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GEOLOGICAL SURVEY OF KENYA

# GEOLOGY OF THE LOIYA-LORUGUMU AREA

DEGREE SHEETS 17, N.E. QUARTER and 18, N.W. QUARTER
(with two coloured geological maps)

by

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## ABSTRACT

The report describes an area of approximately 1,800 square miles in south-west Turkana bounded by latitudes 2°30′ N. and 3°00′ N. and by longitude 35°30′ E. and the Kenya-Uganda border. Physiographically the area can be divided into three units: (1) The Turkana Plain formed by end-Tertiary erosion, (2) the Uganda Escarpment bounding the western edge of the area, and (3) the Uganda peneplain which is represented by erosion residuals.

The rocks in the area comprise folded gneisses, schists, granulites and limestones of the Basement System cut by acid pegmatites and basic intrusions. In the north-west the Basement System rocks are covered by a thick series of basalts, andesites and rhyolitic ignimbrites. Apart from small north-south displacements in the volcanics, the area is traversed by only one major fault line, the Turkana fault.

Details are given of the petrology of the rocks and the structural features observed in them. Economic prospects in the area are also considered.

## I—INTRODUCTION

The area covered by this report comprises the north-eastern quarter of Degree Sheet 18 (Kenya) and part of the north-western quarter of Degree Sheet 17 (Kenya) corresponding to the Directorate of Overseas Surveys Sheets Nos. 38 and 37 respectively. The area, which is approximately 1,800 square miles in extent, is bounded by latitudes 2°30′ N. and 3°00′ N. and by longitude 35°30′ E. and the Kenya-Uganda border. Lodwar, the administrative centre of the Turkana District of the Rift Valley Province in which the greater part of the areas lie, is 20 miles away to the north-east. The hills along the southern boundary are the northern part of the Karasuk Hills, a part of Kenya presently administered by the Uganda Government, control resting with the Assistant District Commissioner stationed at Amudat 35 miles to the south of the area.

The area was mapped in reconnaissance style, as part of the programme of primary geological mapping of Kenya, from March to July 1959 and between September and November 1959. The area may be separated into five major divisions:—

(1) The Karasuk Hills.

(2) The hills east of the Uganda Escarpment.

(3) The Puch Prasir Plateau.

(4) The Turkana Plain including the Turkwel River.

(5) The Ngamatak Hills.

*The Karasuk Hills* extend as a series of narrow ridges running north from the main mass of the hills into the Turkana Plain before they die out completely. The hills are covered with thorn bush and are generally too steep and narrow to permit settlement but occasional Suk *manyattas* are present in hollows.

*The hills along the Uganda Escarpment* are more irregular and broken than the Karasuk Hills and many Turkana live along the valleys where sufficient water to keep cattle can be obtained by digging in the sand rivers. This sub-division includes the basin of the Tarach River which flows to the Lotigipi Swamp to the north, in contrast to the easterly flow of the other rivers.

*The Puch Prasir Plateau,* which rises in locally sheer cliffs to about 1,500 feet above the surrounding hills, is broken by many deep valleys often containing permanent water in pools. The soil on top of the plateau itself is poor so grazing is limited. Accordingly few people live on the plateau itself but the lower slopes are well populated.

*The Turkwel River* is included in the *Turkana Plain* since it does not form a deep valley and the plain slopes gently down to it. Water flowed in the river during the greater part of the period of the survey so the Turkana were able to grow maize on the rich alluvium, in addition to keeping numerous cattle which are able to find good grazing in the dense forest along the river banks. On the west bank the plain consists of sandy soil with isolated trees and a sparse cover of grass which provides only poor grazing, while the stony soil on the east bank of the river is even more infertile. The rivers running through the plain contain good waterholes only near the hills and the population there is more nomadic than that living in the hills and along the Turkwel.

*The Ngamatak Hills* on the east bank of the Turkwel are rugged hills with a quick run-off and so settlement can only be supported at waterholes near their base.

*Climate.*—Rainfall figures have never been recorded within the area but those from Lodwar and Moroto (taken from the records of the East African Meteorological Department) are quoted since they can be taken as representative of the plain and the hilly parts of the area respectively.

| *Station* | *Altitude (feet)* | *Average annual rainfall* (*in.*) | (*mm.*) | *No. of years recorded* |
|---|---|---|---|---|
| Lodwar .. .. | 1670 | 6·67 | 169·4 | 42 |
| Moroto .. .. | 4900 | 34·86 | 885·5 | 35 |

The rainfall at Lodwar is probably slightly lower than that of the Turkana Plain in the Loiya-Lorugumu area because Lodwar is more distant from the Uganda Escarpment, which causes precipitation from the rain clouds brought from the east by the prevailing wind. Moroto, situated on top of the escarpment and shielded by the mass of Moroto Mountain, is considered likely to enjoy a rather heavier rainfall than the lower hills of Turkana. Both stations show peaks in the rainfall figures in April and May but that of July and August at Moroto is not reflected in the Lodwar figures. There is a slight increase in rainfall at Lodwar during November and December. The hottest part of the year falls in January, February and March, with July being the coolest month. Daily recordings of maximum and minimum shade temperatures were made by the writers in 1959 during July and between September and November, and are illustrated in Fig. 1. It is of interest to note that the rainy days did not produce

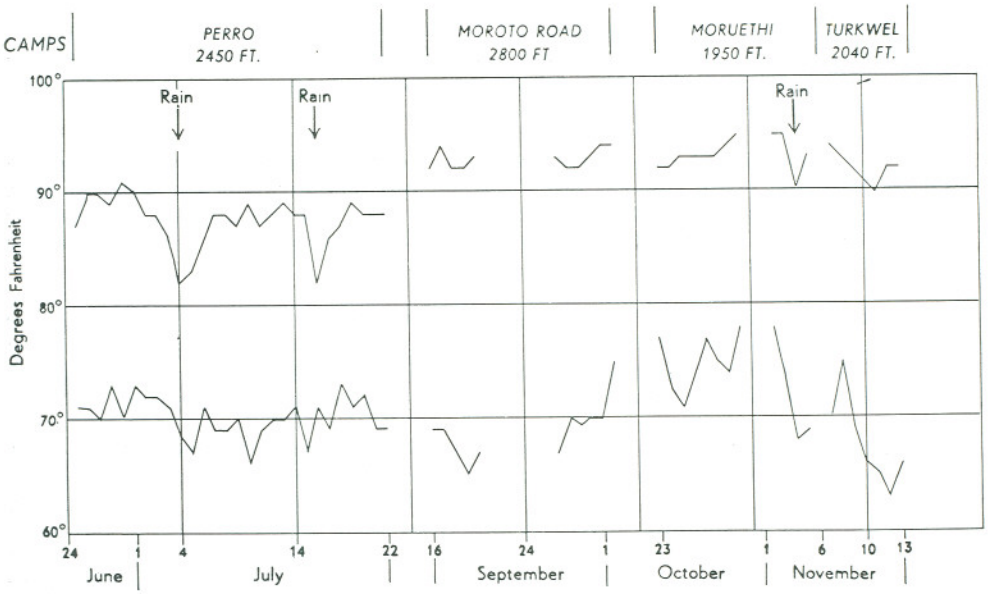



Fig. 1—Maximum and minimum temperatures recorded in the Loiya-Lorugumu Area.

such a large drop in the minimum temperatures as in the maximum. Between September and November the readings are discontinuous because of frequent absences from the main camp during short safaris.

*Population.*—Apart from a small number of Suk living among the hills in the southern part of the area, the Turkana tribe (Nilo-Hamitic in origin) form the whole of the population. They are essentially nomadic in their way of life, moving frequently from waterhole to waterhole where they can obtain water and grazing for their large number of livestock. Sheep, goats and donkeys abound everywhere but cattle are found mainly in the hills and along the Turkwel, while camels are most numerous on the open plains. The staple diet of the Turkana is blood and milk, the blood being drawn from the jugular veins of their animals by piercing with an arrow. An unskinned goat roasted on an open fire for ten minutes is esteemed a great delicacy while maize meal, even in poor condition, is eagerly sought. Camels are never used for transport since donkeys are adequate to transport the scanty belongings of the Turkana. Von Höhnel (1938)* suggested that the Turkana have only recently migrated into their present home and have acquired camels from their neighbours to the south and east. The administration hold regular goat auctions throughout Turkana with the double object of reducing the number of goats, which are largely responsible for soil erosion, and making money available for the collection of taxes. The goats sold are mainly moved to Uganda.

Only near the Uganda border, particularly near the Kaimo River, have the Turkana attempted to build huts, copying the example of the Uganda Karamojong, and for the most part they use shelters of branches which they cover with goat skins during rain. The only permanent buildings within the area are a mission and shop at Lorugumu and a Police Post at Loiya, built to control entry into Turkana.

The only abundant varieties of game are the ubiquitous dik-dik and Grant's gazelle which are chiefly found on the plains, and impala along the larger rivers. Occasional small groups of oryx were seen and small numbers of both lesser and greater Kudu live along the Uganda Escarpment. Leopard live in some of the rocky hills, often raiding the flocks of the Turkana. Snakes of several varieties live mainly in the shady wooded river banks. Spur-fowl and some of the smaller varieties of francolin live along the wooded river banks where guinea fowl were also sometimes seen. Vultures, hawks and buzzards represent the predators.

*Communications.*—The main Kitale-Lodwar road passes through the area from south-west to north-east and, although sandy, is usually in reasonable condition. The main obstacle to traffic is the crossing of the Lorugumu River, which consists of over a quarter of a mile of soft sand. The old road to Moroto branches off the main road at Lorugumu and is still in good condition for the first 15 miles but afterwards deteriorates and is impassable beyond the Uganda border. The track running from the Kitale-Lodwar road through the Kakep Pass to Napotimoru and the Turkwel is still passable to a Land-Rover but only traces of other tracks shown on old maps were found. The greater part of the Turkana Plain can be crossed by lorry, but towards the eastern part of the Karasuk Hills the numerous sand rivers make travelling difficult even by Land-Rover. The large sand rivers among the western hills are usually passable to a Land-Rover but the Puch Prasir Plateau and the basin of the Tarach River in the north-west of the area are accessible only by foot.

*Maps.*—The southern half of the area is covered on the scale of 1:50,000 by Preliminary Plots comprising Uganda sheeet N. A-36/K-11-S.E., and Kenya sheets N. A-36/L-1-S.W. and N. A-36/L-1-S.E., while the north-western corner is covered by the Uganda sheet N. A-36/K-11-N.W. The whole area is covered by the G.S.G.S. 4801

* References are quoted on page 51 and 52.

sheet N. A-36-8 (Moroto) on the scale of 1: 250,000 but this map is locally inaccurate. The areas not covered by Preliminary Plots were mapped on print lay-downs of an approximate scale of 1:50,000 from R.A.F. photography. During the survey data were plotted on the 1:30,000 photographs and transferred to the Preliminary Plots or print lay-downs, the latter being controlled by points resected by plane-table. Spot heights were recorded by aneroid barometer, corrected for diurnal variation and checked with the heights of trigonometrical stations of the Uganda network, and they and the form-lines must be regarded as only approximate.

ACKNOWLEDGEMENTS

The administrative officers at Lodwar provided considerable assistance and hospitality. Thanks are also due to the Survey of Kenya for providing print lay-downs and provisional plans of the boundary between Kenya and Uganda.

## II—PREVIOUS GEOLOGICAL WORK

The first Europeans to travel through the area were Count Teleki and R. L. Von Höhnel who returned along the Turkwel after their discovery of lakes Rudolf and Stefanie in 1888. Von Höhnel (1938) gave a brief description of their journey and an account of later expeditions to Turkana up to 1909. Von Höhnel gave reference to more detailed reports of his own work, which included the first map of the region, and also to the writings of members of other expeditions. All those expeditions which passed through the present area followed the route of Teleki and Von Höhnel with the exception of Wellby (1900) who traversed the north-eastern corner of the area. All these expeditions were geographical rather than geological in character, the chief ones being those of Delamere and Atkinson, 1896-97; Austin and Pringle, 1898 and 1900 (Austin 1899 and 1902); Wellby (1900); Macdonald, 1898-99; the East African Syndicate 1902-1903.

J. W. Gregory did not visit the area but thought (1921, p. 215) that the eastern scarp of the Suk and Karasuk hills represented the continuation of the Elgeyo fault of the central Rift Valley.

Glenday and Parkinson (1926 and 1927) described some of the rocks from the Basement System in the Karasuk Hills and correlated the Kateruk Series there with Parkinson's Turoka Series of southern Kenya (1927, p. 797). Murray-Hughes (1933) showed faulting and a tentative boundary between the Basement System and volcanics on his map, and described (p. 6) the Turkana Grits as a series of pebbly conglomerates, felspathic grits and sandy shales.

The first serious geological work in the area was done in 1932-33 by Arambourg (1935 and 1943) whose map shows the eastern and central parts of the Loiya-Lorugumu area. He delimited the boundary between recent soils and the outcrops of the Basement System and also recognized that the rhyolites of Muruasigar were underlain by basalts. In a section on petrography Mme. Jérémine described specimens from both the volcanics and the Basement System (in Arambourg, 1935 pp. 17-59).

Champion (1937) discussed the geology of both the Turkana Plain and the hills to the west, commenting on the rhyolites of the Puch Prasir Plateau and Muruasigar and their underlying basalts. As regards structure he thought that there was a rift fault at the eastern edge of Muruasigar to the north of the present area, where he found Basement System rocks to a height of 5,500 feet under the lavas. This represents a height of nearly 4,000 feet above the surrounding plain. He also held that the Uganda Escarpment to the north of and including Moroto Mountain was a fault scarp, and that the embayment in the escarpment east of Moroto was due to erosion along a cross-

fault. He considered that the Turkana Plain was peneplaned after the formation of the Uganda Escarpment. The specimens collected by Champion were described by Campbell Smith (1938).

The map by Fuchs (1939) covers the whole of the present area and shows the same rock types recognized by Arambourg, linking the rhyolites of Muruasigar and the Puch Prasir Plateau together as one outcrop. He gave no petrological descriptions, but recognized that the Kapel Dome was a plug of microgranite with a high proportion of orthoclase (p. 242). Fuch's structural ideas were similar to those of Champion, but he considered (p. 264) that the Turkana Plain represented part of the Uganda peneplain which had been let down by faulting and that the fault running along the eastern side of Muruasigar was later than that of the Uganda Escarpment because it affects the lavas while the Uganda Escarpment affects only the Basement System. He also believed that there had been uplift in the Muruasigar block.

Dixey (1948, p. 25) thought that the Basement System of the Muruasigar range represented remnants of a Cretaceous peneplain corresponding in age to the Kitale Plateau. He referred the Turkana Plain to the end-Tertiary peneplain and the residual hills to the mid-Tertiary peneplain which included the Uganda peneplain (p. 29).

In their classification of the soils of southern Turkana C. F. Hemming and C. G. Trapnell (1957, p. 173) described the sandy soil of the Turkana Plain west of the Turkwel River as low chestnut-coloured dunes with a maximum height of six feet, which are now practically stable. In their map (p. 168) they showed the boulder beds west of Lorugumu and the stony soil near the Karasuk and Ngamatak hills as stone mantles. They ascribed (p. 175) the formation of stone mantles to the wash of stony soils by periodic rainstorms which remove the soil leaving an almost complete layer of wind-polished stones on the surface.

The areas to the north (Walsh and Dodson, 1969), south (Walsh 1966), south-east (Joubert 1966), and east (Dodson awaiting publication) have recently been mapped as part of the programme of primary geological mapping of Kenya.

## III—PHYSIOGRAPHY

### 1. Land Forms

The Loiya-Lorugumu area can be divided into three distinct physiographic units (Fig. 2) each of which is of considerable importance in a study of the geographical evolution and geological history of the area. These three natural divisions are:—

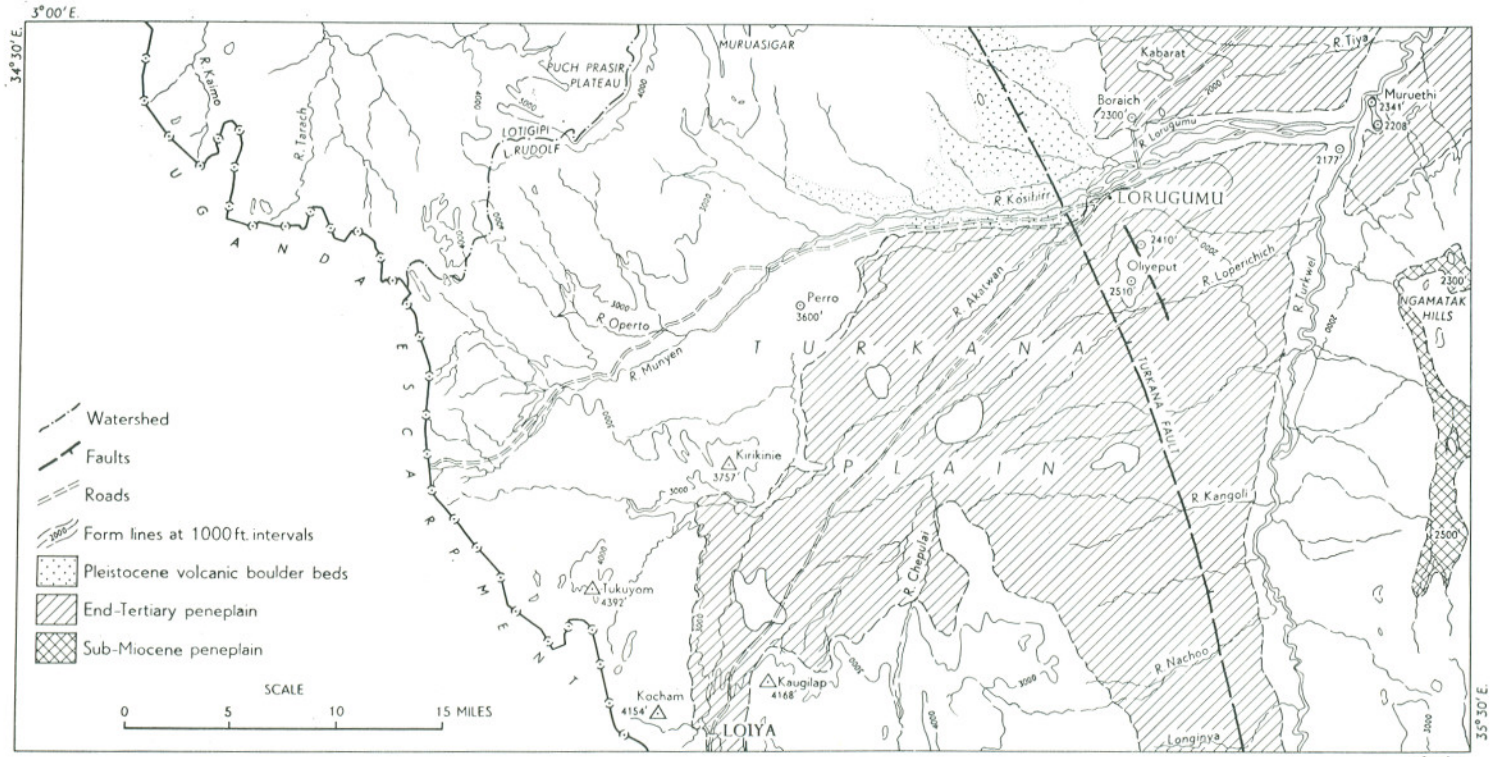



Fig. 2—Physiography of the Loiya-Lorugumu Area.

(1) The Turkana Plain.

(2) The Uganda Escarpment.

(3) The Uganda peneplain.

