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# GEOLOGY OF THE LOPEROT AREA

DEGREE SHEET 18, S.E. QUARTER
(With coloured geological map)

by

P. JOUBERT, M.Sc.
Geologist

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## FOREWORD

The mapping of the Loperot area involved living and working for many months in one of the most remote and inhospitable regions of Kenya, and Mr. Joubert is to be commended on the thoroughness with which he carried out his work.

A complete account is given of the very varied rock types of the region, which comprise Basement System crystalline rocks, and sediments and lavas of Tertiary and Recent age, and the author has been able to draw up a detailed geological history of the area. He also gives a convincing explanation of the origin of the complicated structures seen in the crystalline rocks, and relates the structures in the later rocks to the pattern of Rift Valley faulting in other parts of Kenya, pointing out the close relationship between structures in these later rocks and those in the Basement System gneisses.

The economic potential of the area is small, for although good deposits of graphite and sillimanite were found their remoteness makes them of little importance at the present time.

B. H. BAKER,
*Commissioner (Mines and Geology).*

21st February 1966.

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Geological Map of the Loperot Area (Degree Sheet 18, S.E. Quarter), Scale 1:125,000 at end

## ABSTRACT

The report describes an area in the southern Turkana District of north-western Kenya bounded by latitudes 2° and 2° 30′ N., and longitudes 35° 30′ and 36° E. Four morphological surfaces are recognized: (1) scattered relics of an old peneplain probably of end-Cretaceous age, (2) the sub-Miocene peneplain, (3) the extensive end-Tertiary erosion surface, and (4) disjointed surfaces formed by the pediments accumulated during Pleistocene times.

The rocks exposed in the area are: (1) folded Basement System consisting of metamorphosed sediments and volcanic rocks intruded by basic and ultrabasic bodies and dykes, all probably of Precambrian age. (2) Tertiary sediments. (3) Tertiary olivine basalts, phonolites. phonolitic trachytes and micro-foyaites. (4) Pleistocene and Recent lake beds, alluvium and soil. The petrography of the rocks and the major and minor structural features of the area are discussed. An account of the evolution of the area and age relations of the rocks is given and the economic prospects of the area are considered.

# GEOLOGY OF THE LOPEROT AREA

## I—INTRODUCTION

### 1. General Information

The Loperot area as defined for this report comprises the south-east quarter of degree sheet 18, Kenya (D.C.S. No. 51), bounded by latitudes 2° N. and 2° 30′ N. and by longitudes 35° 30′ E. and 36° E. The area which is approximately 1,200 square miles in extent, lies within the Turkana District of the Rift Valley Province of Kenya. Lodwar, the administrative centre, is about fifty miles by road north of the northern boundary of the area. At present the only two shops in the area serving the simple needs of the inhabitants are at Lokichar, where there is also a Locust Control bait store, but in the past small administrative outposts, now abandoned, existed at Loperot and Lokichar, the ruins of which can still be seen.

The area is inhabited by nomadic Turkana tribesmen who for most of the year live in rude branch shelters in close proximity of water holes where overgrazing is now pronounced. During and after the rains the population is sparsely scattered over the area, with the majority of people spreading along the fringes of the Basement hills where the best grazing for their goats, sheep and camels is to be had.

Permanent water is found at the wells of Kamuthia, three miles north-east of Loperot, and at Lokwamuthing, in the south, where seepages from the fault zones collect in small pools with fringes of vivid green grass forming an unexpected oasis in this semi-desert. Other water-holes which also occur along fault zones, such as at Akhuryo, Loporor, Luturere, etc., are semi-permanent. The most important water-holes, however, are those dug in the sand of the larger river courses, where solid rock close to the surface forms subterranean barriers. These places are numerous in the area, but only those at Gochodin, Lachararakhyang and Loperot in the Kalabata river, as well as those of the lower reaches of the Timtim and Kalabata rivers, have been known to fail during exceptionally dry spells. Otherwise these water-holes, especially those along the Basement escarpment, have water only for a very limited period after the rains. Two similar water-hole groups at Lokhangamata and Lokhosinyakhori in dry river courses were dug in impermeable gritty clays of Pleistocene age.

Rainfall is scant and is more concentrated on and around the hills. There are no meteorological stations in or near the area and the rainfall is thought to be less in the Loperot area than at Lodwar or Lake Rudolf. Nevertheless the rainfall statistics for these places give a reasonable idea of the precipitation in the Loperot area:—

RAINFALL STATISTICS

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

| Station | Altitude in feet | Annual Total—Inches | | | | Number of Years Recorded |
|---|---|---|---|---|---|---|
| | | 1955 | 1956 | 1957 | Average | |
| Lodwar .. .. | 1,660 | 6·61 | 3·76 | 6·66 | 5·65 | 32 |
| Ferguson's Gulf .. | 1,230 | record not complete | | 4·86 | 6·49 | 3 |

The average monthly rainfall chart indicates rain from March to August for Lodwar, with predominant precipitation during April and May. Another feature of the climate which requires mentioning is daily dust storms before and during the onset of the rains, when parts of the area become completely shrouded by clouds of dust. They usually commence in the afternoons and precede the localized thunder storms.

*Vegetation.*—Three distinct regions of vegetation can be recognized, the control being geological. Firstly, the vegetation of the hills and fringes of the hills composed of Basement System rocks where low thorny bush, dense in parts, predominates. Secondly the area of featureless plains carved by numerous small dry river courses along which large and small thorn trees of the *acacia* family and occasional *doum* palms grow, while the plains themselves are bare or covered by patches of grass and hard scrub which increase in density as the hills

are neared. The third region is comprised by lava boulders and flows of Tertiary age and the Pleistocene pebble sheets where no vegetation can exist, except the occasional bush or tree along gullies draining these hills and ridges.

*Communications.*—The road leading south from Lodwar enters the area in the north and bifurcates at Lokichar. The branch to the east passes through Loperot and proceeds out of the area to Kangetet, where it turns west and enters the area in the south-eastern corner and joins the road from Kalossia in the south at Lokwamuthing. The other branch from Lokichar proceeds in a south-westerly direction and leaves the area near Kaputir which is just west of the southern part of the area. This road again enters the area near the south-western corner and then continues south to Lotongot and Kalossia. These roads are occasionally patched up, but the frequent soft sandy river beds crossed by them make the journey by ordinary vehicles extremely difficult.

Another track, although not maintained, leads due west from Lokichar to the Turkwel river west of the area and is in good condition over most of the way in the present area. Two tracks, now mostly overgrown and which can only be negotiated by small four-wheel-drive vehicles, link Lokichar to Lokwamuthing and Lokwamuthing over the hills to Kaputir.

*Maps.*—Maps available during the survey were the 1: 500,000 Moroto sheet, E.A.F. No. 1570 (1949) and the 1: 250,000 Moroto map, G.S.G.S. No. 4801, sheet N.A–36–8 (1st edition, 1956). These proved to be sketchy and inaccurate for the purposes of this survey. The area is partly covered by aerial photographs flown during the early months of 1952.

The Kenya trigonometrial survey does not extent into the Loperot area, so that control was obtained in the area to the west. For this purpose three determined points (Tarakit, Tenus and Kachagalau) on the Turkwel escarpment were used and the survey carried by plane-table across to longitude 36° E. The necessary ground control for the aerial photograph flight strips was obtained in this way, while the region not covered by aerial photographs was mapped by plane-table on a scale of 1: 62,500. The mapping of the geology was done directly on transparent overlays on aerial photographs in parts covered by them and afterwards transferred to the field sheets by reduction.

The form-lines on the geological map were drawn as accurately as possible with the aid of an aneroid barometer corrected for diurnal variations.

## 2. Previous Geological Work

Very few geologists visited the area in the past, the early travellers either passing the area to the east along the Suguta or Kerio valleys or following the course of the Turkwel river to the west.

The first geological map of the Loperot area to appear is a small scale map by Murray-Hughes (1933)* of the western half of Kenya. This map shows the main part of the area as consisting of Basement Complex with Turkana Grits along the eastern boundary and a little volcanic rock in the north-eastern corner of the area. The Turkana Grits are here provisionally dated as Jurassic.

A. M. Champion (1937), during his tour as Administrative Officer in Turkana, assisted greatly in the topographic mapping of the district and made many physiographical and geological observations in the area. His geological collections were petrographically described by Campbell Smith (1938) to which Champion supplied notes on the field occurrence of the rocks.

V. E. Fuchs (1935, 1939) made a rapid reconnaissance into the Loperot area in 1934, but in his description of the area relies mostly on information gained from Champion.

F. Dixey spent several months during the latter part of 1943 on an extensive tour of the Northern Province and also passed through the Loperot area. Since then he has written several papers in which he expands on the geology, physiography and hydrology of southern Turkana (Dixey 1944A, 1944B, 1945, 1946 and 1948).

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*References are quoted on p. 52.

C. Arambourg (1933A, 1933B, 1943, 1947) never visited the Loperot area, but his geological and palaeontological work in the Rudolf basin is of importance in deciphering the geological history of the Turkana District.

P. Mason and A. B. Gibson (1957) mapped the geology of the areas immediately to the south of the Loperot area during 1952 in the course of their duty as geologists of the Geological Survey of Kenya. This work is now being extended in the present area.

## II—PHYSIOGRAPHY

The Loperot area can be divided into four natural regions in each of which the type of relief and vegetation are more or less uniform:—

(1) The hills composed of Basement System rocks and the *inselbergs* on the plains.

(2) The featureless plains for the main part covered by alluvium.

(3) The hills composed of volcanic rocks.

(4) The area sloping to the east away from the hills composed of volcanics.

The Basement System hills form the most prominent features in the area, becoming smaller in stature and extent northwards, and eventually only forming isolated monadnocks on the plain in the north-west. The main hill group represents a denuded *horst*, being bounded by north-west south-east striking faults on both sides. The western scarp has retreated to such an extent that the existence of a fault could only be proved there by displacement of related surfaces. On the eastern flank however, the scarp is distinct although it has retreated to nearly five miles in places. The Basement System has been folded in a series of steep-sided folds, usually isoclinal, which result in hogback ridges along the steeply dipping resistant gneisses, while bald crags and exfoliation domes also mark the strike of such gneisses. Some of the crags have been named by Champion, (Oterrkott needle, Natai obelisk) but as these names are not known to the people in the area, they have not been repeated on the map. The highest peak is Kaimeruk, which has been measured by aneroid barometer to reach just over 5,200 ft. Other high peaks are Lokhosiniogurr and Lopatumuthingo (*see* Fig. 1) measured to reach 4,510 and 4,970 ft. respectively. Both these latter peaks are hogbacks composed of resistant leuco-gneisses, while the Kaimeruk massif is formed by an elongated isoclinal domal structure.

The plains fringing the hills and separating the Basement hills from the Tertiary volcanics are of a two-fold nature. The western half consists mostly of the end-Tertiary peneplain and the area draining to the east. On the end-Tertiary erosion surface angular felspar and sub-angular quartz pebbles occur profusely, in many places forming disconnected sheets. Subsequent deep dissection of this surface by numerous dry river courses has produced a quilted or dimpled surface.

The eastern half of the plains is a wide smooth surface covered by alluvium formed by the convergence of alluvial fans and is dissected by numerous tree-lined dry gullies (Plate I). Near the scarp fans of pebbles, sometimes extensive, occur just below the larger valleys draining the Basement hills. The upper parts of this piedmont plain are now again being incised by the waters rushing down the mountains after thunderstorms.

Dixey (1948, p. 24) mentions a clearly defined terrace bluff, about 10 ft. high, that can be followed for many miles south of Lodwar along the track leading south. It consists of coarse, slightly water-worn, gneiss debris, and although it resembles a lake-eroded cliff, Dixey considers it to be the result of sub-aerial erosion of the lower erosion surface consequent upon the falling of the lake base level as it increases steadily in elevation southwards. In the Loperot area it is still evident north and south of Lokichar at an elevation of just above 2,500 ft., where it separates the alluvial plains from the end-Tertiary erosion surface.

Another feature which requires mentioning is the open grassland in the south-western corner of the area. It is situated on the plain west of the hills and is distinctive in having a fairly thick grass cover and no trees. In contrast the surrounding plains themselves have a fairly dense low thorny scrub cover with hardly any grass. The slope of the grassland is low and it is thought that it may have been swampy in the past. Another factor noticed at the time of mapping, which may also partly account for its existence, is the fact that it receives more rain than other parts of the Loperot area.

The hills to the east are of two types. Usually they are composed of basalts and flat-topped remnants of lava plateaux. Occasionally they are capped by plateau phonolites, and very often the eastern flanks represent retreated fault scarps. Their surfaces are boulder-covered and dips can only be measured from a distance. Because of the absence of vegetation, these parts of the area are indescribably bleak. Later micro-foyaite intrusions form steep-sided isolated conical hills in the south-eastern part of the area, such as Lokhoriokhot, Morutena and Kakhapit. The flat tops of the basalt hills either slope to the east or west due to faulting, while the conical hills were intruded along major fractures.

Sloping away from the basaltic hills of Nakuagale, Hadukhungele, Auwerwer and those north of Loperot, are smooth pebble sheets, which become bouldery as the hills are neared. These sheets have been described as shingles along the beach of a Pleistocene lake (L. S. B. Leakey, personal communication), but because of their extent and smoothness are thought to be alluvial fans from which the finer material has been removed to leave desert pavements. Subsequent dissection of the desert pavement overlying soft Turkana Grits, has left smooth-topped ridges and pillars in parts where it can be shown to have been continuous. These desert pavements are usually composed of small pebbles of basalt, and grade into the bouldery end-Tertiary surface, where the boulders are mostly composed of phonolite.

Dunes are also found in the same region and are normally of a longitudinal (*seif*) type, this being indicated by the shape of the sandy outliers, as the prevailing wind is easterly. The effect of wind abrasion is seen in the formation of *yardangs* mainly in the soft grits between the Auwerwer and Hagit hills, but also in the lower regions of the Kalabata river.

### 1. Drainage

Although there are three directions of discharge, all the water of the area eventually drains into the closed basin of Lake Rudolf. The rivers draining to the west discharge into the Turkwel river on its way to Lake Rudolf, while the Lomenyenkoporat and its tributaries drain to the north straight into Lake Rudolf. The rivers in the east such as the Kalabata, Timtim and Kangetet, discharge into the Kerio river to the east and thence to Lake Rudolf.

Dendritic drainage patterns are most common in the area, but other types of patterns are also frequently found, such as parallel patterns on alluvial plains, trellis drainage on the Basement System hills where the drainage follows the strike of the rocks and cuts across along major joints, while faulting produced rectangular drainage between the Nakuagale and Hadukhungele hills. Radial drainage is uncommon, and is usually found in association with the conical micro-foyaite hills, while annular drainage resulting from slight doming of the basalts was seen on aerial photographs just to the south-east of Lokwamuthing.

A distinctive feature of southern Turkana is the large number of dry river channels, which is unexpected in view of the low annual rainfall. This can be ascribed to the localized flash floods, however, when relatively small areas have to cope with large amounts of water in a very short time. The streams normally soak into the parched sand in a relatively short time and within a few miles of the rain. The sudden discharge of large volumes of water is manifested in unusual drainage phenomena. Braiding of the channels and river capture are commonly encountered. Often gullies with high banks occur situated on higher ground than that found in the immediate surroundings. In cases like these, the streams are likely to breach their banks, the channel bifurcating and forming a new channel without relinquishing its old course.

Nearly all river channels in the area are young due to faulting and the lowering of the base level by the retreat of Lake Rudolf. The valleys on the Basement hills are deeply incised and erosion is taking place rapidly along the scarps where waterfalls are retreating. Large boulders and smaller debris are being washed down by every rain and deposited as soon as the plains are reached. Along the western flanks of the hills there is now a narrow zone of pediment but further down the incision of the end-Tertiary peneplain is pronounced. Beyond this surface the channels become gradually shallower farther to the west.

A significant feature of the drainage is evident on the plains east of the main Basement hills. When looking at the drainage here, it is obvious that discharge was mostly to the north in previous times, but now the slope of the plain is easterly, with the resultant change in drainage direction. This change in drainage direction can be ascribed to late Pleistocene tilting of the area to the east or may be due to the numerous examples of capture of rivers

flowing north by rivers flowing east. By river capture and consequent fast erosion, much of the alluvium could have been removed, thereby changing the slope of the alluvial plain. The Gochodin river which made a straight line for the Hadukhungele hills, and probably formed the headwaters of the Akhuryo river, was captured by the Timtim river and since then has shortened its route to the east, as it was captured by another tributary of the Timtim river. It must have been at approximately the same time when the Kalabata river breached the lava barrier at Loperot and captured the headwaters of the Lomenyenkoporat river. This capture must have been the cause of the removal of much of the material previously deposited to the west of the Auwerwer and Loperot hills.

The degree of maturity reached by the Kalabata river in parts along its course can be ascribed to several obstructions it encounters on its way to the Kerio river. The upper reaches of this river are aggraded to the point where it cuts through the lava barrier about a mile west of Loperot and further down it is again obstructed by several Tertiary dykes impeding its gradation. The same applies to the Timtim river which has cut its way through a wide barrier of lavas to the east of the area.

The terrace bluff in the vicinity of Lokichar, described above, is thought to be remnants of a terrace of the Lomenyenkoporat river which has migrated steadily to the east, and when it reached the resistant lavas north of Loperot, incised its channel in the softer alluvium, resulting in the excavation of the Pleistocene deposits there. Previously it may have been a tributary of the Turkwel river and joined the river somewhere east of Lodwar, but since then has been captured by a river draining into Lake Rudolf beyond the Kamutili hills north of the present area. If this is correct, it would explain the decrease in elevation of the terrace to the north.

A similar step also occurs on the western boundary of the end-Tertiary peneplain, but here it is not so marked as it has been cut far back in parts and is also much more dissected.

### 2. Erosion Surfaces

The physiographic history of the Loperot area is displayed by remnants of three distinct peneplains, the oldest of which occurs at an elevation of approximately 4,400 ft. (Fig. 1). This surface bevels a large area on the Kaimeruk hills, where it has an appreciable soil cover, and tops the highest hills composed of Basement System rocks such as Buradyakim, Lopatamuthingo, Kamunono and the northern promontory of Lokhosiniogurr.

The surface below is more distinctive in having a thick soil cover and is particularly well preserved in the Lopatamuthingo, Lokhosiniogurr and Kaimeruk hills where it occurs at an elevation of 3,800 ft. above sea-level. This surface slopes demonstrably to the north, also occurring at 3,600 ft. on the Lobopakeyu hills further north and a small remnant is preserved on Gathuroi hill near the northern boundary of the area at 3,290 ft.

The lowest surface, 600 ft. below the middle peneplain, is widespread in the area and the most distinctive of the three surfaces. In the western parts of the area this lowest surface is always covered by sub-angular pebbles and pebble sheets derived from Basement System rocks. Whenever isolated pebble sheets were found in that part of the area, they are co-planar with the lowest erosion surface. In the vicinity of the Habokok river, the pebble sheets are terminated to the west by thin layers of ferruginous pellets which underlie them there.

The slope of this surface is nearly 18 ft. per mile to the north, which is consistent with the slope of the middle erosion surface. In the south of the area the lower peneplain nearly reaches 3,200 ft. and slopes down to below 2,600 ft. on the northern boundary. Faulting has affected this surface since its formation so that the isolated patch in the south-western corner of the area at 2,500–2,600 ft. is at least 500 ft. lower than the same surface bordering the hills in the same vicinity. Further indication of the lowering of the south-western corner of the area is found in an isolated sheet of ferruginous pellets on the Lokichar–Kaputir road just east of the Khoringyang river at an elevation of 2,480 ft. Mason and Gibson (1957) also map an outlier of Turkana Grits bevelled by the lowest surface to the south-west of Laiteruk mountain, which substantiates evidence for a fault along the western side of the main hills.

The inlier of Basement System in the north-eastern corner of the area is also covered by the distinctive pebble sheets, sometimes massed in heaps and small ridges. Here the surface occurs at approximately 2,200 ft. which would mean that it was lowered by faulting further

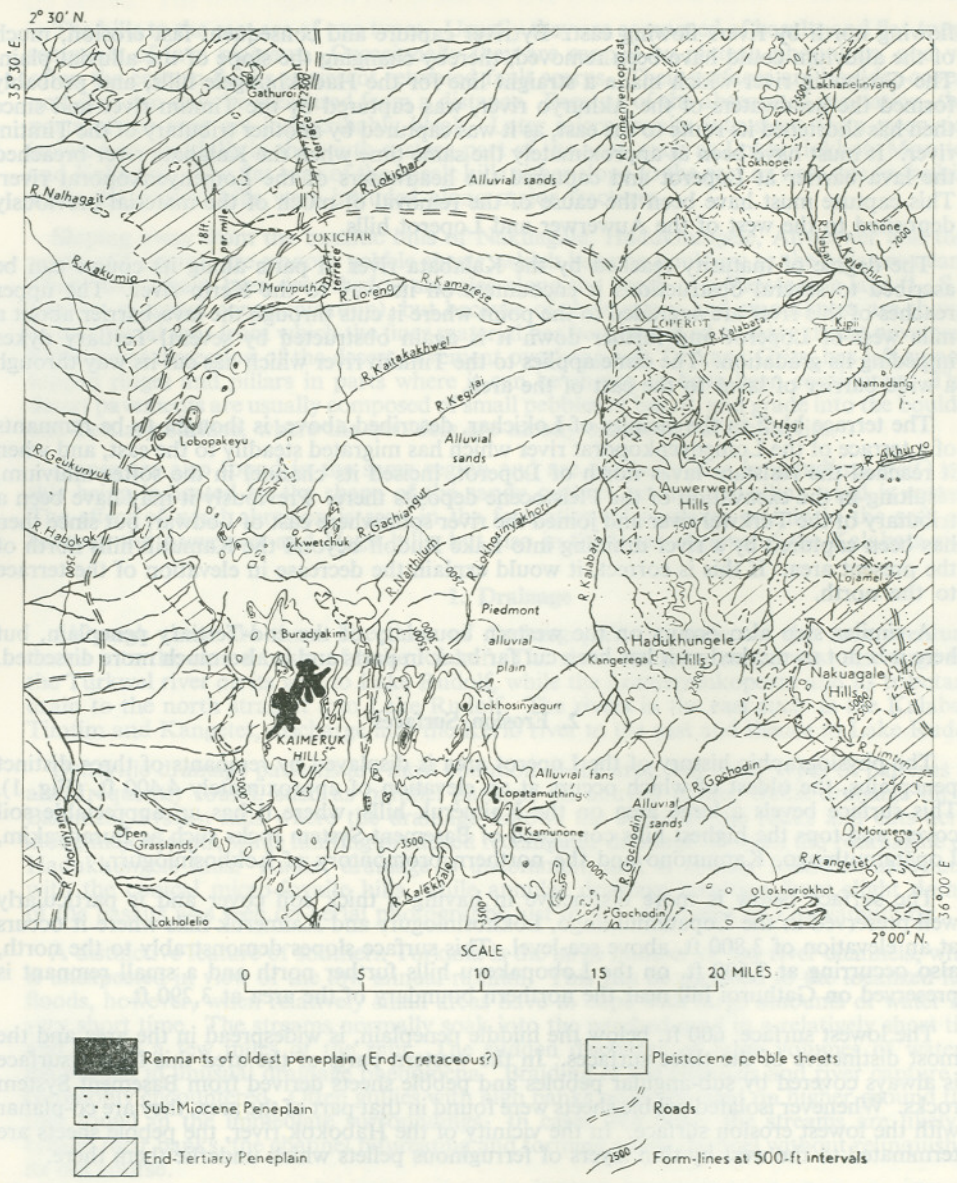



**Fig. 1.—Erosion surfaces of the Loperot Area.**

west by as much as 400 ft. From here this erosion surface can be extended onto the lavas down to the south-eastern corner of the area. On the lavas this lowest bevel is not so easy to follow as on country underlain by Basement, but by the fact that it is usually overlain by thick slightly sloping phonolitic boulder beds, it is possible to demarcate the extension of this surface southwards, much of it being in the nature of a pediment.

Along the southern boundary faulting also disturbed the lowest peneplain as it was measured at an elevation of 3,100–3,200 ft. just west of Gochodin, but further east at Lokhoriokhot and east of Lurutum it appears at 2,700–2,800 ft. To the south-east of Lokhoriokhot it again appears as flat-topped boulder-strewn ridges above Lokwamuthing at +2,500 ft., while further east the boulder beds occur at an elevation of between 2,100 and 2,200 ft.

Here the surface has been lowered to such an extent that sands derived from the piedmont alluvial plains have been washed onto it quite recently. The total throw of the faults in this area from Gochodin to the south-eastern corner of the area would then amount to 1,000 ft.

The definition of the lowest peneplain in the eastern part of the area is further obscured by the pebble sheets encroaching upon this surface. These desert pavements have been described above, consisting of cobbles near the hills, but with decreasing size to pebbles away from the hills with a concomitant decrease in slope. They often grade into the lowest erosion surface, but it is important to note that the boulders of the lowest erosion surface are mostly composed of phonolite while the pebbles of the desert pavement are mainly of basaltic origin.

The lowest peneplain continues to the north and forms the greater part of the plain between the northern boundary of the present area and Lodwar, some forty miles farther north. The slope of the surface must increase as Lodwar is approached as it descends to an elevation of 1,500 ft. there. To the west of Lodwar the erosion surface increases in elevation to 2,000 ft. at Lorugumu, thirty miles west of Lodwar. Champion (1937, p. 119) also measured a gradient of 19·7 ft. per mile from the foot of the Turkwel escarpment to Lake Rudolf. From this it is evident that the actual slope is to the north-east and not north, as is suggested by evidence in the Loperot area, and that the slope is approximately 24 ft. per mile in that direction.

Fuchs (1935, p. 119) considers this surface to be the same as the bevel on the top of the Sekerr–Chemorongi (Turkwel) escarpment, which has been lowered to its present position by Rift Valley fractures. Champion (1937, p. 105) concurs on the existence of the Turkwel fault-scarp, but regards the plain as an area peneplained after the formation of the Rift Valley. Dixey (1948, p. 29) however, enumerates reasons for the Turkwel escarpment being an erosion scarp and compares the Turkana plain with the end-Tertiary surface. Mason and Gibson (1957, p. 11) also accept this plain as representing peneplanation towards the close of the Tertiary period in the Kalossia area, where it does not seem to show any slope (fig. 1), and is said to occur at an elevation of 3,200 ft. As this surface bevels volcanic rocks overlying Miocene sediments, it can only be ascribed to late Tertiary peneplanation.

