is present in this region, and those beneath the Tiva valley may be a westward embayment from the main mass of sediments to the east. They may rest on either a surface of Duruma Sandstones or Basement System rocks at Ndiandaza, but the exact nature of the underlying rock can only be proved by drilling.

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