### (1) The Turkana Plain

The Turkana Plain which forms much of the present area is a well-smoothed plain, dipping gently at about 19.7 feet per mile from the foot of the Uganda Escarpment at about 3,000 feet to Lake Rudolf at about 1,230 feet. Near Lorugumu the elevation of the plain is 2,000 feet. At its maximum the plain is 90 miles from north to south and 200 miles from east to west, being continuous east of Lake Rudolf with the plain of the Northern Frontier District. The surface of the plain is covered by sand or sandy soils with occasional stretches of quartz-rich gravel and volcanic boulder beds. Vegetation is sparse except near shallow dry-sand rivers which may support a fringe of vegetation. In the case of the larger rivers a thickly wooded zone may exist confined to the river alluvium. Rock exposures on the plain are rare or absent and usually found only near hill masses forming erosion surfaces. Rising above the plain in the Loiya-Lorugumu area are numerous hills of Basement System rocks which have been left as highly eroded residuals after the retreat of the Uganda Escarpment. These hills, usually steep sided and well gullied with poor soil cover, give good exposures of the Basement System rocks. In the south-western part of the Loiya area west of the Lodwar road the residuals are usually of uniform elevation and often flat topped, indicating that they once formed part of the Uganda peneplain. Along the northern border east of the Lodwar Road the residuals show much greater variations in elevation and mainly occur as spurs projecting northwards from the highly mountainous country of Karasuk, much of which stands above the level of the Uganda peneplain. The residual hills usually stand about 1,000 feet above the general level of the Turkana Plain but near Karasuk this increases to about 2,000 feet.

Fuchs (1939, p. 264) regarded the Turkana Plain as representing a down-faulted part of the Uganda peneplain which was fractured along the Uganda Escarpment. Champion (1937, p. 105) however thought the plain to be an area peneplaned later than the Uganda peneplain and after formation of the separating fault scarp. Dixey (1948, p. 30) described the Turkana plain as a plain of erosion upon which some slight degree of aggradation has taken place and thought that the plain represents part of a widespread post-Miocene erosion cycle. The present authors consider that the Turkana Plain is a feature produced partly by faulting and partly by late Tertiary erosion, which has cut back the scarp some considerable distance.

### (2) The Uganda Escarpment

The Uganda Escarpment is a conspicuous geographical feature, the base of which demarcates the boundary between Kenya and Uganda. South of the Loiya-Lorugumu area the escarpment forms the boundary between Karasuk and Turkana. In general the escarpment is the dividing line between the Turkana peneplain to the east and the higher Uganda peneplain to the west, with a difference in elevation of over 1,000 feet. Erosion and retreat of the escarpment is indicated by projecting spurs and isolated residuals on the Turkana Plain.

Fuchs (1939, p. 221) described the Uganda Escarpment as a great fracture bounding the Lake Rudolf basin and regarded it as the northward continuation of the rift wall from the Elgeyo Escarpment. Dixey (1948, p. 26) on the other hand described the scarp as essentially an erosion scarp which may be related to an ancient fracture.

### (3) The Uganda Peneplain

The Uganda peneplain at an average elevation of 4,300 feet is usually regarded as being mid-Tertiary in age. It is inclined gently westward towards Lake Kyoga and is terminated to the east by the Uganda Escarpment. Although the Uganda peneplain is generally outside the present area it is probably partly represented by spurs from the escarpment and residuals on the Turkana Plain.

The Puch Prasir region which forms an area of quite considerable relief in the north-west corner of the area is almost entirely volcanic in origin. This volcanic belt, which rises from about 2,800 feet to over 5,500 feet, is dominated by two impressive rhyolite scarps separated by a sequence of more basic lavas. The lower rhyolite which dips gently westwards and is underlain by olivine basalts has a vertical or near vertical eastern edge capping a scarp feature somewhat in excess of 200 feet in height which runs from near Kalolokwel at the southern end of the Muruasigar range to Muru Ngiriderin, a distance of about 12 miles. The scarp is broken in places by narrow defiles of drainage cutting eastwards, and north-south faults which are often clearly indicated by gorge-like valleys. This system of easterly drainage and north-south trending faults has led to the development of a rectangular drainage pattern. Another spectacular feature of the lower scarp is the intrusive plug of the Kapel Dome. The upper rhyolite which forms the Puch Prasir Plateau has an even more impressive development, giving a high relatively flat area at about 5,500 feet cut by steep sided deep valleys, bounded to the east and south-east by precipitous cliffs often reaching 1,000 feet in height. Drainage on the Puch Prasir Plateau is mainly to the north-west so that the eastern lip of the plateau marks an important water-shed.

The Muruasigar-Puch Prasir region was described by Champion (1937, p. 114) as being "made up of a series of fault scarps and dip slopes with the result that the country may be likened to a series of waves breaking on a sandy shore".

## 2. Drainage

The most important direction of drainage in the Loiya-Lorugumu area is by way of the Turkwel River to the Lake Rudolf basin which is believed by Fuchs (1939, p. 223) to have been a closed basin since the beginning of the Upper Pleistocene. A second important direction of drainage occurs in the north-west corner of the area through the Tarach River to the Lotigipi Swamp, some 60 miles to the north, which is another closed drainage basin. The Lotigipi Swamp, a feature of tectonic origin, has been termed the Lotigipi syncline (Fuchs, 1939, p. 265). The watershed between the two drainage systems follows the eastern and southern edge of the Puch Prasir Plateau as far as Tarona and then swings south-westwards to the Uganda border round the southern headwaters of the Tarach River. The Nile-Rudolf watershed lies just outside the area to the west.

The Turkwel River which rises on the slopes of Mount Elgon some 100 miles to the south (where it is known as the Suam) flows across the area in a northerly direction. The river, which follows a rather meandering course in a shallow valley, is locally as much as half a mile wide and is for most of its length bordered by a belt of alluvium which in places is over a mile wide. In the Lorugumu area the gradient of the Turkwel is about 10 feet per mile as measured between the 2,000-feet contour and the northern edge of the area.

The main tributary of the Turkwel in the present area is the Lorugumu River which, apart from the Tarach drainage system, receives all the drainage from the eastern side of Moroto and the Uganda Escarpment west of the Lodwar Road. East of the road-crossing the Lorugumu River from bank to bank is extremely wide, and with its system of braided channels and islands of alluvium reaches a width of over a

mile. On the eastern side of the Lodwar Road, which follows the top of the watershed between the Turkwel River and the Lorugumu drainage system for about 30 miles north of Loiya, drainage from the Turkana Escarpment is mainly by small tributaries to the Turkwel.

Drainage on the Turkana Plain is inclined to be sluggish and often considerable aggradation takes place in the river valleys, causing braiding in the larger rivers. Braiding is particularly common near the foot of the Puch Prasir Plateau as the mountain torrents quickly lose their suspended loads on reaching the plains, where a considerable increase in stream width often takes place. Drainage patterns are usually dendritic; this is particularly true of the drainage from the Ngamatak Hills on the eastern bank of the Turkwel.

A much younger drainage system is present on the Puch Prasir Plateau where narrow river valleys with numerous waterfalls have cut deeply into the rhyolite lava. Trellis drainage is usually more common than dendritic drainage and near the Kapel Dome faulting has produced small areas of rectangular drainage.

### 3. Erosion Surfaces

A correct interpretation of erosion surfaces in the Loiya-Lorugumu area can be of considerable importance in determining the tectonic history and physiographic evolution of the Turkana Plain and the Uganda Escarpment during Tertiary times. The only conspicuous erosion surface is the broad, flat, gently dipping Turkana Plain. This surface, which laps round the edges of eroded residuals, slopes towards Lake Rudolf in a north-easterly direction from about 3,000 feet near Loiya to below 2,000 feet near Muruethi, an overall slope of 22 feet per mile (*see* fig. 2). The surface probably also underlies the volcanic boulder beds north-west of Lorugumu while near hill masses such as Ngamatak it grades into gently sloping pediment areas. Rivers cutting the surface are broad and shallow, often with poorly defined banks.

Rising above the Turkana Plain west and north-west of Kaugilap are a series of residual hills which have summits at about 4,000 feet, which may represent an older level now much eroded. It is noticeable that the general level of the residuals falls away to the north-east from Kocham (4,154 ft.) and Tuyukom (4,392 ft.) to such hills as Kirikinie (3,737 ft.) and Perro (3,600 ft.) The bevel may also be represented by the lava-capped hills near the Kaimo River in the north-west, which show a fairly uniform Basement-Volcanic contact at about 3,600 feet. Accepting a north-easterly or north-north-easterly dip for this older bevel, it has a gradient of about 27 feet per mile. A third erosion surface in the area is marked by a poorly defined bevel forming a fringe round the Ngamatak Hills, varying in altitude from about 2,500 ft. in the south to about 2,300 ft. in the north. The bevel is bordered by a gravel-covered pediment area which passes down to the Turkwel River on the west and the Turkana Plain to the north.

Before any attempt can be made to correlate erosion surfaces in the Lorugumu area with those in adjoining areas the nature and age of faulting causing displacement of surfaces must be determined and also the age of related sediments. The major fault in the area, the Turkana fault throwing down to the east, crosses the area in a north-north-westerly direction just west of Lorugumu. The exact position of the fault is not fully known because it is recognized only by a series of crush fault breccias near Oliyeput, but it must be related to the Turkwel Escarpment fault (Walsh, 1966) to the south and the Muruasigar scarp fault to the north (Fuchs, 1939 p. 265). McCall (1964, p. 57) has also proved the fault in the West Suk area, indicating that this fault line is one of considerable magnitude. There seems to be no evidence of faulting along the Uganda Escarpment near Moroto as shown by Fuchs (1939) on his provisional geological map of the Lake Rudolf basin.

The age of the fault is obviously greater than the age of formation of the Turkana Plain as the Turkana erosion surface extends over the fault line without a break for several miles to the west. Fuchs (1939, p. 264) suggested that the Uganda Escarpment was formed by fracturing of the Central African peneplain (sub-Miocene) in the late Oligocene (op. cit. p. 267), a date that is supported by McCall (1964, p. 11) who records the fault in West Suk as cutting the sub-Miocene bevel. It is therefore obvious that erosion bevels which were mature before faulting will be at a much lower level east of the fault than to the west.

The Turkana Grits were believed by Fuchs (1939, p. 228) to be of Oligo-Miocene age, and Miocene in age by Dixey (1948, p. 20). Similar sediments to the Turkana Grits occur in the Lorugumu area on the west bank of the Turkwel River south-east of Lorugumu and in some small river cuttings north-west of the Kabarat Hills. In all cases the Turkana Grits, which must have accumulated in hollows on an unevenly eroded sub-Miocene surface (Dixey, 1948, p. 25), occur east of the Turkana fault and show signs of being bevelled by later erosion.

There seems little doubt that the Turkana Plain was formed by erosion in late-Tertiary times and is similar in age to the end-Tertiary peneplain described elsewhere in Kenya. Faulting must have been of great importance in initial development of this plain but could not have been the only factor responsible as extensive erosion has cut back the Uganda Escarpment for many miles from the faults.

The Uganda peneplain, including the Karamoja peneplain, has been described by Dixey (1948, p. 4) as being of mid-Tertiary (sub-Miocene) age and having an average elevation of 4,300 feet. A slightly older peneplain level has also been recognized under Moroto at 4,900 feet, (op. cit. p. 5) and under Kadam at 4,900 to 5,000 feet (Trendall, 1959, p. 4). The youngest peneplain in Uganda, regarded as being end-Tertiary in age, occurs around Lake Kyoga. The Turkana Plain west of the Turkana fault can be directly correlated with the Uganda peneplain. The residuals west of the Lodwar Road showing a uniform elevation closely correspond to an extension of the Uganda Peneplain.

East of the Turkana fault the age of erosion surfaces, apart from the end-Tertiary Turkana Plain, are more difficult to determine but it may be expected that if a sub-Miocene bevel is present it will have a north-easterly slope down towards the Lake Rudolf depression. About 35 miles north-west of the northern end of the Ngamatak Hills there is a Basement System residual on the Turkana Plain, known as Lomil Hill, which has a capping of Tertiary lava. The Basement-Tertiary contact on this hill occurs at an elevation of about 2,200 feet (Joubert, 1966, p. 7), an elevation closely corresponding to the height of the erosion bevel on the Ngamatak Hills which at the northern end of Ngamatak is at 2,300 feet. Largely on this evidence the erosion bevel on the edge of the Ngamatak Hills is regarded as being of sub-Miocene age, with the tops of the Ngamatak Hills standing above the sub-Miocene peneplain possibly representing an older period of erosion. The approximate slope of the sub-Miocene bevel on the Ngamatak Hills is 22 feet per mile down to the north-east. The sub-Miocene bevel may also be represented by the tops of the isolated hills on the Turkana Plain east of the Turkana fault and west of the Ngamatak Hills. These hills, which include Oliyeput (2,510 ft.), Boraich (2,300 ft.) and Muruethi (2,341 ft.) tend to conform to the south-westerly rise of the sub-Miocene bevel.

The difference in elevation between the sub-Miocene and end-Tertiary surfaces east of the Turkana fault is 300 feet, whilst west of the Turkana fault near Kocham the difference in elevation must be in excess of 1,000 feet. It is probable that towards Lake Rudolf the sub-Miocene and end-Tertiary surfaces are very close together and that the end-Tertiary surface may represent an only slightly eroded sub-Miocene bevel. It is of interest to note that ten miles north-east of Lomil Hill the Basement-Tertiary contact

in the Muruanachok Hills is at plain level, (Dixey, 1948, p. 20), a fact again indicating a north-easterly slope for the sub-Miocene bevel. Warping or erosion of the sub-Miocene bevel prior to the formation of the Turkana Plain is clearly indicated by the bevelled Turkana Grits on the west bank of the Turkwel which are some 500 feet below the sub-Miocene bevel of the Ngamatak Hills.

There is no evidence in the Loiya-Lorugumu area of any erosion bevels older than sub-Miocene although the tops of the Ngamatak Hills and the tops of some of the hills north of the Karasuk boundary may represent eroded residuals of the sub-Moroto surface.

A comparison of the base of the lowest volcanics with the altitude of the erosion surfaces can be of value in determining an approximate age for the volcanics. South of Moruangiliop, the Kapel Dome and Muru Ngiriderin the base of the volcanics shows a steady rise to the west from about 2,400 ft. to about 3,000 ft., a level which agrees closely with the altitude of the end-Tertiary bevel. West of the Tarach River however the base of the lavas shows considerable variation; in places they rest on relics of the sub-Miocene bevel while in others they are well below the sub-Miocene. It would seem probable from the evidence available that the volcanics in the Lorugumu area are late Tertiary in age.

## IV SUMMARY OF GEOLOGY

The succession of rocks found in the area is:—

| *Age* | *Formation* | *Tectonics* |
|---|---|---|
| Recent .. .. | Soils | |
| Pleistocene .. .. | Boulder Beds | Erosion and formation of the end-Tertiary surface. |
| Pliocene to Miocene .. .. | Puch Prasir Rhyolites<br>Andesites<br>Muruasigar Rhyolites<br>Olivine Basalts<br>Turkana Grits | Rifting and minor faulting. |
| | | Erosion and formation of the sub-Miocene surface. |
| Precambrian.. .. | Basement System | Folding and metamorphism of Basement System. |

The oldest rocks in the area are gneisses of the Basement System, of Precambrian age. Radioactive dating of samarskite from pegmatites in the Sekerr area to the south (McCall, 1964 p. 74) gave an age of 636 ± 20 million years, and the gneisses there can be correlated with those of the Loiya-Lorugumu area. The gneisses are chiefly of sedimentary origin but the metadolerites, plagioclase amphibolites and amphibolites

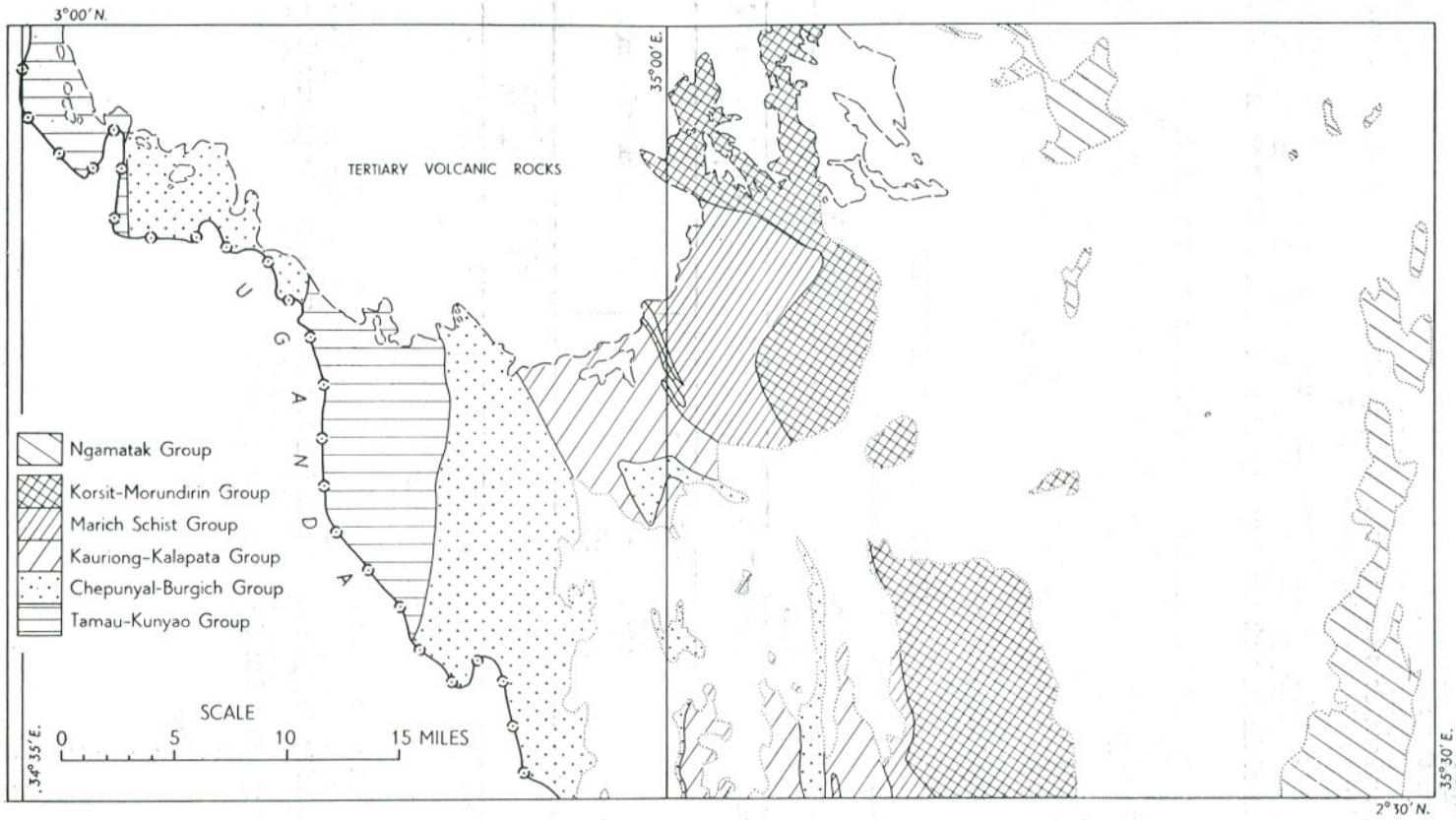



Fig. 3—Subdivisions of the Basement System in the Loiya-Lorugumu Area.

are thought from their form and aspect to be of igneous origin. The Basement System can be divided into six groups as shown in Fig. 3, which can be approximately correlated with those described and named in adjoining areas (McCall 1964, Walsh 1966, Joubert 1966). The lowest group, the Tamau-Kunyao group, is a uniform series of flaggy, grey semi-pelitic gneisses which outcrop near the Uganda Escarpment. Overlying them are the Chepunyal-Burgich group of alternating plagioclase amphibolites and biotite gneisses with thick crystalline limestones at the top of the sequence. These groups were named by McCall (1964) from localities in the Sekerr area. The crystalline limestones are succeeded by biotite gneisses which were termed the Kauriong-Kalapata group by Walsh (1966) from localities in the Karasuk Hills. They are much more massive and felspathic than those of the Tamau-Kunyao group and so are easily distinguished in the field. The next group is the Marich Schist group (McCall 1964) which usually consists of metadolerites and plagioclase amphibolites but in the south, thin limestones and biotite gneisses are intercalated in the plagioclase amphibolites. The Marich Schist group is followed by the Korsit-Morundirin group (Walsh 1966) which in the south contains pelitic gneisses at the base and biotite gneisses in the upper part, with several plagioclase amphibolite bands. To the north it passes into granitoid gneiss.