Collation of the level of the Tertiary–Basement unconformity at various localities in Turkana, where the sub-Miocene peneplain can often be expected to be preserved, is perplexing due to displacement by faulting, especially as Lake Rudolf is neared. Such an unconformity is seen in the present area, but since this contact has been lowered by faulting in relation to the Basement System hills probably both in Tertiary and Pleistocene times, it is valueless in collating the sub-Miocene surface remnants.

Major displacement was found along faults striking to the N.N.W. and if such displacement is to be taken into account, it is essential to follow related surfaces in that direction. Dixey (1948, p. 22) mentions the frequent occurrence of Miocene rocks perched on residuals of the Basement System standing several hundred feet above the end-Tertiary peneplain. On p. 15 he states that the base of the volcanics at Lomil hill, about sixty-five miles N.N.W. of Gathuroi in the present area, occurs at about 250 ft. above the plains. The elevation of the plain at this particular locality is given as 1,950 ft. on the map (Moroto sheet, E.A.F. No. 1570), and this would place the unconformity at 2,200 ft. Now if the middle peneplain, occurring at 3,800 ft. in the Kaimeruk hills, is projected from the Loperot area to Lomil hill at a slope of 18 ft. per mile, it would concur exactly with an elevation of 2,200 ft. at Lomil. Therefore, if the thick red soil cover on hills mentioned before is taken into account, it is almost certain that the middle peneplain of the Loperot area represents the sub-Miocene erosion surface as known in Kenya. In this connexion it is also of interest that the unconformity between gneiss and sediments within the Muruanachok hills, ten miles north-east of Lomil hill, appears to lie at or near plain level (Dixey 1948, p. 20), and it therefore seems as if the slope of the sub-Miocene surface here is also to the north-east at a much steeper angle than that of the end-Tertiary peneplain as Lake Rudolf is approached, and that the two surfaces actually cross along a line passing through the Muruanachok hills.

Dixey (op. cit., p. 27) mentions that the much dissected Kailongol and Kaimaruk hills, when viewed at a distance from any direction, present a well-defined summit level at 4,200 ft. which he regards as relics of the mid-Tertiary (sub-Miocene) surface. Mason and Gibson (1957, p. 11) also tentatively correlate benches and isolated hill-tops at 4,200–4,400 ft. around the Masol, Laiteruk and Kailongol hills with sub-Miocene peneplanation. In view

of what has been said before, it is suggested here that the surface occurring at 4,400 ft. in the Kaimeruk hills represents end-Cretaceous peneplanation, which is the next older surface postulated for Kenya.

Younger surfaces in the present area form the alluvial piedmont plain to the east of the Basement System hills and the desert pavements in the eastern part of the area. The pediments of these surfaces lie on sediments almost certainly of Middle Pleistocene age, and must therefore be of Upper Pleistocene and in part of Recent age.

## III—SUMMARY OF THE GEOLOGICAL HISTORY OF THE AREA

The physiography and the sequence of rocks mapped suggest that the main events in the evolution of the area that have left their traces were as summarized in the table below:—

| *Age* | | *Formation* | *Earth Movements and Erosional Phases* |
|---|---|---|---|
| Recent | | Wind-blown sands and dunes. Alluvial sands. Red brown sandy soils on Basement rocks | Change in direction of drainage, river capture, and re-excavation of Pebble sheets, alluvium and soil. |
| Pleistocene | U | Piedmont plain alluvium<br>Desert Pavements | |
| | M | Calcareous lake deposits and volcanic ashes derived from the east | Faulting. Barriers in Lomenyenkoporat and Kerio valleys. |
| | L | Pebble sheets and boulder beds (?) | |
| Pliocene | | | End-Tertiary peneplanation |
| Miocene | | Intrusion of micro-foyaites<br>Phonolitic trachytes<br>Plateau Phonolites<br>Trachybasalts<br>Analcite-olivine basalts<br>Inter-volcanic sediments<br>Olivine basalts<br>Tuffs<br>Turkana Grits with minor interbedded volcanics | Faulting<br>Warping and initiation of faulting |
| | | | Long period of uplift and erosion ended in the formation of the sub-Miocene peneplain |
| Precambrian | | Granitization, folding, faulting and intrusion of pegmatites and dolerites<br>Intrusion of basic and ultrabasic bodies<br>Basement System–sediments and extrusives | |

The crystalline gneisses, schists and granulites of the Basement System, believed to be of Archaean age, form the base on which all other sediments and lavas in the area were deposited and extruded. After the deposition and deformation of the Basement System there was a very long period of which there is no record preserved and it is only since lower Miocene times that the geological sequence of events can again be deciphered.

The Basement System is represented by two groups of rocks, a lower gneiss series representing psammitic sediments with hornblende-rich rocks probably of volcanic origin, and an upper pelitic gneiss series which contains some crystalline limestone horizons. These groups differ somewhat in lithology and it is thought that they may possibly be separated by an unconformity. During Precambrian times a vast accumulation of sediments was laid down in a large depression which was also invaded by large extrusions of lavas. These rocks were intruded by basic and ultrabasic bodies and dykes and the whole sequence subsequently compressed resulting in their subjection to intense heat, pressure and deformation, transforming the succession into a metamorphic series of crystalline gneisses, schists and granulites. During this period the rocks were granitized and overfolded to the west with some of the folds extending into thrust-faults. Other north-westerly striking faults also developed, dividing the area into large blocks in which differential movement to the north-west took place.

Pegmatitic dykes and quartz veins were intruded into the Basement System towards the close of the period of deformation, while the lack of metamorphism in the dolerites and lamprophyric dykes indicates that they were intruded after the deformation of the crystalline rocks had ceased.

Now followed a long period during which the area was repeatedly uplifted and eroded, of which only one stable period, which resulted in the formation of the end-Cretaceous erosion surface now represented by soil-covered hill-tops and ridges in the higher regions of the Basement hills, can be recognized. An early Tertiary period of stability culminated in a fairly smooth sub-Miocene surface on which only scattered monadnocks remained, and on which the lower Miocene sediments were deposited. Before the deposition of the sediments however, the surface was warped and posthumous faulting along the existing north-westerly striking faults took place. The material deposited in the depression resulting from the warping was derived from the fault-scarps, and from the present position of the lower Miocene sediments it seems that this depression was situated to the west of the present position of Lake Rudolf.

The initial deposits of the Turkana Grits indicate fluviatile conditions, with boulder beds deposited in hollows, followed by gritty limestones deposited when the water deepened. Crocodiles and tortoises lived in the water, but fluviatile conditions again slowly obtained the upper hand, and the first manifestations of vulcanicity are of limited extrusive flows and fairly widespread ashes overwhelming the plants growing in the region at that time. Fluviatile conditions recurred with increasing vigour and continued up to the time of the extrusion of the basalts with only minor breaks during which silty and calcareous sediments were deposited.

Faulting must have continued during this time and along these faults numerous dykes were intruded to serve as channels of the basaltic flows. The area was at first patchily covered by volcanic ashes, which were succeeded by basalts which invaded the area from the south and north. At first porphyritic olivine basalts were extruded and formed thick successive flows in the south, but are of patchy occurrence in the north where fine-grained basalts invaded the area from the north. The first flow in the north did not reach as far as Loperot, but the succeeding flows were more extensive.

The difference in the succession to the north of Loperot from that in the south-eastern part of the area can possibly be explained by an easterly slope of the country at that time, so that the porphyritic basalts are thick in the east but they thin out rapidly to the north-west and dovetail with the fine-grained basalts in the Auwerwer hills. It must have been since the extrusion of the basalts that mild folding of the beds initiated a slight anticline which was mainly responsible for the present disposition of the volcanic rocks and underlying sediments, and resulted in an elongated lake on its western side.

The vulcanicity temporarily ceased when the intervolcanic limestones were deposited, but again resumed in the north where basalts invaded the lake, and tuffs were deposited along its western margin.

Following on the inter-volcanic sediments there was another basaltic flow from the north, this time slightly more alkaline and interspersed by the deposition of volcanic ashes and tuffs. Judging from the higher alkalinity of the rocks, several small bodies of analcite-olivine basalts were intruded all over the area at this time, occurring in the Basement System south of the present area, in the vicinity of Gochodin and in the inlier in the north-eastern corner

of the area. Extensive trachybasalts were then extruded over the basaltic sequence emanating from numerous dykes and several small intrusive bodies. This formation also thickens to the south-east so that it is represented by thick layers at Nakuagale, but if it reached north of Loperot it has since been removed by erosion. The intrusion of trachybasalt dykes seems to have been accompanied by greater intensity of faulting, mainly along the north-westerly direction along which the dykes and small bodies are aligned.

How much of the area was covered by the succeeding Plateau Phonolites is conjectural, as these rocks now only cap the basaltic hills on the western side of the volcanic area, but it is certain that, as there are no phonolitic dykes in the area, and from the distribution of the phonolites elsewhere, the phonolites invaded the area from the south. It also seems probable that a period of erosion, during which some of the trachybasalts were removed, preceded the extrusion of the Plateau phonolites.

The main period of volcanic eruption ceased with the extrusion of phonolites and was then followed by intense fracturing in a north-north-easterly direction, causing the Miocene sediments and volcanics to assume their present disposition. Further south phonolitic trachytes were intruded into the basalts there in the form of dykes and small bodies which sometimes domed the basalts. The phonolitic trachytes are frequently faulted and often show sheeting due to faulting during or immediately after intrusion, and it is thought that they were emplaced towards the close of Miocene faulting. Microfoyaite plugs, following on the trachytes and intruded along fault-zones, terminated the vulcanicity in the area.

The period of erosion which succeeded the volcanicity eventually produced a configuration of the area very similar to the picture presented today in which a widespread plain, the end-Tertiary erosion surface, was formed. Much of the surface was boulder-strewn and it also sloped away from the Kaimeruk hills which formed the water divide as at present, and the hills composed of lavas formed northerly striking ridges in the east, but drainage took place mainly to the north.

During or just before the Middle Pleistocene, further faulting disturbed the stable conditions of the end-Tertiary, and the peneplain was transformed into steps. The valleys of Lomenyenkoporat and Kerio rivers were obstructed to the north and north-east of the area and the waters ponded back to form two lakes separated by the Auwerwer–Loperot line of hills. The sediments in the eastern lake indicate fairly quiet sedimentation, but the vulcanicity to the east of the area is represented by inter-bedded volcanic ashes thickening to the east. The lake was inhabited by small fish and molluscs while horses and bovine animals roamed in areas adjacent to the lakes, as is indicated by the fossils collected from isolated lacustrine deposits on the Basement System further west. In the lake of the Lomenyenkoporat valley sedimentation was fairly rapid and much of the material deposited was contributed by the newly formed scarps along the east of the Kaimeruk hills. Eventually, as this lake dried up, the Lomenyenkoporat river flowed north and joined the Turkwel river somewhere to the east of Lodwar. It also formed a pronounced river terrace along its western bank, but slowly migrated to the east until it encountered the resistant basalts and started incising its course. Large pediments formed on the eastern sides of the hill ranges, resulting in the piedmont plain east of the Kaimeruk hills and the desert pavements east of the lava hills. The Lomenyenkoporat river was captured north of the present area by a stream flowing directly into Lake Rudolf, while upstream it was captured at Loperot by the Kalabata river, resulting in the lowering of the base level of erosion and the re-excavation and removal of much of the material already deposited. Several other rivers flowing north were captured by east-draining streams, so that the direction of drainage was changed and is even now changing course so that the face of the Loperot area is continuously altered. At present much of the younger deposits are being removed by fluviatile agency after violent localized storms, while aeolian sands are invading the area from the east.

## IV—DETAILS OF THE GEOLOGY

### 1. The Basement System

Several geologists of the Kenya Geological Survey have commented on the fact that the Basement System is a stratiform sequence of successive layers of differing lithology, persistent over long distances along the strike regardless of present disposition and structure. There can be no doubt that it represents a sedimentary succession which has been subjected to granitization and metamorphism of a high degree.

In the course of mapping the Basement System in the Loperot area it became increasingly evident that the sequence mapped previously in the Namanga–Bissel area (Joubert, 1957) is also represented here. The existence of an upper fine-grained pelitic series with crystalline limestones and quartzites overlying a series of coarse gneisses containing prominent amphibolitic bands, and the fact that these two groups are separated by leucocratic banded biotite gneisses or migmatites with semi-pelitic host-rocks in both areas cannot be fortuitous. It is also stated (Joubert, *op. cit.*, p. 31) that there is marked increase in granularity of the gneisses where they are lighter in colour below the Turoka Series, which is also distinctive in the Loperot area, so much so that the difference is immediately evident in the field. Other features common to the rocks in both areas are the occurrence of two prominent hornblendic gneiss horizons in the lower group, the biotite schists at the top of the banded gneisses separating the upper and lower groups, as well as kyanite, which in Loperot is represented by either sillimanite or corundum and graphite in the lower parts of the Turoka Series.

Parkinson (1913) designated a group of altered sediments occurring in the Turoka and Bissel areas as Turoka Series, a name which has now been extended to cover that part of the sequence in the Basement System which contains numerous crystalline limestone horizons. The sequence in the Namanga–Bissel area has since been defined and it is now proposed to extend the stratigraphical succession lower down in the sequence, as this part of the Basement System forms the main part of the succession in the present area. For several reasons it is now apparent that the banded biotite gneisses (migmatites with semi-pelitic host-rocks on the map) of the Namanga–Bissel area forms the base of the Turoka Series and not the top of the "Lower Banded Gneiss Group". In several places in the Loperot area there are indications of transgression of the semi-pelitic rocks onto the amphibolitic gneisses of the lower group and the nature of the rocks indicates a break in sedimentation. The succession referred to as the "Lower Banded Gneiss Group" at Namanga will here be referred to as the Kaimeruk Series.

Very little can be gained from the patchy exposures of the Turoka Series in the Loperot area, and it is certain that only the lowermost members of it occur here, whereas a fairly complete sequence for the Kaimeruk Series could be obtained although the base could not be defined. The general sequence with roughly approximating thickness is as follows:—

| | *Thickness Feet* |
|---|---|
| Turoka Series | |
| 2. Pelitic biotite gneisses, sillimanite and graphite gneisses and schists, crystalline limestones and minor quartzites .. .. .. .. | ? |
| 1. Leucocratic semi-pelitic biotite gneiss with mesocratic biotite and hornblende gneiss lenses .. .. .. .. .. .. | 300–500 |
| Kaimeruk Series | |
| 5. Main amphibolitic band with many serpentinite and other ultrabasic intrusives and occasional small crystalline limestones. One prominent granitoid gneiss band .. .. .. .. .. | 350–800 |
| Hornblende-biotite gneiss underlying in the east .. .. .. | 0–1100 |
| 4. Granulitic biotite gneiss .. .. .. .. .. .. | 400 |
| 3. Plagioclase amphibolites with minor hornblende-biotite gneisses, calc-silicate granulites and occasional basic intrusives .. .. | 3,500 |
| 2. Brown-weathering biotite gneiss .. .. .. .. .. | 700 |
| 1. Biotite migmatites .. .. .. .. .. .. .. | 1000 exposed |

It is uncertain where the gneisses of the inlier of Basement System in the north-eastern corner of the area fit into the succession, but they are thought not to belong to the Turoka Series as the rocks are hard and coarsely crystalline and have a siliceous appearance which is typical in parts of the Kaimeruk Series.

### (1) Kaimeruk Series

(*a*) The lowest horizon of the Basement System exposed in the Loperot area crops out just south of the area to the south-east of Gochodin and also forms the highest ground of the Kaimeruk hills. In comparison with the biotite gneisses generally encountered in the area, these gneisses do not form topographically prominent features, except for the residual peak of Kaimeruk itself. Streaks and small lenses of dark hornblendic rocks are not rare, but the poorly developed banding and irregularity of form assumed by the leucocratic material metasomatically introduced, obscure the strike and dip of the gneisses. In specimen 18/485* collected about five miles south-east of Gochodin, vague foliation is noticeable in the orientation and concentration of small biotite flakes. The groundmass of quartz and felspar is fairly fine-grained, but the large vein-like pinkish knots of introduced pegmatitic material are coarse and discordant. Under the microscope it is seen to consist of microperthite, microcline, myrmekite, oligoclase, quartz and biotite. Green hornblende, a minor constituent, occurs as small green prisms, while accessory apatite and magnetite complete the composition of the rock. Although not noticeable macroscopically, specimen 18/481 from the peak of Kaimeruk also contains a little hornblende, but here it is altered and contains small ferruginous granules along the cleavages. In hand-specimen this rock is much darker than the gneiss described above and banding is even less distinct. The weathered surface, however, shows fairly obvious thin light-coloured zones. The potash felspar in this rock is untwinned and is cloudy in parts due to alteration. Sericite and calcite are seen as alteration products of the potash felspar, while oligoclase is only slightly altered along cleavages and around peripheries of crystals. The biotite forms fresh brown flakes and the quartz is distinctly strained. Apatite again appears as an accessory mineral.

(*b*) The succeeding horizon, a brown-weathering biotite gneiss, could be distinguished east of Gochodin as a line of small isolated hills, but is not evident in the Kaimeruk hills. It is a fairly leucocratic gneiss, similar to other gneisses in other parts of the sequence, and also contains small amphibolitic lenses.

(*c*) The basal member of next group in the succession is a distinctive coarsely spotted grey biotite-hornblende gneiss. This group consists mainly of plagioclase amphibolites with calc-silicate granulites and rare concordant basic intrusives, and is again terminated at the top by a thin band of the distinctive biotite-hornblende gneiss. The difference between this amphibolitic group and the main amphibolitic band higher in the sequence lies in the frequency of garnetiferous rocks as well as a greater number of interbedded biotite gneisses and granulites in the lower amphibolitic group.

Typical rocks of this band were all collected in the vicinity of Gochodin and they consist mostly of banded plagioclase-amphibolite gneisses which are similar to the striped hornblendic rocks described by Shackleton (1946, p. 13) for the Maralal area. The biotite gneiss horizons all carry some hornblende in their composition and are usually separated by and include numerous thin amphibolitic bands and lenses. The coarse spotted hornblende-biotite gneiss of Gochodin (specimen 18/469) is the most distinctive horizon encountered here. Because of the coarseness and even granularity of the rock, foliation and lineation are both indistinct. Microscopically it consists of untwinned potash felspar, plagioclase determined as oligoclase-andesine, undulose quartz and ragged prisms of hornblende and flakes of biotite. The hornblende and biotite are usually associated to form aggregates of dark minerals in a granoblastic matrix of quartz and felspar. Myrmekitic intergrowths of quartz and plagioclase are occasionally encountered, while the cleavage traces and twinning lamellae of the plagioclase are often bent.

Another distinctive horizon occurring within this group is a garnetiferous granulite of which specimen 18/461 was collected one mile west of Gochodin. It is a medium-grained, vaguely banded, grey rock with small red garnets scattered evenly throughout. On the weathered surface the garnets appear black, while the rest of the rock weathers to a light colour, making this rock easily recognizable in the field. Under the microscope it is seen to consist of small irregularly shaped crystals of green augite and hornblende, occasional small rounded pink garnets with poikilitic inclusions of quartz, and fairly large aggregates of magnetite in a granoblastic matrix consisting of pools of strained quartz with oligoclase-andesine and untwinned potash felspar. Apatite and zircon occur as accessory minerals.

*Numbers 18/485, etc., refer to specimens in the regional collection of the Geological Survey, Nairobi.

(*d*) Where exposed, the overlying granulitic biotite gneiss becomes topographically prominent. It is usually quite thin but often forms a series of parallel ridges where it has been repeated by isoclinal folding. In the Gochodin area it forms the hills on both sides of the river as well as the prominent ridges of Lokhosiniogurr and west of Lokhosiniogurr, and is mainly responsible for the steep slopes surrounding the Kaimeruk hills. The main ridges from Buradyakim to Kwetchuk and the southern extension of the Kaimeruk group of hills is composed of this horizon. The gneiss of this horizon is normally leucocratic and hard, and where it has been folded severely it becomes granulitic.

Specimens collected along this horizon are remarkably alike in having a white to pink colour, are even-grained and usually hard, but become friable on weathering. Under the microscope specimens 18/490 from the hills of the southern extension of Kaimeruk, and 18/492 from Kwetchuk appear identical, except that the latter rock contains occasional flakes of biotite which are absent from the other. Otherwise both specimens consist of an equigranular mosaic of microcline, microperthite, quartz and oligoclase with some magnetite or hematite, occasional apatite, and small rounded zircons. Secondary minerals noticed include opal, chalcedony, calcite, sericite and rarely muscovite. The upper part of this horizon becomes richer in biotite and sometimes has large scattered garnet crystals.

(*e*) The succeeding main amphibolitic horizon proved to be the most useful marker in the area, as it has several distinctive features distinguishing it from all other horizons. It is nearly devoid of leucocratic beds and includes all the serpentinites and nearly all other basic intrusives found. It further distinguishes itself by including small lenses of impure crystalline limestones and very often the uppermost horizon is a distinctive fine-grained melanocratic garnetiferous biotite gneiss. Like the lower amphibolites, the main amphibolite horizon can be delineated by its dark red soil cover in areas of poor exposure.

In the folds to the east of Lokhosiniogurr the main amphibolitic horizon is underlain by an appreciable thickness of hornblende-biotite gneisses which do not appear west of this hill, and also, together with the amphibolites, thin out to the east. The hornblende-biotite gneisses are spotted with clusters of amphiboles and shiny black mica flakes evenly distributed in the quartz-felspar mosaic. The microscopical description is identical with that of specimen 18/469 (p. 12), and this rock-type is thought to have originated by the granitization of the amphibolites.

The sequence in the main amphibolitic horizon is normally commenced by a biotite gneiss which is very similar to the gneiss forming Kaimeruk peak. In specimen 18/477, collected four miles south of Kaimeruk peak, the pinkish felspathic material is rodded and imparts lineation to the rock, while the foliation is still vague. Microscopically it is seen to consist of a granoblastic matrix of untwinned potash felspar, oligoclase and quartz with poorly formed flakes of biotite. Small granular patches of epidote are seen, one group enclosing a crystal of pink thulite, while green hornblende forms an accessory mineral. Other accessories, associated with or poikilitically enclosed by biotite, are apatite, sphene and magnetite.

Typically the rocks of the main amphibolitic group are red-weathering black or greenish black, finely banded, fine-grained plagioclase amphibolites. Banding is pronounced in most cases, usually depending on the ratio of dark- to light-coloured constituents, but lineation is usually either vague or non-existent, and is only rarely distinct as in specimen 18/404 collected three miles south-west of Lokichar. The basic intrusive bodies emplaced along the main amphibolitic horizon are always sheathed by plagioclase amphibolites and it is thought that most of the rocks found here have been derived from these basic intrusives and their volcanic counterparts. The amphibolitic rocks are composed of hornblende, augite and plagioclase. The hornblende is of the green variety, rarely showing a brownish tinge and occurs as subhedral prisms or sometimes as aggregates of euhedra. Occasionally the parallel orientation of the hornblende prisms impart linearity to the rock and, as hornblende is the major constituent, it sometimes comprises as much as 75 per cent of the total composition. In the majority of cases the pyroxene is pale green, slightly pleochroic augite which occurs as stout subhedral prisms edged or irregularly replaced by hornblende. In specimen 18/404, mentioned above, the pyroxene was determined as being diopside, but the pyroxene is a minor constituent, and may be as little as 2 per cent of the total composition of the rocks. In all cases the plagioclase proved to be labradorite, forming the granoblastic groundmass for the dark minerals. The felspar plates, usually varying greatly in size and shape, are

fresh, well-twinned and often distinctly zoned. Accessory constituents are few, but apatite, magnetite and in one case sphene, were found. In specimen 18/407, found in the lower Kalokhole valley, epidote is also present as equidimensional grains, sometimes replacing augite, or as large anhedra in association with a little quartz.

A variety of quartzo-felspathic and calc-silicate granulites are also frequently encountered along the main amphibolitic horizon. They vary widely in appearance and mineralogical composition, and form lenses within the amphibolites and occasional interbedded biotite gneisses. A grey compact, rather nondescript granulite (18/465) was collected two miles south of Lokichar. Although banding is not seen in the hand specimen, it is distinct in the thin section by the elongation of quartz, untwinned potash felspar and plagioclase, as well as by the orientation of altered flakes of biotite. The plagioclase is determined as oligoclase and nearly all the biotite is seen altered to a dense chloritic mass containing numerous ferruginous globules. Apatite and magnetite are present as accessory minerals, while thin sericite veins replace the felspar. One mile further west, a calc-silicate granulite (18/411) was collected which is a dark grey rock with a fine sugary texture and a rough black weathered surface. The texture under the microscope is seen as finely granoblastic, formed by epidote aggregates, stringers of pink garnet, pale green augite in a matrix of labradorite and scapolite. Sphene is the only accessory mineral and small amounts of calcite patchily replace the felspar. Other granulites of this horizon were found where the beds have been intensely folded, and they have distinctively spotted weathered surfaces. Specimen 18/414 from four miles west of Kaimeruk peak, is a grey finely granular rock with large green spots which are seen under the microscope to consist of large diablastic crystals or aggregates of actinolite and epidote in a granular mosaic of bytownite. This felspar is found also in a similar granulite (18/415), collected five miles north-north-east of Murilling hill, but this rock consists only of granoblastic aggregates of equidimensional crystals of clinozoisite and plagioclase. The only other mineral is green spinel occurring as a few small grains associated with the clinozoisite.