The relative ages of all these groups can be determined with certainty because they occur in virtually continuous exposures, but the last group, the Ngamatak group, is separated from the others by the thick sand cover of the Turkana Plain and so its position in the sequence cannot be ascertained. It consists of psammitic gneisses which are more felspathized than any others in the succession and so could correspond with McCall's Malmalte group (1964). He places this group at the top of the succession in the Sekerr area. On the other hand the Ngamatak group is very similar to Joubert's Kaimeruk Series which underlies his Turoka Series (Joubert 1966). The Turoka Series at Loperot appear to be very similar lithologically to the upper parts of the sequence in the Loiya-Lorugumu area, from the Chepunyal-Burgich group to the Korsit-Morundirin group.

Estimated thickness of the groups are as follows:— Tamau-Kunyao group 8,000 feet; Chepunyal-Burgich group 6,000 feet; Kauriong-Kalapata group 6,000-8,000 feet; Marich Schist group 7,000 feet; Korsit-Morundirin group 4,000-7,000 feet; Ngamatak group 6,600 feet. The base of the Tamau-Kunyao group is not seen and the thickness quoted is only a minimum value, while much of the Ngamatak group is obscured by sandy soil and so its structure and hence its thickness cannot be determined with any accuracy.

Orogenic folding produced north-south trending structures in the Basement System rocks. The folding was accompanied by regional metamorphism which mainly took the form of recrystallization with minor felspathization. The latter process was more pronounced in the east and granitoid gneisses are more abundant there.

Isostasy led to the uplift of the folded metamorphic rocks which suffered prolonged erosion, and the rocks now exposed were originally the roots of ancient mountain chains. By the beginning of the Miocene period erosion had reached a mature stage as shown by the formation of the sub-Miocene peneplain. No evidence of earlier peneplains was found in the Loiya-Lorugumu area but in the Suk Hills remnants are found of peneplains believed to date back to the Cretaceous. The Turkana Grits were formed by erosion of the Uganda Escarpment in the Miocene. The deposition of these sediments was followed by the eruption of the Tertiary volcanic rocks. The olivine basalts and the andesites were formed by the outpouring of lavas, and the two rhyolite series are thought to have been produced as ignimbrites. Faulting affected the olivine basalt group, the Muruasigar rhyolites and the andesite group, but not the later Puch Prasir rhyolites.

A further cycle of erosion reached maturity at the end of the Tertiary era. Volcanic boulder beds were produced during the Pleistocene chiefly from the Muruasigar rhyolites but also from the olivine basalt group. The sandy soils of the Turkana Plain were formed during Pleistocene and Recent times.

## V—DETAILS OF GEOLOGY

### 1. Basement System

The greater part of the gneisses and limestones of the Basement System are of sedimentary origin but most of the amphibolites are probably of igneous origin. The stratiform sequence of successive layers of differing lithology, persistent over long distances along the strike regardless of present disposition and structure, and the occurrence of numerous limestone horizons can only be attributed to a sedimentary succession. Although the foliation is of mechanical origin and is often lensoid in form it follows original bedding planes since it parallels geological boundaries and compositional banding, not all of which can be attributed to metamorphic differentiation. The amphibolites chiefly take the form of layers parallel to the foliation of the sedimentary gneisses, and the authors consider they were emplaced as sills rather than as lava flows. The metadolerite of Perro represents a larger intrusion into the sedimentary sequence. The rocks of the Basement System are classified into the following groups for purposes of description:—

1. Metamorphosed calcareous sediments
   - (*a*) Crystalline limestones.
   - (*b*) Calc-silicate gneisses
2. Metamorphosed pelitic sediments
   - (*a*) Biotite-kyanite gneisses
   - (*b*) Sillimanite gneisses
3. Meamorphosed semi-pelitic sediments
   - (*a*) Biotite gneisses
   - (*b*) Muscovite-biotite gneisses
   - (*c*) Hornblende-biotite gneisses
   - (*d*) Hornblende gneisses
4. Metamorphosed psammitic sediments
   - (*a*) Quartz-felspar gneisses
   - (*b*) Quartz-felspar-biotite gneisses
   - (*c*) Quartzites
5. Anatectic or palingenetic rocks
   - (*a*) Granitoid gneisses
   - (*b*) Pegmatites
   - (*c*) Giant white quartz veins
6. Metamorphosed igneous rocks
   - (*a*) Metadolerites
   - (*b*) Plagioclase amphibolites
   - (*c*) Amphibolites

### (1) Metamorphosed Calcareous Sediments

These rocks are found only to the west of the inferred fault running between the eastern scarp of the Karasuk Hills and the Turkwel River, no trace of them being found among the biotite gneisses to the east of the fault. Their chief occurrence is in the Chepunyal-Burgich group, which is the lowest recognized in the succession of the Loiya-Lorugumu area.

#### *(a) Crystalline Limestones*

The main limestones belonging to the Chepunyal-Burgich group outcrop in two main belts, one of which forms steep hills on the west bank of the Chepulai River and then runs northwards across the Turkana Plain, where it forms low isolated ridges, to the massive outcrops on the Emuroy and Kirikinie hills, dying out farther north due to folding. The other belt, which outcrops near the Looya water hole, forming three steep ridges due to folding, runs northward from the Uganda Escarpment before disappearing under the Tertiary volcanics. The smaller limestones in the Kauriong-Kalapata and Marich Schist groups occur as discontinuous bands associated with plagioclase amphibolites. Because of their petrological similarity all the crystalline limestones are described together.

The limestones are usually coarsely crystalline, often white or greyish white in colour but sometimes pink and more rarely of a blue tinge. Banding within the limestones parallel to the foliation of the surrounding gneisses is a constant feature, usually formed by alternating white and coloured layers, which vary in thickness from a fraction of an inch to several feet. Banding is also produced by variations in crystallinity or by concentrations in bands of graphite or calc-silicate minerals such as diopside and epidote, and sometimes muscovite.

The great majority of the limestones are composed of a mosaic of interlocking calcite grains with some dolomite, which only rarely is more abundant than calcite. Specimen 17/108* from the Nangole-Pak pass is a white medium-grained limestone which in thin section is seen to be composed of a mosaic of calcite grains with only a little dolomite. Diopside, muscovite and magnetite are accessory while a little graphite is disseminated through the carbonate crystals. Nearly all the crystalline limestones of the area contain a certain proportion of diopside, which Joubert (1957, p. 10) thought separated during de-dolomitization of a limestone originally richer in dolomite than at present. The diopside usually occurs as isolated rounded crystals, sometimes twinned, but in specimen 18/514 from the Lakuakoma Hills the sometimes chloritized diopside occurs in layers associated with calcite grains finer than, and containing more disseminated graphite than the diopside-free layers of calcite. Epidote often accompanies diopside while rounded quartz grains are present in 18/520 from the Lokoyam Hills and muscovite and magnetite are widespread.

Specimen 17/33 from the Emuroy Hills consists of alternating bands of medium-grained blue grey crystals and darker layers with ex-solution cavities perpendicular to the banding. In thin section the blue grey layers are seen to be formed of about equal proportions of calcite and dolomite but the ex-solution layers are composed of finer redeposited calcite and dolomite. There is also some accessory quartz and much limonitic iron-staining which is strongest round the cavities. The pink colour in some of the marbles such as 18/536 from the Loperichich River is presumably due to the presence of very small amounts of iron within the carbonate molecule, while the rarer blue tinge, according to Rosenhaltz and Smith (1950), is caused by strain.

* Numbers 17/108 etc. refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

### (*b*) *Calc-silicate Gneisses*

These rocks are found as small lenses and bands associated with the limestones and only rarely become important enough to show on the map, as in the case of the band running between the low hills of Loolung and Kalokodo near the Uganda border. Specimen 17/63 from this outcrop is a medium-grained rock of dark green colour with occasional leucocratic patches and is only poorly foliated. Under the microscope it is seen to be composed chiefly of colourless or pale brown diopside, some crystals of which are partly replaced by pale green hornblende. Some smaller grains of diopside occur in patches of untwinned plagioclase (andesine) crystals which are interstitial to the larger crystals of diopside. A few flakes of biotite, magnetite, epidote and apatite are accessory.

Specimens 17/41 from the foot of the hills to the east of Tukum and 17/57 from two miles south-east of Kochom are medium-grained rocks composed of alternating layers of felspar and ferromagnesian minerals. In the thin sections green hornblende, pleochroic from pale yellow to dark green, the chief constituent, is accompanied by a good proportion of very pale brown diopside, crystals of which are often corroded by the hornblende. Some small hornblende grains are enclosed in the diopside. Plagioclase ranging from oligoclase to andesine is the main constituent of the leucocratic bands and is accompanied by a little orthoclase which is more altered than the plagioclase. There is some anhedral quartz in both specimens and 17/57 also contains a few grains of microcline microperthite, indicating that the rock has undergone some granitization. Accessories are magnetite, epidote and sphene. Some estimated modes of the calc-silicate gneisses are as follows:—

| | *Percentages* | | |
|---|---|---|---|
| | 17/41 | 17/57 | 17/63 |
| Diopside .. .. .. .. .. .. | 20 | 20 | 47 |
| Hornblende .. .. .. .. .. .. | 28 | 37 | 32 |
| Plagioclase .. .. .. .. .. .. | 30 | 21 | 15 |
| Orthoclase .. .. .. .. .. .. | 7 | 6 | — |
| Microcline .. .. .. .. .. .. | — | 5 | — |
| Quartz .. .. .. .. .. .. | 5 | 4 | — |
| Sphene .. .. .. .. .. .. | 6 | 4 | — |
| Epidote .. .. .. .. .. .. | 2 | 2 | 2 |
| Magnetite .. .. .. .. .. .. | 1 | — | 3 |
| Apatite .. .. .. .. .. .. | 1 | 1 | 1 |

17/41—5 miles east of Tukum

17/57—2 miles S.E. of Kochom.

17/63—Kalokodo hill.

### (2) Metamorphosed Pelitic Sediments

The Korsit-Morundirin group is the chief representative of the pelitic gneisses, its lower part being almost entirely composed of them, although its upper part becomes more psammitic. Pelitic gneisses in other groups form only isolated knots and lenses.

### (*a*) *Biotite-kyanite gneisses*

The main outcrop of the Korsit-Morundirin group occurs in the eastern part of the Karasuk Hills around the Kakep Pass. The most abundant and distinctive rock type is a biotite-kyanite gneiss which passes laterally from a semi-pelitic biotite gneiss in the south to a kyanite-bearing biotite gneiss. In the Loiya-Lorugumu area the rock is a good pelite, of which specimen 18/553 from five miles south-east of the Kakep Pass is a good example. The hand specimen is a grey brown, fine-grained rock with large blades of kyanite set in a quartzo-felspathic matrix, with a foliation produced by

numerous plates of biotite with lesser amounts of muscovite arranged in parallel layers. The thin section contains only small crystals of kyanite oriented parallel to the biotite. Orthoclase, which is the most abundant leucocratic mineral, is accompanied by quartz and rare albite, and magnetite and apatite are accessory. Large blades of kyanite associated with yellowish quartz make up 18/516 from the eastern bank of the Kabokuli River.

A garnetiferous variety of kyanite-biotite gneiss (specimen 17/64) is found as a lens within biotite gneiss on the south bank of the Loolung River. It is a friable rock, of reddish-brown colour due to iron staining. Small garnet porphyroblasts and blades of kyanite deflect the foliation which is picked out by flakes of biotite. Under the microscope the garnet is seen to occur chiefly as porphyroblasts, with smaller grains enclosed in the quartzo-felspathic layers. The garnets are chloritized along cracks and contain inclusions of quartz-felspar and iron ores. The kyanite occurs as large porphyroblasts elongated parallel to the foliation and unaffected by other constituents. The quartz and felspar, mainly orthoclase with a little oligoclase, form small iron-stained patches with a granulose texture. It is this feature as much as the porphyroblasts which gives the rock its nodular appearance and friable character. In places epidote is abundant as an accessory and magnetite occurs most frequently near the garnet crystals, while chlorite patches enclosed by iron staining may represent altered garnets.

### (*b*) *Sillimanite gneisses*

This group occurs only in thin discontinuous bands in the biotite-kyanite gneisses, especially towards their base. In hand specimen, e.g. 18/538 from the western side of the Kakep Pass, it is a silver-grey, medium-grained friable rock, the foliation of which is produced by layers of mica, chiefly biotite, and felts of sillimanite needles. The leucocratic layers consist of quartz with some orthoclase and a little albite; magnetite is accessory.

Estimated modes of the pelitic gneisses are as follows:—

| | *Percentages* | | |
|---|---|---|---|
| | 18/553 | 17/64 | 18/538 |
| Quartz | 30 | 15 | 31 |
| Orthoclase | 20 | 10 | 15 |
| Plagioclase | 11 | 5 | 10 |
| Muscovite | 7 | — | 5 |
| Biotite | 18 | 10 | 30 |
| Garnet | — | 20 | — |
| Kyanite | 10 | 32 | — |
| Sillimanite | — | — | 5 |
| Magnetite | 3 | 5 | 4 |
| Epidote | — | 3 | — |
| Apatite | 1 | — | — |

18/553—Biotite-kyanite gneiss, 5 miles south-east of Kakep Pass.

17/64 —Garnet-kyanite gneiss, south bank of Loolung river.

18/538—Sillimanite gneiss, hill on west side of Kakep Pass.

### (3) Metamorphosed Semi-pelitic Sediments

#### *(a) Biotite Gneisses*

The rocks included in this group are well foliated, fairly fine-grained gneisses with a conspicuous development of dark biotite on foliation surfaces. Biotite gneisses and related types are the most abundant of the Basement System rocks and show a considerable variation in grain size, nature of foliation, in the quantity of biotite present and the degree of granitization.

Perhaps the most typical and consistent group of biotite gneisses occur in a broad, highly folded zone along the western edge of the area in the region of the Nasogolo Hills. These biotite gneisses are usually well foliated, quartz-rich rocks, greyish in colour and with an abundance of black biotite. Specimen 17/94 from the road crossing on the Makiriethia River, south of the Nasogolo Hills is fairly representative of this group, and consists of quartz, biotite and sodic plagioclase. Accessory minerals include epidote, muscovite, apatite and iron ore and secondary calcite is also present. The sodic plagioclase, generally untwinned and sometimes kaolinized, is albite-oligoclase and together with quartz makes up the bulk of the rock. Two varieties of biotite are present, one type showing pleochroism from straw-yellow to dark brown or black and the other showing pleochroism from pale yellow or green to dark green. Epidote is the most abundant of the accessory minerals.

Most of the other biotite gneisses in the area are of a similar nature, with sodic plagioclase as the dominant or only felspar. Specimen 18/540 from south-east of the Kakep Pass has an abundance of twinned oligoclase. In this specimen as in many of the biotite gneisses, epidote is a very common accessory mineral. The biotite gneisses which show the main variation from the types already described are those which contain secondarily introduced felspar. Specimen 18/525 from the northern end of Amuton is of this type, with knots and veins of pink felspar along the foliation planes. In some places the biotite gneisses of Amuton have developed into augen gneisses or porphyroblastic gneisses. In thin section specimen 18/525 differs considerably from the other biotite gneisses in that potash felspars are very abundant while sodic plagioclase is rare. The potash felspars include orthoclase, showing considerable alteration to sericite and clay minerals, and microcline with generally much less alteration. Accessory muscovite is much more common than in the other biotite gneisses. Similar augen gneisses have been mapped on Lakuakoma.

#### *(b) Muscovite-biotite gneisses*

The muscovite-biotite gneisses are mainly restricted to the Kaimo-Tarach river region. They occur generally in poorly defined zones which grade imperceptibly into biotite gneisses with muscovite and finally into biotite gneisses. These zones, although usually elongated paralled to the foliation, are extensive and may cut across the foliation. In most cases it may be accepted that the muscovite-biotite gneisses owe their origin more to some form of metamorphic differentiation than to the nature of the original sediments.

Specimen 17/110 from east of Looya is a fine-grained, well-foliated gneiss with muscovite conspicuous on the foliation surfaces. Biotite although common is much less apparent. In a section cut parallel to the foliation the rock consists mainly of quartz, muscovite and green biotite. The muscovite generally occurs as cleavage flakes but occasional crystals showing cleavage indicate that it is partly intergrown with the biotite. Accessory minerals include pink euhedral garnets, epidote, apatite and iron ore. Patches of carbonates, sometimes showing slight iron staining, are fairly common.

### (c) *Hornblende-biotite gneisses*

This group of semi-pelitic gneisses is represented in the area by one thin band outcropping at the trigonometrical beacon of Tukum. The rock (17/48) lacks foliation and is fine grained, grey in colour but speckled with darker ferromagnesian minerals. Under the microscope the ferromagnesian minerals are seen to consist of roughly equal proportions of hornblende and biotite. The former occurs in anhedral grains which are pleochroic from pale green to pale brown while the latter forms small isolated plates pleochroic from straw yellow to dark brown. In some crystals the biotite appears to replace hornblende. Andesine crystals form the dominant leucocratic constituents but some smaller quartz grains are also present. Sphene, epidote and apatite are accessory.

### (d) *Hornblende gneisses*

These rocks again occur in only one band in the upper part of the easternmost extension of the Marich Schist group. Outcrops of the rock are present on the western side of the Akeop Hills to the west of the Kakep Pass where, on account of its easterly dip and poor resistance to erosion, the band forms a steep and broken scarp. To the north, where the hills descend into the Turkana Plain, it outcrops in low ground to the west of the Otopai Hills. The hornblende gneisses then disappear below the thick cover of sandy soil on the plain under which they are thought to pass laterally to plagioclase amphibolites occupying an analogous stratigraphical position.

Specimens 18/528 and 18/539, from the Akeop Hills and two and a half miles south-south-west of the Kakep Pass respectively, are medium-grained rocks with alternating bands of hornblende and quartzo-felspathic minerals which are more distinct than those of the average plagioclase amphibolites. The hornblende is of a lighter green colour than that in the plagioclase amphibolites and as the leucocratic bands are more pronounced the colour of the rock as a whole is lighter. In thin section the hornblende is strongly pleochroic from light green to dark green and in 18/539 it is accompanied by scattered flakes of biotite. Oligoclase is the chief felspar, with orthoclase being somewhat less abundant and quartz interstitial. Epidote and sphene are important as accessories in 18/528 with a small amount of magnetite, which is more abundant in 18/539, where apatite is also found and there are many patches of yellow and brown alteration products. Estimated modes of the hornblendic gneisses are given below:—

| | *Percentages* | | |
|---|---|---|---|
| | 17/48 | 18/528 | 18/539 |
| Hornblende | 25 | 45 | 55 |
| Biotite | 25 | — | 5 |
| Quartz | 12 | 7 | 8 |
| Orthoclase | — | 9 | 12 |
| Plagioclase | 30 | 20 | 15 |
| Epidote | 4 | 9 | — |
| Sphene | 3 | 8 | — |
| Magnetite | — | 2 | 4 |
| Apatite | 1 | — | 1 |

17/48 —Hornblende-biotite gneiss, 1½ miles south-south-east of Tukum.

18/528—Hornblende gneiss, Akeop Hills.

18/539—Hornblende gneiss, 2½ miles south-south-west of the Kakep Pass.

### (4) Metamorphosed Psammitic Sediments

The rocks which are included in this section are those which are believed to have been formed from arenaceous sediments, mainly sandstones and arkoses, which are represented by quartzites and quartz-felspar gneisses respectively. In both these rock types biotite and muscovite may be present in small amounts. A third group of rocks included in this section are the quartz-felspar-biotite gneisses which contain a more conspicuous development of biotite. They are included in the metamorphosed psammitic sediments and not the biotite gneisses mainly on the coarseness of grain size and their lower biotite content.

#### (*a*) *Quartz-felspar gneisses*

The quartz-felspar gneisses are fairly fine-grained leucocratic granulitic rocks displaying rather weak foliation due to the lack of flaky minerals. Biotite or muscovite are commonly present but rarely exceed two per cent of the rock by volume. They correspond very closely to the quartz-felspar para-granulites of Shackleton (1946 pp. 11-12).

Generally the quartz-felspar gneisses, e.g. specimen 17/61 collected about three miles north of Ropetari, occur in fairly narrow bands associated with the biotite gneisses. In thin section specimen 17/61 consists almost entirely of quartz and felspar, with the felspar rather more abundant. The felspar, as in many of the biotite gneisses, is mainly albite or soda-oligoclase occuring as both twinned and untwinned crystals and occasionally as myrmekite. Commonly interstitial between the plagioclase crystals, and often showing replacive contacts with them, are small irregular crystals of microcline. Brown biotite is the most common of the accessory minerals, making up about 2 per cent of the slide, and a few grains of iron ore are also present.

Where thick zones of plagioclase amphibolite are exposed, as in the Ropetari region, they often have a supporting rib-like structure of narrow discontinuous sill-like or dyke-like bodies of quartz-felspar gneisses and granulites. The origin of these bodies is not known. Specimen 17/97 from north-east of Ropetari is from one of these bands and in thin section it closely resembles 17/61 in that it is largely comprised of quartz and sodic plagioclase. The plagioclase however, except for a few rare crystals, is untwinned and shows a higher degree of alteration to sericite. Biotite is rare, its place being taken by muscovite which is fairly common and may show intergrowth with biotite. Patches of carbonate are also present in the rock.

#### (*b*) *Quartz-felspar-biotite gneisses*

The quartz-felspar-biotite gneisses are essentially coarse grained, rather flaggy biotite gneisses in which biotite, although common, is not abundant. Foliations are poorly developed and are due to a vague banding in the felsic minerals rather than to a more perfect foliation caused by the parallelism of flaky minerals. Alteration of these rocks by alkali metasomatism seems to be more common than in the biotite gneisses, although in the biotite gneisses sodic plagioclase is usually the most common of the felspars. Rocks of this type are extremely common in the Ngamatak Hills, where they are often cut by pegmatites, but also occur fairly commonly in other regions associated with biotite gneisses.

Specimen 18/568 is a typical quartz-felspar-biotite gneiss from the southern end of the Ngamatak Hills which shows a marked banding on weathered surfaces due to differential hardness of the layers of leucocratic minerals. Small flakes of biotite with less common muscovite are conspicuous on the foliation surfaces. In thin section the rock consists of quartz, sodic plagioclase (albite-oligoclase), microcline, biotite and

muscovite with minor accessory minerals. The maximum grain size is about 2mm. Microcline is not abundant and mainly occurs as small irregular crystals interstitial to the larger crystals of plagioclase with which it often shows replacement textures. The biotite is pleochroic from yellow to dark brown or black.

### (*c*) *Quartzites*

Only one band of quartzite large enough to show at the scale of the map was found, which outcrops on the western side of the crystalline limestone at Lomoti Hill below the Uganda Escarpment. Elsewhere quartzites occur only as thin lenses enclosed in other rocks.

The quartzite at Lomoti, specimen 17/105, is a medium-grained rock which is glassy when fresh but when weathered shows iron staining along joints and in cavities. In addition some of the cavities contain a pale yellow amorphous mineral which may represent impure kaolinized felspar. The thin section is almost entirely composed of a mosaic of clear unaltered quartz grains. A little interstitial felspar, probably orthoclase, is only slightly less clear than the quartz; otherwise only a few blebs of accessory magnetite are present.

## (5) Anatectic or Palingenetic Rocks

In many parts of Kenya it is possible to detect a gradation from biotite gneisses to granites of possible palingenetic origin. The change is usually marked by a loss of foliation and by a conspicuous increase in the proportion of potash felspar, usually microcline, over the other constituent minerals. In between the regionally metamorphosed rocks and the truly palingenetic rocks there must be a group of rocks showing considerable alteration and addition due to potash enrichment by alkaline metasomatism. Most attempts to subdivide this gradation series have been largely based upon mode of outcrop with particular reference to the presence or absence of foliation.

In the Loiya-Lorugumu area most of the biotite gneisses and related rocks are albitic in nature and rarely contain an abundance of potash felspar. An exception is provided by the porphyroblastic biotite gneisses of Amuton, described earlier, which show an obvious enrichment of potash felspar (orthoclase and microcline). It would seem likely that the biotite gneisses of Amuton are partly metasomatic in origin and similar to granitoid gneisses described from many other localities of Kenya. A more advanced stage in the passage towards true granite is provided by the granitoid gneisses of Emuruchorod, which are regarded as being of palingenetic origin.

### (*a*) *Granitoid Gneisses*

The only granitoid gneiss exposed in the area is that which forms a roughly circular area some 25 square miles in extent just south-east of Perro and includes the rugged tor of Emuruchorod. Foliations within the granitoid gneiss are uncommon and rather vague, while the relationship between the margin of the granitoid gneiss and the surrounding rocks is not known, due to lack of contact exposures. Although the mapped boundaries of the granitoid gneiss must be generally regarded as approximate there is no linkage of the granitoid gneiss with the banded Basement System rocks to the south but it occupies a stratigraphical position analogous to the pelitic gneisses of the Korsit-Morundirin group. The Emuruchorod granitic or granitoid gneiss can alternatively be regarded as an intrusion into the Basement System.

In the hand specimen the granitoid gneiss is of markedly coarse grain with crystals over 4mm. in size, and although there is a slight trace of foliation the rock has a typical granitic granular texture which is quite distinct from any of the biotite gneisses. Distinct in hand specimen is the abundance of pink potash felspar along with quartz and dark biotite.

In thin section specimen 18/544A from Emuruchorod is quite distinct from the biotite gneisses (except 18/525 from Amuton) and the quartz-felspar-biotite gneisses in that potash felspar, mainly microcline with associated microperthite, is extremely abundant. Oligoclase, sometimes with fine twin lamellae and sometimes untwinned, is also present. Quartz is fairly abundant and there are a few crystals of myrmekite. Biotite is pleochroic from straw yellow to nearly black and occurs with accessory muscovite.

An estimated mode for the granitoid gneiss is given below, with figures for some of the biotite gneisses and related rocks.

| | *Percentages* | | | |
|---|---|---|---|---|
| | 18/544A | 17/61 | 17/94 | 18/568 |
| Quartz .. .. .. .. | 32 | 40 | 40 | 38 |
| Microcline and microperthite .. | 28 | 5 | — | 2 |
| Plagioclase .. .. .. .. | 30 | 52 | 48 | 55 |
| Myrmekite .. .. .. .. | 1 | 1 | — | — |
| Biotite .. .. .. .. | 9 | 2 | 10 | 5 |
| Muscovite .. .. .. .. | + | — | + | + |
| Accessory Minerals.. .. .. | + | + | 2 | + |

18/554A—Granitoid gneiss, Emuruchorod.

17/61 —Quartz-felspar gneiss, Ropetari.

17/94 —Biotite gneiss, Makiriethia River.

18/568 —Quartz-felspar-biotite gneiss, Ngamatak Hills.

*(b) Pegmatites*

Pegmatites mostly occur in the eastern part of the area, especially to the east of the Turkana fault. Intrusive cross-cutting pegmatites greatly predominate over smaller concordant ones, most of which are identical petrologically.

The cross-cutting pegmatites, which often stand out as ridges above the country rock, range in thickness from two to 20 feet. They usually trend north-south, roughly parallel to the strike of the foliation, but in the Moruantoko Hills they form a series of low parallel ridges running east-west. In this locality (e.g. specimen 18/519) they are cream rocks almost entirely composed of felspar with only a little quartz and a few plates of muscovite. Under the microscope the most abundant felspar is seen to be altered and sericitized orthoclase with subsidiary clearer albite and a little microcline. Some small grains of quartz are interstitial to the felspar and small flakes of biotite sometimes accompany the muscovite. Small quantities of magnetite and epidote are accessory. Specimen 18/535 from the River Kabokuli is coarser grained than 18/519 but is petrologically similar except that quartz, oligoclase and muscovite are more abundant and microcline is lacking. Biotite forms numerous "books' in the hand specimen.

Pegmatites from farther east, e.g. 18/561 from the small hill on the western bank of the Turkwel south-west of Muruethi, tend to be more sodic than those of the west. In hand specimen this is a coarse-grained rock composed chiefly of pink felspar with subsidiary clear quartz. There are only small patches of mica, both muscovite and biotite. In thin section the felspar is seen to be altered oligoclase, against which pools of clear quartz show lobate margins, as does the quartz in 18/535. Sericite and disseminated iron ores are contained within the felspar while there are some larger grains of accessory magnetite. In the Ngamatak Hills the pegmatites contain a much higher proportion of microcline. Specimen 18/565 is a coarse rock dominantly com-

posed of pink felspar with subsidiary grains of clear quartz and isolated knots of muscovite flakes. The section is almost entirely composed of microcline microperthite with only small patches of lobate quartz, some of which are enclosed in the microcline. There are a few small flakes of muscovite and some patches of magnetite.

The following volumetric modes were estimated for the pegmatites:—

| | *Percentages* | | | |
|---|---|---|---|---|
| | 18/519 | 18/535 | 18/561 | 18/565 |
| Quartz .. .. .. .. | 7 | 10 | 33 | 27 |
| Orthoclase .. .. .. .. | 45 | 40 | — | — |
| Microcline .. .. .. .. | 10 | — | — | 68 |
| Plagioclase .. .. .. .. | 26 | 30 | 57 | — |
| Muscovite .. .. .. .. | 8 | 9 | 5 | 3 |
| Biotite .. .. .. .. | 2 | 10 | 3 | — |
| Magnetite .. .. .. .. | 2 | 1 | 2 | 2 |

18/519—Moruantoko Hills.

18/535—Kabokuli River.

18/561—Muruethi.

18/565—Ngamatak Hills.

### (c) *Giant White Quartz Veins*

Several veins of pure white quartz, which are common in the Basement System of Kenya, outcrop on the eastern side of Kaugilap where they vary in width between 50 and 100 feet but are seldom more than a few hundred feet in length. The neighbouring exposure is poor and the relationship between the quartz veins and the country rock is obscured, but in spite of their width they appear to have been emplaced along joints.

## (6) Metamorphosed Igneous Rocks

Amphibolites and plagioclase amphibolites comprise the great majority of metamorphosed rocks in the Loiya-Lorugumu area. The two types are separated for the purposes of description on their content of plagioclase, but both varieties are locally to be found in the same outcrop and their differentiation is thought to be a metamorphic effect. All are considered to be of igneous origin because plagioclase amphibolites pass laterally into the metadolerite of Perro which still retains an igneous texture.

### (a) *Metadolerites and metagabbros*

The most important metamorphosed igneous rocks which still retain an igneous texture outcrop in the hill mass of Perro covering an area of approximately 12 square miles. The metadolerites are more resistant to erosion than the surrounding gneisses and the highest of the several peaks rises to a height of 3,600 feet, over 1,000 feet above the surrounding plain. The greater width of outcrop of the metadolerite than its equivalent plagioclase amphibolites causes it to bulge into the adjacent gneisses and deflect their strike.

The typical rock type (18/554) is a dark green, medium-grained rock largely composed of mafic minerals with subordinate felspar. The texture is entirely igneous with no sign of foliation. Under the microscope the texture is seen to be ophitic but the minerals are metamorphic in character. The most abundant mineral is green hornblende forming large plates which are paler and less pleochroic than that of a typical amphibolite or plagioclase amphibolite. The hornblende plates are somewhat broken

and are associated with numerous elongated crystals of clinozoisite, which are often enclosed in the hornblende, and a few small laths of colourless pyroxene. The felspar was determined as andesine but is more albitic towards its margins. In one part of the slide both it and the hornblende are sericitized and contain much disseminated iron ore. Magnetite and apatite are accessory.

The only other metamorphosed rock of igneous aspect outcrops on the eastern boundary of the area to the north of the Ngamatak Hills and extends into the adjoining area to the east. The outcrop stands up from the Turkana Plain as a low isolated hill which is whale-backed in shape when viewed from the south-west. A few exposures are found to the west of the hill but no indication of the relation to other rocks in the Basement System can be found due to the thick soil cover. The rock itself (18/731) is coarse-grained with a speckled appearance due to green hornblende crystals set in waxy felspars. Under the microscope it is seen to be less metamorphosed than specimen 18/554 from Perro since the igneous texture is better preserved. The chief constituent is sodic labradorite felspar which shows pericline twinning in addition to the usual Carlsbad and albite twins. Green pleochroic hornblende, presumably produced by alteration of augite, represents the ferromagnesian minerals. Fairly large plates of epidote are the most abundant accessory mineral, while magnetite also occurs.

### (*b*) *Plagioclase amphibolites*

This group chiefly outcrops in thin bands which are often lensoid and die out in a short distance along the strike, though some of the larger persist for considerable distances. The largest occurrence is that of the plagioclase amphibolites which pass laterally to both north and south from the metadolerite of Perro, and the corresponding band running to the west of Tukum. Both of these outcrops fall within the Marich Schist group. The margins of plagioclase amphibolites are often agmatitic towards the neighbouring biotite gneisses with the result that the boundary between the two formations can only be drawn approximately. Plagioclase amphibolites are much more abundant than the amphibolites and can be subdivided into two main categories according to whether they are garnetiferous or not. The non-garnetiferous variety is the more usual, but this probably does not indicate a change in the degree of metamorphism, since following Wiseman (1934, p. 378) the production of garnet depends on the original chemical composition of the rock as well as on the grade of metamorphism.

Specimen 17/47 from the north peak of Tukum is a fine-grained garnet-free plagioclase amphibolite consisting of alternating bands of plagioclase and dark green hornblende, with the latter predominating. The hornblende, which in thin section is pleochroic from yellowish green to dark green, is arranged in parallel discontinuous layers of elongated crystals separated by grains of andesine. Sphene, epidote and magnetite are accessory.

The plagioclase amphibolites usually contain relics of diopside enclosed in the hornblende crystals, which were produced by alteration of the pyroxene. Typical examples are 18/513 from the Lakuakoma Hills and 18/523 from the Akeop Hills, the former being of coarser grain than the latter. In 18/513 the layers of alternating plagioclase and hornblende impart a good foliation but in 18/523 the banding is indistinct. In both thin sections the hornblende shows pleochroism from pale to dark green and encloses small relics of diopside. The plagioclase, which was determined as oligoclase, shows antiperthitic structure in 18/513 and is associated with a little quartz in both specimens. Sphene, magnetite, epidote and apatite are accessory.

A leucocratic variety is represented by 17/52 from the Nakodi Hills to the north of Perro where it forms a lens-shaped outcrop within typical plagioclase amphibolite. It is a coarse rock, light grey in colour since it contains much more felspar than a normal plagioclase amphibolite. Thin bands of hornblende within the plagioclase give a faint

foliation but the hornblende crystals are often scattered irregularly among the felspar. Under the microscope the plagioclase is seen to form a granular matrix with only a faint suggestion of orientation of grains parallel to the hornblende layers. No twinning was observed in the plagioclase but from its refractive index it has the composition of andesine. The hornblende shows pleochroism from pale green to pale brown and magnetite and apatite are accessory in very small quantities.

Specimen 18/543 from one and a half miles south-east of Kirikinie contains a much higher proportion of epidote than is usual in the plagioclase amphibolites.

Some estimated modes of the plagioclase amphibolites are given below:—

| | *Percentages* | | | | |
|---|---|---|---|---|---|
| | 17/47 | 17/52 | 18/513 | 18/523 | 18/543 |
| Plagioclase .. .. | 41 | 70 | 30 | 32 | 36 |
| Quartz .. .. | — | 10 | — | — | 5 |
| Hornblende .. .. | 50 | 18 | 52 | 48 | 40 |
| Diopside .. .. | — | — | 8 | 12 | 10 |
| Sphene .. .. | 4 | — | 3 | 3 | — |
| Magnetite .. .. | 3 | 1 | 3 | 2 | 2 |
| Epidote .. .. | 2 | — | — | 2 | 7 |
| Apatite .. .. | — | 1 | 1 | 1 | — |

17/47 —North peak of Tukum.

17/52 —Nakodi.

18/513—Lakuakoma Hills.

18/523—Akeop Hills.

18/543—South-east of Kirikinie.

Garnetiferous varieties are represented by 17/37 and 18/541 from Lotepesit Hill and the Otopai Hills respectively. In thin section the garnets show no sign of helicitic growth but chlorite fills cracks in them at right angles to the foliation. The garnets only slightly deflect the other minerals, many layers of which stop against the garnets, indicating that the latter crystallized early during metamorphism. The garnet makes up about ten per cent of the rocks with a corresponding decrease in the proportions of the other minerals which are similar to those of the non-garnetiferous plagioclase amphibolites.

### (*c*) *Amphibolites*

The amphibolites are separated from the plagioclase amphibolites on their lower plagioclase content, which never exceeds 25 per cent of the rock. The amphibolites are not distinguished from the more abundant plagioclase amphibolites on the map since the two types frequently grade into each other in the same outcrop. Representative examples are specimens 17/93 from four and a half miles north-north-west of Tukum and 18/109 from the Nangole Pak Pass. Both are dark green, fine-grained rocks composed mainly of laths of hornblende whose orientation gives a good foliation. Under the microscope the hornblende is seen to be a pale green variety which is less pleochroic than that of the plagioclase amphibolites. Associated with the hornblende and often enclosed in it are laths and grains of pale brown diopside, which, in 17/109, also forms some very large elongated crystals. The small grains of plagioclase which are interstitial to the hornblende were determined as calcic andesine. Sphene, magnetite and apatite are accessory.

An amphibolite which does not contain diopside (17/32) was found in the Emuroy Hills. In thin section the hornblende crystals are usually pleochroic from pale brown to pale grey, but sometimes to pale green, the change often occurring within a single

crystal. The subordinate felspar appears to be oligoclase. Yellowish sphene, which is usually enclosed in the hornblende, is an abundant accessory while magnetite is less frequent.

Specimen 17/50 from the south bank of the Kosibirr River is a tremolitic amphibolite; it is a medium-grained rock containing many laths of brownish tremolite, patches of which stand out from the surface on weathering. In thin section the rock is seen to be largely altered, long prismatic crystals of tremolite with a radiating, fibrous habit forming the major constituent. There are also some laths and grains of plagioclase which lies between oligoclase and andesine. Magnetite and epidote are accessory and there is much secondary calcite and iron staining.