Small lenses of impure crystalline limestones are infrequently found along this horizon. It is possible that more occur than shown on the map, where they have been exaggerated in size, as they are so small and therefore easily missed. Such an impure marble was collected about one mile west of Kwetchuk hill where the amphiboles and mica are seen as black stringers, parallel to the lineation of the marble. Under the microscope the rock is seen to consist of a sutured mosaic of dense calcite containing small idiomorphs of diopside, flakes of phlogopite and some green spinel. The phlogopite is pleochroic from pale brown to colourless and the diopside sometimes has poikilitic inclusions of epidote, while small apatites are rare. Specimen 18/440, from four miles south of Gochobolok hill, is a greyish green coarse crystalline limestone containing in thin section large idioblasts of diopside which in parts is being replaced by tremolite with the release of calcite and small pools of quartz.

The crystalline limestones which occur as small lenses in the amphibolites of the Kaimeruk Series are indistinguishable from those of the Turoka Series. The crystalline limestones on the western boundary of the area on the track west of Lokichar, are taken as belonging to the main amphibolitic group, only because they are thin, impure and interbedded with amphibolitic rocks. Specimen 18/436 collected here, is coarse and white, with small yellowish grains and aggregates of green crystals. Vague banding is caused by the concentration of dark minerals and difference in coarseness of crystallinity. In thin section perfectly rounded grains of forsterite altering along the cleavage to antigorite, small anhedra of diopside and scarce tremolite are seen in a coarse granoblastic matrix of calcite. Specimen 18/437 from the same locality is much finer grained, and brown phlogopite flakes, tiny yellowish brown grains of forsterite and large equidimensional crystals of diopside are seen as impurities in the hand specimen. The rock displays a typical rough limestone weathering with aggregates of impurities forming knobs on the surface. In thin section the forsterite is seen partly replaced by antigorite and showing a reaction corona of diopside between the antigorite and the calcite of the matrix. Diopside is always found in association with forsterite, either occurring as described or forming stout idioblasts in aggregates with forsterite. Phlogopite is present as small books while apatite forms small rounded grains. A tremolite-calcite granulite (specimen 18/456) also collected here consists of large crystals of tremolite which are broken up by alteration to calcite, so that it now appears as islands in a calcite matrix. A few flakes of muscovite associated with some talc are present, and the calcite has recrystallized in parts to form clear lenticular crystalline veins in the dense calcareous matrix.

Biotite gneisses of the main amphibolitic band are usually coarse, fairly leucocratic and nearly always contain some hornblende. The conical hill of Gochobolok has two prominent granitoid gneiss bands, one of which forms the peak in the form of a hogsback. From the structure in this region it has been deduced that the two bands are the same horizon which has been isoclinally folded. This hard band is found as lenses along the main amphibolitic band and forms distinctive hogsbacks and exfoliation domes such as the small steep hills west of Kwetchuk-Buradyakim ridge and those of the Lobopakeya hills. In hand specimen (18/486) the granitoid gneiss from Gochobolok is leucocratic with large white and yellowish patches of felspar and quartz in a fine-grained biotite-rich matrix in which vague banding can be seen. Microscopically it is seen to consist of a fairly even-grained mosaic of quartz, oligoclase, microperthite and a little microcline, and biotite. The potash felspars are somewhat altered, sometimes with a little muscovite forming. Biotite-rich gneisses and schists are often found at the top of the amphibolitic band, indicating the base of the Turoka Series.

### (2) Turoka Series

Sub-division of the Turoka Series in the Loperot area is not as readily accomplished as that of the Kaimeruk Series, for the outcrop areas are lens-like in character due to their occurrence in the cores of tight synclines enclosed by rocks of the Kaimeruk Series. The structure and sequence of the Turoka Series rocks is complicated to such an extent that only a generalized division is possible. It is possible to distinguish between lower leucocratic and upper darker micaceous parts however, the latter having all the distinctive features considered to be typical of the Turoka Series of the type-area (Joubert 1957, p. 32), such as crystalline limestones, quartzites, and minerals like sillimanite, kyanite and graphite.

(*a*) Typically the rocks overlying the main amphibolitic band are friable leucocratic migmatitic biotite gneisses, and often contain small irregular lenses and "schlieren" of amphibolitic gneisses. The main part of this band is normally topographically prominent, forming low ridges along the strike, while higher the rocks become richer in biotite and sometimes contain some hornblende. In the vicinity of Kwetchuk hill it also includes a distinctive amphibolitic band, which is not noticeable to the south. In the north-western part of the area this basal member of the Turoka Series could not be separated from the rocks overlying it, as the increase of biotite there renders the two types indistinguishable. This band is still present there, however, because certain rock types typical of this horizon were found near Namurutom hill.

At the contact with the main amphibolitic horizon, the sequence of the Turoka Series very often commences with thin biotite-rich gneisses or coarse biotite schists, which are sometimes garnetiferous. Specimens 18/474 and 18/462, from two miles and five miles west of Kwetchuk hill respectively, were collected at the base of the Turoka Series. The first is a fine-grained dark mica schist with red garnet porphyroblasts flattened parallel to the foliation. Under the microscope it is seen to consist of irregularly shaped flakes of olive-green biotite, rounded porphyroblasts of garnet and some yellowish green hornblende prisms in a fine-grained granoblastic matrix of andesine and quartz. The garnets sometimes contain poikilitic inclusions of felspar and quartz and the accessory minerals present are apatite, rutile and magnetite, the latter mineral being occasionally edged by hematite. Specimen 18/462 is also fine-grained, but is lighter in colour having less biotite, and the garnets are small and weather out, producing a finely pitted surface. Here the felspathic content is microperthite, microcline and oligoclase with some myrmekite. Apatite is the only accessory mineral present and the alteration of the potash felspars produces a little sericite and muscovite.

The main rock type of this band is distinctly banded, with alternating white, thin biotite-rich layers. The development of felspar porphyroblasts and small irregular quartz veins impart a granitoid appearance to the rock. Lineation is ill-defined and produced by streaks of aggregates of biotite or by elongated leucocratic minerals. Elongated stringers of garnets are sometimes present, and in the small hills two miles west of the southern Lobopakeyu hills the stringers are of allanite. When biotite is absent as in specimen 18/493 collected two miles west of Lopatamuthingo, the gneiss takes on a granulitic appearance, with only the quartz-rich layers imparting a faint banding. Microscopically it consists of microcline, oligoclase and quartz, with minor amounts of microperthite and some muscovite and magnetite. In specimen 18/482 collected just west of the south-western corner of the area, biotite is present and occurs along fine-grained bands in a mosaic of felspar and quartz.

The quartz pools are elongated parallel to the banding and show undulose extinction, and in addition to the minerals described above it also contains a few small grains of zircon. Granitization of this horizon also produces muscovite migmatite, which contains large pink felspar porphyroblasts and flakes of muscovite. Specimen 18/494, collected four miles south-south-west of Lopatamuthingo, is an example of this migmatite variety, and in thin section is composed of microcline, microperthite, oligoclase, quartz, muscovite and rare altered flakes of biotite.

It is notable that actinolite-tremolite-talc rocks are distinctive of the lower part of this band. These rocks are usually bright green in colour, but weather red and are therefore unmistakable in the field. Unfortunately they are not continuous along the strike, being lens-like in character, and appear in isolated localities always in the same stratigraphical position. Typically the rocks consist of radiating fibrous masses of tremolite interspersed with aggregates of acicular actinolite prisms, with the ratio of tremolite to actinolite variable. This is seen in the thin section of specimen 18/420 from four miles west of Murilling hill, which also contains small interstitial patches of talc. Specimen 18/417, collected three miles south-west of Kwetchuk hill, is banded and the parallel orientation of the prismatic crystals imparts a strong lineation to the rock. The section was cut perpendicular to the lineation so that the texture appears granoblastic showing equidimensional crystals of tremolite and actinolite with only rare prisms, and some magnetite in clusters of anhedral grains. The same mineral composition is seen in specimen 18/418 from the same locality, but specimen 18/419 from four miles west-south-west of Kaimeruk peak has very little tremolite as occasional needles in a granular mosaic of faintly pleochroic pale green actinolite. Specimen 18/416, collected three miles south-west of Murutom peak, is greenish brown to yellow in colour and is vaguely foliated, containing radiating masses of fibrous tremolite in soft green talc. Under the microscope sheaves of tremolite needles are seen with a vague linear orientation, embedded in a groundmass of talc. Limonitic patches and occasional flakes of hematite occur along the cleavages of the talc while occasional grains of magnetite can be seen in the talcose groundmass.

Specimen 18/438 collected four miles west-north-west of the Lobopakeyu hills, is a light greyish green coarsely crystalline granulite. It also occurs at about the same stratigraphical position in the lower group of the Turoka Series as the tremolite-actinolite schists, and is seen in thin section to consist of diopside, some of which forms fairly large euhedra, calcite in irregularly shaped pools, prismatic tremolite crystals and small patches of quartz. Tremolite is seen replacing diopside, sometimes as complete pseudomorphs so that the cleavage traces now form an oblique angle with the crystal faces. Calcite is also being formed at the expense of diopside which it is irregularly replacing along cracks. The actinolite-tremolite rocks described above are thought to have been derived from ultrabasic intrusives, but specimen 18/438 seems to have originated from a dolomitic limestone.

(*b*) The upper part of the Turoka Series is very similar to the type-section in the Namanga–Bissel area (Joubert 1957, p. 31). The following generalized sequence could be deciphered in the Murilling hills and in the syncline to the west of Lopatamuthingo:—

7. Dark pelitic biotite gneiss.
6. Porphyroblast gneisses between plagioclase amphibolites.
5. Sillimanite schists and gneisses with one thin quartzite, amphibolites which are sometimes garnetiferous, and a quartzo-felspathic gneiss.
4. Graphitic gneisses with or without sillimanite.
3. Three crystalline limestone horizons separated by pelitic schists and gneisses. The lowest horizon is lens-like and discontinuous; the middle horizon is the thickest and most constant while the upper crystalline limestone increases in thickness southwards and becomes the most important marble in southern Murilling hill, south of the present area.
2. Sillimanite schists and gneisses.
1. Leucocratic biotite and muscovite gneisses.

The biotite gneisses of the Turoka Series can easily be distinguished from those underlying them in being much finer grained and containing a greater proportion of biotite. Microscopically they distinguish themselves, apart from often containing minerals like sillimanite and graphite, by having relatively large amounts of the accessory minerals sphene, apatite

and zircon, and usually by the preponderance of plagioclase over potash felspar. Under the microscope these gneisses are fine-grained, granoblastic, and consist of plagioclase, quartz and potash felspar containing ragged flakes of brown biotite. The plagioclase is nearly always oligoclase, but was found to be andesine-oligoclase in specimen 18/470, collected three miles south of the Lobopakeyu hills, and andesine in specimen 18/471 collected five miles west of Lokichar. The potash felspar is usually untwinned, but microcline was noticed in some of the thin sections. Hornblende is sometimes sparingly present lower in the sequence and in specimen 18/471 mentioned above it contains small poikilitic inclusions of quartz and felspar, a feature also noticed in the biotite here. Apatite is nearly always fairly abundant forming stout euhedral prisms, while sphene occurs in aggregates, usually associated with some ilmenite. Zircon occurs as well-formed prisms or as rounded grains. Muscovite is usually present in small amounts replacing the potash felspar, and opal forms interstitial patches in specimen 18/476 from three miles south-west of Gathuroi hill.

Higher in the sequence of the Turoka Series the biotite gneisses show felspar porphyroblasts, and in the syncline to the west of Lokhosiniogurr a relatively thin band of augen gneiss is widely exposed because of its position in the core of the syncline. Specimen 18/478, collected three miles north-west of Lopatamuthingo peak, is a fine-grained biotite gneiss, typical of the Turoka Series except that it has distinctive porphyroblasts of oligoclase and microperthite. The cleavage traces and twinning lamellae of the plagioclase porphyroblasts are often distinctly bent, and these porphyroblasts are smaller than those formed by microperthite. Specimen 18/484, collected one and a half miles further west, has been granitized to such an extent that the banding has been destroyed and is now coarse-grained with large felspar phenocrysts, and consists of a granoblastic mosaic of microcline, microcline microperthite, myrmekite, oligoclase, greenish biotite associated with sphene and small flakes of secondary muscovite. A little apatite and some magnetite are present, usually aggregated with biotite. Overlying this porphyroblastic gneiss is another amphibolitic band followed by a remnant of a dark pelitic gneiss which is the uppermost horizon of the Turoka Series seen in the Loperot area.

Amphibolitic rocks are prominent in the Turoka Series. They are lens-like in the south but are conspicuous in the north-western part of the area, where it is often impossible to distinguish them in isolated outcrops from the amphibolites of the Kaimeruk Series. A most distinctive specimen (18/406) was collected in the hills four miles north of Murilling hill. This amphibolite is a hard finely banded black gneiss seen under the microscope as a fine-grained granoblastic mosaic of quartz and labradorite, with hornblende forming imperfect prisms and fibrous patches, the orientation of which impart a lineation to the rock. Vague banding is seen in the distribution of small rounded magnetite grains vaguely concentrated along zones. The other mineral recognized is apatite as an accessory mineral. Normally quartz is absent in these rocks and epidote is sometimes sparingly present. Calc-silicate granulites are infrequently found along the amphibolitic horizons and one such a rock was collected four miles west of Sabaa hill. It is sugary-textured, brownish red with green granular streaks of pyroxene and white streaks of calcite. The thin section shows anhedra of pink garnet, pale green augite, quartz and scapolite as a granoblastic mosaic, with sphene and apatite as accessory minerals.

When sillimanite appears in the pelitic gneisses of the Turoka Series it often imparts a lineation to the rock. Specimen 18/447, collected four miles west of Kamunono, contains green sillimanite which, under the microscope, appears in colourless sheaves forming bands alternating with quartz and potash felspar with an association of biotite and magnetite. The biotite is brown in colour and a little muscovite is seen replacing the sillimanite. In specimen 18/460 collected four miles north of Murilling hill, the sillimanite again is responsible for the well-lineated appearance of the rock, which is similar to the rock described above except for the presence of a little oligoclase. Specimen 18/458, a garnet-sillimanite-quartz schist from Murilling hill, is a fine-grained red and white banded rock showing fine needles of sillimanite on the foliation surfaces and some garnet porphyroblasts. In thin section it is seen to consist of large pink garnets, sometimes with poikilitic inclusions of quartz and hematite flakes in cracks, in a sutured mosaic of undulose quartz. Sillimanite, as indistinctly orientated slender prisms and needles, occur in bands, curving around garnet porphyroblasts or enclosed by quartz. These gneisses sometimes contain corundum and along valleys draining these horizons brown corundum crystals are often found concentrated in the coarser alluvium of the rivers. Large corundum crystals are also encountered in the leucocratic pegmatitic material in these gneisses. A corundum-bearing schist (18/455) was

found at Murilling, showing growths of white felspar nodules the larger of which are cored by corundum. These nodules form a distinctive knobby weathered surface on the rock. The thin section has no corundum, the rock being composed of microcline, microcline-microperthite, microperthite and oligoclase containing small flakes of biotite, while other parts of the thin section are made up of large flakes of muscovite with poikilitic inclusions of potash felspar.

Graphite is prominent in the southern exposures of the Turoka Series, but only infrequently encountered further north, where it also serves to distinguish the Turoka from the Kaimeruk Series. Sillimanite still appears in these rocks but its place is usually taken by muscovite. Typically the graphitic rocks of Murilling hill are very dark with a large proportion of graphite, often showing white to greenish prismatic muscovite crystals of random orientation. In thin section these schists exhibit a granoblastic matrix of quartz and microcline containing large flakes of graphite, numerous flakes of muscovite or biotite, and rarely a little plagioclase. Isotropic material thought to be opal, occurring in irregularly shaped patches, is normally present also. Sillimanite, when present, appears as tufts of needles associated with muscovite, or as acicular remnants enclosed by muscovite. In specimen 18/453 from Murilling hill, small graphite flakes occur scattered throughout the potash felspar, and in specimen 18/454 from the same hill, the graphite and muscovite flakes are often curved forming curious swirl structures, which can probably be ascribed to rotation during growth. In this rock opal is not present and its place is taken by a yellowish dense amorphous aggregate which sometimes contains tiny granular crystals of epidote. In the Murilling area graphite-rich lenses, appearing in the hand specimen to consist of pure graphite, are found interbedded with the other graphitic gneisses. Under the microscope, however, they are seen to contain quartz, felspar and flakes of biotite and hematite, in addition to the graphite. Further north in the Turoka Series graphitic rocks are thin and uncommon, but they still have the same mineral assemblage and can be used as markers near the base of the Turoka Series.

The marble found in the Turoka Series is not nearly as impure as those of the Kaimeruk Series and is usually greyish white, with vague banding produced by bands of varying grain size or by the concentrations of small amounts of dark minerals. Under the microscope they are seen to consist of granoblastic magnesian carbonate with a few flakes of phlogopite and some small grains of diopside.

Quartzites are only infrequently encountered in the present area, all of them occurring as small lenses in the vicinity of Murilling hill. The quartzite (18/443) found four miles north of Murilling hill, is coarsely crystalline and translucent. Under the microscope it is seen to contain a little microcline microperthite, albite and some replacive muscovite in a coarse sutured mosaic of strained quartz. Specimen (18/444) from four miles west of Murilling is brownish grey, coarsely crystalline, and with soft ferruginous lines and aggregates elongated parallel to the "bedding" produce a pitted brown weathered surface. Under the microscope the quartz is seen to contain parallel lines of tiny inclusions passing from one crystal to the next without regard to crystal boundaries. Garnet is also present as small well-developed crystals occasionally associated with some magnetite. In specimen 18/445 from Murilling hill, garnet is also present, but forms vein-like aggregates in the granoblastic quartz matrix. Other impurities here are muscovite, magnetite and hematite, while the whole rock is stained brown by limonite. Microlites in the quartz have been determined as muscovite and only occasionally as zircon or colourless spinel.

### (3) The Basement System Inlier at Lokhone

Although the rocks of this inlier are covered by pebble sheets, they are remarkably well exposed, and by following along the strike until an exposure is found every inch of the ground can be mapped. There can hardly be any doubt that the rocks here belong to the Kaimeruk Series, but as the same beds are repeated several times, the succession here is too restricted to allow exact correlation with the sequence deciphered in the Kaimeruk hills. It is thought that the amphibolitic band here is the same as the lower amphibolitic band outcropping at Gochodin. The sequence is as follows:—

3. Biotite gneiss with a prominent calc-silicate granulite near the base and a distinctively spotted augite gneiss band higher.
2. Amphibolitic band, bounded by wide plagioclase amphibolite bands both below and above; 1,200 ft. thick.
1. Biotite-hornblende gneiss with one distinct plagioclase amphibolite bed and numerous quartz veins. A thickness of at least 3,000 ft. is exposed.

(*a*) The lower gneiss group has a granitoid or sometimes granulitic appearance. Specimen 18/487 from Lokhone hill is an even-grained hard coarse siliceous-looking rock with patchy distribution of the dark minerals, and consists of a granoblastic matrix of microperthite, oligoclase and quartz containing greenish biotite, hornblende and magnetite. A granulite (18/463), also collected at Lokhone, has approximately the same composition but contains a few garnets instead of hornblende.

A calc-silicate granulite from Lokhone (18/412) is an olive green rock with coarse white spots associated with garnet. Under the microscope it appears as a granoblastic matrix of bytownite and scapolite containing large and small equidimensional subhedral to euhedral crystals of faintly pleochroic epidote. Small dark green clusters are formed by diopside and occasionally hornblende, while sphene and calcite are also present.

(*b*) The amphibolitic beds are very prominent as their black outcrops contrast with the white ubiquitous pebble sheets. A typical rock from this band is specimen 18/403, from three miles north-north-west of Lokhone, which is a coarse-grained, greenish black amphibolite with yellowish green greasy-looking "schlieren". Some garnet is seen in the hand specimen and it also contains small specks of chalcopyrite and pyrite. In thin section it appears as a granoblastic aggregate of green hornblende, diopside, labradorite, garnet, epidote and minor magnetite, calcite and apatite. The garnet forms irregularly shaped grains, usually enclosed by plagioclase and the epidote is present as aggregates of small grains. Along this band leucocratic gneisses are rare, but when they do occur, they are hornblendic and sometimes garnetiferous.

(*c*) The gneisses overlying the amphibolitic band are usually pink coarse-grained biotite gneisses consisting typically of microperthite, microcline, oligoclase, quartz and biotite with accessory zircon. Quartz is sometimes seen forming stringers parallel to the banding, while calcite and muscovite are secondary products. Specimen 18/488 collected from the same horizon about four miles north-north-west of Lokhone hill has tiny red garnets distributed evenly throughout the rock, and a few grains of apatite. These gneisses contain two distinctive bands, both of which are constant along the strike, the lower being a calc-silicate granulite and the upper a distinctively spotted garnetiferous augite gneiss. The calc-silicate granulite (18/413) consists of granular aggregates of epidote, large irregular garnets with poikilitic inclusions of epidote and quartz, and a little diopside as clusters of small grains in a groundmass of labradorite. There is a fair amount of sphene present, usually associated with diopside, and a few small prisms of zircon enclosed by felspar. The spotted garnetiferous augite gneiss horizon (18/464) is very thin, but it has a characteristic field appearance. The light-coloured fine-grained matrix contains lenticles of dark minerals, and under the microscope is seen to be a granoblastic matrix of quartz, andesine and occasional large potash felspar anhedra with irregular crystals of augite, in parts uralitized, and large rounded garnets with poikilitic inclusions of quartz. Ilmenite rimmed by colourless sphene and some apatite are the accessory constituents present, and a little sericite occasionally occurs along the cleavages of the felspar.

## (4) Intrusive Rocks

### (*a*) *Pegmatites and Quartz Veins*

*Quartz veins* are not numerous in the area, but it is of importance to note that they were intruded prior to the period of major deformation of the area. It is also remarkable that in two localities where quartz veins feature fairly prominently, they were intruded along hornblendic horizons. In the Lokhone area where they are most numerous and occasionally occur in the form of giant veins, they are concordant to the foliation of the host rocks and can often be followed around the closures of the major folds. There is no doubt that they are of intrusive origin as they often contain a few large felspar phenocrysts which weather out, leaving crystal-shaped holes in the quartz. It is also clear that they were intruded prior to the emplacement of the serpentinite body three to four miles south-west of Lokichar, as xenoliths of vein quartz occur in the serpentinite there. The quartz loses its translucency, becoming milky white, and the xenoliths are surrounded by a felted corona of dark green acicular actinolite. The milky white colour may be ascribed to the numerous small inclusions in the quartz seen under the microscope. Several samples of quartz veins were crushed and panned and were found to be barren, but they often showed green copper staining and in one instance, about three miles south-west of Lokichar, a quartz vein contains small aggregates of bornite and chalcopyrite.

*Pegmatites* of the present area are of the types normally found in the Basement System described severally by geologists of the Kenya Geological Survey, and are only mentioned here because they assist in deciphering the geological history of the area. The strike of the intrusive pegmatites are most commonly concordant with the strike of the country rock and in these cases they frequently show the development of lineation, the direction of which concurs with the lineation direction of the country rock. It is clear therefore that these pegmatites are the oldest, and were emplaced prior to the major deformation of the Basement System. Pegmatites also strike parallel to the faults and minor fractures found in the area, and it is significant that pegmatites striking N.40°W. to N.50°W. sometimes show the effects of shearing and brecciation, proving posthumous movement along the faults along which they were emplaced. About three miles south-west of Kwetchuk hill a pegmatite cuts the serpentinite body there and it therefore seems that intrusion of pegmatites occurred both before and after the emplacement of the serpentines. Magnetite is constantly found in the intrusive pegmatites, sometimes associated with green copper staining, and epidote nearly always appears in the pegmatites when they cut amphibolitic rocks. Pegmatitic stringers in the lowest migmatitic horizon of the Turoka Series also contains elongated nodules of allanite two miles west of the southern Lobopakeyu hills.

### (*b*) *Basic intrusives*

(i) *Meta-intrusives*. All meta-intrusives encountered in the area were emplaced along the amphibolitic bands of the Basement System. The numerous intrusives in the Kaimeruk Series are all ultrabasic in character, while one of the few intrusives found in the Turoka Series, a small gabbroic body one mile south-east of Gathuroi hill, still retains an intrusive character. The *hyperite* found here (18/396) cores a small anticline formed by the amphibolites sheathing the intrusive which is exposed in several patches as rounded black boulders. It also appears in the stream channel to the north where it is seen as a green altered rock with tiny veinlets of magnesite with flakes and small books of mica (vermiculite?). Green copper staining is often seen in the immediate vicinity of the intrusive, but no sulphide mineralization was noticed. From the disposition of the intrusive body it seems possible that it consists of several small pod-shaped lenses, orientated parallel to the strike of the country rock. Under the microscope the hyperite is seen to consist of large idiomorphs and small anhedra of hypersthene, stout prismatic subhedra of schillerized diallage which is edged by strongly pleochroic brown hornblende, and some accessory sphene in a xenomorphic matrix of labradorite. Some of the idiomorphs of hypersthene also contain schiller inclusions, while the plagioclase has minute fluid-pores and is distinctly zoned. Magnetite occurs only as an alteration product associated with hornblende.

Thin lenticular bodies, sometimes as thin green bands, are frequently encountered in the amphibolitic bands of the Kaimeruk Series. They are always granular and friable, so that it is impossible to collect samples for sectioning in most cases, and are of two types: first, they are sometimes amphibolites like specimen 18/402, from five miles north-north-east of Murilling hill, which is a green and red crudely banded rock which weathers black. The rough weathered surface reveals its coarse grain and lineation is poorly developed. In thin section it is seen to consist only of idiomorphic prisms of green hornblende of random orientation with a few small grains of magnetite. Other intrusives of similar appearance are pyroxenites usually consisting of diopside, hornblende and plagioclase with minor sphene, ilmenite or magnetite. *A hornblende pyroxenite* (18/405), collected just south of the present area about three miles east of Lurutum ridge, is a medium-grained greenish black rock seen under the microscope as a xenomorphic mass of stout, nearly colourless crystals of diopside, prisms of green hornblende and aggregates of small equidimensional crystals of hypersthene. Magnetite is the only accessory constituent present and occurs as small grains scattered throughout the rock. The *hornblende hypersthenite* (18/397) from the southern Lobopakeyu hills, occurs as a large black lens-shaped body fringed by plagioclase amphibolites. It consists of subhedral crystals of hypersthene which occur with and are being replaced by green hornblende. Occasionally prisms of hypersthene become disjointed by encroaching hornblende, while small and large irregular lumps of chromite, often enclosing or edged by green spinel, as well as magnetite in small rod-like bodies along cleavage traces of hornblende, form the accessory mineral content.

In the outlier of Basement System at Lokhone only one basic intrusive was found as a thin conformable band, two and a half miles south-east of Lokhone hill. Specimen 18/399 is a *diopsidite* composed of massive brownish green crystals containing small green and red

inclusions, and weathers to a rough grey surface. Under the microscope it is seen that the major constituents of the rock are large diopside crystals which are being replaced along the cleavages by pale green hornblende or calcite. Calcite also forms large nodules, the outer fringes of which are usually stained yellow by limonite. Small secondary veins and rounded growths of sutured mosaics of quartz, often cored by calcite, occur within the rock, while occasional small grains of magnetite occur only as an accessory mineral.

*Olivine hypersthenites* (bahiaites) form two distinctive reddish black ridges within the precincts of the syncline in the Turoka Series west of Lokhosiniogurr. The outcrops are unmistakable in their prominence and dark colour and the ridges are overgrown by a thick cover of low thorny scrub. The southerly intrusive (18/394) from four miles west of Lopata-muthingo peak, is a dark brownish grey coarsely crystalline rock which weathers to a rough brown surface. Under the microscope it is seen to have a xenomorphic granular texture composed of large crystals of hypersthene and diallage, large interstitial flakes of biotite, anhedral crystals of olivine and interstitial labradorite. Olivine is usually enclosed by hypersthene, the latter mineral together with magnetite forming a reaction rim between olivine and biotite. Biotite is replacing diallage which is also being replaced by greenish brown hornblende along crystal edges. Labradorite is well-twinned and anhedral, but one large phenocryst containing numerous tiny inclusions as well as some biotite, is seen in the thin section. Calcite is rare and spinel (?) occurs occasionally as small dark green grains, while one fairly large grain of pyrite was noticed. Biotite often poikilitically encloses hypersthene and many small magnetite globules. Hypersthene is always schillerized, while olivine occurs as large clear anhedra or as aggregates of smaller grains. In this rock diopside is a very minor constituent but in the olivine hypersthenite (18/393), collected one and a half miles west of Lokhosiniogurr peak, diopside occurs instead of diallage, and contains small dark green inclusions of spinel (?) which are also seen enclosed by plagioclase here. The plagioclase in this rock is not as well twinned as in the specimen described above, but as the refractive index of the plagioclase is greater than that of Canada balsam and is optically positive it is thought also to be labradorite. The schillerized hypersthene rarely forms euhedra, but often encloses small grains of diopside. The diopside, which is being replaced by green hornblende, is often found bordering hypersthene, while biotite occurs in fairly large intensely pleochroic interstitial flakes.

Serpentinites are numerous in the area within the main amphibolitic band of the Kaimeruk Series, and serve to distinguish this horizon from other amphibolitic bands. The serpentinite bodies vary greatly in size, but are usually elongated parallel to the strike of the country rocks. The largest of these occur at Muruputh hill, about three miles west-south-west of Lokichar, where it forms an outcrop of nearly one mile long and about 600 ft. wide, while the serpentinite just west of Kwetchuk hill is nearly one mile long and over 1,000 ft. wide. Numerous small serpentinites too small to show on the map occur just west of the Lobopakeyu hills and in the anticline west of Kwetchuk hill. The serpentinites can be recognized from a distance because they are usually topographically prominent, forming conical hills or ridges which are of a distinctive pale greenish grey to greyish white colour. They very rarely contain xenoliths, but at Muruputh the serpentinite contains small floating blocks of unaltered biotite gneiss and the vein quartz mentioned before (p. 19). The contact with the host rocks was seen only at Muruputh where it is sharp but irregular, without alteration to the country rock, but the serpentinite forms successive layers of fibres arranged perpendicular to the line of contact. At Muruputh the serpentinite is traversed by dolerite dykes, and two miles south-west of Kwetchuk hill the serpentinite is cut by a pegmatite. No linear features were observed in the serpentinites, but faulting of the intrusive at Muruputh produced slickensiding, with the direction of grooving coinciding with the lineation of the country rock measured there, a concurrence which may be accidental. Alteration of the serpentine produces veinlets of magnesite, vermiculite, amosite and talc. Sampling and assaying of the serpentinite body just west of Kwetchuk hill shows 0.41 per cent $Cr_2O_3$, while in the eastern extension of Muruputh the serpentinite contains nearly 3 per cent, while both serpentinites have little more than a trace of nickel.

Macroscopically the serpentinites are usually resinous-looking greenish or bluish grey with darker irregular veins and patches which are sometimes somewhat fibrous. Banding is rare and is usually formed by fibrous serpentine with fibres arranged perpendicular to the banding. Darker brown and brownish black colours are not infrequently seen and tiny chromite veins are common. The rocks are nearly always so soft that they can be cut by a penknife. Specimens 18/432 and 18/432a collected one mile and three miles west of Kwetchuk

hill respectively, give an indication of the composition of the rocks from which the serpentinites have been derived. Microscopically 18/432 consists of large phenocrysts of enstatite and olivine, usually broken up into small fragments as islands in serpentine, which is mostly antigorite with a little chrysotile. Interstitially there is some muscovite associated with talc and scarce thin veins of magnetite. In specimen 18/432a the pyroxene is augite and instead of muscovite and talc, phlogopite is present. Chromite is also abundant as small rounded grains and occasional large blobs. Complete replacement of olivine leaves a core of serpophite, but alteration sometimes produces a fine-grained, somewhat amorphous ferruginous mass, which seems to be an intermediate stage in the alteration. The chromite is often associated with or has an ophitic relationship with platy chlorite.

In other serpentine rocks sliced no vestige of the original minerals remains, all being serpentinites consisting of a mesh of antigorite, usually with some chrysotile and sometimes serpophite. Antigorite is usually colourless but is sometimes stained yellow and generally forms the divisions in the "knitted" or cellular structure normally observed in serpentinites, while serpophite is restricted to the cores of individual "cells". Magnetite occurs as small veinlets occasionally forming divisions, with or without antigorite or associated with magnesite. Magnesite also appears with serpophite in the cores of the "cells", while brucite occurs as small fragments in antigorite in specimen 18/428 from Muruputh. The serpentinite (18/424) collected one mile south of Lokichar, was found to contain small highly pleochroic flakes of deep bluish green chlorite, usually occurring in clusters aggregated with chromite grains. This rock also contains garnierite which was not seen in the thin section, but was found in the examination of the crushed rock.

### (*c*) *Post-Metamorphic Dykes*

The post-metamorphic dykes are of two types—dolerites and lamprophyres. Apart from the mineralogical difference, these dykes also occur in different parts of the area, with the dolerites nearly always occurring in the proximity of the main fault scarp to the east of the Basement System hills, as they were intruded along faults responsible for the formation of the scarp, while the lamprophyres were only found in the south-western part of the area, intruded along fractures subsidiary to the main fault zone.

It is to be expected that the strike of the *dolerites* will conform to the strike of the faults of the main fault zones, and they are found to strike generally N.40° W. along the escarpment and further north become N.25° W. Other directions are found in the vicinity of Lokichar, such as N.15° E., where the dykes follow faults striking in those directions. The widths of the dykes are much exaggerated on the map; usually they are seen as lines of black angular dolerite pebbles on the surface only a few feet wide. Exposures of dolerites are few, occurring only occasionally in gullies, and they rarely occur singly, but in parallel pairs and sometimes as many as six together. There must be more dolerite dykes than those shown on the map since their discovery is fortuitous when they happen to be crossed on a traverse. Outcrops consist of piles of greenish brown or dark brown cobbles with typical spheroidal weathering. Specimen 18/388, collected in the south-western corner of the area, has a few felspar phenocrysts of random orientation, but the dolerites are normally black fine-grained rocks with a red-brown or dark brown weathered skin.

In thin section ophitic texture is always developed, with laths and plates of labradorite with interstitial anhedral, rarely subhedral, crystals of augite. The augite is usually purplish revealing a titaniferous composition, and in specimen 18/388 mentioned above the felspar phenocrysts have also been determined as labradorite. Olivine is present in small amounts partially altered to chrysotile and antigorite, but is absent in specimen 18/389 from three miles south-west of Lokichar, where iddingsite (?) has taken the place of olivine. Other alteration products of olivine seen, in specimen 18/387 from four miles west-north-west of Lopatamuthingo peak, are calcite, chlorite, quartz and opal. Magnetite occurs fairly abundantly as anhedra or angular subhedra, but in two instances it forms a mesh-structure of spindle-shaped needles or worm-like rods enclosing a dense interstitial mass of small crystals of augite and plagioclase.

The *lamprophyres* are usually emplaced along fractures striking north-north-west, but in two cases they strike east-west. In most cases their discovery was also fortuitous, but in one case a minette forms an unmistakable black conical hill four miles north of Murilling hill. It is most likely that more lamprophyric dykes occur in the area than those mapped, as they are usually only a few hundred yards long and a few yards across.

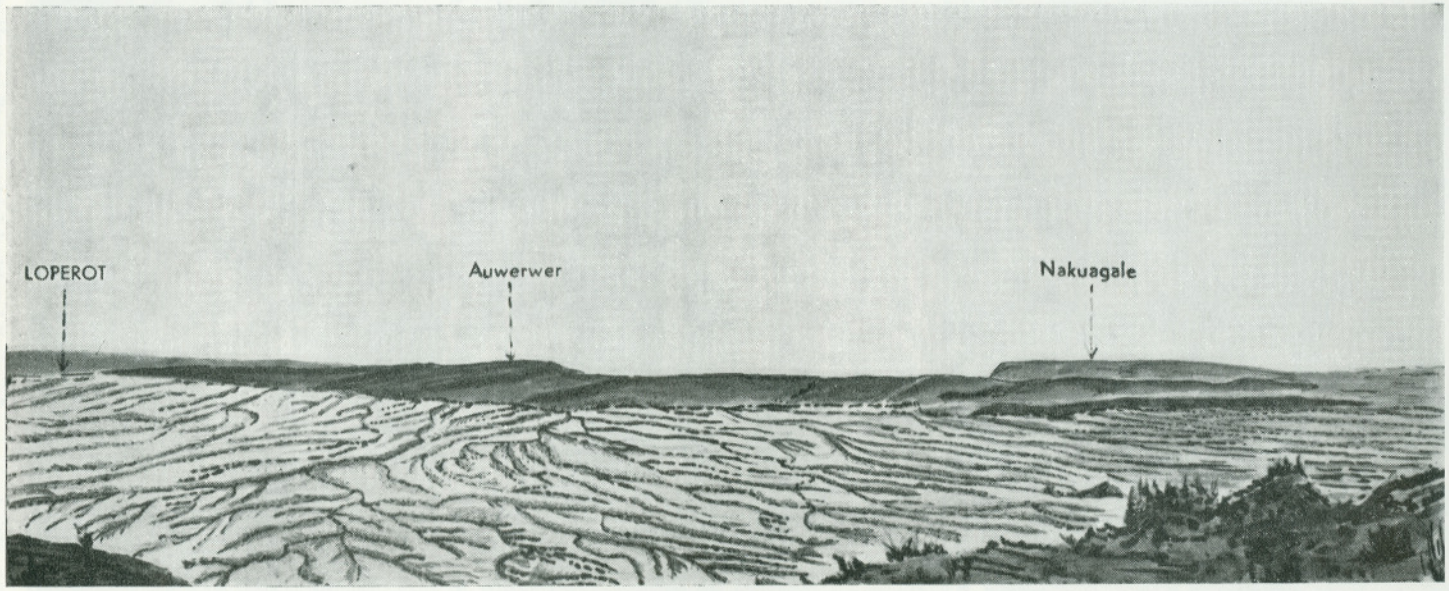



Plate I.—General view of the piedmont plain from Lokhosiniogurr peak.



Plate II (a).—Trench formed by a basaltic dyke two miles south of the Namadang hills.



Plate II (b).—Displacement of a small basaltic dyke by a north-westerly striking reverse fault, four miles south of Lokhone hill.

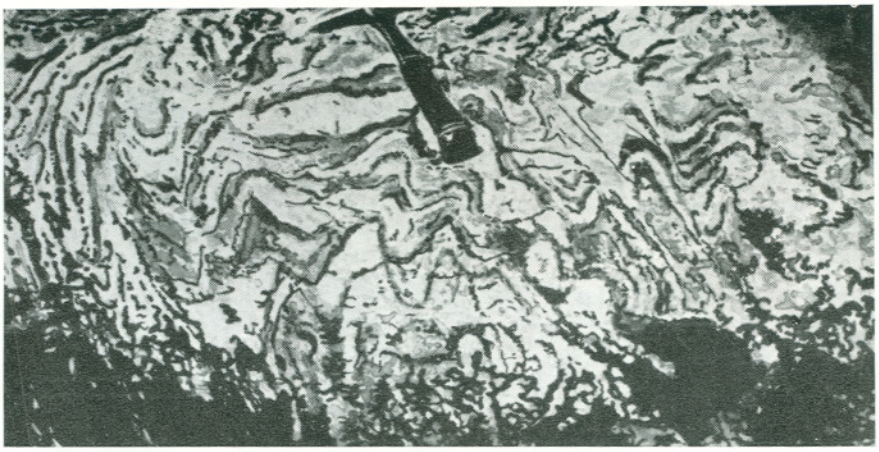


Plate III (a).—Flexural slip folding in the Turoka Series four miles west of Murilling hill.



Plate III (b).—Arching of a small fold four miles north-west of Murilling hill.

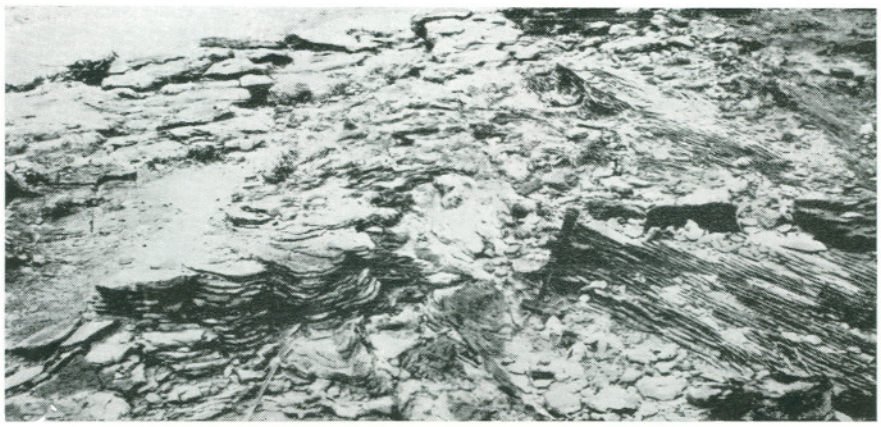


Plate III (c).—Folding and fracturing of incompetent laminated beds of the Turkana Grits in the Kalachir river channel.

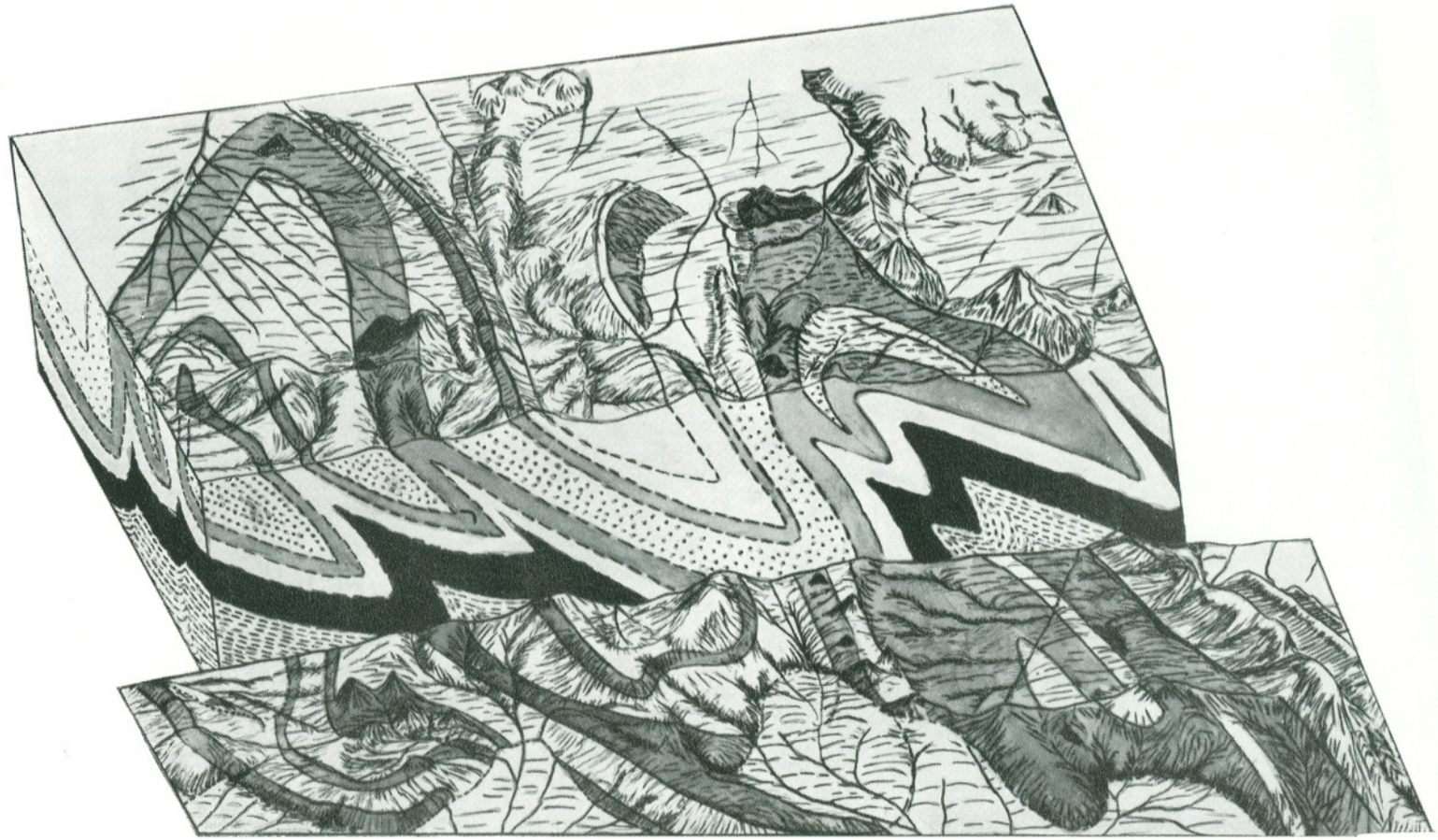


Plate IV.—Block diagram of the area to the north-west of Kaimeruk peak showing the nature of the folds.

The largest of the lamprophyric intrusives is the *minette* (18/400) mentioned above. It is a coarse-grained biotite-rich rock, somewhat schistose, and crops out as a small hill of huge rounded red-weathering boulders. Under the microscope it is seen to have a xenomorphic-granular texture and consists of large flakes of biotite, microperthite and pale green diopside. Prisms of apatite and euhedral crystals of sphene, sometimes also as aggregates of small anhedra associated with biotite and apatite, are abundant as accessory minerals. The diopside forms clusters of rounded crystals sometimes, or occurs as small euhedral prisms enclosed by felspar. The biotite is sometimes altered and greenish, and contains small inclusions of sphene, felspar and diopside. The felspar is strained showing faint undulating extinction and has bent perthitic lamellae.

A small *vogesite* dyke (18/386) crosses the road between Kaputir and Lokichar near the Nabokok river. This dyke is seen on the surface as large rounded boulders which have been found to be slightly radioactive. The rock is medium-grained, fairly leucocratic and contains small black, green and grey minerals. The texture is granitoid and the weathered surface is light brown and finely pitted. Under the microscope it is seen to consist of large anhedra of green hornblende, often in ophitic relationship with the abundant diopside, as well as a quantity of lozenge-shaped crystals of sphene in a xenomorphic groundmass of orthoclase and some microperthite. Smaller subhedral prisms of diopside, often associated with sphene and apatite, form clusters in the groundmass, while calcite is an infrequent alteration product. Minor amounts of oligoclase, fairly abundant small euhedral prisms of apatite, and tiny zircons complete the composition of the rock.

In a valley two miles south-south-west of Gochobolok hill a small dyke of a very fine-grained brownish grey augite vogesite (18/391) with tiny felspar crystals displayed on the weathered surface, was encountered. It consists of a matrix of large anhedra of orthoclase containing subhedral crystals and aggregates of augite and magnetite, with the latter mineral occasionally forming needles. Quartz occurs as fairly large irregularly shaped pools, while zoned oligoclase is present as well-formed stout laths. Nearly all the felspars have been subjected to incipient alteration with the formation of calcite. Augite is sometimes rimmed by fibrous bastite, while apatite, a mineral typical of vogesites, is absent in this thin section. The augite-vogesite (18/392) collected in the Kalokhole valley is similar to that described above, but contains no quartz and the felspar content is mainly microperthite. Serpentine is an alteration product, while both augite and orthoclase occur as idiomorphic phenocrysts.

In the gap between the hills three miles west of Murilling hill a number of large brown coarse-grained biotite-rich boulders occur. This rock (18/401) is a *hypersthene kersantite*, consisting of large phenocrysts of biotite, large anhedra of hypersthene rimmed by replacive hornblende, and interstitial pools of andesine. A fair amount of clear secondary quartz is present, as well as large prisms of apatite and scarce tiny zircons. The plagioclase contains numerous acicular microlites, the larger of which are pleochroic and have been determined as biotite.

### (5) Cataclastic Rocks

Mason and Gibson (1957, pp. 23–24) describe "Tertiary silicified superficial deposits" occurring in a series of elongated hills trending in a north-north-westerly direction at the foot of the Elgeyo escarpment. Although they noticed the effects of shearing and brecciation in them, they decided that the rocks were originally unconsolidated superficial deposits cemented by hydrothermally derived silica along fault lines. They also mapped them as "coarse and fine-grained grits and sandstone, usually quartzo-felspathic" and grouped them with the Tiati Grits which they assumed to be of Miocene age.

In the Loperot area small red hills also lie along a north-north-westerly trend at the base of an escarpment and in the vicinity of Lokichar, and there is no doubt that they represent breccias and microbreccias derived from the crushing of Basement System rocks. The north-north-westerly trend of the hills, the fragmentation, chalcedonic veining and limonitic staining of the rocks leave no doubt that these rocks are of the same origin as those described by Mason and Gibson (*op. cit.*) from the area to the south.

The effects of major faulting can be seen in the Basement System in the south just to the south-west of the Lokhoriokhot hills, and continued to the north-north-west on small isolated hills and outcrops along the base of the escarpment up to Lokhosinyakhori. Further north several of these hills and numerous small brecciated outcrops appear again in the vicinity

of Lokichar, the biggest of which is Ngahukon-Harengak hill, three miles south-west of Lokichar. The original composition of the rocks is often completely obscured, but in several cases distinct foliation produced by hard lighter coloured bands along which movement took place, dips at angles ranging from 12° to 23°, and suggests thrusting.

In the Loperot area it is clear that faulting occurred simultaneously with folding, for opposing dips occur on either side of faults, and the movement along thrust-planes occurred in the same direction as translation by folding. The strike of thrust-planes is therefore parallel to the strike of the folded rocks, and lineation, in the form of elongated minerals measured in the breccias three miles south-west of Lokichar, trends in the same direction as lineation of the country rock, suggesting that the breccia was subjected to the same compression as the surrounding gneisses after its formation. Later movement along the faults took place towards the end of the Tertiary, but the indications are that the movement was local and of minor importance.

Several faults occur along the escarpment, cutting the promontories of the scarp, and they increase in number and magnitude of displacement to the east. The lenticular outcrops extending east of Lopatomuthingo show well-developed sheet-structure; although the rock collected there (18/491) shows no clear cataclastic deformation, the felspars have prominent spindle-shaped perthitic lamellae both as micro-perthite and microcline-microperthite. This "exsolution" in felspar is ascribed to "the contracted limits of solid solution consequent upon lowering of temperature" by Harker (1939, p. 353), but here it is such a dominant feature in all potash felspar that it is felt that the forces responsible for the sheeting contributed to the formation of perthitic intergrowths.

Strike faulting in the Gochodin area produced a fine-grained well-lineated biotite gneiss (18/467) in which the mica forms trains of fine flakes on the foliation planes. Under the microscope the biotite is seen to be altered to a greenish colour and the quartz and microcline show distinct strain shadows. Crystal edges have been shattered to produce mortar structure and even magnetite has been broken up and now form irregular lenticles in the crushed matrix. Lines along which movement took place now appear as zones of fragmentation. Faulting in a north-easterly direction is often suggested by lines of flags along the strike of the faults. These flags are fine-grained, and the streaked appearance and fissility parallel to the fault-line, suggest movement and cataclasis. A thin section of a rock of this type, specimen 18/379 from two miles east of Lurutum ridge, shows "eyes" of strained quartz surrounded by fine-grained recrystallized quartz and shreds of biotite, with the flakes of the latter mineral arranged parallel to the fracture zones.

A north-easterly fracture direction is frequently followed by pegmatites, and occasionally when repeated movement has taken place along the fracture granulation of the pegmatite results. Granulation is often accompanied by the introduction and replacement of existing minerals by calcareous and ferruginous material. The hand specimens of a sheared pegmatite (18/370) from three miles north-north-west of Lokhone developed yellowish dense streaks which appear in the thin section as shattered minerals in a calcareous matrix. The pegmatite (18/385) from three miles south-west of Kwetchuk hill shows cataclastic deformation to a greater extent. Here mortar structure again developed, but the quartz is frequently recrystallized and the plagioclase developed secondary twin lamellae. Ferruginous matter has been introduced along fine-grained fracture zones and along cleavages of the felspars. Surfaces of discontinuity in the felspar often contain sericite.