Garnet amphibolites are represented by specimen 18/510 from the east bank of the Kabokuli River, a dark, fine-grained rock dotted with numerous garnets. Foliation is marked by thin plagioclase layers between thicker ones of hornblende as well as by the orientation of the hornblende crystals themselves. Under the microscope the garnets are seen to be very impure with numerous inclusions of plagioclase and hornblende and streaks of iron staining. The margins of the garnets are embayed by the other minerals but no internal helicitic structure is seen. The most abundant mineral is hornblende in large plates pleochroic from yellowish-green to dark green and sometimes enclosing a little pale brown diopside. The subsidiary oligoclase felspar sometimes encloses small pools of quartz. Magnetite and apatite are accessory.

Some estimated modes of the amphibolites are as follows:—

| | *Percentages* | | | | |
|---|---|---|---|---|---|
| | 17/32 | 17/50 | 17/93 | 17/109 | 18/510 |
| Plagioclase .. .. | 24 | 14 | 8 | 15 | 8 |
| Quartz .. .. | — | — | — | — | 3 |
| Amphibole .. .. | 68 | 75 | 75 | 63 | 69 |
| Diopside .. .. | — | 6 | 12 | 15 | 7 |
| Garnet .. .. | — | — | — | — | 10 |
| Sphene .. .. | 6 | — | 3 | — | — |
| Magnetite .. .. | 2 | 3 | 2 | 6 | 2 |
| Epidote .. .. | — | 2 | — | — | — |
| Apatite .. .. | — | — | — | 1 | 1 |

17/32 —Emuroy Hills.

17/50 —Kosibirr River.

17/93 —North-north-west of Tukum.

17/109—Nagole Pak Pass.

18/510—Kabokuli River.

## 2. Turkana Grits

The first use of the term "Turkana Grits" according to Champion (1937, p. 111) was by H. L. Sikes when Director of the Public Works Department. Reference was also made to the Turkana Grits by Murray Hughes (1937, p. 6) who described them as being a series of pebbly conglomerates, felspathic grits and sandy shales. Fuchs (1939, p. 228) regarded these grits as being of Oligo-Miocene age while Dixey (1948, p. 20) thought them to be Miocene. Mason and Gibson (1957, p. 18) divided the Tertiary sedimentary rocks of the Kalossia-Tiati area into two major groups; the Turkana Grit Series deposited before the outpouring of the Tertiary lavas and composed of fragments of Basement System gneisses, and the Tiati Grit Series deposited during or after volcanic times and containing material derived from volcanic rocks.

In the Lorugumu area Turkana Grits are exposed on the west bank of the Turkwel River about 16 miles south-east of Lorugumu and in the bend of a small river cutting three miles to the west of the Kabarat Hills north of Lorugumu. The Turkwel deposits which are composed of coarse grits and conglomerates cover an area of about five square miles and at their eastern edge form low bluffs above the plain of the river alluvium. To the west an accurate limit for the grits cannot be drawn as the quartz and gravel surface of the grit deposits passes imperceptibly into the sands and gravels of the Turkana Plain. It would thus seem that the Turkana Grits are older than end-Tertiary as they are bevelled by the end-Tertiary erosion level, and younger than sub-Miocene, as the general level of the deposits is between 2,000 and 2,200 feet, which is about 400 feet lower than the supposed sub-Miocene bevel in the Ngamatak Hills to the east. As has already been suggested it is probable that the Turkana Grits accumulated in hollows on an eroded or warped sub-Miocene surface, and are probably of Lower Miocene age.

The Kabarat deposits are not well exposed and are seen only in one exposure where about ten feet of felspathic grits with calcrete horizons are exposed in a small river gorge. Lack of further exposures is due to the area being blanketed by younger volcanic boulder beds.

The Turkana Grits appear to have been derived completely from Basement System rocks, and would thus agree with Mason and Gibson's definition of their lower group of sediments (1957, p. 18). A typical specimen, 18/566 from the Turkwel exposure, is a coarse conglomeratic grit mainly composed of quartz, microcline and sodic plagioclase in a carbonate cement. Accessory minerals include hornblende, epidote, garnet and augite. Occuring within the Turkana Grits on the Turkwel River there is a small circular patch of basalt which appears to be of intrusive origin.

### 3. Tertiary Volcanic Rocks

The volcanic rocks which outcrop over about 450 square miles in the northern and north-western parts of the Loiya-Lorugumu area, and exceed 5,000 feet in thickness, can be subdivided into four main groups as follows:—

Puch Prasir Rhyolites.
Andesites.
Muruasigar Rhyolites.
Olivine Basalts.

The olivine basalt group is composed almost entirely of olivine basalts with subsidiary trachytes and trachyandesites, whereas trachytes and phonolites are numerous in the andesite group.

There is no direct evidence of the ages of the volcanic rocks within the present area. Walsh and Dodson (1969) show the Tertiary succession in the Northern Turkana area, immediately north of the present area, to be as follows:—

Rhyolites with intercalated andesites.
Phonolites.
Olivine basalts.
Augite and analcime basalts.
Turkana Grits.

An angular unconformity divides the lower basalts and the overlying olivine basalts. Fossil evidence from intercalated sediments suggests a Middle or Upper Miocene age for the lower basalt group at Lothidok, 20 miles north-east of the Lorugumu area, and therefore the olivine basalts are probably of late Miocene age.

The upper limit of age of the volcanics is less certain. The upper members of the sequence are dissected by numerous deep valleys which were probably produced during the end-Tertiary (mid-Pliocene) erosion cycle. No lavas flowed down these valleys and all the volcanic rocks must have been erupted prior to the mid-Pliocene.

The only significant break in the various groups in the present area is between the olivine basalts and the Muruasigar rhyolites. The latter rest on an eroded surface of olivine basalt and locally overstep the basalt on to Precambrian rocks.

### 1. Olivine Basalts

These flows are well developed in the lower part of the Loleka Escarpment and below the Kapel Dome, extending westwards to outcrop in the valleys running north from the Operto River before dying out against the higher level of the Basement System in the Kadoupokimak River. East of Loleka the outcrop is less continuous but is strongly developed on the eastern side of Kalolokwel and in the lower part of the southern end of the Muruasigar range.

Thin isolated patches of the olivine basalts are found still farther east and as far south as the Munyen River. South-east of the Kapel Dome the base of the volcanics rests on Basement System gneisses at a height of 2,500 feet, rising to 3,500 feet at the Kadoupokimak River. Farther east the surface on which much of the basalt was laid down was uneven as shown by the irregular distribution of the basalt and thin outcrops through which inselbergs of Basement System rise.

The maximum thickness of the olivine basalt group is 600 ft. at the Kapel Dome and the Loleka Escarpment. Farther east, on the eastern side of Kalolokwel, the basalts are 500 feet thick but the western side of the hill is entirely composed of Muruasigar rhyolites which extend down to the same level as the basalts in the Loleka Escarpment across the valley. As Kalolokwel was probably one of the volcanoes from which the rhyolites were extruded it would appear that the rhyolites masked the discontinuous outcrops of the basalts. There is no indication of fracture lines and this discontinuous surface apears to have been produced by erosion rather than by faulting. Across the valley to the east of Kalolokwel the Muruasigar rhyolites not only cap the olivine basalt group but also outcrop below them at the base of Muruasigar and it appears that here too, some of the rhyolites flowed down over an eroded slope of basalt and later erosion exposed the present outcrops of basalt.

The rocks of the group are predominantly olivine basalts; olivine or relics of it are present to some degree in all specimens. Specimens 17/51 from the south bank of the Kosibirr River and 18/559 from the hills five and a half miles south-west of Moruangiliop contain numerous olivine crystals which are only slightly altered. Both are dark, fine grained rocks with microphenocrysts of olivine and pyroxene. Under the microscope the olivine microphenocrysts are seen to be relatively fresh, with green serpentine along cracks and some patches of serpentine representing completely altered olivine. The pyroxene is titanaugite which is accompanied in 18/559 by some brown amphibole, and there is one phenocryst of magnetite in 17/51. Labradorite laths, which are the most abundant constituent of the groundmass, are accompanied by grains of serpentinized olivine and titanaugite, and magnetite and apatite are accessory. An example of less mafic basalt is 17/92, from three and a half miles north-north-west of the Kapel Dome, in which olivine and pyroxene are less well developed and there are microphenocrysts of labradorite. Trachyandesites are of minor importance in the group and are only found locally in the upper part of the sequence. They outcrop in the upper part of the Loleka Escarpment but are probably best developed in the southern part of the Muruasigar range from which specimen 18/547 was collected. It is a fine-grained grey rock with numerous phenocrysts of pink andesine felspar. Andesine laths make up the greater part of the groundmass together with a little

orthoclase and analcite. The ferromagnesian minerals, olivine and titanaugite are both largely altered and magnetite is abundant; some patches of a reddish-brown mineral are probably cossyrite. A few biotite flakes in the slide appear to be secondary, as are small patches of yellowish zeolites.

A trachyte, specimen 17/102, outcrops in the upper part of the basaltic sequence in the Apeimukat Hills to the east of the Kadoupokimak River, but appears to be thin and of local significance only. It is a greyish-brown, medium-grained rock with small microphenocrysts of anorthoclase. The matrix consists largely of laths of anorthoclase whose orientation imparts a trachytic texture to the rock. Small anhedra of nepheline are intersertal to the felspar. There are some small patches of aegirine-augite which are subordinate to both cossyrite and kataphorite. Magnetite is accessory and calcite secondary.

A phonolite (18/549) found among the basalts at the southern end of Muruasigar, due west of Moruangiliop, is indistinguishable in the field from the basalts since it is dark and fine-grained with occasional microphenocrysts of mafic minerals. In thin section however the microphenocrysts are seen to be of altered biotite with reaction rims of iron ore against the matrix. The most abundant mineral in the matrix is oligoclase in laths with much interstitial analcite. The chief ferromagnesian minerals are green aegirine-augite with kataphorite and some cossyrite, while magnetite is accessory.

In places secondary minerals are thickly scattered over the surface of the olivine basalts. These minerals, which presumably weathered out of amygdales, are especially abundant at the southern end of the Muruasigar range and on the low hills south of the Kosibirr River. Specimen 17/44 from the latter locality consists of radiating natrolite fibres and octagonal analcite crystals with red iron staining.

### 2. Muruasigar Rhyolites

As indicated above, the eastern part of these rocks flowed out on an uneven surface and so their outcrop is irregular. In the Loleka Escarpment and farther west however, they were poured out on a flat surface which is now tilted gently to the west and broken by faults. The faults cause the olivine basalt group to reappear to the west of Loleka where it is overlain by the rhyolites, which themselves are succeeded by the andesite group. The outcrop thins gradually to the west and dies out and it is overlapped towards the west by the andesite group. The upper part of the Loleka Escarpment consists of precipitous cliffs of rhyolite, 300 feet high, which can be climbed only with difficulty at isolated points and so the main routes to the top are through narrow deep gorges cut by rivers. The gorges are so shielded from the sun that they often contain permanent pools of water. Similar but lower cliffs of rhyolite cap Muru Ngiriderin to the west of the Kapel Dome.

The picture in the east is much more complicated, for although the rhyolites capping Kalolokwel and Muruasigar are similar to those of Loleka and link up with them farther north, other flows as mentioned previously descend into shallow valleys eroded in the olivine basalt group. In addition the hill of Moruangiliop, like Kalolokwel, is thought to be a volcano from which the rhyolites were erupted. Finally there are numerous sheets of rhyolites forming low escarpments above plains to the east of Kalolokwel and surrounding Moruangiliop. These sheets are formed of boulders of rhyolite with very little solid rock, in contrast to the massive outcrops of the main occurrences. They are distinguished from true boulder beds, which contain various rock-types of different sizes, by being formed only of rhyolite boulders about a foot in diameter. These rhyolites rest on Precambrian rocks, having overlapped the olivine basalts.

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Petrologically all the Muruasigar rhyolite flows are similar, in spite of their different forms of outcrop. Rhyolite tuffs can be recognized by their angular fragments and their greenish colour, in contrast to the red or purple flows. Typical examples of the latter are specimens 17/90 and 18/552 from Muru Ngiriderin and Moruangiliop respectively. In hand specimen the two rocks are somewhat different, 17/90 being reddish-purple with numerous phenocrysts of felspar and streaks and patches of non-crystalline dark material while 18/552 is dark red and finer grained, with fewer microphenocrysts of felspar and numerous vesicles partly filled with zeolites. The thin sections of both rocks are similar except for the proportion of phenocrysts and the zeolites in 18/552 which appear to be analcite and fibrous natrolite, but in some amygdales the crystals are heavily stained by limonite. The anhedral felspar phenocrysts prove to be sodic sanidine with a 2V between that of ordinary sanidine and anorthoclase while the dark patches are aggregates of an altered mineral thought by Campbell Smith (1938, p. 516) to be riebeckite on account of its mossy habit. Small flakes of it are also scattered among the groundmass in which felspar laths, sodic sanidine like the phenocrysts, are the most abundant mineral and some quartz is interstitial to the felspar. Magnetite is accessory. Specimen 17/54 from two and a half miles north of Nakodi, which is an example of the rhyolites outcropping on the Turkana Plain, is essentially similar to the rocks of the main outcrops except that it contains some rounded quartz phenocrysts and one crystal of unaltered riebeckite.

The agglomeratic varieties are formed by large boulders of rhyolite in a similar but finer-grained matrix and so are only distinguishable from ordinary rhyolites in the field. Specimen 18/551 from one of the boulders in the agglomeratic rhyolites of Moruangiliop is somewhat coarser and more porphyritic than the normal rhyolite. In addition to felspar, quartz and amphibole are represented among the phenocrysts which are set in a fine purplish-grey matrix. Under the microscope the felspar phenocrysts prove to be sodic sanidine and the amphibole altered riebeckite. The groundmass is largely composed of sodic sanidine with a little interstitial quartz, some altered riebeckite and accessory magnetite.

Typical rhyolitic tuffs are represented by 17/89 from Muru Ngiriderin which is an olive-green, fine-grained rock containing numerous phenocrysts of altered felspar and quartz together with darker patches of non-crystalline material. A certain amount of flattening was observed and the lower part of the specimen is coarser-grained than the top. In thin section the phenocrysts are seen to be angular quartz and sanidine but the dark fragments are of more basic rocks with aegirine-augite and plagioclase. The greater part of the groundmass is formed of felspar, quartz and altered riebeckite and is similar to that of a normal rhyolite but there are many glassy patches, often with flattened shards. Magnetite is accessory. Specimen 18/550 from the southern end of Muruasigar is a more unusual type of tuff. It is pale buff in colour with a very fine-grained matrix in which are set pale green microphenocrysts. Under the microscope a few microphenocrysts of quartz were seen in addition to those of altered felspar which are probably sanidine. They are set in a matrix consisting of more altered felspar, a little quartz and altered amphibole.

The origin and mode of emplacement of the rhyolites present some difficulties since it is difficult to reconcile the high viscosity of a rhyolite magma with the wide extent, thickness and constant character of the rhyolites in the Loiya-Lorugumu area. It is thought that Kalolokwel and Moruangiliop represent volcanoes from which the rhyolites were extruded, so accounting for the greater thickness and often agglomeratic character of the rocks in these localities.

The non-agglomeratic rhyolites could have been produced by lava flows which on account of their high viscosity (*see* Birch, Schairer and Spicer, 1942 p. 135) would be thick and of limited area and so be well able to build these steep hills.

The theory that Kalolokwel and Moruangiliop were built by lavas from ancient volcanoes however, explains the occurrence of only a small part of the rhyolite outcrop. Undoubted tuffs form only thin bands interbedded with what appear to be lavas and so constitute a very small proportion of the total volume of the outcrop. It would appear that both the main flat-lying outcrops in the west and the eastern irregular outcrops on the Turkana Plain could most easily be explained as being emplaced by *nuées ardentes* which have since been welded to form ignimbrites. Points in favour of this theory are that the viscosity of a rhyolitic melt would be too high to explain the wide spread of the rhyolite outcrop which is very uniform throughout its considerable thickness. The *nuées ardentes* could have originated from Moruangiliop, Kalolokwel and other similar vents farther north to explain the general westerly dip of the western rhyolites. The eastern, low-lying rhyolites dip more gently towards the south-east away from the same two hills. The *nuées ardentes* are believed from observations in the Valley of Ten Thousand Smokes, Alaska, by Fenner (1923) and in Martinique by Perret (1935) to consist of intensely hot, discrete fragments of viscous magma, each fragment rapidly and continuously emitting gases. The dense extremely hot gases cushion the fragments so that the cloud can move extremely rapidly down a gentle slope under gravity because there is no friction between the gas-enveloped particles. The flow can surmount the smaller obstacles in its paths and has a flat top, which is typical of most of the Muruasigar rhyolites except for the valley flows at the southern end of Muruasigar itself.

Against the emplacement of the rhyolites by *nuées ardentes* is the fact that welding is not common in the relatively few specimens collected during a reconnaissance survey. Little however is known about the conditions under which welding of a tuff takes place. Gilbert (1938, p. 1855) thinks that the weight of the overlying deposits is the main controlling factor because the degree of welding in the Bishop Tuff of eastern California decreases upwards so that the top layer of this continuous formation is an unconsolidated tuff. He also believes that the viscosity of the fragments, controlled by the temperature, is very important and so, if the temperature of emplacement of the Muruasigar rhyolite was lower than that of the Bishop Tuff, a lower degree of welding could be expected. The lowering of temperature would be most easily caused by the escape of gases but the Muruasigar rhyolites are only vesicular in parts. On the whole it is thought more likely that the Muruasigar rhyolites are ignimbrites emplaced as *nuées ardentes* rather than lava flows.

### 3. Andesites

The andesite group is composed of a series of intermediate, melanocratic, mainly porphyritic lavas which, where the full volcanic sequence is well represented, lie between the Muruasigar rhyolites and the younger Puch Prasir rhyolites. The group consists mainly of porphyritic andesites but phonolites are also present in the region of the Tarach and Kaimo rivers. Trachytes, although not found near the base of the sequence, become more important near the top and in some places directly underlie the Puch Prasir rhyolites.

The lavas are exposed in a broad semi-circular arc round the base of the Puch Prasir scarp and extend from just west of Kalolokwel in the east to as far as the Kaimo River in the west. They usually give rise to a barren, rocky, undulating belt of country in which the steep-sided hills and ridges may be flat topped due to the horizontal or near horizontal nature of the variable lavas. In places however, as on Moru Angkadelio, the lavas have a marked easterly dip. Near the western edge of the Loiya area lavas of this group form numerous outliers on the Basement System and in the case of the outliers west of the Kaimo River have probably preserved the sub-Miocene bevel on the tops of some small hills. The thickness of the andesites is fairly uniform, being about 800 feet at Kalolokwel, 700 feet at Moru Ngiriderin and about 900 feet on Moru

Angkadelio. Generally the base of the lavas shows no great undulations although a variation was measured from about 3,300 feet at Moru Ngiriderin to 3,600 feet at Kalolokwel and west of the Kaimo River.

Accurate demarcation of the andesite group is only possible where the Puch Prasir rhyolites and the Muruasigar rhyolites are exposed, as is the case between Moru Ngiriderin and Kalolokwel. West of Moru Ngiriderin the Muruasigar rhyolite is generally missing and the true base of the andesite group in many places is not perfectly known, especially near Apeimukat where the andesite appears to overstep the olivine basalt. The distinction between the lavas of the andesite group and the olivine basalt group is not apparent in the field and was only made from thin sections. It seems likely that all the melanocratic lavas in the Tarach River region belong to the andesite group while the lower basalts and rhyolites are missing. The most common lavas in the andesite group are porphyritic pyroxene andesites and porphyritic felspar andesites. Non-porphyritic andesites also occur. Phonolites are not common and only occur in narrow bands too small to be shown at the scale of the map. Trachytes however, although seldom thick, tend to be fairly extensive, due to the fact that they often form cappings to certain flat-topped hills south of Tarona.