When the gneisses of the Basement System are affected by faulting it is often seen first by the introduction of yellowish brown ferruginous layers which normally react violently with diluted hydrochloric acid. The normal-looking gneiss material diminishes until it only has light-coloured streaks which, with increased cataclastic deformation, disappear completely. The alteration is seen under the microscope as dense ferruginous matter, usually limonite in calcite, separating fragments of quartz and felspar. Biotite becomes dense green and eventually passes into chlorite. When granulation is not accompanied by shearing, the resulting rock is a breccia consisting of a dense ferruginous calcite matrix containing large angular fragments of quartz and felspar, with the latter mineral being replaced by calcite. The fragments of quartz and felspar form angular protruberances on dark weathered surfaces, and tiny fractures trending in all possible directions are often filled by finely crystalline carbonate.

Shearing produces thin dark fine-grained micaceous zones however, which under the microscope are seen to consist of flakes of biotite and hematite arranged parallel to the direction of movement, with some granulated quartz. In a thin section of a micaceous shear (specimen 18/380) from three miles south of Gochobolok hill, hematite is absent, but magnetite occurs in large irregular insets in the biotite. The hand specimen consists of a mica schist containing thin lenticles of quartz, felspar and occasional garnets, which are seen to be fine-grained aggregates under the microscope, while zircon is unaltered as tiny prisms enclosed by biotite.

The micro-breccias normally encountered along the fault-zone are dense red-brown rocks with fine, often banded, chalcedonic veining. Under the microscope they are usually seen as a finely crushed quartzitic matrix containing large and small angular fragments of quartz, microperthite, microcline-microperthite, plagioclase and a few small flakes of muscovite. Iron ore, which is responsible for the colour of the rocks, occurs as irregular stringers of limonite and rare hematite, or is densely scattered as tiny grains throughout the matrix. Aggregates of iron ore are also seen, in which case they usually have a halo of limonitic staining. It is remarkable that apatite and zircon retain their original shape and are only very rarely fractured.

The most interesting cataclastically deformed rock was collected from the breccia hills four miles north-east of Lopatamuthingo peak. The specimen (18/376) has a granitoid appearance, apparently consisting of pink and grey felspars and quartz. The rock has lost all vestiges of foliation and lineation, but has some irregular ferruginous veins and fine micaceous flakes. Under the microscope it is seen that the rock is completely crushed, and consists of very fine-grained quartzitic material in which chert lenticles have formed. Tiny shreds of green biotite, usually bent, occur scattered in the matrix, and quartz has recrystallized to form "eyes" of interlocking strained grains. Stringers of limonite occur usually associated with some biotite, and zircon and apatite form sometimes as small aggregates, presumably where a single crystal was crushed. Well-formed laths of zoisite with ragged edges and small inclusions arranged parallel to the lengths of the crystals occur sparsely in the matrix, and have obviously formed after deformation.

A sheared basic rock (specimen 18/421) of which the original composition is unknown, was collected on Lurutum ridge. It occurs along a fault and now appears as a thin brownish green fine-grained band which is somewhat schistose. Microscopically it is seen to consist of nodules of brown dense calcite, large rounded plates of albite being replaced by calcite, rare highly pleochroic brown hornblende (kataphorite ?) grains sometimes fringed by some epidote, occasional ragged crystals of epidote, many prisms of apatite, and a little sphene in a fine-grained matrix of felspar, quartz, chlorite and tufts of green hornblende needles. The chlorite plates are bent around the calcite nodules and tiny veinlets of dense white material (leucoxene ?) traverse the thin section.

Faulting of the serpentinite bodies has fundamentally altered the rocks. At Muruputh hill tiny magnesite bands parallel to fractures with irregular veinlets of magnesite appear in the serpentine of specimen 18/429. Under the microscope it is seen that the mesh structure is almost completely destroyed by parallel veins of magnesite, the serpentine lamellae all lie perpendicular to the banding, and the veins of magnesite are bordered by altered ferruginous serpentine. Magnesite veinlets are also seen cross-cutting the banding and secondary magnetite is aggregated in patches. Profound changes were found in the same vicinity along the strike of the main faults. Here circular rough black outcrops consisting of a light red-brown dense rock (18/381) with small micaceous flakes occur along the fault line. The rock also has tiny irregular veinlets and is traversed by thin resistant fracture lines in two directions, producing a kind of boxwork and a rough weathered surface. In thin section it consists of calcite lenticles separated by fine veinlets of chert associated with limonite. Dark patches (manganese ?) which are dull in reflected light occur between the lenticles, and some flakes of chlorite and muscovite are present. One thin section also has an appreciable amount of muscovite associated with talc. A similar rock was found about four miles west of Kaimeruk peak (specimen 18/433), and is a light brown aphanitic rock with tiny dark veinlets containing occasional shiny micaceous flakes. It weathers in an unusual way, having irregularly shaped holes in the surface. Microscopically it consists mainly of dense limonitic opal in irregularly shaped bodies and veins, with some hematite separated by fine-grained chert. Small flakes of muscovite, sometimes with talc, and brucite occur in patches or veinlets associated with magnetite.

## 2. The Tertiary Rocks

### (1) The Turkana Grits

The Turkana Grits were first referred to by Murray-Hughes (1933), who showed them as appearing in the eastern part of the Loperot area in his geological sketch map of western Kenya. He tentatively dated them as Jurassic, while Arambourg (1935) in describing the northern extension of these grits along the western side of Lake Rudolf called them the "Lubur Series", and correlated them with the Adigrat Sandstone of Ethiopia, said to be of Triassic age. The presence of dicotyledonous fossil trees in the grits proved that the grits are not earlier than Cretaceous in age (Fuchs 1939, p. 228), and Fuchs advanced further evidence to show why he considered the Turkana Grits to be of Oligocene-Miocene age. Dixey (1945, p. 13) also noted the existence of sediments yielding a Miocene fauna, which includes *Deinotherium hobleyi* in the Loperot area, while Mason and Gibson (1957, pp. 17–23) in the area farther south distinguish between the "Turkana Grit Series" which they think may be as old as late Mesozoic, and the "Tiati Grit Series" which is mainly composed of material derived from and interbedded with rocks of volcanic origin, and according to them may be of Miocene age.

The Turkana Grits occur in the eastern parts of the Loperot area where they are overlain by Tertiary lavas, and appear on the map as fringing the Basement System inlier, with the central part of their outcrop covered by younger sediments, while to the west and south they are surrounded by rocks of volcanic origin. Exposures of the Turkana Grits are poor, the best being near the Basement System inlier, where they consist of more resistant calcareous rocks, while others occur along the escarpments, where gullies are carved into the talus of the retreating scarps. Further complication is caused by faulting and gentle folding, and repetition of beds is not only due to successive sediments of similar nature, but is also caused by strike faulting. As can be expected in a deposit of this nature beds are frequently lens-like, and variations along the strike distinct, complicating unravelling of the succession which has to be pieced together from widely separated outcrops. It is impossible to calculate the thickness of the Turkana Grits in the southern part of their exposure as the base is not seen and frequent small folds repeat the succession there. An inferred thickness of approximately 700 ft. was calculated for the section east of Lakhapelinyang, taking faulting into account.

A generalized sequence of the Turkana Grits, with thicknesses which must be considered as approximate, is as follows:—

| | *Thickness Feet* |
|---|---|
| 6. Cross-bedded gritty sandstones and grits, usually yellow or yellowish red, conglomeratic in parts, with occasional thin laminated and puckered sandstones. Yellowish and greyish conglomeratic grit is the major rock type in the lower 100 ft. | 260 |
| 5. Deep red-brown laminated silts in the north, mainly sandstones in the south, with whitish and green silts and sandstones with mammalian remains | 40 |
| 4. Greyish buff to yellow silty grits with interbedded brown sandstones which are usually calcareous and sometimes contain thin yellow limestone bands. Lowermost part consists mainly of green silts and mudstones | 250 |
| 3. Black, grey, red and green silts and tuffs with gypsum and trona, associated with green tuffs and fossil tree trunks in the lowermost parts | <30 |
| 2. Sandstones and some grits, nearly always somewhat calcareous and occasionally interbedded with green tuffs associated with gypsum | 80 |
| 1. Mainly yellow impure limestones and gritty limestones with mammalian remains, becoming sandy towards the top. A boulder bed is occasionally encountered at the base | 50 |
| Total | 710 |

The Turkana Grits lie with marked unconformity on the Basement System, with the contact only exposed along the western and southern boundaries of the Basement inlier. In the north the rocks of the Basement System are much altered and discoloured at the contact, while in the south they are fresh and very often have a black veneer at the contact. Small pockets of the Turkana Grits are found on the Basement System, and in the south the basal limestones are found deposited in fractures in the Basement System. From the evidence it is clear that minor fracturing of the Basement System happened just prior to the deposition of the Turkana Grits, since two pockets of Turkana Grits are found on opposite sides of a small *horst* structure which has now been eroded away. Small blocks of Basement gneisses are sometimes found in the Turkana Grits, enclosed and incorporated by the basal calcareous grit just as they lay on the surface. Farther north along the Basement inlier the contact is marked by a boulder bed of rounded Basement rocks and much grit cemented by red or purplish clay. This gritty clay is also sometimes found in open fractures in the Basement rocks. The boulder bed only occurs patchily along the contact, for its place is often taken by a conglomerate consisting of well-rounded grains and pebbles of quartz and occasionally felspar and garnet, or even by finer deposits such as calcareous or silicified grits. Near the southern extremity of the Basement inlier the contact between the Basement and Turkana Grits is a fault-line with numerous small slickensided flags lying on the surface, indicating the nature of the contact.

Except in places where conglomerates or boulder beds occur at the base, the lowest rocks found in the Turkana Grits are distinctive yellow calcareous grits or sandstones, or yellow gritty limestones. The amount of grit varies considerably along the strike and individual limestone beds grade into calcareous grits both downwards and upwards. Near the Kalabata river these beds consist of calcareous sandstones and grits alternating with sandy limestones, and contain numerous tortoise scutes, crocodile bones and teeth and mammalian remains. Farther north however the lower 20 ft. consist of yellow calcareous grits with scarce rounded pebbles, occasional boulders and pockets of grit, grading upwards into thick yellow gritty limestones, which again grade into calcareous sandstones at the top. The gritty limestones and calcareous grits all have a distinctive yellow colour, but one thin limestone horizon near the base east of the Kalachir river is a pure almost translucent limestone which contains numerous tiny and a few larger gastropods and some bones. The weathered surfaces of these basal rocks reflect the composition in having the typical rough weathered surface of limestone when fairly pure, but smooth when impure with the sand or grit appearing in bands on the surface. They normally outcrop as rounded boulders but are sometimes fissile, and break along sandy layers. The brownish yellow colour is due to ferruginous material which is seen under the microscope to be densely distributed in the calcareous matrix, rarely forming small globules, whereas in cases where the carbonate has started to crystallize, it forms aggregates between areas of clear crystalline calcite.

The rocks react only slowly to diluted hydrochloric acid, but when crystallization has taken place reaction is violent. The amount of detrital grains varies considerably, and these have been derived from the Basement system, and consist of angular to sub-rounded grains of quartz, microcline, orthoclase, perthite and oligoclase, with a few flakes of biotite, muscovite and rarely garnet. The pure organic limestones, specimens 18/356 and 18/360 from three miles south of Lokhone, have very few detrital grains, but are crammed with shells which are partly destroyed by the crystallization of the carbonate matrix.

The sandstones following on the basal limestones are also calcareous to a certain extent, and in some beds partial crystallization is reflected by the knobbly weathered surface. They are usually soft and friable, range from grits to silts, and sometimes contain white calcareous nodules. Their provenance is again the underlying metamorphic rocks, with quartz and felspar forming the main constituents. The fine material of the sandstones is mainly quartz; other minerals noticed in a panned concentrate are garnet, hornblende, zircon, magnetite, ilmenite, sphene and apatite. In the upper part of this group some tuffs appear, sometimes associated with thin bands of trona and gypsum, and in the Kalachir river the tuffs contain a thin ignimbrite band. The ignimbrite is of a light brown colour and is finely but irregularly banded, and is seen under the microscope to consist of slender laths of labradorite, pools of analcite and a few grains of magnetite which are oxidized around the edges, in a partly ferruginous dense granular matrix containing some antigorite and palagonite.

The tuffs succeeding the sandstone are relatively thin, but are distinctive because of their bright colours, and are the most useful markers in the Turkana Grits. They crop out between the Kalachir and Nabar rivers as dense bright red and green horizons containing pockets of

grey and pitch-black tuffs. They appear further south at the northern extension of the Namadang group of hills where the volcanic ashes have overwhelmed *dryoxylon* sp. trees, and are also exposed in the channel of the Akhuryo river about four and a half miles north-north-east of Lojamei hill. At this latter locality these tuffs are the lowest beds exposed, and at Namadang they underlie the basaltic lavas which were extruded there. A small basalt flow also overlies the tuffs between the Kalachir and Nabar rivers, and these basalts probably represent the first extrusives of the Tertiary lavas. The tuffs are very fine-grained and appear under the microscope as finely divided ferruginous material with tiny globules of limonite and occasional labradorite crystals. The green tuffs, when weathered, form bentonitic clays which have thixotropic properties. Fresh exposures of these greyish green laminated clays occasionally exhibit yellow laminations with yellow staining and dendritic markings on bedding planes. Mudcracks and rainprints were noticed in these rocks.

The overlying beds form about three-quarters of the thickness of the Turkana Grits, and the monotony of the buff and yellow grits and sandstones, which are sometimes conglomeratic, is only relieved by the appearance of red laminated silts and sandstones. In the north these laminated silts are underlain by a hard consolidated light grey clay which contains elongated pellets along the ill-defined bedding planes. These pellets were tentatively identified by Dr. L. S. B. Leakey as coprolites of fish two or three feet long, and it is significant that mammalian remains also occur in these beds. The red-brown laminated silts are cross-bedded and very often ripple-marked, with the ripples suggesting fast currents from the west.

To the south these beds are represented by distinctive dark red ferruginous sandstones. They are particularly well exposed in the lower reaches of the Akhuryo river where there is a distinct increase in grain size from west to east. Both in the north and south ferruginous opal and chert were found as cementing media of the detrital grains composing these rocks. The laminated silts often react violently with diluted hydrochloric acid, and their calcareous nature is often displayed in the formation of cylindrical calcareous concretions and the filling in of cracks and fissures by the same material. The grits and sandstones with pockets of conglomeratic rocks which form the major part of the Turkana Grits are all calcareous, and sometimes have thin layers formed by calcareous concretions. Sorting is normally fairly good and cross-bedding occurs throughout, but in many areas no bedding except vague colour banding was noticed. Just west of the Hagit hills and just north of the Auwerwer hills a colour sequence begins with red, followed by yellow, to buff, purple, red, pink with red with some whitish coarse gritty layers at the top. Just above the laminated silts some clay galls were found in the grits and some of the sandstones also have ferruginous nodules. A typical succession in the north of the area was measured in the valley north of Lakhapelinyang:—

| | *Thickness* |
|---|---|
| | *Feet* |
| 6. Basalt | |
| 5. Sandstone with gritty base and top becoming gritty to pebbly . . . . | 40 |
| 4. Yellow grits becoming coarse at the top . . . . . | 20 |
| 3. Cross-bedded and laminated sandstones, light-coloured and puckered | 12 |
| 2. Green and red grits with conglomeratic lenses . . . . . | 10 |
| 1. Cross-bedded and laminated sandstones, light-coloured and puckered | 8 |

At the contact with the basalts a thin white calcareous layer was often noticed, but in the north-west tuffs occur underlying the basalts. In the escarpment to the west of Lomerimong a bright green tuff is exposed underlying the lava, and in the area to the west of Loakwa much of the material forming the upper part of the Turkana Grits is composed of brightly coloured tuffs.

Microscopically the rocks are all very similar, with detrital grains cemented in a ferruginous calcite matrix. Calcite is sometimes crystallized in clear veins which enclose detrital grains. Minerals identified in the grits are mainly quartz and felspar, with some garnet, hornblende, magnetite, ilmenite, zircon, epidote, hematite, sphene, actinolite and rutile. One peculiarity noticed in the grits at Lokhopel is the occurrence of irregularly shaped nodules of chert which have a white outer skin with tiny wart-like growths. The microscope shows clear patches of secondary chalcedony rimmed by bands of limonite and clear calcite in the matrix of the grit.

The Turkana Grits are riddled with dykes which normally stand out as ridges above the surrounding country. The dykes have been intruded along faults in the grits, as contrary dips are frequently observed in the proximity of dykes, and in one case slickensiding in the grits bordering on a dyke south of Namadang was observed. Recrystallization of the matrix in the grits is frequently observed in the wall rocks of dykes thereby increasing the resistance to erosion, and in rare cases dykes weather more quickly than the country rock leaving a trench bounded by walls sloping away from the trench (Plate III, Fig. 1.).

Although the fossils collected during the present survey have not yet been identified, there can be no doubt that they are similar to the deposits described by Fuchs (1939, pp. 223–231) and Arambourg (1943, pp. 161–171), and that they are lower Miocene in age.

### (2) The Tertiary Basalts (Samburu Series)

#### (*a*) *General Disposition and Sequence*

On the map the Tertiary Basalts are seen to surround the Turkana Grits where they overlie these sediments to the west and the south, and occur as isolated hills or hill groups which are remnants of flows, denuded volcanic cones or in some cases large dyke-like bodies extruded along major faults. The basalts must have covered the whole of the eastern part of the area where the Turkana Grits are now exposed, but to the west they disappear under the alluvium of the piedmont plain. It is thought that the basalt outcrops along the Kalabata and Lomenyenkoporat rivers are terminated to the west by *en echelon* faulting, but it is also clear that the basalts thin out to the west, for on the western bank of the Lomenyenkoporat valley only the lowermost and uppermost of the basalt flows are present, with the place of the basalts in between taken by a tuffaceous bed.

The dominating feature of the basaltic sequence is the increasing alkalinity of the successive flows higher in the sequence, so that the lower parts are normal olivine basalts which have little analcite in their composition, but the higher flows are richer in the analcite component and are olivine-analcite basanites. The sequence is terminated at the top by trachybasalts which have some interstitial potash felspar.

The basaltic flows thicken and increase in number to the south-east, for there are at the most only five flows in the north (Fig. 2), while at Nakuagale nine horizons were counted. The basalts and basanites also become distinctly more porphyritic further south, and it is possible that they are not continuous, but represent flows derived from different areas which interfinger in the Auwerwer and Hadukhungele hills.

The contact between the Turkana Grits and the basalts is only rarely seen, but just east of Badatum the grits show a deep red coloration for about two inches below the contact, which is sharp. At the northern foot of the Auwerwer hills there is a patchy development of a white calcareous layer in the grits immediately below the contact.

The basal basalts are patchily distributed and also vary considerably in appearance from place to place and are nearly always much altered. In the Lomenyenkoporat valley for instance, the basal basalts are porphyritic with augite and/or olivine phenocrysts, while five miles north of Loperot and at Muruangpei their place is taken by agglomerates. In the northern Auwerwer hills the lowest lava is a highly weathered grey and reddish dense amygdaloidal basalt, but in all other places these basal basalts are absent, and their place is taken by the lowermost flow of the main basaltic succession, which is normally a vaguely fissile basalt or, in the case of the Nakuagale succession, by porphyritic olivine basalts. It therefore appears likely that there is an unconformity between the basal basalts which are localized in their distribution, and the main group of basalts, and that the basal basalts, which are usually interbedded with tuffs, represent the initial stages of the Tertiary volcanic period.

Following on the basal basalts in the north there are four fine-grained basalts which are macroscopically much alike, but they have certain distinguishing features. In the first place, the lowest of these is slightly fissile, so that the cobbles produced by weathering are smaller than those of the overlying basalts, while the third flow in this succession usually develops a finely pitted weathered surface, and sometimes displays a pelleted appearance on freshly fractured surfaces due to a cumulophyric texture. Other distinguishing macroscopic features are the presence of tiny phenocrysts of felspar in the lower two flows of this group, while the third flow usually contains small phenocrysts of augite or olivine or both. Microscopically

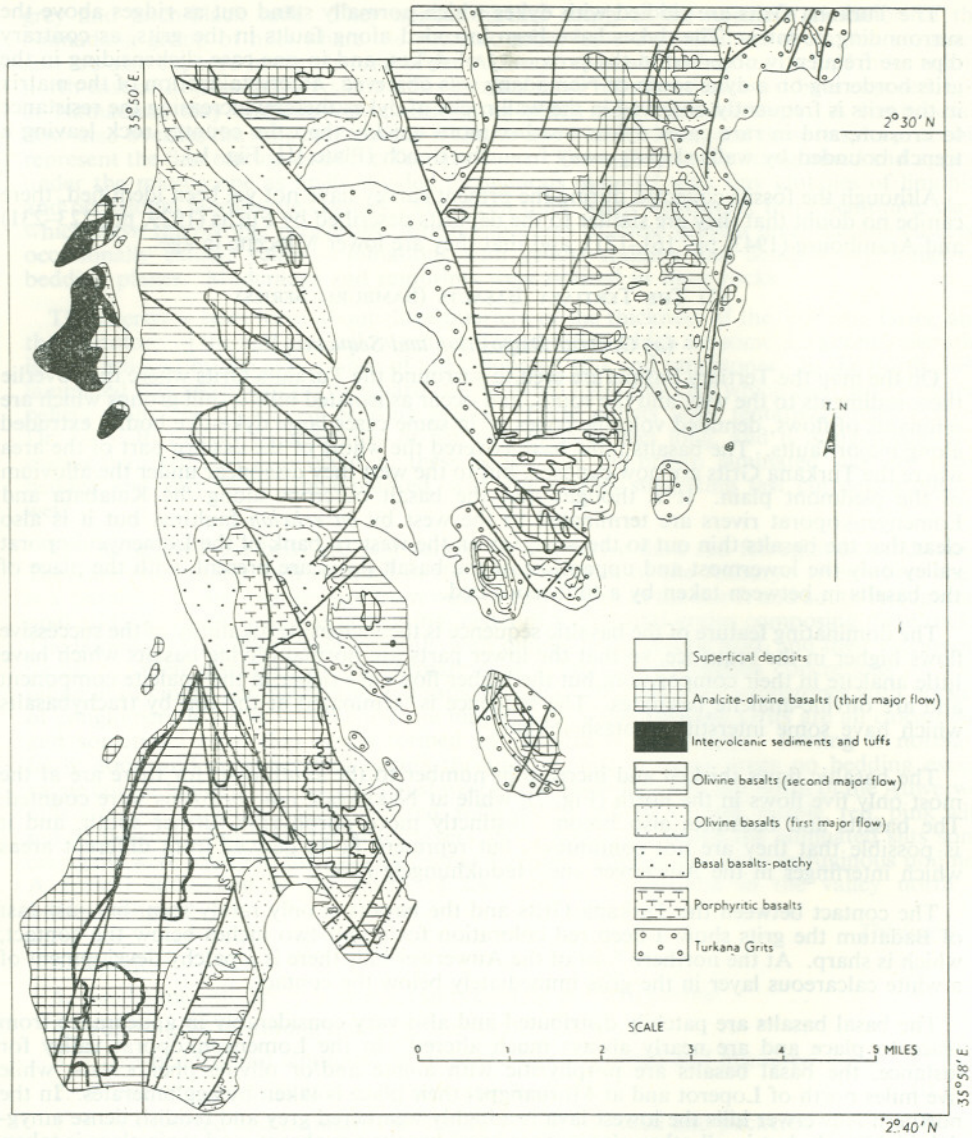



**Fig. 2.—Map showing distribution of successive basaltic lava flows and intervolcanic sediments north of Loperot**

however the distinction lies mainly in increase of the amount of analcite higher in the succession, and it is also seen that an increase in analcite goes hand in hand with an increase of iddingsite as an alteration product of olivine. The fluxional arrangement of the plagioclase laths is much more pronounced in the first and third of these flows than in the second, where the "trachytoid" texture is rather vague and there is an increase in the size of the augite crystals. It is on these distinctions that it is inferred that the basalts of the isolated hills of Lomerimong and Murillim belong to the third flow, although they rest directly on the Turkana Grits. The uppermost or fourth flow of the sequence is dense dark grey and always slightly amygdaloidal, and occurs only as small remnants on the tops of some of the hills. Microscopically it is easily distinguished in being a trachybasalt or augite melabasalt which contains some interstitial potash felspar. This last-named rock also occurs overlying and separated from the basal porphyritic basalts by tuffs just west of the Lomenyenkoporat

river, and it is thought that the other basalts in between never reached as far west. The melabasalts appear in the extreme north, but further south the fourth flow is composed of trachybasalts and appears at the top of the basaltic sequence of the Auwerwer hills, and also forms a prominent horizon high in the sequence at Nakuagale where the hills are also capped by trachybasalts. The isolated hill groups of Hagit, the small hills three miles west of the Hagit hills, as well as the central core of Lojamei hill, are all composed of trachybasalts. These small isolated occurrences are rather limited in distribution and lie along faults striking in a north-westerly direction. The trachybasalt flows must have been much more extensive in the past and it is clear that they thicken to the south-east.

The most useful marker in the basaltic sequence in the north of the area is either a thin magnesian limestone or a gritty tuffaceous bed which separates the second and third basaltic flows in the main sequence and occurs some 200 ft. from the base of the basalts. A brownish red tuffaceous horizon also separates the third flow from the trachybasalt just west of Kamuthia water-hole and at Auwerwer. The succession at Lokhopel is as follows:—

| | *Thickness Feet* |
|---|---|
| 4. Olivine basanitoid basalt with distinct cumulophyric texture | 30 |
| 3. White magnesian limestone—very prominent here.. .. | 30 |
| 2. Olivine basalts with tiny plagioclase phenocrysts .. .. | 200 |
| 1. Turkana Grits. | |

Where the full thickness of band 4 is seen, it can be measured to be nearly 100 ft, thick and is followed by the trachybasalts of which no thickness can be measured north of Loperot. The interbedded sediments and tuffs can be followed from Lokhopel to the south, and at the north Auwerwer hills they also occur 200 ft. above the base of the basalts, but they were not seen in the Hadukhungele hills. In the southern part of these hills however a thick tuffaceous bed appears about 150 ft. from the base of the basalts and it is thought that it represents the southern extension of the interbedded sediments. It must also be mentioned that south of the present area a 50 ft. thick agglomerate appears still lower in the basaltic sequence of Marua-are hill, four miles south of the main Lokhoriokhot hills. No tuffaceous beds were seen in the sequence at Nakuagale, and it therefore seems as if these deposits were laid down in a restricted lenticular basin stretching from Auwerwer in the south nearly to the northern boundary of the area.

The full sequence in the northern Auwerwer scarp is as follows:—

| | *Thickness ft.* |
|---|---|
| 6. Greyish green phonolite .. .. .. .. .. | 60 |
| 5. Prominent trachybasalt horizon .. .. .. .. | 100 |
| 4. Dense amygdaloidal basanitoid basalt with occasional greenish tuffaceous lenses, underlain by vitrophyric basalt which shows columnar jointing and thins out to the north | 140 |
| 3. White fossiliferous magnesian limestones, partly recrystallized in veins and patches .. .. .. .. .. | 40 |
| 2. Fissile and dense olivine basalts vaguely folded in the lower parts and underlain by the basal grey and reddish amygdaloidal basalts .. .. .. .. .. .. | 200 |
| 1. Turkana Grits. | |

The volcanic rocks farther south and east differ from the Auwerwer lavas mentioned above in being nearly all porphyritic, but at Nakuagale trachybasalts appear twice in the succession and it is likely that the lower of these can be correlated with the trachybasalts of Auwerwer. At Nakuagale the sequence is:—

| | *Thickness Ft.* |
|---|---|
| 5. Grey trachybasalts with felspar phenocrysts.. .. .. | 60 |
| 4. Olivine-analcite basanites which include a thin porphyritic olivine basanite and become amygdaloidal at the base.. | 150 |
| 3. Fine-grained trachybasalts with folded flow-lines in places, amygdaloidal in the lower parts and forms the most prominent horizon on the steep slopes .. .. .. | 100 |
| 2. Porphyritic olivine basalts which become basanitoid higher in the sequence .. .. .. .. .. .. | 550 |
| 1. Turkana Grits. | |

The lower part of the Nakuagale sequence also appears in the basaltic succession at Kabruriongor and in the south-eastern corner of the area.

### (*b*) *Petrography and Petrology*

The *basalts* are usually very fine-grained, dark grey, brownish black to black in colour, and weather to dark brown, brown or yellowish brown rounded boulders and cobbles. Rarely an indistinct fissility is noticeable in certain localities, especially at the base of the flows. The weathered surfaces are usually smooth and frequently display the fine crystalline character of the rocks. Sometimes weathered surfaces are finely pitted and small phenocrysts are seen in most of the basalts. Some of the basalts are spotted due to cumulophyric texture and banding is only rarely encountered. Porphyritic basalts are more common in the southern part of the area than in the north and phenocrysts of the dark constituents predominate. Amygdaloidal basalts are frequently encountered but agglomeratic and vesicular types are rare. The petrographical characters of the basalts conform closely with those of the basalts of the Samburu Series (Shackleton, 1946, p. 30) and the Simbara Series (Shackleton. 1945, pp. 16–17), which have been considered to be of Miocene age, and the Kijabe type described by Shand (1937, pp. 265–267). Champion collected similar rocks in the Loperot area and surrounding country and these were described by Campbell Smith (1938, p. 527).

A total of 138 thin sections of basalts were examined. Most of them, especially in the northern parts of the area where they are fine-grained, have a distinct trachytoid texture imparted by fluxionally arranged plagioclase laths which lie in sheaves around clusters of dark minerals. When augite and/or olivine occur as phenocrysts the flow structure is formed around them, the larger felspar laths occasionally being bent. Some of the basalts are extremely fine-grained and the ilmenite is seen to form the largest crystals.

The plagioclase is usually labradorite but acid bytownite is also commonly encountered. Microphenocrysts of plagioclase are distinctly zoned and have cores of acid labradorite. Frequently there are two generations of plagioclase; one which forms the normal acicular laths and the other interstitially as plates in which twinning is not so pronounced as in the laths. Usually plagioclase crystals are clear, but occasionally the microphenocrysts contain small inclusions of other minerals in linear arrangement, and in weathered rocks the plagioclase is altered to a yellow granular isotropic mass or partly replaced by calcite or analcite.

Augite is most commonly of a titaniferous variety and is sometimes distinctly pleochroic in deeply coloured crystals. Colourless or light brown augite is only infrequently seen while greenish yellow augite occurs rarely in the basanitic types. Augite usually forms clusters with other dark minerals, but with an increase in the size of crystals it has a sub-ophitic relationship with the felspar laths or forms small microphenocrysts. Augite microphenocrysts are usually clear, but are often zoned with the crystal edges more deeply coloured than the cores of the crystals, and sometimes they enclose small grains of olivine and felspar. When augite microphenocrysts occur the rock is somewhat impoverished in that constituent in the fine-grained clusters of dark minerals of the second generation. Hour-glass structure in the augite microphenocrysts is occasionally seen, and alteration produces a green edge to crystals

with fine ferruginous granules in the altered rim. Some zoned augite phenocrysts also have granules of iron ore in the outer zone. Macrophenocrysts of augite are not as common as those of olivine, but when they do occur they are prominent on the weathered surfaces.

The olivine of the basalts is variable in amount, and is only rarely absent. It usually occurs with other dark minerals in fine-grained clusters and often forms phenocrysts together with augite microphenocrysts. Exceptionally, as in the southern Hadukhungele hills, olivine and plagioclase form microphenocrysts, and in specimen 18/181 from the Nakuagale hills olivine forms the only phenocrysts present. Olivines are usually equidimensional and somewhat rounded, and in the second generation are commonly smaller than the augites. As can be expected, olivine is the first mineral to show alteration around the peripheries of crystals. Antigorite is the most common alteration product, and frequently altered olivine grains consist of cores of iddingsite rimmed by antigorite. Iddingsite was found to be more prominent in the basanitic types than in the normal olivine basalts, and in highly weathered basalts bowlingite, hematite, carbonates and opal are found as alteration products of olivine.

The iron ore, thought to be mainly ilmenite, is usually present as subhedral, rarely euhedral or anhedral crystals, which either occur evenly scattered throughout the rock in clusters with other dark minerals, or as cumulophyric aggregates. Specimen 18/152 collected in the low hills three miles south of Lokhopel hill, is very fine-grained and here the iron ore forms the largest crystals.

Biotite is very infrequently found in much altered basalts, and is thought to be secondary, while apatite occurs sometimes as small prisms in association with the clusters of dark minerals.

The matrix is usually analcite, a mineral which is also highly variable in amount, but which increases upwards in the succession. It is usually clear but also shows a faint yellow staining in some thin sections and is infrequently dense with minute inclusions. In altered basalts pools of analcite are formed, but small isotropic crystals found in one thin section were thought to be analcite, and in the altered basalt (specimen 18/202) from four miles south of Loperot, analcite can be seen replacing plagioclase. Higher in the basaltic series, potash felspar enters the composition of the basalts and occurs interstitially in small amounts associated with analcite. The rocks containing potash felspar are described below. Glass forms the base in the lowermost basalts in the north of the area where it is seen to alter to palagonite, while zeolite occurs in the base in altered basanites.

Amygdales, although frequently formed, are usually small and inconspicuous. They are seen in thin section as irregularly shaped pools of zeolite, and when they become larger in size they are sometimes cored by calcite. In a specimen from the low hills three miles south of Lokhopel, amygdales are formed by soft powdery greenish serpentine. The banding of specimen 18/214 from Aluaran is seen as bands or lines where the rock is finer-grained with a relative increase of the amount of analcite.

Minor variations in petrographical character are numerous, but some of the variations can be related to the succession as described before. One peculiar type of basalt, specimen 18/183 from seven miles west-south-west of Lojamei hill, is very dark, with much augite which forms a fine-grained mesh containing needles and zoned microphenocrysts of bytownite, olivines of varying sizes, all bordered by granules of iron ore, larger prisms of titaniferous augite as well as euhedra of ilmenite.

The *vesicular basalt* (specimen 18/190) collected at Kangerega has large and small vesicles, some of which are filled by white finely granular material, and is seen under the microscope to consist mainly of plagioclase needles of random orientation, small yellowish augite prisms, much ilmenite and iddingsite (?) in a matrix of glass and analcite, with the glass containing many minute inclusions concentrated in spots. A similar rock is the vitrophyric basalt (specimen 18/191) which forms a distinctive grey flow with well-developed columnar jointing on the north-eastern slope of the Auwerwer hills. The rock is dense brownish black with numerous black and greenish phenocrysts, and in this section is seen to contain numerous laths of bytownite and small crystals of augite, a few phenocrysts of augite and partly altered olivine as well as small angular crystals of iron ore in a dense brown glassy base containing numerous microlites.

*Agglomerates* are rare, but are occasionally found at the base of the basaltic series. These are dense purplish or reddish brown in colour, with lava fragments containing some black phenocrysts, some of the fragments being vesicular. Under the microscope the dense matrix of the lava is seen to consist of analcite with a multitude of black granular inclusions and needles of plagioclase. The irregularly shaped amygdales usually consist entirely of calcite.

One of the small cones in the north-eastern corner of the area is composed of an *olivine-free basalt*. In this rock (specimen 18/216) augite forms the main constituent and occurs in crystals varying greatly in size. The faintly purplish augite crystals are distinctly zoned and commonly twinned, and have a fairly low birefringence. Ilmenite subhedra are scattered throughout the rock, usually associated with the augite, while plagioclase, here determined as bytownite, occurs mostly as laths but also as occasional large zoned plates.

The basalts of Lungumur differ from other basalts in the Loperot area in being of a much lighter grey colour. They are even-grained with occasional large augite phenocrysts evenly scattered throughout the rock. These basalts weather to a dark brown colour, but in highly altered specimens they take on a greenish tinge with copious formation of zeolites. Augite occurs as slightly titaniferous stout euhedral prisms, while olivine is present as small microphenocrysts which are bordered by alteration rims or completely serpentinized in weathered specimens. Plagioclase forms fairly large labradorite laths and is altered to a white amorphous material or replaced by zeolite in weathered specimens. Concentrated with the dark minerals are subhedral to anhedral ilmenite grains and occasional small prisms of apatite. Small flakes of biotite also occur in the matrix, which consists mainly of analcite with fine plagioclase crystals. The matrix is often dense with brownish inclusions, while zeolite occurs interstitially as fibres or as irregular patches replacing the felspars and increases in amount in weathered specimens. Analcite and calcite sometimes form large clear pools in altered specimens.

Occasionally at the top of the basaltic sequence in the north there are small patches of *melabasalts*, but these rocks, although their occurrences are widespread, did not form extensive flows. They mainly occur as small denuded cones, such as the two in the north-eastern corner of the area, at Namadang, the two small hills just north of Lokhoriokhot, the cones in the Basement System west of Gochodin and several just south of the southern boundary of the area. These melabasalts were most probably extruded just after the extensive basaltic and basanitic flows for they overlie these just north of the present area, and in agreement with the increasing alkalinity in the basaltic series they always contain some potash felspar in the matrix. Plagioclase is usually a minor constituent and in some cases it is entirely absent. The rocks are dark grey with a microcrystalline matrix containing phenocrysts of olivine and augite and have black weathered surfaces on which the augite phenocrysts appear prominently. In thin section the augite phenocrysts are always zoned with brown or greenish yellow cores and darker coloured borders which are sometimes titaniferous and contain small granules of ilmenite. Olivine phenocrysts are large and usually fringed by serpentine with iron ore. Other alteration products of olivine also occur, but olivine is usually not as much altered as in the normal basalts. The matrix consists of fine crystals of augite, olivine, magnetite and sometimes some laths of labradorite with a little interstitial analcite and some potash felspar. Well-developed cumulophyric texture is apparent in the melabasalt (specimen 18/218) which forms the small cone five miles east of Lakhapelinyang, and crystals in the matrix are finer-grained in narrow zones bordering on the phenocrysts. Zeolite is sometimes also present, while in specimen 18/289 from one of the basalts of southern Namadang, a small patch of glassy interstitial material was seen. A little biotite infrequently appears as small ragged secondary flakes and calcite is sometimes present in small amounts in the base.

The thin section of specimen 26/1049 from a small melabasalt cone south of the present area and about four miles south of the main Lokhoriokhot hills includes a large rounded grain of quartz. The quartz was probably derived from the Basement System, through which the basalt was extruded. The quartz is being resorbed by the basalt and is surrounded by a reaction rim of fine prisms of aegirine-augite, and in another part of the thin section a circular structure of aegirine-augite indicates complete absorption of another grain of quartz.

The *trachybasalts* following or interbedded with the uppermost basaltic flows form hard conspicuous black horizons. The rocks are greyish black, finely crystalline, occasionally with either small felspar or small augite and olivine phenocrysts. The rocks weather to various shades of brown, but the uppermost trachybasalt on Nakuagale hill resembles a phonolite

with a greyish green colour and felspar phenocrysts. It even weathers like a phonolite in having a light grey weathered skin. In the field it was taken to be a phonolite, but even after staining no nepheline was found in the thin section.

The main dark constituent of the trachybasalts is pale greenish augite which occurs very much in the same way as in the basalts, but the crystals are usually smaller. The titaniferous variety of augite is rare, and although stout euhedral prisms do occur, the augite crystals are usually rather ragged. Augite is nearly always aggregated with ilmenite in patches, with the ilmenite crystals varying greatly in size. Olivine occurs in aggregates of small equidimensional grains, while a little brown hornblende appears in most of the rocks as subhedral prisms. In specimen 16/213 from Nakuagale, hornblende is surrounded by thick rims consisting of globules of iron ore. Biotite appears in some of the rocks, while two fairly large patches of a dense brownish black mineral (cossyrite?) surrounded by and enclosing augite occur in the thin section of specimen 18/258 from Nakuagale. The plagioclase, determined as acid labradorite and in some cases andesine, occurs in varying amounts and small laths, sometimes in sub-ophitic relationship with augite, or as larger zoned plates in the matrix. The matrix in some cases is mainly analcite with a little potash felspar, but when the potash felspar, thought to be orthoclase, increases in amount, the amounts of analcite and plagioclase present decrease accordingly. The potash felspar is usually somewhat altered and is interstitial, but sometimes also occurs as simply twinned fairly large laths. Zeolite sometimes forms part of the base and can usually be distinguished by a pale brownish colour in ordinary light. Calcite only appears in small amounts and sometimes occurs with zeolites in amygdales. Alteration of the trachybasalts also produces serpentine and chlorite, which are prominent in some sections as interstitial dense patches, while iddingsite and bowlingite are only rarely encountered. Some specimens collected in the small hills three miles west of Hagit (18/255), and on the small hill just east of Nakuagale (18/256), require special mention. They are similar to the trachybasalts, but contain no olivine. The felspars are seen to grade into isotropic analcite in places in specimen 18/255, while orthoclase forms large tabular plates in the other rock. Although these rocks were stained no nepheline was observed, and if it were present originally it has now been analcitized and zeolitized. Specimen 18/256 also contains a small amount of aegirine as small prismatic crystals.

Only two specimens collected in the area proved to be true *mugearites;* one collected on the top of Lakhapelinyang, and the other forming an isolated hill three miles north of Lojamei hill. Microscopically they are essentially the same as the trachybasalts, but the plagioclase present was determined as oligoclase. Specimen 18/269 from the Lojamei area has fairly large simply twinned plates of plagioclase, some of which have cores of a more basic composition and rimmed anti-perthitic borders. This rock also contains a small amount of aegirine-augite.

### (*c*) *Correlation and Age*

The Tertiary basalts of the Loperot area are the southern extensions of those of the Lake Rudolf basin (Arambourg, 1935; Fuchs, 1939, pp. 230–246), overlying sediments of Lower Miocene age, and they are represented south of the present area by the "Lower Volcanic Series" of Mason and Gibson (1957, pp. 25–26). Arambourg (1933a, p. 25) compares the basalts of Lake Rudolf with the lower Laikipian basalts and basanites, and states that the basalts, phonolitic trachytes and phonolites there correspond in their unity to the Miocene period. The basalts of the Loperot area can also be correlated with the Samburu Series (Shackleton, 1946, pp. 29–31) and the Simbara Series (Shackleton, 1945, pp. 9–11) on petrological grounds. Thus there can hardly be any doubt that the onset of the eruptions occurred during the lower Miocene and that the basaltic lavas of the Loperot area represent the initial stages of the volcanic history of the Rift Valley in this area.

## (3) The Tertiary Dykes

Numerous dykes are intruded into the Turkana Grits and they increase in number and size to the east, so that the Miocene sediments along the eastern boundary of the area are intensely dissected by dykes of all sizes striking in all directions. All the dykes could not be shown on the map for they are far too numerous in places, and many of them are too small, or exposures are too fragmentary, especially in areas covered by Pleistocene deposits.

The larger dykes are usually prominent topographically, but occasionally a dyke is softer than the recrystallized country rock and its position is marked by a trench along the strike (Plate II, (*a*)). Recrystallization of the Turkana Grits is fairly common in the immediate

vicinity of dykes, and joints are common along and parallel to the contacts of dykes. The dykes generally occupy faults and fractures in the Turkana Grits, and occasionally slickensiding in the Turkana Grits occurs at or near their contacts. Posthumous movement along such faults resulted in the shearing of the dyke rock which takes on a pronounced cleaved appearance, or faulting after intrusion of dykes is indicated by displacement along the strike (Plate II, (*b*)). All dykes show strong jointing parallel to their walls, as well as feebly developed joints perpendicular to their strike. Although dykes strike in all possible directions, there are three principal trends—west-north-west, north-north-east and east-west. The dykes of west-north-westerly trend are usually of an alkaline character, and if the sequence in the lavas is considered, it seems to indicate that fractures in this direction were formed after fractures of north-north-easterly trend.

The dyke rocks resemble the basalts, basanitic basalts and trachybasalts both macroscopically and microscopically, and they are undoubtedly the channels through which the basalts were erupted. All the variations found in the basalts appear in the dyke rocks which have the same mineralogical and petrographical characters.

There are some varieties, however, for which no counterparts exist amongst the basaltic lavas. Specimen 18/272 collected two miles east-north-east of Lojamei for instance, is a typical example of basalt, but contains in addition to the usual minerals numerous small flakes of biotite while the prismatic brown amphibole in the mugearite (specimens 18/280 and 18/281), collected from the prominent dyke east of Lojamei hill, was determined as barkevikite. Quartz occurs in two of the basaltic dykes: in specimen 18/249, a dyke six miles north-east of Lakhapelinyang, small xenoliths of quartz occur surrounded by reaction rims of fine-grained aegirine-augite, and are similar to the quartz found in the basalts of the small cones in the south of the area. Quartz also appears in a dyke (specimen 18/242) two and a half miles south of Namadang as small irregularly shaped pools or veins separated from the rest of the rock by calcite containing much finely divided limonite. The rock itself is reddish brown, aphanitic, and has a cleaved appearance, and is thought to have resulted from posthumous faulting along the fracture into which the dyke was intruded.

Nephelinites and olivine nephelinites occur at Kaureta Authrui and Gautere just north and north-east of the present area (Campbell Smith, 1938, pp. 533-534 and 546–547), and these rock types are represented by two olivine nephelinite dykes in the north-eastern part of the present area. One of these forms a prominent dyke about four miles north-north-west of Lokhone hill (specimen 18/220) while the other (specimen 18/222) is a small dyke two and a half miles south-west of Lokhone hill. They are similar in nearly all respects to the porphyritic basalts, but contain large and small interstitial patches of nepheline and some analcite instead of felspar. Hornblende is present as brown subhedral phenocrysts, while biotite appears as rare small flakes. Augite occurs both as phenocrysts and as fine prisms in the groundmass, which also contains some small prisms of aegirine-augite in specimen 18/222. Only small remnants of olivine remain, nearly all olivine having been altered to serpentine and some iddingsite, while ilmenite occurs as occasional fairly large crystals or small grains scattered in the matrix.

### (4) Intervolcanic Limestones and Gritty Tuffs

Fuchs (1939, pp. 245 and 270–272) described magnesian limestones collected by Champion to be interbedded and seemingly concordant with the volcanic rocks. Partial analyses of two samples were given, and Fuchs enumerates the reasons for considering the limestones to be of primary origin, the magnesia having been derived from thermal springs. Champion (Smith 1938, pp. 514–515 and 536) referred to the inter-volcanic magnesian limestones at Kaureta Authrui, and mentioned that the relation of the limestones to the inter-basaltic deposits of upper Miocene age discovered by Arambourg is obscure.

Lokhopel hill is a prominent point that can be seen from several parts of the area miles away, and is especially distinctive in having a 30-ft. thick layer of magnesian limestone 30 ft. below the summit. This magnesian limestone is a consistent marker between the second and third basaltic flows in the north-eastern part of the area. In the extreme north of the area it is seen as a 6-ft. layer about four miles west of Loakwa, and here another poorly exposed thin limestone appears a few feet higher with the two layers separated by a thin basalt. The limestone here is porcellaneous and has small vugs and irregular veinlets of white material which effervesces with dilute hydrochloric acid. Under the microscope the rock appears as finely divided calcareous matter, sometimes forming small dense globular bodies of which

the cores are somewhat recrystallized. Another specimen collected about three miles north of Loakwa is massive and greenish buff in colour and has fine yellow spots and dendritic markings. The microscope reveals very dense calcareous matter with tiny black veins and rounded yellow ferruginous spots. At Lokhopel the magnesian limestone is white to buff in colour, heavy, hard and dense with occasional yellowish blobs, but on the hill about four miles north-west of Lokhopel the limestone is interbedded with gypsum which forms bands of recrystallized fibers alternating with cellular gypsum containing some greenish clay interbedded in the "cells". The limestone here is also impure and has a nodul arappearance. The thickness of the limestone varies considerably, and at Badatum it is so thin that it was only found by searching the scree on the sides of the hill, but it again thickens farther south. Banding is normally absent but secondary banding was noticed in the scarp west of Lomerimong as thin recrystallized layers, and south of Badatum as faint iron-stained bands. Specimen 18/312 collected five miles north of Loperot is an exception in being completely recrystallized and has small spots formed by aggregates of ferruginous or manganiferous granules. Here, in the area west of Kamuthia, the limestone becomes very impure and the dusty calcareous matrix contains numerous angular grains of quartz, felspar, amphiboles. pyroxenes and small altered flakes of biotite. To the south-west the place of the limestone is taken by fine-grained green tuffaceous and calcareous grits. South of Loperot grits and calcareous sediments reappear containing thin red silty lenses, while at the eastern foot of Lorukia hill a down-faulted 5 ft. thick limestone is exposed containing numerous gastropods similar to those found in the limestones near the base of the Turkana Grits. The most southerly of the magnesian limestones occurs in the northern flank of the Auwerwer hills, where it also contains some gastropods as well as plant remains. The limestone here is also 40 ft. thick and two types of magnesian limestone are present. One is chalky white, partly recrystallized to buff porcellaneous limestone, and has fine veinlets and small patches of recrystallized calcite. The other is buff in colour and finely recrystallized with a vague conchoidal fracture and contains tiny organic remains, clay pellets and a few angular grains of quartz and felspar.

The sediments described above all appear at the same stratigraphic position between the second and third basaltic flows, and in the southern Hadukhungele hills there is a 50 ft. bed of yellowish tuffaceous material which occurs about 150 ft. above the base of the basalts.

From the above it is clear that the limestone is of organic origin and was deposited during a quiescent period marked by phases of fluviatile deposition and local volcanic activity. The origin of the crystalline limestone on the eastern side of Hagit hill, however, is not so clear, for it forms a dyke-like body of coarsely crystalline white limestone which effervesces freely with dilute hydrochloric acid. A vague banding on the weathered surface and linearity of the calcite crystals forming the mosaic in thin section are noticeable. There are tiny holes in the rock which are elongated parallel to the long axes of the calcite crystals and along these lines of holes, and also to a lesser extent in the matrix, there are small aggregates of dense material. Fuchs (1934, p. 106; 1939, p. 272) found similar dykes north of the present area, but one of these is composed entirely of scoriaceous calc-tufa, and is also thought to represent precipitates from thermal waters.

### (5) Plateau Phonolites (Losiolo Phonolites)

The phonolites capping the basaltic sequence in the area appear as thin remnants on the Auwerwer and Hadukhungele hills. They must have been much more extensive at the close of the Micocene as numerous boulders, cobbles and pebbles of phonolites of this type figure prominently in the boulder beds on the end-Tertiary peneplain and in the pebble sheets of Pleistocene age. In several localities it is impossible to determine the true character of the underlying rocks as they are completely blanketed by the boulders on the surface. The phonolites are somewhat fissile with the typical platy jointing, and usually have a greenish grey aphanitic matrix containing occasional small anorthoclase phenocrysts. Typically they have a grey weathered skin with a light brown finely pitted surface.

Under the microscope they are seen to consist of microphenocrysts of anorthoclase and rare turbid stout prisms of nepheline in a dark base of mossy aegirine and cossyrite, clearer areas of alkali felspars, minute nephelines and analcite. Analcite often forms clear patches, with or without some zeolite, usually surrounded by rims of aegirine. Nepheline is often replaced by fibrous zeolite around the edges of crystals or becomes dense by alteration. Calcite and antigorite sometimes occur in small amounts as secondary products. The thin sections examined are very similar and only differ in the amount of nepheline present.

Smith (1938, pp. 522 and 535) described similar phonolites which Champion collected farther south and in the Rift Valley to the north-east of the present area. Although they contain no soda-amphiboles, he referred them to the Kenya type of phonolite because they contain small nephelines surrounded by aegirine. Mason and Gibson (1957, p. 26) showed that the phonolites are much more extensive in the area to the south, and included intrusive syenitic rocks with them; similar intrusives are referred to as micro-foyaites in the present area. They correlated the phonolites of the area to the south with the Losiolo Phonolites of Shackleton (1946, p. 34), and it seems possible that the phonolites of the present area represent the north-western extension of the plateau phonolites found on the eastern side of the Rift Valley in the Maralal area.

Shackleton (1945, table facing p. 6) dates the Losiolo Phonolites as upper Miocene, and in the present area this age is accepted in the absence of new evidence. Unfortunately the relationship between the phonolites and phonolitic trachytes described below cannot be ascertained in the present area, for they are never found in contact with one another. It is thought however that the trachytes followed on the phonolites and were in turn succeeded by the microfoyaites.