The porphyritic pyroxene andesites are melanocratic fine-grained rocks of basaltic appearance containing conspicuous phenocrysts of idiomorphic dark green or black augite. The phenocrysts vary in size up to about 15mm. Specimen 17/112 from Moru Abwal west of Urum is a highly porphyritic variety with phenocrysts forming about 30 per cent of the rock. In section this specimen contains colourless to pale brown generally idiomorphic phenocrysts of augite which are seriate down to the groundmass from a maximum length of about 6mm. Some of the phenocrysts are rather corroded, with narrow reaction rims, while others show slight alteration to chlorite. The augite phenocrysts in specimens 17/73 and 17/88A from west of Kalolokwel seldom exceed 2mm. in length. They are usually pale green or pale yellow, the yellow varieties showing pleochroism to grey or light brown. Simple twinning of some of the phenocrysts as well as zoning is fairly common.

Phenocrysts of brown basaltic hornblende (lamprobolite) although not apparent in hand specimen are quite distinctive in some thin sections and may be as large as the augite phenocrysts in the same slide. The hornblende clearly shows that it is not in equilibrium with its parent magma, and exhibits all degrees of magmatic corrosion. In specimen 17/88 from west of Kalolokwel the hornblende phenocrysts, up to 2mm. in length, are strongly pleochroic from light to dark brown and their corroded margins are bounded by narrow reaction rims formed by dense zones of small colourless pyroxene crystals, numerous minute granules of iron ore and greenish alteration products. Some of the hornblende phenocrysts, as in 17/73, have been completely replaced, being now represented by rounded patches of alteration products which usually have a dense outer rim of magnetite octahedra surrounding an inner zone where hornblende may be visible but which is more usually composed of colourless augite, pale green chlorite, hydrated iron ores and occasional zeolitic infillings.

In most examples the groundmass of the porphyritic pyroxene andesites is very fine-grained, and often isotropic. The essential minerals of the groundmass are oligoclase felspar and colourless or brownish augite. Due to the smallness of crystal size and lack of distinctive twinning the felspar is often difficult to determine, but refractive index determinations suggest that in all cases it is oligoclase. Augite is not very abundant in the groundmass and usually occurs as small laths or granules, usually colourless, sometimes light brown or pale green with the brown varieties showing faint pleochroism. Iron ore is extremely abundant, being particularly dense where replacement of brown hornblende has taken place. Some of the large plates of magnetite present may be primary although in specimen 17/73 some seem to be replacements of original ferromagnesian minerals. The high Shand colour index of the andesites is probably due to

the abundance of iron ore. Apart from iron ore the most conspicuous accessory mineral is apatite which occurs as large euhedral crystals in specimen 17/88A. Secondary minerals in the pyroxene andesites include pale green chlorite which is occasionally fibrous, calcium carbonate as a weathering product, and zeolitic infillings, which in specimen 17/112 include analcite and fibrous natrolite.

The porphyritic felspar andesites like the porphyritic pyroxene andesites are again very fine-grained melanocratic rocks but are characterized by a fissility caused by the parallel banding of large platy felspars at fairly regular intervals throughout the rock. Due to this banding these andesites, even under arid conditions, tend to split very readily and break into small fragments. Specimen 17/77 from the Kapel Dome contains phenocrysts of felspar, augite, serpentine and iron ore. The felspar phenocrysts, which are up to 8 mm. in length, display either complex twinning or finely developed zoning. Particularly in the case of the zoned crystals the felspar phenocrysts are highly corroded, and would not appear to be in equilibrium with the base. The felspar phenocrysts are andesine, and where zoning is developed the outer zones are of oligoclase composition. A few small phenocrysts of augite display slight marginal corrosion. One euhedral phenocryst of serpentine in the slide appears to be a pseudomorph after olivine, and several large plates of magnetite appear also to be pseudomorphs after original ferromagnesian minerals.

The groundmass of the rock is very fine-grained and consists mainly of small plagioclase laths arranged in sub-parallel orientation. This plagioclase, like that of the augite andesites, is oligoclase. Biotite is the principal ferromagnesian mineral in the groundmass, occurring as small flakes closely associated with pale green serpentine. Both the biotite and the serpentine probably represent replacements of original pyroxene or olivine. Small granules of iron ore are abundant in the groundmass, and secondary calcite is also present as a product of weathering.

Specimen 17/68 from Loleka is a non-porphyritic olivine-bearing lava and for this reason the rock might be regarded as a basalt, although the plagioclase present is in the andesine range. Apart from subhedral altered olivine and laths of andesine, which are up 1 mm. in length, the rock is composed of poikilitic augite and euhedral iron ore in a brown glassy base.

Two occurrences of phonolite were recorded within the andesite group: one is on the western slope of Moru Angkadelio and the other on the eastern side of the Tarach River at the northern edge of the area just east of an exposure of down-faulted rhyolite. Specimen 17/111 from near the Tarach River is a very fine-grained, nearly glassy, black phonolite with numerous euhedral phenocrysts of nepheline. These phenocrysts, which measure up to 8 mm. in rectangular sections, are associated with smaller, less common phenocrysts of black pyroxene. In section the nepheline phenocrysts show considerable alteration to calcite, zeolites and possible gieseckite. The pyroxene phenocrysts are euhedral and subhedral augite, pleochroic from yellowish or greenish grey to purplish grey. Dense reaction rims round the augite phenocrysts consists of aegirine-augite and iron ore. The groundmass of this rock is largely composed of faintly pleochroic green aegirine-augite, iron ore, slender laths and pools of alkali felspar, probably anorthoclase, and euhedral nepheline, while secondary alteration products are mostly carbonate after nepheline. Specimen 17/115 from Moru Angkadelio is a porphyritic phonolite containing short prismatic phenocrysts of anorthoclase up to 10 mm. in length in a very finely crystalline groundmass. The felspar phenocrysts are colourless to pale green, glassy crystals which in thin section show alteration cracks, usually parallel to the cleavage, and containing calcite. Euhedral microphenocrysts of apatite are fairly common. The groundmass is micro-crystalline and almost isotropic due to the absence of felspar and the abundance of analcite. Much of the analcite occurs in cubic or hexagonal crystals which appear to be pseudomorphs after nepheline. Green aegirine-augite is abundant in the groundmass, occurring as fibrous crystals in small radial felted patches. Iron ore is not common.

Trachytes and trachyandesites occur within the andesite group, fairly high up in the series, being best exposed to the south and south-west of Tarona where they cap flat-topped hills and form minor scarp features on the sides of other hills. In places they are exposed at the base of the Puch Prasir rhyolites with no intervening andesites.

Most of the trachytes are greyish in colour and extremely fine-grained, with only a few phenocrysts of felspar and rarer smaller phenocrysts of sodic amphiboles. A typical specimen, 17/118 from south of Tarona, is a platy, grey soda-trachyte or trachyandesite with scattered small phenocrysts of felspar up to 3 mm. in length in a very fine-grained groundmass which has irregular black patches of soda amphiboles. The phenocrysts are subhedral in shape apart from some crystals which are highly corroded and have rounded or elongate oval forms surrounded by an irregular felspathic fringe. Some of the phenocrysts have fine multiple twinning and would seem to be oligoclase, but many others which are devoid of twinning have low axial angles and are probably anorthoclase. The groundmass of this rock is of extremely fine grain and is composed mainly of anorthoclase, though a little oligoclase may also be present. Scattered through the groundmass are small crystals of a soda-amphibole related to kataphorite which are trichroic from nearly colourless through pale green to brownish green. Associated with the kataphorite in melanocratic patches throughout the rock are clusters of dark brown to black crystals of cossyrite. Greenish or yellow alteration products are common in the groundmass but apart from a few large microphenocrysts iron ore is rare.

Related to the trachytes and trachyandesites, although not so common, are a set of leucocratic lavas which are probably best described as leuco-andesites. These lavas (specimen 17/75) have been recorded from only one locality, a hill top north-west of Loleka. They differ essentially from the trachytic rocks in that, although much of the groundmass felspar lacks distinctive twinning, there are numerous laths of oligoclase with multiple twinning. Some of the untwinned felspar may be anorthoclase but this cannot be proved due to the very small crystal size. As with the trachytic rocks the felspar phenocrysts are of two types: finely twinned phenocrysts of oligoclase and untwinned phenocrysts of probable anorthoclase. Iron ore is common in this rock; much of it is granular and probably secondary after original mafic minerals.

### 4. Puch Prasir Rhyolites

The volcanic country in the north-west corner of the Loiya-Lorugumu area is dominated by the Puch Prasir Plateau, a high area of vigorous relief composed of rhyolitic rocks. The plateau, which in the present area rises to over 5,800 ft. at Cheptakenya and over 6,000 ft. in places on the eastern edge, occupies a semi-circular area of some 50 square miles and is bounded to the east and south by precipitous cliffs. These cliffs rise steeply or vertically for over 1,000 feet from an altitude of about 4,400 ft. west of Kalolokwel and east of Tarona. Along the western edge, which has been more deeply indented by rivers flowing west and north-west to the main Tarach River, the cliffs give way to more gentle slopes.

The Puch Prasir Plateau is formed almost entirely of rhyolitic rocks, including lavas, tuffs and agglomerates, with only minor quantities of other rocks such as trachytes. Generally the margins of the plateau mark the limit of the rhyolitic rocks although in several localities, particularly north-west of Loleka, rhyolites extend away from the boundary cliffs of the plateau for distances of up to two miles. These lower rhyolitic rocks have rather different characteristics to the rhyolitic rocks of the plateau.

The base of the Puch Prasir rhyolites nearly everywhere overlies the andesite group, the contact being at 4,400 ft. west of Kalolokwel, 4,200 ft. south of Tarona and 3,800 ft. along the western margin, but at one point on the eastern side of the plateau they overlap the andesite group and rest on the Muruasigar rhyolites. Particularly near

Tarona, thin trachyte horizons occur locally between the andesites and rhyolites. This sequence of rhyolites on andesites is similar to the geological setting of the Bishop Tuff described by Gilbert (1938, p. 1831). Small outliers of the main rhyolitic mass occur south of Tarona and in the region of Urum on the Tarach River. Structurally the most distinctive feature of the rhyolite plateau is the occurrence of vertical columnar jointing which is best displayed in the vertical cliffs at the southern end of the Puch Prasir Plateau. The columnar structure seems to suggest that the Puch Prasir Plateau was built up by a single volcanic outburst and that the observed horizontal layering or banding is not caused by repetitions of volcanic activity.

Uniform rhyolite lava is well developed only in the basalt zone around the foot of the main Puch Prasir Escarpment north-west of Loleka. In this region the fine-grained, cream-coloured rhyolites, which weather to a rich red brown, form a gently sloping fringe between the vertical cliffs of the plateau above and the undulating hilly country formed by the andesites below. Just at the base of the cliffs the rhyolites occasionally form small flat areas strewn with boulders. The exact origin of these rhyolite lavas is not known as they often differ considerably from the columnar jointed cliffs which are partly agglomeratic. It is possible that they represent small flows of rhyolite squeezed out from the base of the plateau.

Trachytes associated with the Puch Prasir rhyolites are never very abundant and only occur in small exposures or on the tops of certain hills overlying rhyolitic rocks. These trachytes differ considerably from the trachyte found within the andesite group in that they are usually porphyritic and of much coarser grain. The phenocrysts, which are of anorthoclase and reach a length of 8 mm., occur as euhedral and subhedral crystals and occasionally in clusters. Carlsbad twinning is common and some crystals show very fine scale multiple twinning. Axial angles are moderate, usually being about 40 degrees. Replacement textures occur in some crystals. The groundmass consists mainly of small laths of potash felspar which impart a trachytic texture, and highly pleochroic green aegirine. Iron ore is usually abundant along with much secondary goethite and haematite.

Varieties of rhyolitic tuff are extremely common on the Puch Prasir Plateau, but perhaps the most distinctive are the pale yellow or cream friable tuffs which are exposed in two areas, one about a mile west of Tarona and the other about five miles west of Cheptakenya. In both these areas the tuffs are fairly uniform in nature and have sharp boundaries against the harder and darker rhyolitic rocks forming the rest of the plateau. The more southerly deposit is exposed on a low-lying plain of about two square miles in area, bordered by steeply rising hills. The deposit farther north has a similar physical and geological setting, except that some rivers have exposed fairly deep sections. In hand specimen these tuffs are soft and pale yellow in colour and contain rare small crystals and irregular shaped patches of pumice-like material which only show slight flattening. Thin sections reveal that the tuffs are largely composed of dust-like material which is almost certainly glass and patches up to a millimeter in length of glass shards or vitreous pumice. Crystals of sanidine, highly irregular in shape, are scattered throughout the rock. No microlites are seen.

A more common variety of tuff is illustrated by specimen 17/106 from Urum. This specimen is a hard, dark red brown tuff characterized by a crude type of banding caused by the parallelism of flattened pumice-like fragments. Crystals are again small and barely visible in hand specimen. Microscopically this tuff is quite distinct from the soft yellow tuffs in that the matrix of the rock is weakly birefringent instead of being completely isotropic. True vitreous pumice is largely absent and its place is taken by small crystalline patches composed of small circular rosettes of radiating crystal fibres with a pectolitic appearance. The crystalline material is too fine-grained to identify but is probably tridymite or sanidine. Some of the crystalline areas show distinct growths of crystals normal to the edge of the crystalline cavities. All of the larger crystals in the

tuff are again sanidine, usually with rather corroded margins. There seems little doubt that the Urum tuff has undergone a higher degree of compression and alteration by heat, causing devitrification and crystal growth, than the soft yellow tuffs. Colour variation between the two types of tuff is due to the varying intensity of iron staining.

An even more advanced example of flattening and devitrification with resultant crystallization is exhibited by specimen 17/113 collected from the Puch Prasir Escarpment south-west of Tarona. This tuff, which is a hard, compact, fine-grained green rock not far removed from a lava, shows an almost perfect parallelism of vitreous and crystalline layers and is probably best regarded as welded tuff. Small shining crystals of sanidine are much more numerous in this rock than in either of the two other varieties of tuff and are clearly visible in hand specimen. In section the parallelism and fishtailing of the vitreous and crystalline components are clearly seen and in most cases each component band is elongated by much more than ten times its width. The vitreous bands are not truly anisotropic and usually contain numerous minute crystal fragments. The subhedral sanidine crystals in the tuff occur more often in the vitreous bands where they show considerable elongation parallel to the banding. The crystalline layers, which may be up to 2 mm. thick, contain crystals of sanidine, quartz, riebeckite and possibly tridymite. The crystalline texture of the layers is similar to the Urum tuff, with a fringe of crystals which grow normal to the cavity sides bordering a wider central area where "pectolite" type texture predominates and crystals may reach a size of 0.05 mm. Generally the harder layer is formed by potash felspar, probably sanidine, but tridymite may also be present with riebeckite. The centres of the radial rosettes are probably of sanidine associated with riebeckite, highly pleochroic from green to dark greenish blue, and larger plates of quartz; tridymite may also be present.

North of the present area the Puch Prasir rhyolites extend into the Muruasigar range and Fuchs (1939, p. 243) has shown that the rhyolites can be traced as far north as Pelekech, a distance of about 90 miles. The rhyolites of Muruasigar cover an area of about 1,300 square miles and if the great thickness of rhyolite which is observed at the southern end of the Puch Prasir Plateau is maintained the total volume of material involved must amount to several hundred cubic miles.

The main problem concerned with the Puch Prasir and Muruasigar rhyolites is to account for the origin of such a huge mass of rhyolitic rocks building up a plateau-like area. The conclusion was reached that the plateau was formed by rhyolite lava flows with associated pyroclastic horizons, although individual lava flows were never recognized within the main mass and many thick sections are almost monolithic. Detailed work on specimens has shown however that fragmental rocks, mainly varieties of welded tuff, are extremely common and it seems likely that the Puch Prasir Plateau and Muruasigar are formed by ignimbrites similar in nature to the rhyolitic ignimbrite sheets in New Zealand. Cotton (1952, pp. 204-208) in reference to the plateau-building ignimbrite sheets of New Zealand describes one sheet with a volume of about 2,000 cubic miles which originally was described as a rhyolite plateau consisting of a lava flood or flows. A more detailed account of an ignimbrite sheet of similar nature from south-eastern California, the Bishop Tuff which covers an area of about 400 square miles and has an average thickness of about 500 feet, is given by Gilbert (1938, pp. 1829-1862). In most cases the origin of the ignimbrite sheets is attributed to volcanic eruptions of *nuée ardente* type.

## 4. Major Intrusions

### 1. Kapel Dome

The most important major intrusion in the Loiya-Lorugumu area is the plug of the Kapel Dome which rises to a height of nearly 4,000 ft. above the olivine basalts in which it was emplaced at the southern end of the Loleka Plateau. The original plug

stands up as a dome in the centre of an amphitheatre hollowed out in the basalts. On account of this erosion amphitheatre the dome appears on aerial photographs to be the central plug of a ring complex, but this impression is in fact given by fortuitous erosion of basalts dipping to the north-east and capped by patches of Muruasigar rhyolites. The dome is connected to the basalt plateau on its northern side by a low col reaching about half way up the height of the plug, of which 800 feet is exposed on the southern side of the dome. The width of the dome from east to west is 600 feet and from north to south 1,000 ft. and so it has a fang-like appearance when viewed from the south. This is accentuated by the fact that its sides taper gently inwards from the base before termination at a sharp peak.

The plug consists of two concentric parts, the dome itself which is a hornblende microgranodiorite and an outer ring of gabbro. The gabbro is no more resistant to erosion than the basalts and so does not produce any topographical feature. The basalts metamorphosed during its intrusion in fact stand above the gabbro in low ridges which mark the boundary of the intrusion. The gabbro is normally about 400 feet wide but on its south-western side attains a width of 1,000 feet, so that the central microgranodiorite plug is off centre in relation to the gabbro as seen in the present outcrops. The gabbro is presumably the older of the two components of the plug since it is the outer and more basic, but its contact with the microgranodiorite is obscured by fallen blocks from the latter. Only a few feet away from the presumed contact there is no sign of chilling or baking in either the gabbro or the microgranodiorite so it is thought that the intrusion of the microgranodiorite closely followed that of the gabbro, which had insufficient time to cool thoroughly. The contact of the gabbro with the olivine basalts on the other hand shows that the basalts have been baked for several feet and intruded by veins from the intrusion, while the chilled margin of the gabbro is finer grained than the main body.

Specimen 17/187 from the gabbro at the northern end of the Kapel Dome is a dark, grey green, coarse-grained rock formed of waxy felspar crystals with less abundant pyroxene. The thin section consists chiefly of large plates of labradorite which are euhedral towards the pyroxene, giving the rock an ophitic texture. The pyroxene is titanaugite, forming large grains which are serpentinized along cracks and smaller crystals which are more serpentinized, and patches of serpentine probably represent completely altered titanaugite. Some small crystals of orthoclase are interstitial to the plagioclase and there are rare plates of biotite. Magnetite is accessory, accompanied by a little apatite, while calcite is secondary.