### (6) Phonolitic Trachytes

Phonolitic trachytes appear in the south-eastern corner of the area just south of the Lokhoriokhot hills, and form a collar around the micro-foyaite of the core of Kakhapit hill. South of Lokwamuthing and east of Marua-are hill in the Kalossia area to the south they are also numerous.

South of Lokhoriokhot they appear as poorly exposed reddish outcrops which are covered by boulder beds on the end-Tertiary peneplain, and they may be much more extensive than is indicated by the map. Although several specimens of trachyte were collected in the area to the south, not much time could be spent in deciphering the geology there, but it is certain that they overlie the Samburu Basalts and in places appear to have been intruded into the basaltic succession resulting in doming of the overlying basalts. Several dyke-like bodies of phonolitic trachyte also occur on the north-eastern flanks of Marua-are hill.

Smith (1938, pp. 521–522) described similar rocks collected by Champion in northern Turkana, and used the term, conformed with in this report, in the sense employed by Rosenbusch. The mineral assemblages vary from one outcrop to another, and about two miles south of Lokwamuthing there are two types of trachytes, one overlying the other. They are found grading into trachytoid phonolites, and Smith (*op. cit.*, p. 521) mentions the discovery by Sikes of a trachytoid phonolite dyke north of Lodwar. From the phonolitic trachyte occurrence at Kakhapit hill, which surrounds the central core of micro-foyaite, it is certain that the phonolitic trachytes preceded the micro-foyaites.

Platy flow-structure is prominent in nearly all the exposures of phonolitic trachytes, and it is quite usual in small bodies to observe the fissility dipping at steep angles. The outcrops are often much fractured, and jointing is well-developed producing rectangular flags with distinctive Liesegang rings. The rocks are light grey, brown or greenish grey in colour and fissile surfaces nearly always shimmer in reflected light. Sparse large felspar phenocrysts and small dark needles are usually present in a micro-crystalline matrix and sometimes amygdales or vesicles have developed. Weathered surfaces are usually just a shade darker than the rocks themselves, but darker specimens sometimes weather nearly black on the outside. These surfaces are rough or finely pitted and sometimes display tiny square holes, probably resulting from the solution of nepheline.

Fluxional textures are usually well-developed, but in rare cases trachytic arrangement of the minerals is not perfect, and in specimens 18/294 and 26/1034 from one mile south of Lokhoriokhot and two miles south of Lokwamuthing respectively, felspar is seen to form occasional spherulites. Anorthoclase forms fresh, zoned and simply twinned phenocrysts, and also occurs as slender laths in the matrix. Oligoclase is sometimes present as needles or as sheaves of needles, and occasionally forms fairly large laths which alter along the cleavages to a dense isotropic material. Aegirine is the most common dark mineral and occurs as small prisms with ragged ends, or as mossy crystals enclosing small nepheline and felspar idiomorphs. Kataphorite is usually present in small amounts, but in specimen 26/1037 collected one and a half miles south of Lokwamuthing, kataphorite is the major dark constituent. Aegirine-augite and tufts of cossyrite occur fairly frequently, but are sometimes

absent. Iron ore forms shards or fine grains concentrated in rounded patches, while in highly altered specimens hematite and even limonite figure prominently. Nepheline forms distinctive six-sided or square sections usually much or completely analcitized or zeolitized, and is nearly always enclosed by aegirine. Small amounts of calcite, serpentine and in one rock opal surrounded by dense rims of fine ferruginous globules, form minor secondary products. Specimen 18/298 from one mile south of Lokhoriokhot contains a small patch of interstitial glass, while analcite sometimes forms clear rounded patches, and zeolite and sometimes calcite occur in the infrequent amygdales.

The trachytes of Kakhapit are different and seem to represent a stage between the phonolitic trachytes and the trachybasalts. In hand specimen these rocks resemble the micro-foyaites, but they contain small phenocrysts of felspar which often occur in small clusters. Augite as small pale brown, often twinned, euhedral crystals, is the main dark mineral, and also forms a fair proportion of the fine-grained dark minerals in the matrix where the crystals are sometimes rimmed by aegirine. Both anorthoclase and oligoclase are present as phenocrysts which occur as somewhat altered idiomorphs in clusters, and in specimen 18/285 the phenocrysts were determined as zoned oligoclase-andesine with fine twinning lamellae and undulatory extinction. Serpentine forms rounded blobs surrounded by iron ore and is sometimes associated with calcite and iddingsite, and is taken to represent the alteration products of olivine which has now disappeared completely. Magnetite, as fairly large subhedra, occurs associated with the augite phenocrysts, or forms small grains in the matrix. Biotite and aegirine are sparsely distributed amongst the fine-grained minerals of the matrix, and apatite, not noticed in the other phonolitic trachytes, appears fairly frequently and is plentiful in specimen 18/287.Nephelines are completely altered and replaced by occasional dense isotropic squares, while a little interstitial analcite occurs in specimen 18/285. Specimens 18/292 and 18/293 from Kakhapit represent trachytic tuffs which are brightly coloured in red, yellow, green, often spotted and streaky. Agglomeratic facies are frequent and contain pellets and pebbles varying in size from fine grit to half an inch across. Under the microscope these rocks are seen to consist of dense, drusy, sometimes globular, ferruginous matrices containing altered felspars, yellow pellets and in clearer patches felspar needles in rosettes.

A breccia (specimen 18/374) produced by faulting of trachyte, was collected one mile south of Lokhoriokhot. This rock contains angular chips varying greatly in size cemented by hard yellow and brown greasy-looking material. Under the microscope the chips are seen to be composed of trachyte, and are angular insets in a globular iron-stained isotropic matrix (R.I.$<$Canada balsam) with finely banded opal and some hematite.

The phonolitic trachytes are intruded into the Samburu Basalts of lower Miocene age and are overlain by boulder beds on the end-Tertiary peneplain, and their intrusion must therefore have occurred during the upper Miocene or Pliocene.

### (7) Micro-foyaites

In the same area as the phonolitic trachytes there are several prominent steep-sided conical hills and sharp ridges composed of micro-foyaites. The micro-foyaites, although texturally phonolites, probably never reached the surface and were intruded into the Samburu Basalts and the Basement System. They form the prominent peaks of Morutena, Kakhapit, the hill-group of Lokhoriokhot and, south of latitude 2°, Kolong hill as well as capping the highest peaks of Marua-are and Lurutum there. These rocks do not always form topographically prominent features and several of these intrusions although occurring at lower elevations than the basalts, were mapped by Mason and Gibson (1957) as part of the phonolitic lavas. Mason and Gibson (*op. cit.*, p. 28) describe a micro-foyaite in the north-eastern part of their area and show it on the map as cutting Basement System only, while in actual fact several of these dykes are intruded into the Samburu Basalts and phonolitic trachytes south and south-west of Lokwamuthing. The elevation of 4,470 ft. above sea-level on the micro-foyaite occurrence on the highest peak of Lurutum ridge gives an idea of the elevation of the country towards the close of the Miocene and shows the amount of rock removed since that time. The micro-foyaite here is responsible for the preservation of the peak and forms a narrow dyke which strikes north-north-east and occasionally swells in width to form small sharp hills along its strike.

The largest intrusion of micro-foyaite forms the hill group of Lokhoriokhot which consists of a main group of three peaks and a steep isolated hill one mile to the south. The easterly peak is the most prominent, the central peak is formed by the most extensive intrusion, while

the westerly intrusion forms a ridge which parallels the strike of the north-north-easterly striking fault there. In the east the micro-foyaites of Lokhoriokhot overlie analcite-olivine basalts and in the west the Basement System, while on the north-eastern side the micro-foyaites are underlain by pale grey grits. Grits are also exposed in the river channel on the southern side of the main Lokhoriokhot hills. Here the pale grey grits are 50 ft. thick and have violet-coloured bands. Cobbles and pebbles derived from Basement System rocks are not uncommon but small nodules of ferricrete, obviously derived from some other deposit, are very numerous. These grits can only be Turkana Grits preserved by the micro-foyaites on the down-throw side of a fault. At Lokhoriokhot the central part is composed of a distinctive leucocratic micro-foyaite, which is overlain and intruded by the darker rocks of the eastern and western intrusives.

Morutena is the steepest hill formed by the micro-foyaites and can be seen from many miles away, while Kakhapit again forms a ridge paralleling the north-westerly striking faults. The micro-foyaites are all intruded along fault-zones and appear to occur most frequently where the zones of the two main directions cross, but only in one case in the Loperot area, that of western Lokhoriokhot, were the micro-foyaites themselves seen to be faulted.

The micro-foyaites of the central part of Lokhoriokhot (specimens 18/263, 279, 291) are cream to buff aphanitic rocks with dark green prismatic crystals showing no fluxional orientation. They have a light reddish brown weathered skin which is dark brown on the outside. Under the microscope they are seen to be fine-grained and display a trachytoid texture. Aegirine is the dark mineral present and it forms ragged prisms or aggregates enclosing tiny idiomorphic crystals of nepheline and anorthoclase. This assemblage is usually formed in clear patches in the otherwise somewhat drusy anorthoclase which forms most of the base. Anorthoclase as slender laths and nepheline as tiny idiomorphs also occur in the base, with the nepheline sometimes concentrated in patches, leaving other parts of the thin section free of this mineral. Analcite occurs in the base as small clear pools, while a little cossyrite is sometimes present as tufts of small crystals.

The later micro-fayaites of Lokhoriokhot (specimens 18/261, 264, 265, 277, 278, 288, 290) are darker in colour and are greenish or brownish grey, sometimes spotted and rarely contain small phenocrysts. These rocks weather like the micro-foyaites of the central plug and are microscopically very similar to them except that aegirine-augite, sometimes with aegirine borders, occasionally proxies for aegirine and that both anorthoclase and nepheline frequently form microphenocrysts. There is also some iron ore present in these rocks, but no cossyrite was noticed in any of them. Calcite and zeolite appear rarely in small amounts as secondary minerals.

The micro-foyaites collected at Morutena (specimens 18/283, 284) and that collected on the low hill two miles west of Morutena are light brown in colour and contain prisms and needles of black minerals in a micro-crystalline matrix. Aegirine-augite is the main dark constituent and occurs as green subhedral slender prisms, occasionally large, in aggregates with magnetite. Augite is also present as large distinctly zoned crystals edged by aegirine-augite, while rare large twinned prisms of brown amphibole (kataphorite?) occur with reaction borders of aegirine-augite containing small granules of iron ore. Anorthoclase forms somewhat turbid plates and tabular crystals of which the outlines are rather vague, for they seem to grade into the base which also contains some analcite. Large idiomorphic crystals of nepheline are rare in this rock, but small rectangular crystals are common in the matrix, sometimes also enclosed by analcite. In one of the rocks zeolites appear replacing the felspar.

Specimen 18/286 from Kakhapit is also similar, but green augite as tabular microphenocrysts clustered with magnetite, and scarce prisms of apatite are the only dark minerals present. The felspar and nepheline crystals are all marginally altered to zeolite, which figures prominently in this rock.

The numerous specimens collected south of the present area all show the same mineral assemblages as those described above, varying only in the amounts of the different minerals present. An unusual contaminated micro-foyaite (specimen 18/273) was found in the small intrusion on the northern extension of the Lurutum ridge, where the micro-foyaite incorporates some material derived from the Basement System. The dusty matrix of this rock consists of potash felspar and analcite containing numerous small prisms of aegirine, some slender laths of potash felspar and occasional square sections of a clear mineral, sometimes altered to zeolite which is thought to be nepheline. In addition to the above the rock contains

large and small angular broken fragments of oligoclase, a few fairly large angular grains of quartz bordered by calcite and enclosed by reaction veins consisting of small crystals of aegirine, patches of iron and some serpentine. A fair amount of biotite is also present as angular flakes with very dense granular reaction rims. A few light-green diopside prisms appear as well as one perfect lozenge-shaped crystal of sphene.

The micro-foyaite dyke described by Mason and Gibson (1957, p. 28) is of the same composition as the rocks described above and is no doubt of the same age. Smith (1938, p. 510–511) describes some micro-foyaites and allied rocks collected by Champion and Arambourg in northern Turkana, where they also form dykes and plugs similar to those of the Loperot area. Smith compares these rocks with post-Karroo intrusives in Nyasaland, but the nephelinitic rocks of Western Kenya are all post-lower Miocene and pre-lower Pleistocene, for in the present area they are known to intrude rocks of Lower Miocene age, and must have succeeded the trachytes which are bevelled by end-Tertiary peneplanation.

### 3. Superficial Deposits

#### (1) Lower Pleistocene (?)

On the end-Tertiary surface there are extensive pebble sheets, the pebbles of which are sub-angular and consist of quartz and felspar derived from Basement System rocks. These pebble sheets never attain any great thicknesses, but in the east of the area their place is taken by lava boulder beds which are sometimes as thick as 50 ft. or more. In several localities there are thin layers of ferruginous pellets occurring on the end-Tertiary peneplain, and at Luturere water-hole a ferricrete was formed which contains pebbles derived from both the Basement System and the lavas. Here it is associated with a fairly extensive deposit of ferruginous dolomite. Specimen 18/346 collected here is a hard brown dense rock with zones of small ferruginous pellets. Under the microscope it is seen to contain a few small grains of altered felspar and consists mainly of an even-grained mosaic of dolomite containing small globules of limonite. Parts of the thin section are fairly coarsely crystalline with the cores of the crystals dense with limonite. Because of its position on the end-Tertiary peneplain it is thought to be of Lower Pleistocene age, but it is possible that it is later, when much of the area was covered by isolated bodies of water.

#### (2) Kipii-Namadang Area

In the eastern part of the area pale grey fine-grained lake sediments intercalated with thin soft white calcareous horizons contain numerous gastropod shells as well as fish vertebrae and teeth, and overlie the Turkana Grits. The Pleistocene beds are usually poorly exposed, for they are for the most part blanketed by extensive pebble sheets, but they are well exposed at Kipii, where 30 to 40 ft. of sediments appear in a typical "bad-lands" topography. Other exposures appear to the south-west of Namadang hill, where the basal beds, consisting of yellow and red grits with pockets of pebbles derived from the Turkana Grits as well as some lava boulders, are exposed in the river channel there. To the south-east of Namadang the Pleistocene lake beds include a 4 ft. finely laminated fine-grained volcanic ash composed of tiny shards of glass containing poorly preserved plant material, and is seen to thicken to the east of the present area. The Pleistocene beds slope gently and consistently away from the hills to the east, and they do not seem to have been affected by folding or faulting.

The fossils collected during the survey have not yet been identified, but Dr. L. S. B. Leakey (personal communication) stated that the assemblage is typically that of the Middle Pleistocene. Fuchs (1939) describes similar sediments nearer Lake Rudolf which accumulated during the Middle Pleistocene when Lake Rudolf reached its maximum extension. During this period the water reached up to an elevation of nearly 1,500 ft. above sea level (i.e. 300 ft. above the present lake level), and as the Pleistocene deposits in the Loperot area reach up to above 2,000 ft. above sea level, it is clear that they were deposited in a lake formed to the south-west of Lake Rudolf, and probably originated by the barring of the Kerio river which lies to the east and the ponding back of its waters. Fuchs (*op. cit.*, pp. 223–224) mentions that the Kerio river is at present cutting down through basalts which must have barred its course during the period of Pliocene faulting.

#### (3) Lomenyenkoporat-Lokhosinyakhori Areas

Under the alluvial cover of the piedmont plain east and south-east of Lokichar there is an extensive deposit of grey, reddish or yellowish calcareous grits. The rocks are usually soft

and contain grit and sub-rounded to rounded pebbles derived from Basement System rocks, in a clayey calcareous matrix. These rocks are best exposed near the Lomenyenkoporat river in the northern part of the area where they form smooth low ridges and often appear on the surface as sheets and piles of small pebbles. Because of their impermeability to water they have been exposed in several other localities where the natives have dug wells along river channels. Such places are at Lochwangamata north of Lokichar, Lokhosinyakhori and Kangerega, but as the sandy pockets on the calcareous grits are of small extent, they are not permanent water supplies.

Under the microscope the rocks are seen to consist of angular to subrounded closely packed grains such as microcline, quartz, andesine, hornblende, garnet and bent flakes of biotite in a dense iron-stained calcareous matrix.

The grit (specimen 18/378) collected about four miles north of Gochodin from a small circular outcrop in the alluvium, gives an idea of the cause of the large accumulation of sediments in this area. This rock contains small transparent grains, larger pink and yellow pellets and a few rounded pebbles in a grey matrix which does not effervesce with dilute hydrochloric acid. The microscope reveals that the gritty part is the same as that of the grits described above, but that the matrix consists of a fine-grained yellow chloritic(?) clay. Some of the quartz grains here are crushed and have obviously been derived from the main Kaimeruk fault zone. This rock may be older than the Pleistocene grits described above, but it is most likely that it accumulated on the edge of a small lake in which all these rocks were deposited and that the material was derived from the fault-scarp to the west. It would therefore appear that posthumous faulting along the main Kaimeruk fault zone also occurred in uppermost Pliocene times.

Fuchs (1939, p. 224) also suggests the ponding back of the waters of the Lomenyenkoporat river to explain the presence of intervolcanic limestones in the Kamutili hills. There is however, hardly any doubt that the intervolcanic sediments are lower Miocene in age, and therefore the ponding of the waters in the area west of the lavas resulted in the coarse grits described above. These deposits suggest further that the lake was shallow and that the deposits accumulated fairly rapidly until the lake was emptied when rivers draining east breached the lava barrier.

The thicknesses of these deposits are not known, but they reach from elevations below 2,100 ft. to above 2,500 ft. above sea-level. The terrace bluff described on pp. 3 and 5 can also be mentioned here as it lies on the end-Tertiary peneplain and consists of yellowish sandy loam with numerous angular felspar and quartz pebbles. Large angular boulders within the deposit, usually in pockets, are seen in the occasional exposures along the dry river courses, but the deposit is without the slightest vestige of sorting and most probably fluviatile in origin.

### (4) Isolated Deposits

Several small patches of pale grey calcareous deposits occur scattered all over the area. Usually the deposits are unconsolidated and gritty and sometimes contain molluscs similar to those found at Kipii, such as *Melanoides tuberculata* and *Biomphalaria pfeifferi*. North of Auwerwer, at an elevation of nearly 2,300 ft. above sea-level, a patch of these deposits yielded a horse's tooth, and just west of Murilling hill (elevation 3,100 ft.) a second premolar of a large bovine animal was collected in similar deposits. A small lake also existed on top of the hills just south of Kwetchuk hill in an area now drained by the Gachiangur river. Grits deposited here (elevation 3,110 ft.) are composed of angular grains of quartz, felspar, hornblende and flakes of biotite in a dense calcareous matrix. The Gachiangur river cut its way into this lake along a fracture, and in the narrow gap formed there are numerous large blocks of honeycombed travertine which were never found *in situ*.

### (5) Upper Pleistocene (?)

The central part of the area, separating the hills of Basement from those of the Tertiary lavas, is a wide sandy plain formed by the convergence of alluvial fans which accumulated at the base of the scarp. In places below the larger valleys draining the mountains the alluvial fans are covered by pebble sheets, and here the alluvium reaches its maximum thickness. To the east however the alluvium thins so that the underlying Pleistocene sediments come close to the surface there, and are patchily exposed at Kangerega and west of the Lomenyenkoporat river.

Similarly, large tracts of the area farther east are covered by smooth lava-pebble sheets which slope away from the hills there, and become bouldery and thicker as the hills are neared. These are also thought to represent alluvial fans from which the finer material has been removed and they now appear as desert pavements.

### (6) Recent

Red-brown sandy soils are residual and occur in the western part of the area where all rivers drain to the west, and also on the surfaces bevelling the Kaimeruk hills. As elsewhere in Kenya they are underlain by Basement System rocks from which they are derived.

At the southern extremity of the Hadukhungele hills fine dusty yellow soil appears on the surface. It is overlain by alluvium further south, but its lower contact was not seen. The origin of this soil is obscure, and although it looks similar to soils derived from volcanic ashes elsewhere in Kenya it could possibly be of lacustrine origin, in which case it would most probably be of Pleistocene age, or perhaps even of aeolian origin.

Several fairly large patches of very fine-grained sand occur as dunes in parts of the eastern side of the area. They are increasing in extent at present and similar sandy deposits are accumulating in most parts of the area around small bushes and occasional tufts of grass. The numerous water channels on the piedmont plain remove large amounts of sands from there during times of flooding and these are deposited along the banks or as islands in the larger channels.

## V—STRUCTURE

### 1. Basement System

From the present disposition of the layered sequence in the Basement System it is clear that the rocks have been isoclinally folded about north-north-easterly striking axes, but the distinction between anticlines and synclines is complicated, since lineations plunge at low angles both southerly and northerly, sometimes in one and the same outcrop. The structure as deciphered in the Loperot area is shown in Fig. 3 and for the Basement System involves only one direction of translation.

*Lineations* measured indicate fold axes mainly trending N. 25° E., but mild arching of the fold axes produced southerly and northerly plunge varying in direction from N. 15° W. to N. 65° E. In isolated localities lineations were found to follow horizons around closures mapped on the ground, notably in the folds to the north-west of Kaimeruk peak, but are thought to represent steepening of the plunge of the folds there. At the crests of closures lineations are sometimes fairly steep and occasionally a small area is found there where lineations plunge at all angles in all possible directions. The statistical representation of the measured lineations is shown in Fig. 4 (*a*) where the occasional easterly plunging lineations are dominated by the numerous readings in the north-easterly direction. Occasional a-lineations were also recognized in the field, and as can be expected, plunge at varying angles to just south of east.

*Foliation* strike is regular and is borne out by the stereographic projection of the poles to the foliation, shown in Fig. 4 (*b*), where a distinctive east-west girdle with prominent dip from 20° to 50° to the east is seen.

*Folds* observed in the field are usually seen as closures on the ground which are commonly fairly regular, but are sharp in the Basement inlier in the north-eastern corner of the area where folding is extremely tight and produced a zig-zag pattern on the ground. From the dips of the foliation measured it is clear that the folds are usually asymmetric isoclinal being overfolded to the west, but sometimes they become open along the strike, while a major open syncline of which the opposing dips are clearly exposed in the escarpment occurs just west of the Lokhosiniogurr hills. Small folds seen in single exposures are of a flexural slip type (Turner, 1948, pp. 217–220), an example of which appears in Plate III (*a*). All folds are mildly arched due to differential movement during overfolding producing canoe-shaped structures, the axes of which lie along the axial planes of the main folds and perpendicular to the axes of the main folds. Curvature due to arching is therefore visible in plan and also in vertical section with the arches varying in size from a few yards to several miles in length. Such an arch with the lineations pitching in opposite directions is shown in Plate III (*b*).

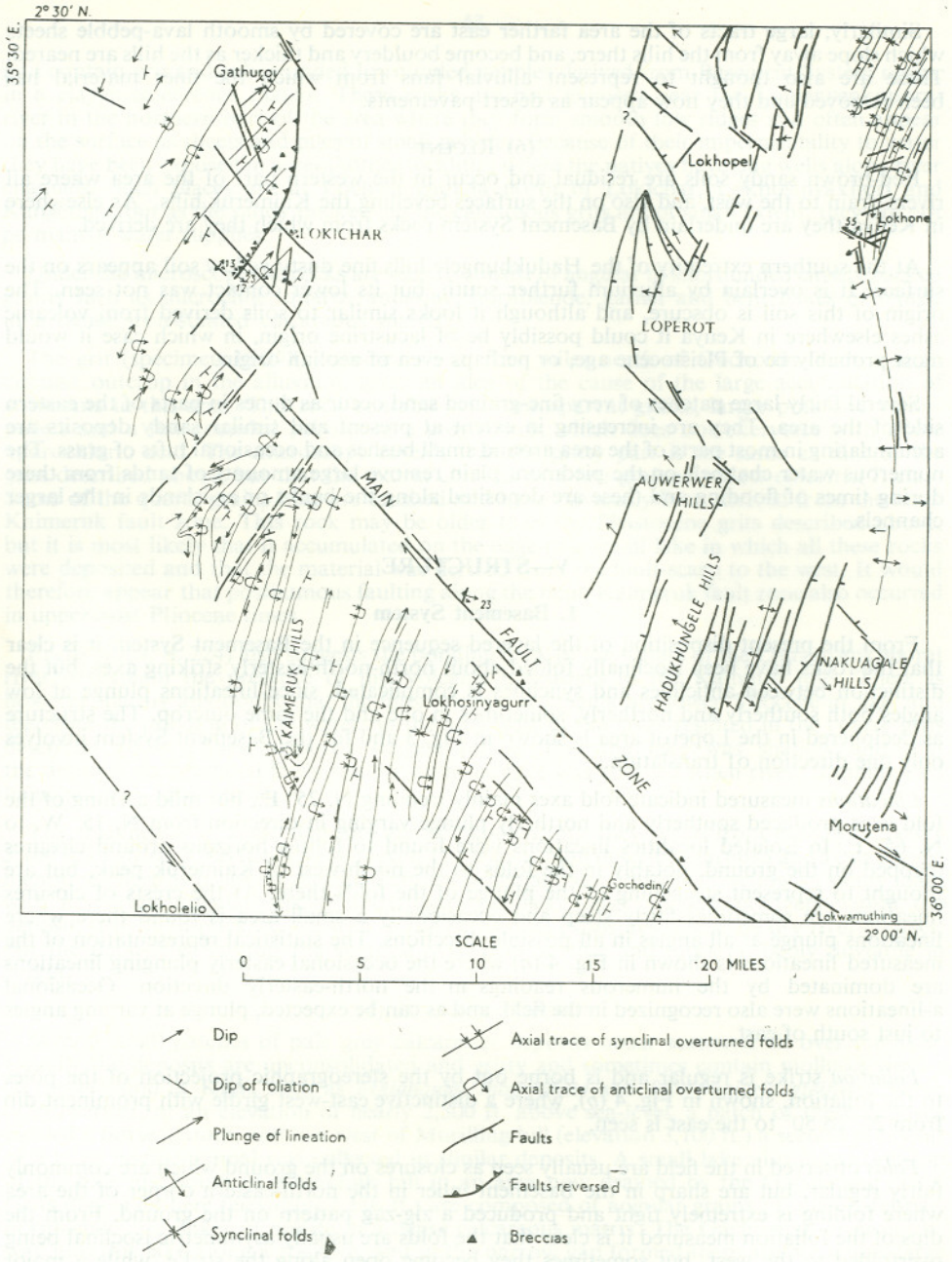



**Fig. 3—Diagram of the structures in the Loperot area.**

Where exposures allow examination, arches are terminated by fractures on both sides, with the fracture taking the place of the corresponding depression between arches, so that opposing plunges of lineations meet at fracture planes. The same seems to be valid for arches of large magnitude which are bounded by the main fault zone in the north-east, but to the south evidence of faulting is lacking, although the area is strongly jointed along a zone with the same north-westerly strike as the main fault zone.