The microgranodiorite which forms the dome itself (specimen 17/79 from the northern side of the plug) is a pale cream, medium-grained rock, chiefly composed of felspar with some quartz and ferromagnesian minerals which are mostly represented by a brownish alteration product. Fuchs (1939, p. 242) thinks it may be related to solvsbergites found elsewhere in Turkana but a plate of one of them shown by Campbell Smith (1938, pl. XLV, fig. 1) has an entirely different texture from that of the microgranite from the Kapel Dome. Under the microscope the subordinate quartz is clear in contrast to the partly altered felspar, which proves to be dominantly albite with a little orthoclase. A few crystals of green hornblende were observed, partly transformed to the brown alteration product which largely represents the ferromagnesian minerals and is probably mostly composed of haematite. Magnetite, ilmenite and apatite are accessory and calcite secondary.

An acid vein (17/80) cutting the metamorphosed basalts near their contact with the gabbro at the southern end of the intrusion is similar to the microgranodiorite but is darker and finer grained and its felspar is more altered. Some basaltic xenoliths are present in the hand specimen. The baked basalts in the same locality show no discernible changes from unaltered basalts in the field, but, under the microscope several

mineralogical changes were noticed in specimen 17/81. The labradorite microphenocrysts are cloudy on account of the separation of inclusions while the texture of the groundmass is more granulose than that of a normal basalt. The titanaugite has been partly broken down into pale green hornblende and biotite and magnetite, but the olivine crystals are unaffected.

Analyses of gabbro and microgranodiorite from Kapel Dome are as follows:

| | *Gabbro* | *Microgranodiorite* |
|---|---|---|
| | *Percentages* | |
| $SiO_2$ .. .. .. | 51·85 | 58·09 |
| $Al_2O_3$ .. .. | 19·80 | 16·06 |
| $Fe_2O_3$ .. .. | 3·29 | 6·42 |
| FeO .. .. .. | 5·05 | 0·89 |
| MgO .. .. | 2·00 | 0·35 |
| CaO .. .. .. | 8·15 | 3·43 |
| $Na_2O$.. .. .. | 5·00 | 6·00 |
| $K_2O$ .. .. .. | 1·26 | 3·96 |
| $H_2O$ .. .. .. | 0·20 | 1·16 |
| $CO_2$ .. .. .. | 0·42 | 1·46 |
| $TiO_2$ .. .. | 1·67 | 0·69 |
| $P_2O_5$ .. .. .. | 0·41 | 0·17 |
| MnO .. .. | 0·08 | 0·11 |
| TOTALS .. | 99·41 | 99·33 |

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Norms for the two rocks are shown in the table below:—

| | *Gabbro* | *Microgranodiorite* |
|---|---|---|
| Q .. .. .. | — | 4·99 |
| or .. .. .. | 7·23 | 23·35 |
| ab .. .. .. | 41·92 | 50·83 |
| an .. .. .. | 28·08 | 5·00 |
| di .. .. .. | 5·69 | 1·30 |
| hy .. .. .. | 6·17 | 0·28 |
| mt .. .. .. | 4·64 | 1·04 |
| he .. .. .. | — | 5·68 |
| il .. .. .. | 3·19 | 1·37 |
| ap .. .. .. | 1·01 | 0·40 |
| ca .. .. .. | 0·90 | 3·30 |

The norms reveal that the gabbro is slightly more leucocratic than average (Johanssen, 1937, p. 221, Table 78) confirming the impression given in hand specimen and thin section. The norm of the microgranodiorite illustrates the difficulty about its nomenclature. As it contains only five per cent quartz it lies at Johanssen's boundary between the granodiorites and quartz diorites or tonalites (Johanssen, 1932, p. 320 and p. 378) and below that given by Hatch, Wells and Wells (1949, p. 196 and p. 260). Nevertheless it is regarded as a microgranodiorite rather than a tonalite because of the albitic composition of the plagioclase and the low proportion of mafic minerals.

### 2. MORUANGORO

The rounded hill of Moruangoro and the small hill to the south of it are formed by an intrusive mass of dolerite which cuts through the lower basalts east of the Loleka scarp about four miles north-east of the Kapel Dome. The intrusion is about one and

a half miles long and just over half a mile wide: Moruangoro rises to a little above 3,300 ft., some 500 feet above the basalts below. Intrusive contacts round the base of the dolerite are masked by scree cover, but the boundary between the dolerite and the basalts is fairly well defined by a marked change in relief.

The dolerite is a fairly coarse-grained variety which throughout the intrusion displays no marked variations in texture or composition. Petrologically it consists of olivine, augite, plagioclase, biotite, iron ore and minor alteration products and accessory minerals. The olivine, which makes up about 25 per cent of the rock, occurs in euhedral and subhedral pale green crystals up to 2 mm. in length with rather rounded outlines due to slight corrosion at the margins, and alteration cracks filled by pale green antigorite. Augite is mainly in the form of faintly pleochroic pale brownish-purple plates which are often markedly ophitic or poikilitic. The plagioclase is labradorite. Biotite, which is the most unusual mineral in the dolerite, occurs in irregular plates strongly pleochroic from pale yellow to dark golden brown, usually associated with the olivine. Iron ore is abundant in the dolerite and other accessory minerals include rare apatite and a few patches of fibrous zeolite. In general the composition of the dolerite from Moruangoro agrees closely with the composition of the dolerites from the basic dykes described later and as a rule is much richer in olivine than the basic lavas that surround it.

## 5. Minor Intrusions

### 1. Acidic Dykes

The great majority of the acidic minor intrusions in the area cut the volcanic rocks or the Basement System in the immediate vicinity of the volcanics, where the latter have presumably been removed by erosion. These intrusions are sodic in character and so are probably genetically connected with the rhyolite eruptions. They occur as vertical or near-vertical dykes and their trend is usually north-south. The dykes, the longest of which is about a mile and a half long, and which average about 20 feet in width, often occur in groups of several parallel or sub-parallel members which, because of their superior resistance to erosion, rise above the country rock in low ridges.

A sodic microgranite from Loleka (17/72), representative of the most abundant variety, has a pale pink, fine-grained matrix in which paler phenocrysts of felspar are set. In thin section the felspar phenocrysts are seen to be sodic sanidine, laths of which form the greater part of the groundmass. A little quartz and albite are subordinate to the sanidine in the groundmass. The ferromagnesian minerals are represented by an opaque alteration product probably replacing riebeckite. Specimen 17/86, from a dyke which cuts andesites below the Puch Prasir Plateau, is similar to 17/72 but is somewhat more basic. It contains a higher proportion of felspar phenocrysts set in a matrix which is pinkish grey in colour. Under the microscope the phenocrysts prove to be sodic sanidine with a high 2V which, as laths, also forms the greater part of the groundmass. There is some oligoclase interstitial to the sanidine but quartz grains are rare. Some small flakes of riebeckite are seen but again the majority of the ferromagnesians are represented by opaque iron ores. There are a few flakes of biotite with magnetite and apatite is accessory. A dyke (17/103) which cuts the Basement System to the north of the Kadoupokimak River is coarser than the two preceding examples, and contains microphenocrysts of quartz and a ferromagnesian mineral set in a pink matrix. In thin section the ferromagnesian phenocrysts are seen to be altered amphibole but their habit is more compact than the typical mossy aggregates of riebeckite. They and the subhedral quartz grains are set in a matrix of orthoclase laths which are cloudy with alteration products. The matrix also contains some small crystals of quartz and altered amphibole while magnetite is accessory.

A different type of acidic dyke is represented by specimen 18/564, a potassic microgranite from the Ngamatak Hills. It is a pinkish, medium-grained rock composed of quartz, pink felspar and biotite flakes. As it is slightly foliated it may have been intruded into the Basement System before folding had ceased completely but it could only have been affected by the very last stages of folding because the foliation is paralled to the walls of the dyke and not to the foliation of the gneisses. Under the microscope the most abundant mineral is orthoclase which is cloudy through alteration in contrast to the clear quartz. A little albite present is hardly affected by alteration. The flakes of biotite, which are accompanied by a little muscovite, follow the foliation. Magnetite and apatite are rare as accessories.

## 2. Alkaline Dykes

Phonolitic and trachytic dykes are the most common of the minor intrusives in the area, being particularly well developed in the region east of the Kakep Pass near the Okobaa Hills and the Otopai Hills. These dykes, which are seldom more than 50 feet wide, in some cases can be traced for considerable distances, usually running in a north-north-westerly direction parallel to the general strike in the Basement System rocks. One of the dykes, which is first seen in the Okobaa Hills and disappears into the sandy plain north of the Otopai Hills, is over nine miles long, while a second dyke farther east, the southern part of which was first mapped by Walsh (1966) in the Karasuk area, is about 16 miles long. In most cases these dykes give prominent geographical features which are readily visible on aerial photographs. Smaller alkaline dykes have been mapped elsewhere in the area. With only one exception all the alkaline dykes examined were either phonolites or their coarser-grained equivalents nepheline microsyenites. The one exception is a small dyke of quartz-trachyte which occurs about five miles east of Ropetari.

The phonolites are fine-grained, non-porphyritic black rocks, usually with analcite-filled vesicles. Microphenocrysts can however be detected in most specimens, both anorthoclase and pale green augite, the latter often surrounded by a ragged fringe of aegirine-augite crystals. Nepheline is rarely found in the phonolites, but is represented by six- and four-sided crystals of analcite which have replaced it. Analcite is also common as interstitial material between the bladed felspar in the groundmass or as cavity infillings. Groundmass felspar in the phonolites is anorthoclase in lath-like crystals which may often be arranged in radial texture. Aegirine-augite is always the most abundant of the sodic pyroxenes and it, together with less common aegirine, may be partly intergrown with or overgrown by brown pleochroic acmite. The most common sodic amphiboles in the phonolites are chestnut brown cossyrite, which is rarely pleochroic and often nearly opaque, and kataphorite which is pleochroic from pale yellow or brown to dark greenish brown. One of the most distinctive features of the soda pyroxene and amphiboles is their textural arrangement which may be radial or follow a herring-bone pattern.

The nepheline microsyenites are similar in composition to the phonolites and represent the coarse-grained parts of dykes which are dominantly phonolitic. Specimen 18/532 from the more easterly of the two large dykes east of the Kakep Pass is a phanerocrystalline nepheline microsyenite of speckled appearance in which the mineral constituents rarely exceed 1.5 mm. Texturally the microsyenites differ considerably from the phonolites but mineralogically they are very similar. The radial and herring-bone texture of the phonolites is not present but is replaced by a crude trachytic texture in which the sub-parallel laths of felspar are paralleled by the mafic minerals which may occupy wedge-shaped interspaces between the felspar crystals. Nepheline is present in the microsyenites as subhedral, rather corroded crystals but analcite is much more common, often forming interstitial fillings between the anorthoclase crystals in the groundmass. The sodic pyroxenes and amphiboles are the same as those of the phonolites, with

aegirine-augite in euhedral and subhedral bright green, faintly pleochroic crystals which often have a marginal rim of darker green aegirine, causing the crystals to have a cored appearance.

The small dyke about five miles east of Ropetari is composed of non-porphyritic, fine-grained, grey quartz-trachyte. It is characterized in thin section by containing two to three per cent of subhedral quartz in poorly developed six-sided crystals which appear as clear glassy patches among the more dusty felspar laths. The groundmass is composed mainly of potash felspar crystals varying in length from about 0.5 to 1.0 mm. in sub-parallel orientation. Wedge-shaped spaces between the felspars are filled by aegirine showing strong pleochroism from pale yellowish green to dark green. Aegirine also occurs in the groundmass as small euhedral crystals, in most cases with a pronounced overgrowth of dark red translucent haematite. Nepheline is not present and the little analcite that can be observed is probably secondary. Secondary calcite is also present.

### 3. Basic Dykes

The basic dykes, like the alkaline dykes, are found only as intrusions in the Basement System rocks and never in the volcanics. They are however, smaller and much more limited in extent than the alkaline dykes; the largest is only about a mile long. All of the basic dykes examined are doleritic in composition, although the finer-grained varieties might be regarded as basalts.

Specimen 18/555 from a small dyke near the Kabarat Hills is a typical blue-black dolerite composed of purplish faintly pleochroic titanaugite, labradorite felspar, subhedral to euhedral olivine and a fairly high proportion of euhedral magnetite. A rather more unusual type of dolerite was recorded from a dyke exposed over a distance of about a mile a few miles north of Kirikinie. This dolerite (specimen 17/34) is a fairly coarse-grained rock in which the olivine, where not completely replaced, is considerably corroded and contains numerous cracks filled with serpentine. Surrounding the olivine there is usually a broad rim of pale green faintly pleochroic fibrous antigorite which often has a microvermicular texture. The antigorite in some of the coronas appears much darker in colour due to a peppering of black iron ore. Sometimes the antigorite is separated from the olivine by a narrow inner zone of colourless orthopyroxene, probably hypersthene. Where the olivine has been completely replaced the orthopyroxene is absent and the outer corona of antigorite surrounds an inner core of black iron ore and bright green pleonaste spinel. Pale brown strongly pleochroic hornblende is also present in the rock, and as this commonly contains inclusions of antigorite, iron ore and pleonaste it may also be a replacement after olivine. The labradorite felspar is well twinned and displays a poikilitic relationship with anhedral dusty augite.

An example of one of the finer-grained dykes of basaltic type is provided by specimen 17/46 from Tukum. This dyke is of porphyritic olivine basalt in which euhedral and subhedral phenocrysts of olivine up to 1.5 mm. in length are seriate to the groundmass and form about ten per cent of the rock whose groundmass is composed of minute crystals of iron ore, colourless augite and plagioclase.

The mode of occurrence of some of the minor intrusions is uncertain and this is particularly true of a very small circular patch of basalt which occurs among the Turkana Grits south-east of Lorugumu near the Turkwel River. Due to poor exposure no evidence was found to indicate whether the basalt represents a small intrusive plug or is the remnant of a basalt sheet. As the nearest exposure of basalt is about 12 miles away it has been assumed that this outcrop represents a small intrusion.

### 4. Intrusions of Unknown Origin

The most peculiar set of intrusive rocks in the Loiya-Lorugumu area are a group of biotite-rich rocks which have proved difficult to classify due to the fact that they have probably suffered some degree of metamorphic alteration. In all cases rocks of this group are found as intrusions in the Basement System and always display deformation textures due to mechanical metamorphism, although chemical alteration may also have taken place. Where exposures are good and contacts are visible these intrusions have always proved to take the form of small sill-like bodies which are rarely more than a few feet thick. Typically they strike parallel to the normal regional trend and appear as melanocratic bands or discontinuous knots or swellings in the lighter coloured gneisses, as in the Lakuakoma Hills.

Specimen 17/45 from Tukum is a crudely foliated rock with an abundance of black biotite, green pyroxene and knots of white felspar. The biotite is strongly pleochroic from nearly colourless to light brown, while the pyroxene is colourless augite. Optical determination of the plagioclase indicates that it is an acidic oligoclase, very similar to the plagioclase occurring in many of the Basement System gneisses, which suggests that the felspar of the intrusions may be original but could have undergone albitization. Textural relationships between the mineral components of this specimen are not easily observed due to the friable nature of the rock and the consequent difficulty in preparing good thin sections. Replacement textures do not appear to be present and the augite is only slightly altered. It is possible that the biotite may have formed at the expense of augite. Intrusions similar to the Tukum occurrence are very common on the Lakuakoma Hills.

Another series of biotite-rich intrusions are frequently exposed in a zone a few miles east of Ropetari and these are probably of similar origin to those already described. They differ considerably however, in that augite is absent and biotite is much more abundant, often reaching as much as 90 per cent of the rock. Other minerals occurring in these intrusions are potash felspar, quartz and apatite. The increased percentage of biotite to the exclusion of augite in these rocks is suggestive of replacement of the augite by biotite. The origin of the biotite-rich intrusions must remain rather doubtful but they may be related to the meladiorites or possibly to some of the lamprophyres such as augite-kersantite.

## 6. Recent Deposits

Superficial deposits are mainly confined to the end-Tertiary surface of the Turkana Plain since most of the hills, whether formed by lava or rocks of the Basement System, are largely devoid of soil cover. Typically the end-Tertiary surface is either covered by light brown to yellow sandy soils with a varying content of angular quartz fragments or by thick pebble beds. These pebble beds, which are usually composed of quartz and felspar fragments derived from Basement System rocks, may, near the volcanic areas, contain a considerable percentage of rhyolitic and basaltic pebbles and pass laterally into the well-developed volcanic boulder beds west and north-west of Lorugumu.

Generally the volcanic boulder beds are confined to an area north of the Kosibirr and Munyen rivers, and between Loleka in the west and the Kabarat Hills in the east, ranging up to the base of the rhyolitic hills of Moruangiliop and Kalolokwel. Along their southern edge, particularly just west of Lorugumu, the boulder beds give rise to conspicuous scarps and cliffs above the lower alluvial flats of the Kosibirr River. Often the upper surface of the boulder beds is quite smooth and, as is the case at the beginning of the old Moroto Road near Lorugumu, give a good surface not readily affected by erosion. Contrary to what might be expected the surface of the boulder beds is often badly drained, allowing the formation of a much darker soil than is

normally found. The most conspicuous volcanic boulder beds are those formed of rounded cobbles of rhyolite, each cobble measuring six to eight inches across. These rhyolitic boulder beds only rarely contain fragments of basaltic lava or other lava types and it may sometimes be difficult to differentiate between a boulder bed and a rhyolite lava flow *in situ*.

The only other superficial deposits which are distinctive in the area are the thick sand deposits in the major rivers and the dark friable alluvial deposits which form extensive flats supporting dense vegetation along the Turkwel River.

## VI—METAMORPHISM AND GRANITIZATION

The higher zonal minerals of the Barrovian zones, although present in some of the metamorphic rocks of the Loiya-Lorugumu area, are never common and it proves impossible to delimit zones of this type. Sillimanite is present in some of the pelitic gneisses near the Kakep Pass but is not seen elsewhere in the area, while kyanite, which is very abundant in the gneisses east of the Kakep Pass, is seen elsewhere only in a few scattered localities near the Uganda border west of Ropetari. Almandine garnet is much more common, and may occur in both the pelitic gneisses and the metamorphosed intrusives, but is usually absent from the biotite gneisses.

The general grade of metamorphism for the area can be established by the comparison of mineral assemblages of certain rock types with the metamorphic facies proposed by Fyfe, Turner and Verhoogen (1958, pp. 199-239). The most useful rocks in this respect are the metamorphosed basic intrusives (mainly the plagioclase amphibolites), the calc-silicate gneisses and the pelitic gneisses with kyanite and sillimanite. The plagioclase amphibolites in the area typically have a mineral assemblage composed of dark green, strongly pleochroic hornblende and calcic plagioclase, usually andesine. Accessory minerals include clinozoisite-epidote, sphene, iron ore and diopside. This mineral assemblage is in agreement with the stable assemblage of hornblende-calcium-bearing plagioclase with or without epidote that is suggested for the almandine-amphibolite facies which covers the higher grades of regional metamorphism from the middle of the garnet zone. Almandine is characteristic of many rock types in the almandine-amphibolite facies but its absence from most of the plagioclase amphibolites in the Loiya-Lorugumu area may be due more to chemical variations than to variations in grade of metamorphism (*see* Wiseman 1934 p. 378). Probable agreement with the kyanite-muscovite-quartz sub-facies of the almandine-amphibolite facies is provided by kyanite-biotite gneisses which have an assemblage of kyanite-biotite-orthoclase-quartz-albite-muscovite with or without almandine. The sillimanite-bearing gneisses also belong to this facies but are probably best included in the sillimanite-almandine sub-facies.

The calc-silicate gneisses, which are fairly common in the area as thin bands and lenses in the crystalline limestones, are essentially composed of diopside and hornblende with plagioclase in the oligoclase-andesine range. Accessory minerals include biotite, epidote, apatite, orthoclase and quartz. This type of association is also characteristic of the almandine-amphibolite facies and is probably representative of the staurolite-quartz sub-facies.

An incomplete stage of metamorphism and therefore a grade of metamorphism more characteristic of grades lower than the almandine-amphibolite facies is shown by the metadolerites. Specimen 18/554 from Perro is a metadolerite with an igneous rather than a metamorphic texture, with a mineral composition similar to the assemblages proposed by Turner (1948 pp. 88-89) for his original albite-epidote-amphibolite facies which represents the lower part of the almandine zone. The metadolerite is composed of pale green hornblende which is only slightly pleochroic, andesine felspar tending to be more albitic at the crystal margins, and clinozoisite.

Granitization features are not strongly marked in the area but there appear to have been two separate periods of felspathization. Most of the homogeneous semi-pelitic biotite gneisses contain albite or albite-oligoclase as their principal or only felspar and only rarely contain orthoclase or microcline. Replacement textures are not usually observed in these albitic rocks. This presumably early period of albitization was followed by a period of potash felspathization during which knots and veins of pink felspar, mainly microcline, were introduced into the biotite gneisses producing augen gneisses and porphyroblastic gneisses of the type seen at Amuton. In many of these gneisses potash felspar is as abundant or more abundant than albite-oligoclase. Characteristic of these rocks is the replacement of earlier minerals by microcline. It is probable that the granitoid gneiss of Emuruchorod was produced as an extreme case during this later period of felspathization.

## VII—STRUCTURE

### 1. Folding

#### (1) Major Structures

Although some of the volcanic rocks are tilted, folding is confined to the Basement System. In these latter rocks the main planar element is foliation, which is always parallel or sub-parallel to the bedding and boundaries of formations and so can be taken as the equivalent of bedding in consideration of the major structures. The strike of bedding and foliation is generally north-north-westerly but on the east bank of the Turkwel River and in the north-western corner of the Loiya sheet the usual trend is north-north-easterly. Local variations in the strike of the foliation can be seen in Fig. 4

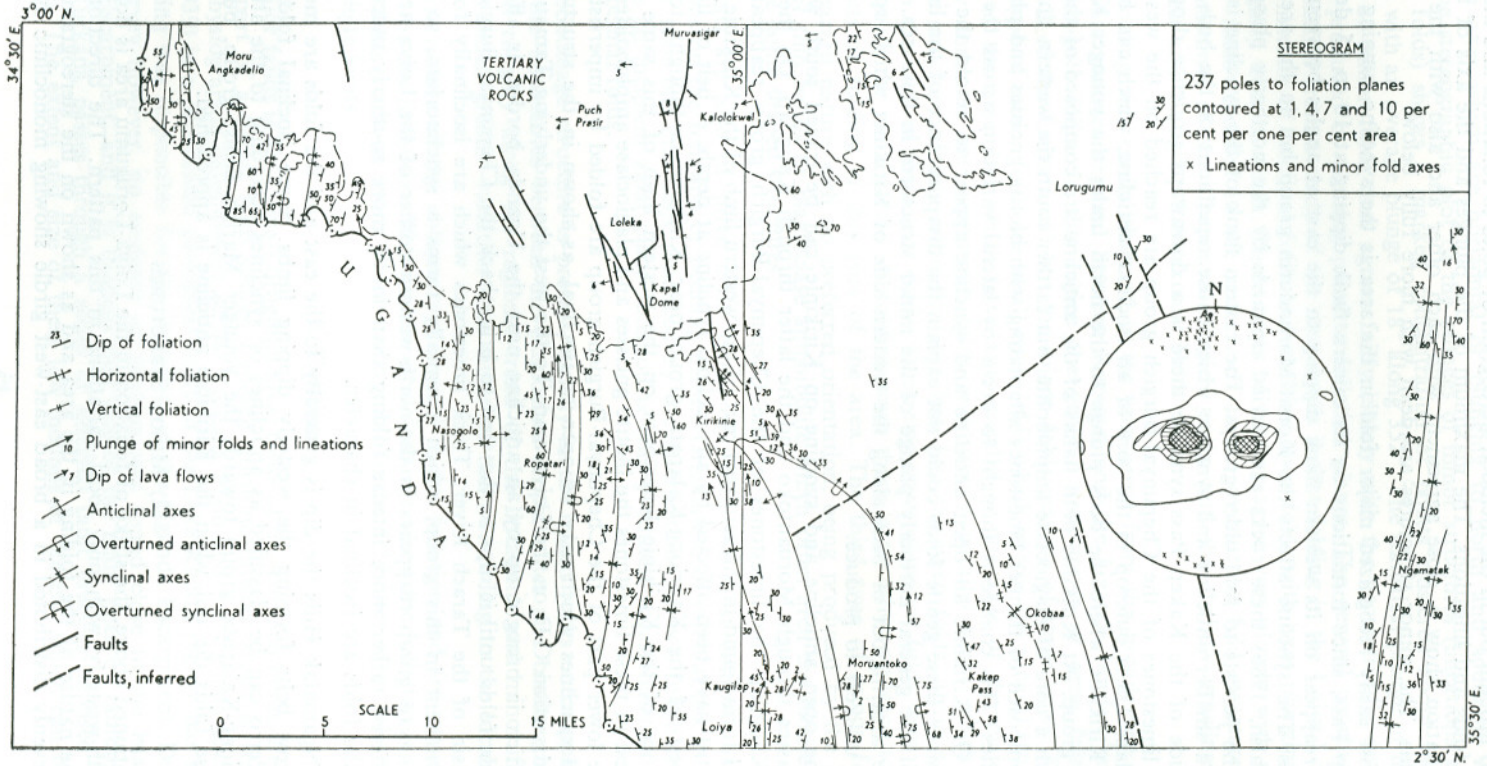



Fig. 4—Structural map of the Loiya-Lorugumu Area.

and is also brought out in the included stereogram of poles to foliations and the plunges of minor folds and lineations. The maximum of the plunges and the axis of the poles to the foliation show a close agreement with each other and also with the axes of major folds. The minor structures are dealt with more fully below.

The most easily recognized major fold in the area is the syncline running through the Kakep Pass, since formations on its eastern flank dipping at 10 to 15 degrees to the west reappear on its western flank dipping to the east at angles between 25 and 50 degrees. The syncline affects the Korsit-Morundurin group but in the area to the south (Walsh, 1966) these rocks are carried upwards by the northerly plunge while the syncline persists to fold older groups. The eastern flank of the syncline is complicated by a smaller anticline and syncline which cause repetitions of the beds. On the western side of the Kakep Pass syncline there is a downward sequence dipping east until the limestones of the Chepunyal-Burgich group are reached on the western side of Kaugilap. These outcrop in the core of an isoclinal anticline, which can be traced north to Kirikinie where the beds plunge to the north under the younger Kauriong-Kalapata group. At Kirikinie both flanks of the anticline are composed of thick limestones with a core of plagioclase amphibolite, but farther south the western limb of the fold is composed of thinner limestones alternating with biotite gneisses and plagioclase amphibolites. This change is thought to occur by lateral variation across the nose of the fold. On Kirikinie an open anticline and syncline appear to refold the isoclinal anticline since these gentle folds could not explain the disappearance of the limestones in view of the general northerly plunge of the minor structures in this area. There is also some shearing-out of beds along the western side of Kirikinie which open folds would be unlikely to produce.

Both the open anticline and syncline on Kirikinie can be traced south where the former passes through Moruantoko and the latter through Kaugilap. On the western side of Kaugilap the limestones of the Chepunyal-Burgich group reappear in the attenuated form found in the southern part of the western limb of the Kirikinie anticline and so must have been affected by an isoclinal syncline at depth. A belt of limestones to the west of the Kauriong-Kalapata group near Kirikinie is thought to be the reappearance of the Kirikinie limestones on the western limb of this same syncline. To the west of these limestones the biotite gneisses and plagioclase amphibolites belonging to the lower part of the Chepunyal-Burgich group are folded by impersistent anticlines and synclines which may be open or isoclinal, as shown in the structural map Fig. 4 and section C-D on the Loiya map. To the west the underlying Tamau-Kunyao group, which is brought up by an anticline near the Uganda border, is affected by gentle open folds until it dips to the west to bring back the Chepunyal-Burgich group in the basin of the Tarach River. Thick limestones which are isoclinally folded are again prominent in this group, which essentially forms a synclinorium, so that the Tamau-Kunyao group reappears in the north-western corner of the Loiya area. Here it has suffered rather more intense folding than in its more southerly outcrop, and some of the folds are isoclinal in character.

In the Ngamatak Hills the dip is generally to the east and the folds are monoclinal with narrow belts forming the westerly dipping limbs. Some isoclinal folds to the west of Perro can be classified as anticlines or synclines according to the attitude of the Kauriong-Kalapata group towards the younger Marich Schist group, but to the south these folds die out when the Kirikinie anticline is approached.

### (2) Minor Structures

As mentioned above, the strike of foliation in the Loiya-Lorugumu area is dominantly north-north-westerly with only local variations in this pattern. The direction of dip reflects the nature of the folding in the area and as shown on the stereogram (Fig. 4) is fairly evenly distributed in a broad east-west girdle showing monoclinic symmetry.

This distribution of points seems indicative of either isoclinal folds or shallow open folds with axes which are horizontal or plunging to north and south at very low angles. The stereographic plot of the plunges of minor structures (lineations and axes of minor folds) shows a marked concentration of points clustered about the north-south line with an average plunge of 18° along 352°. The statistical plunge of lineations and axes of minor folds thus agrees fairly closely with the geometrically determined fold axes produced by plotting poles to foliation planes. The general conclusion that may be reached from a study of the stereogram is that folding in the Loiya-Lorugumu area is a mixture of isoclinal folds and shallow open folds with axes plunging at low angles slightly west of north. These types of folding agree very closely with many of the major folds recorded in the area, such as the overturned fold structures found in the limestones of the Chepunyal-Burgich group and the shallow synclines of the Kakep Pass and Kaugilap-Lakuakoma Hills.

Minor folding was rarely observed in the area apart from the broad zone of semi-pelitic biotite gneisses exposed between Ropetari and the Uganda border, and south of the Nasogolo Hills. In this region the general structure is of open folding (*see* section A-B of the Loiya area) but the minor folds may be of three types. The most common type of minor folds are small open folds which mirror the general structure of this part of the area and which have axes parallel to the axes of the major folds. Also very common are overturned folds with nearly parallel limbs which do not reflect the structure of this particular area but, like the open folds, again have axes parallel to the axes of the major folds. These two types of minor folds were probably formed during the main period of folding since there is no other evidence to suggest two periods of folding in this part of the area. The third type of minor folding is of a haphazard nature with no preferred orientation, being produced by the localized swelling of thin bands of plagioclase amphibolite which often arch the biotite gneisses to produce dome-shaped structures.

Lineations are also of three main types, of which the most common is formed by striations on the foliation or bedding planes. Orientation of mineral grains was also frequently seen but lineations produced by the intersections of two foliations is very rare since an incipient axial plane foliation is only produced occasionally in the very tightest isoclinal folds.

When boudinage structure is present, usually in the mixed rocks outcropping along some of the boundaries between the plagioclase amphibolites and biotite gneisses, it is oriented roughly along the regional trend of the lineations and minor fold axes but shows much greater variation than either of them according to the local stresses.

Joints are mainly of the oblique type normal to the foliation and are symmetrically intersected by the lineations. This kind is most frequent where the foliation is unfolded, but when folds occur *ac* joints which are normal to the fold axes often take the place of the oblique joints.

### 2. Faulting

The major faults in the Loiya-Lorugumu area, those of the Turkana Plain, are believed to form part of a major fault system trending north-north-west which is responsible for the physiographic development of the Turkana Plain and the Uganda Escarpment. Fuchs (1939) in a provisional geological study of the Lake Rudolf region, has suggested that faulting was responsible for the evolution of the Uganda Escarpment. During the recent survey however, no evidence of faulting was found close to the base of the Uganda Escarpment, and it is thought that one of the main lines of faulting in this part of Turkana passes through a series of silicified fault breccias exposed south of Lorugumu. The extent and size of these low mounds of breccia, which can be clearly

seen on aerial photographs, seems to indicate that they represent faults of considerable magnitude. As shown on the geological map of the Lorugumu area, four belts of fault breccia were recorded: three of these belts trend north-north-west and the other north-east.

When the lines of the north-north-westerly trending breccias are produced to the south they run into the plain of the Turkwel River in the Karasuk area and follow its valley for a distance of over 10 miles. Walsh's Turkwel Escarpment fault (1966, p. 30), when produced into the Loiya-Lorugumu area, runs about half way between the scarp of the Okobaa Hills and the faults south of Lorugumu on a trend parallel to both the scarp and the fault breccias. No evidence for the continuation of this fault was seen in the present area but it can be drawn approximately just to the east of a low area with stony soil and poor exposures, whereas there are no exposures in the sandy soil farther east. It would therefore appear that the Suk Escarpment is formed by the fault described by Walsh and McCall and the breccias south of Lorugumu were produced along another parallel fault, which continues north to join the Muruasigar Escarpment fault (Fuchs, 1939, p. 265). The north-west trending line of breccias represents a fault which causes the fairly abrupt termination of the northerly trending Karasuk Hills and facilitated erosion along the Moroto embayment.

The age of the Turkana faulting has been suggested by Fuchs (1939, p. 267) to be late Oligocene, being younger than the age of the maturation of the sub-Miocene peneplain. A post-sub-Miocene pre-end-Tertiary age for the faults has been accepted by the authors since the faults appear to displace the sub-Miocene bevel but not the end-Tertiary bevel. The erosion which produced the end-Tertiary surface does in fact appear to cross over the fault lines, etching out the fault breccias and cutting back the original fault escarpment for several miles. Erosional products from this fault scarp filled hollows in the downfaulted sub-Miocene surface to give rise to the Turkana Grits.

All the remaining faulting in the Loiya-Lorugumu area is in the volcanic sequence, particularly in the Muruasigar rhyolites and the olivine basalts. The trend of the volcanic faults is invariably just west of north, and almost parallel to the trend of the Turkana fault line.

The most clearly demonstrated faults occur just west of the Loleka Escarpment where the surface of the Muruasigar rhyolites, which dip gently to the west, have been displaced by a parallel series of small north-south faults throwing down to both east and west. The most important line of these north-south faults is that stretching from between Kalolokwel and the Puch Prasir Plateau in the north to just west of the Kapel Dome in the south. Along its length the fault line, which is followed by drainage lines, downthrows the Muruasigar rhyolites to the east some 700 feet (*see* section A-B, Loiya Area). On the upthrown side of the fault a small scarp is usually present, formed by much-thinned Muruasigar rhyolites resting on the lower basalts. As a general rule faulting is absent in the Puch Prasir rhyolites, the principal exceptions being a line of displacement south-west of Tarona and a fault near Urum which explains some scattered outliers of the Puch Prasir rhyolites.

The possibility of faulting along the Kaimo River near the Uganda border to explain the volcanic scarp of Moru Angkadelio was investigated, but as no evidence of faulting was found it is presumed that the scarp is largely an erosional feature. Similarly there is no evidence to suggest faulting round the edge of the Puch Prasir Escarpment and it seems likely that the Puch Prasir Plateau owes its origin to the nature of its volcanic emplacement.

## VIII—ECONOMIC GEOLOGY

In the Loiya-Lorugumu area no evidence was found to indicate the presence of economically valuable mineral deposits and it is fairly certain that the copper mineralization and graphite deposits described by Walsh (1966, p. 30) from Karasuk do not extend to the northern end of the Karasuk Hills or to this part of Turkana. There are also no recorded occurrences of the mica-columbite-beryl type of pegmatites which are being worked at Kenailment in the southern Karasuk Hills. Brief descriptions are given below of minerals found in the area, but all deposits are too small to be economic in view of the cost of transport to the markets.

### 1. Minerals

*Kyanite* is present in a fairly thick series of pelitic garnet-kyanite gneisses occurring in the synclinal belt east of the Kakep Pass. The kyanite, which forms large-bladed crystals up to three or four inches in length, never makes up more than a few per cent of the host rock and no kyanite segregations were noted. Occasionally kyanite concentrations of loose crystals are formed by weathering in hollows or at the foot of slopes but these are always of only very small extent.

*Crystalline limestones* are fairly abundant in the area, being exposed east of Amuton, at Emuroy and Kirikinie, and near the Uganda border at Looya. Of these exposures the most accessible are at Emuroy and Kirikinie. Microscopic examination of the crystalline limestones revealed that most of them are at least partly dolomitic and so would be unsuitable for cement manufacture. Commonly the limestones contain bands of calc-magnesium silicate minerals as well as small flakes of graphite.

*Quartzite and quartz veins* are not prominent in the area, there being only one known quartzite band which is exposed just east of Looya. Giant quartz veins formed by a mosaic of pure quartz are more common but not abundant, and are best developed in the region just east of Kaugilap.

*Garnet* is chiefly found in the amphibolites and plagioclase amphibolites but is of local occurrence and the crystals themselves are small and of poor quality, as are those in the kyanite-garnet gneisses.

*Mica* is ubiquitous in the rocks of the Basement System but generally occurs as small flakes in hard rocks and so would be unsuitable for working. Some large flakes of suspected vermiculite were tested but proved to be biotite.

*Black tourmaline* associated with quartz outcrops in a small vein east of Kirikinie, but although of good quality is of very limited extent.

*Alluvial gold* derived from the Suk and Karasuk hills is possibly present in the Turkwel, but none was discovered by panning during the present survey.

*Sand* is extremely abundant in the larger rivers, particularly the Lorugumu and Turkwel rivers, but as local demand is nil and the cost of transport would be excessive, it is of no economic value at present.

### 2. Water

The only locality in the area where permanent water occurs is in a narrow rocky gorge just west of Kalolokwel, which runs north-south parallel to the scarp edge of the Muruasigar rhyolites, where deep rock pools support small fish. Many of the pools lying at the foot of waterfalls in deep gorges on the Puch Prasir Plateau may also be permanent but these, like the Kalolokwel pools, are inaccessible to local livestock and are largely ignored by the Turkana.

Generally however, as all the rivers are only seasonal except for the Turkwel, which may become semi-permanent during years of heavy rainfall on the catchment area, the only reliable source of water is from wells dug in the sand rivers. These wells or waterholes are usually sited where rock bars across the rivers form natural sub-surface dams, and digging to no great depths often gives a good supply of water. In the larger rivers such as the Lorugumu and the Turkwel water can always be obtained in wells even during periods of most severe drought. During the present survey the deepest wells recorded were about 15 feet deep, in the Loperichich River. Many of the more important waterholes are shown on the maps.

After periods of rain small springs may be found in certain rivers and some of them may flow for several days. Such a spring is found in a tributary of the Munyen River east of the Nasogolo Hills where partial damming of the river has been caused by a small dyke. Another spring of a rather saline nature but which invariably contains water is situated in the Munyen River at Operto, near the junction of the old road to Moroto and the track to Loiya.

As much of Turkana is undergoing severe erosion, partly due to overstocking, any increase in water supply can hardly be recommended since this would inevitably lead to an increase in livestock and the resultant further deterioration of the country. It can however, be suggested that the water situation could be considerably improved if wells of a more permanent nature with supported sides could be constructed along the banks of the bigger sand rivers at permanent waterholes. Such a well on the Turkwel River at Lodwar has been giving a good yield of water for a number of years and an attempt is now being made to build a permanent well on the Lorugumu River near the road crossing.

In the smaller sand rivers the best way to improve water supplies would be to construct dams which should not rise above the level of the sand. Although this would still entail digging waterholes it would ensure that little water is lost by evaporation. Any large-scale improvement in water supplies however, should be conditional on the acceptance of controlled grazing schemes by the Turkana in order to prevent further erosion.

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