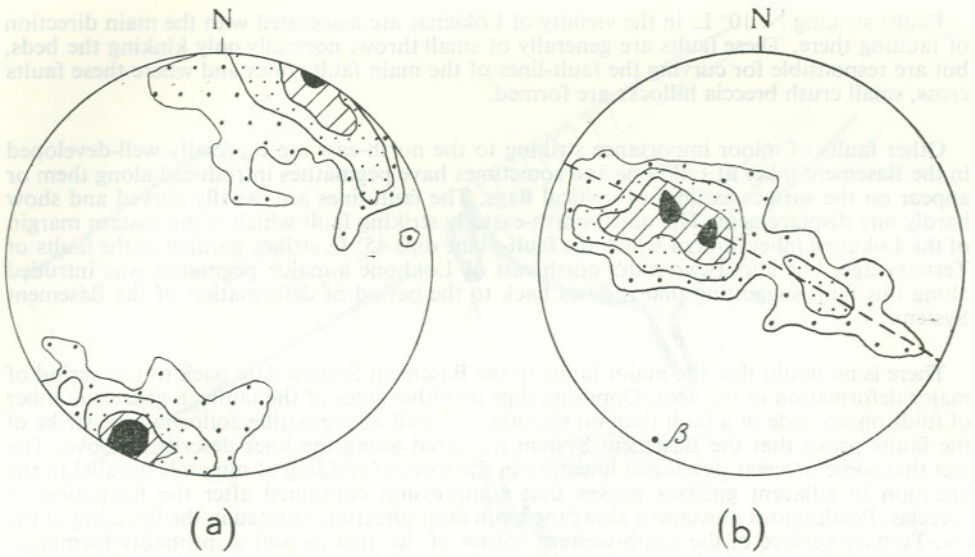



**Fig. 4.—(*a*) Contoured diagram of stereographic projection of all b-lineations measured in the Loperot area.**

**(*b*) Contoured diagram of stereographic projection of poles to all foliations measured in the Loperot area.**

*Faulting* occurred in directions which are in keeping with folding about axes striking in a north-north-easterly direction and with translation in a west-north-westerly direction. The main fault zone striking approximately N. 40° W. is formed by vertical or near vertical tear faults which very often have opposing foliation dips in the hanging and foot wall. Faulting in a north-north-easterly direction is also seen, and as can be expected these faults sometimes tend to extend into low-angle reverse faults along the strike.

The main fault zone is marked by a series of red breccia hills or by dolerite dyke swarms. This zone is responsible for the scarp on the eastern side of the Basement hills. The retreat of the scarp was facilitated by tension fractures and fractures parallel to and west of the main fault zone, and fractures are even now visible in the promontories of the scarp, but decrease in number and effect further west. The existence of another fault or fault zone is postulated on the south-western side of the hills, the evidence for it being based on structural as well as physiographical evidence described before. A third major tear fault is seen at the termination of the outcrop of Basement System north of Lokichar near the northern boundary, and its south-easterly continuation is perhaps reflected in the fractures in Tertiary lavas along the northern flanks of the Auwerwer and Nakuagale hills. A fourth fault is perhaps responsible for the mild curvature to the south of the horizons in the Basement inlier at Lokhone, and belongs to the same fault direction as the main fault zone. These tear faults or fault zones effect the division of the area into five blocks of differential movement.

Reverse faults on a small scale are commonly seen along foliation planes, resulting in the formation of a-lineations and overriding, sometimes producing mild folds with axes parallel to the main direction of folding. The most prominent thrusting however took place along a plane sloping east which now appears as a curved line trending northwards from the Ngahuko-harengak hills west of Lokichar. Ngahukon-harengak ridge consists of a crush breccia which has resistant layers dipping to the south-east at angles varying from 12° to 23°. Further north the fault-line is not marked by breccias but is seen as a line separating a northerly strike on the east and a north-easterly strike on the west in the Basement System. A small knoll of crush breccia occurs about 300 yards to the west of the present fault-line some three miles north of Lokichar and is probably a remnant of the breccia formed on the previous extension of the fault-plane. Similar crush breccia hills displaying low-angle dips occur about half a mile west of the Ngahukon-harengak hills with a 13° dip to the north-east and at Lokhosinyakhori water-hole which has a 23° dip to the south-east.

Faults striking N. 10° E. in the vicinity of Lokichar are associated with the main direction of faulting there. These faults are generally of small throw, normally only kinking the beds, but are responsible for curving the fault-lines of the main fault zones and where these faults cross, small crush breccia hillocks are formed.

Other faults of minor importance striking to the north-east are especially well-developed in the Basement inlier at Lokhone and sometimes have pegmatites introduced along them or appear on the surface as lines of vertical flags. The fault-lines are usually curved and show hardly any displacement. The north-north-easterly striking fault which is the eastern margin of the Lokhone inlier, and of which the fault-plane dips 45° E, strikes parallel to the faults of Tertiary age, but about two miles north-east of Lokhone a major pegmatite was intruded along this fault suggesting that it dates back to the period of deformation of the Basement System.

There is no doubt that the major faults in the Basement System date back to the period of major deformation of the area. Opposing dips on either sides of the faults, a greater number of folds on one side of a fault than on the other, as well as pegmatites following the strike of the faults prove that the Basement System fractured along the lines described above. The fact that some breccias developed lineation in the form of rodding of minerals parallel to the lineation in adjacent gneisses proves that compression continued after the formation of breccias. Posthumous movement along the main fault direction resulted in the lowering of the end-Tertiary surface of the south-western corner of the area as well as probably forming a scarp along the main fault zone from which the grits thought to be of Pleistocene age at Lokhosinyakhori, Kalabata valley and Lomenyenkoporat area were derived.

## Conclusions

During the mapping of the Basement inlier in the north-eastern corner of the area where it is possible to map every inch of the ground, it became increasingly evident that horizons occurred in similar pairs suggesting that the frequency of folding is greater than is suggested by the number of closures. The folding is so tight there that the structure could not be deciphered satisfactorily, and it was only after the area to the north-west of Kaimeruk peak was mapped that a suitable explanation for the folds became apparent. The structure postulated for the area to the north-west of Kaimeruk is shown in the block diagram of Plate IV. The folds are usually normal asymmetric isoclinal folds but occasionally complex lineation directions and contrary dips of foliation occur within a limited area at the crest of closures. In these parts it was at first thought to have resulted from the refolding of folds in two successive periods of folding in different directions, but can be explained by differential translation in different parts of the deforming rock pile, producing folds as shown in Fig. 5. The folds therefore consist of central folds bounded by folds of shorter wavelength which meet along the strike to terminate the central fold which is then continued as a fold of opposite character. In the case of the syncline west of Lokhosiniogurr, the synclinal axis is terminated to the south by the junction of the bordering anticlines and the same central axis is continued in an anticline. The main anticlinal axis of Kaimeruk is continued southwards until it is terminated by the syncline wrapped around the central fold where it becomes the axis of a syncline which, upon reaching the crest of the outer anticline, is continued southwards again as an anticlinal axis. It is clear that in following along this main axis, lineations will plunge either northerly or southerly along the main fold direction, but that the lineations of the minor folds will curve in towards the central fold as the closure is neared, and at the crest where the two fold axes cross an area of complexity will evolve.

If the fault block with the main hills of Basement is considered it can be seen that it moved in a north-westerly direction in relation to the adjoining fault blocks, and that the folds have a smaller amplitude as the faults are neared. Translation to the west-north-west by folding was greater in the centre of this block than near the faults, and is thought to have effected the arching of the folds. The fault block to the east of the main fault zone, although subjected to the same compressive forces, moved to the south-east relative to the blocks on either side and it is therefore not astonishing that thrusting is confined to this block. The horizontal displacement to the north-west of the fault on the north-eastern side of this fault block was even greater than that of the main fault zone and resulted in an increase in the

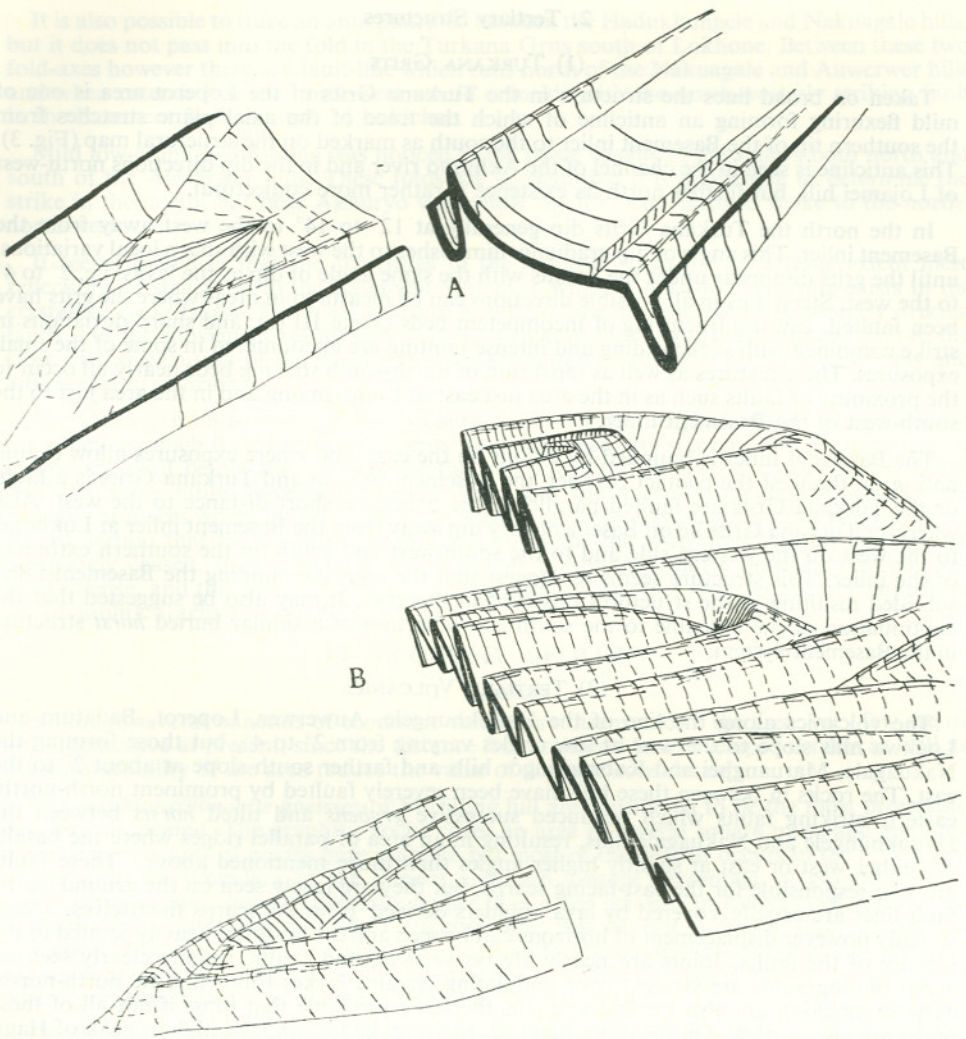



**Fig. 5.—Idealized diagrams showing the nature of the folds:—**

**A. Synclinal structure west of Lokhosiniogurr.**

**B. Structures as visualized for the Kaimeruk hills and area farther north-west.**

number of folds on the eastern side of the fault block in the Gathuroi area, and is also responsible for the reverse fault stretching from Ngahukon-harengak to the north. This thrust is the result of pivoting around a point on the southern extremity of Ngahukon-harengak ridge as is also shown by the contrary dipping reverse fault half a mile west of Ngahukon-harengak.

In conclusion it can be stated that the Basement System was subjected to compressive forces operating east-south-east to west-north-west and that translation and overfolding took place in a west-north-westerly direction, but that differential movement in that direction resulted in fracturing in a north-westerly direction and other structural features described above.

## 2. Tertiary Structures

### (1) Turkana Grits

Taken on broad lines the structure in the Turkana Grits of the Loperot area is one of mild flexuring forming an anticline of which the trace of the axial plane stretches from the southern tip of the Basement inlier to the south as marked on the structural map (Fig. 3). This anticline is seen in the channel of the Akhuryo river and in the dip directions north-west of Lojamei hill, but further north its existence is rather more conjectural.

In the north the Turkana Grits dip generally at 12° to 14° to the west away from the Basement inlier. This angle of dip gradually diminishes to the west with sharp local variations, until the grits disappear under the basalts with the same angle of dip as the lavas, i.e. 2° to 4° to the west. Steep dips in all possible directions can be measured in areas where the grits have been faulted, causing fracturing of incompetent beds (Plate III (*c*), and sharp deviations in strike combined with slickensiding and intense jointing are encountered in some of the small exposures. These features as well as repetition of north-south striking beds nearly all occur in the proximity of faults such as in the area just east of Lomerimong and in the area just to the south-west of the Basement inlier.

The Basement inlier is bounded by a fault on the east, and where exposures allow examination on the west the contact between the Basement System and Turkana Grits is a fault, or the Turkana Grits are faulted parallel to the contact a short distance to the west. Also wherever Turkana Grits lie on Basement they dip away from the Basement inlier at Lokhone, to the west on the western side and to the south-west and south on the southern extremity of the inlier. This structure seems to suggest that the area surrounding the Basement inlier subsided resulting in the structures observed in the grits. It may also be suggested that the continuation of the anticline to the south is a reflection of a similar buried *horst* structure in the Basement System.

### (2) Tertiary Volcanics

The volcanics along the line of the Hadukhungele, Auwerwer, Loperot, Badatum and Loakwa hills slope to the west at low angles varying from 2° to 4°, but those forming the Nakuagale, Maruangpei and Kabruriongor hills and farther south slope at about 2° to the east. The rocks in between these hills have been severely faulted by prominent north-north-easterly striking faults which produced successive *grabens* and tilted *horsts* between the Hadukhungele and Nakuagale hills, resulting in an area of parallel ridges where the basalts dip either west or east at slightly higher angles than those mentioned above. These faults are also responsible for the east-facing scarps, but they are rarely seen on the ground as the fault-lines are usually covered by lava boulders derived from the scarps themselves. Occasionally however displacement of horizons can be seen and the lavas are heavily jointed in the vicinity of the faults. Joints are nearly always vertical, and faults, usually clearly seen on aerial photographs, are straight over undulating terrain. Dykes following the north-north-easterly direction are also vertical and it is therefore probable that most if not all of these faults are also vertical. On the other hand the major dyke forming the highest peak of Hagit slopes 25° to the west-south-west and at Lomerimong the basalt also slopes to the west, with a dip of 18° at the top of the hill but with increasing steepness lower down the hill. It is possible that these are down-faulted blocks, but in both cases the basalts rest directly on Turkana Grits, and as described before they do not belong to the basal basaltic flows and are therefore thought to be major dyke-like bodies, which were most probably intruded along faults and may therefore indicate that at least some of the major faults dip to the west. The fault on the eastern side of the Basement inlier was measured near the Kalabata river to dip at 45° to the east, and it seems possible that these sets of faults also reflect the *horst* structure in the Basement System underneath, which is also tentatively inferred from the anticline in the Turkana Grits as described before.

Other faults striking north-west are not as well-developed and are sometimes curved to coincide with the strike of the main fault direction, such as those just west of Kamuthia water-hole. These latter faults are usually younger as they tend to offset the main faults. The north-westerly striking faults often contain geodes or vugs lined with crystalline calcite encrustations along fault planes and must have allowed the passage of primary water and gases at some time. The position of these faults can usually be traced by numerous calcite crystals on the surface and it seems that these are open fractures reflecting structures in the Basement System.

It is also possible to trace an anticlinal axis between the Hadukhungele and Nakuagale hills, but it does not pass into the fold in the Turkana Grits south of Lokhone. Between these two fold-axes however there is a fault-line which runs north of the Nakuagale and Auwerwer hills and when extended to the north-west would coincide with the north-westerly striking fault in the Basement System north of Lokichar.

Mild low-amplitude folding was noticed in the fissile basalts in the valleys both north and south of the Auwerwer hills. These folds are so mild that it is impossible to determine the strike in the north, but near Akhuryo water-hole the fold axes seem to strike to the north-north-west.

It seems therefore that the structures in the volcanic rocks are to a large extent mere reflections of structures in the Basement System in which a *horst*-like structure exists in the crystalline rocks below. This *horst* seems to be offset along its strike by north-westerly striking faults and the movement responsible for this structure must have been initiated before the close of the extrusion of the basalts as the distribution of the inter-volcanic sediments and tuffs seems to indicate.

The faulting seems to have been fairly continuous since the inception of the warp producing the valley in which the Miocene sediments were deposited, but it seems to have increased in magnitude until before the intrusion of the micro-foyaites. In several cases basaltic dykes intruded along faults have been faulted again and the micro-foyaite bodies which were intruded at places where the main fault zones cross are only very rarely faulted. It is therefore almost certain that by the time of the intrusion of the micro-foyaites faulting had almost completely ceased. Prior to the emplacement of the micro-foyaites however faulting was most intense, and this period seems to coincide with, or was just prior to, the appearance of the phonolitic trachytes.

## VI—ECONOMY GEOLOGY

### 1. General

Although several minerals of economic value were discovered in the area, very few are of any significance at present, since the distance from railhead and developed centres as well as the inaccessibility of the area reduce the value of deposits considerably.

The *graphite-sillimanite* gneisses of Murilling hill are considered to be the most promising deposits discovered. The graphitic rocks cover an area of several square miles and contains many small pockets of nearly pure graphite but most of the deposit occurs in the area south of the southern boundary of the present area. An average percentage of graphite in the gneiss is not known, but it is certainly higher than other deposits in Kenya considered to be of workable quality, and with the distinction that this deposit is much larger. An added attraction of this graphite is the associated sillimanite which does not constitute an economic proposition on its own. The Murilling deposit is from 20 to 25 miles from the Turkwel river where permanent water is available for flotation purposes.

On the south-eastern slope of the same hill *corundum* appears as nodules in the gneiss, but the extent of this deposit is not known as most of it occurs to the south of the southern boundary of the area. The corundum is of patchy distribution and would be difficult to extract, and as the crystals are of a dirty brown colour and much fractured, the corundum could only be used as an *abrasive*. The same applies to the corundum of the dyke-like (pulaskite?) bodies in the valley two miles east of Lopatamuthingo peak. Another abrasive found in the area is *garnet*, which is more abundant in the rocks to the west and south-west of Lokichar than elsewhere, and in this area several pockets of loose crystals of garnet lie on the surface. The volcanic ash found two to three miles south-east of the Namadang hills is an easily obtainable abrasive and would be most suitable as a cleansing and scouring compound if it were not so remotely situated.

Associated with the serpentinite bodies there are thin veins of *asbestos*, *magnesite*, *talc* and *vermiculite*. The vermiculite is of good quality but the asbestos fibres found are short, not flexible and have no tensile strength. Wherever these veins were seen they never attain a thickness which could constitute a deposit of economic importance. *Chromite* was also found as tiny veinlets in the serpentine and sometimes these rocks contain as much as 3 per cent $Cr_2O_3$ as well as small amounts of *nickel*. Some of the *serpentine* rocks however would furnish material for very attractive ornaments, and pulverized serpentine is often used in small amounts as a filler for insulating compositions and plastics.

The tuffaceous deposit about four miles west-south-west of Lokhone includes a greenish horizon composed of *swelling clay*. This deposit, although only partly exposed, is thought to be fairly extensive, but much of it contains a fair amount of grit. Here also there are coloured clays in bands of grey, pale green, bright red and pitch black which could be used as *pigments*. Associated with the clays are thin bands of *trona* and lower in the succession there are also thin veins of *gypsum*. Gypsum also appears in small amounts in other localities where it is interbedded with the Turkana Grits and intervolcanic sediments.

Materials for building purposes are numerous, the best *dimension stone* being the tuff which occurs at the base of the volcanic succession at Maruangpei, while the serpentinites could also be used, but as a durable and very attractive dimension stone some of the microfoyaites would be excellent. The shaping and cutting of this hard rock would no doubt be very expensive. Sources of *crushed stone* are to be had in all the hills, while *sand* is the most common commodity in the area. Some of the alluvial sands examined are extremely pure, with no or hardly any clayey admixture, and these could be most suitable used as abrasives, in refractories or in the manufacture of glass and ceramics.

*Bornite* and *chalcopyrite* were found as small specks in a quartz vein about two miles south of Lokichar and one small flake of *gold* was found in the panned concentrate of the sand from the river draining the south-western Kaimeruk hills.

Radioactive minerals discovered in the area include *allanite*, found as small elongated nodules in the biotite gneisses of the low hills two miles west of the southern Lobopakeyu hills, and a few grains of *monazite* were observed in a heavy concentrate from the river sands of the lower Kalabata river.

Some of the Iceland spar crystals collected along the faults on the northern side of the Nakuagale hills, as well as those on the northern slope of the Auwerwer hills, are so clear and unfractured that they are no doubt of the required optical grade. This market however is now very limited as the place of calcite has been taken by polaroid glass.

## 2. Water

Even during the most severe droughts the Turkana people of the Loperot area always seem to manage to water their stock, so that they hardly ever lose any animals through lack of water. This often involves long daily treks to the permanent water-holes where the conditions of the grazing is worsened. These permanent water supplies are wells dug in the sand of river beds or shallow wells along fault lines, and in one case, that of Lokwamuthing, where the water flows out onto the surface and forms small pools. The yield from the wells is very small and in nearly all cases the water is polluted by organic matter and animal urine. The waters derived from the wells in the Tertiary volcanics also have a fairly high fluorine content as seen in the following analyses:—

| | *Kamuthia* | *Lokwamuthing* |
|---|---|---|
| Turbidity .. .. .. | Heavy brownish opalescence. | None |
| Colour .. .. .. .. | Brownish | Clear |
| Odour .. .. .. .. | None | None |
| Suspended Matter .. .. | Considerable amount organic matter | Small amount organic matter |
| pH .. .. .. .. | 7·8 | 8·2 |
| | PARTS PER MILLION | |
| *Alkalinity:* (as $CaCO_3$) | | |
| Carbonate .. .. .. | Nil | 12 |
| Bicarbonate .. .. | 1,022 | 515 |
| *Ammonia:* | | |
| Saline .. .. .. | 3·44 | 0·06 |
| Albuminoid .. .. | 3·42 | 0·25 |
| *Oxygen absorbed:* | | |
| 4 hrs. at 80° F. .. .. | 32·5 | 0·4 |
| *Chlorides:* | | |
| (as Cl) .. .. .. | 49 | 27 |

PARTS PER MILLION—(*Contd.*)

| | | |
|---|---|---|
| *Sulphates:* (as $SO_4$) | Nil | 18 |
| *Nitrites:* (as $NO_2$) | Nil | Present |
| *Nitrates:* (as $NO_3$) | Nil | Present |
| *Calcium:* (as Ca) | — | 20 |
| *Magnesium:* (as Mg) | — | 4 |
| *Iron:* (as Fe) | 0·4 | 0·5 |
| *Silica:* (as $SiO_2$) | 72 | 80 |
| *Total Hardness* | 30 | 66 |
| *Permanent Hardness* | — | Nil |
| *Temporary Hardness* | — | 66 |
| *Total Solids* | 1,340 | 750 |
| *Fluorides:* (as F) | 3·1 | 2·5 |
| *Heavy Metals* (Lead, Copper, Zinc) | less than 0·1 | less than 0·1 |

*Anal.—Government Chemist, Nairobi.*

During the hydrographical survey of the Norterhn Province, Dixey (1944) saw the greater part of Turkana, and although he recognized the need of the inhabitants for permanent water supplies he also warned that "unless grazing control is put in hand simultaneously with, or before the provision of new water supplies, the development of these new water supplies will merely hasten the process of destruction" (*op. cit.*, p. 3). He also regards the conditions in Turkana unsuitable for the construction of dams, excavated tanks or wells, but points out that bore-holes in the Basement System, the Turkana Grits and the volcanic rocks proved to be very satisfactory in the past. This is also true for the present area with a few exceptions, but it is also clear that increase in the amount of water supplies would result in an increase in the number of stock in areas which are already very much overgrazed.

Cultivation is out of the question in the greater part of the Loperot area, not only because of the low rainfall but also because of the lack of suitable soil. The only part of the area which could possibly be cultivated is the grassy plains at Lokholelio, but it is also here that the best grazing is obtained. The hills composed of Basement System rocks are the only parts where over-grazing is not noticeable, and as Mason and Gibson (1957, p. 33) point out, the water storage capacity of the sand-rivers could be increased considerably by the construction of sub-surface weirs. Such weirs could be constructed at innumerable places in the valleys at the bottom of the escarpments both on the western and the eastern side of the hills, and if these weirs are strategically placed water would still not be ample so that the hills will not be threatened by over-grazing, but it would certainly do much to ameliorate the hard conditions of life of the Turkana people. Small dams could also be constructed in the hanging valleys along the escarpments. It would be a relatively simple matter to close the gap at the top of the Gachiangur river and thereby create a fairly sizeable lake on the hills there. In numerous other cases, such as the Locharakhyang Saja river, the valleys are easily breached narrow rock-bound gorges, and small dams could be constructed which would most probably hold water for long periods after the rains.

Although it would be inadvisable judging by the available grazing, there should be no difficulty in increasing the water supplies in areas near the lava hills. The wells along the faults such as those at Akhuryo, Loperot and Kamuthia could be deepened to yield much more water, and others which at present are only seasonal could be made permanent by the same method.

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