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GEOLOGY OF THE AREA SOUTH OF LODWAR

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

by

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Geologist

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CONTENTS

	Page
Abstract	
I—Introduction	1
II—Previous Geological Work	2
III—Physiography	4
IV—Summary of Geology	8
V—Details of Geology:—	
1. Basement System	9
(1) Metasedimentary Rocks	11
(2) Migmatites	15
(3) Cataclastic Rocks	16
(4) Premetamorphic Intrusives	16
(5) Anatectic Rocks	17
(6) Postmetamorphic Intrusives	19
2. Tertiary Rocks	20
(1) Turkana Grits	20
(2) Tertiary Basalts	21
(3) Intervolcanic Magnesian Limestones	22
(4) Tuffs, Ashes and Agglomerates	23
(5) Phonolites	23
(6) Trachyandesites	23
(7) Nephelinites	23
3. Tertiary Intrusive Rocks	24
(1) Nephelinites	24
(2) Dolerites	25
(3) Teschenites	25
(4) Lamprophyres	25
(5) Microfoyaites	25
4. Nepheline Syenites	26
5. Pleistocene Lake Sediments	28
6. Superficial Deposits	29
VI—Structure	30
VII—Economic Geology	35
VIII—References	36

ILLUSTRATIONS

PAGE

Fig. 1—Physiographical sketch map 6

Fig. 2—Dyke swarm in the Kamutile Hills 27

Fig. 3—Structural sketch map 31

Fig. 4—Structural data of folding in the Basement System 33

PLATES

Plate I—(*a*) Gravels of rock waste near the Emuruanuk Hills .. .. .. } at centre

(*b*) Erosional bluff terrace east of Lochereesokon .. ..

Plate II—(*a*) Pebble sheets west of Napedet derived from basal beds of the Turkana Grits .. ..

(*b*) Barchan dunes east of the Napedet Hills .. ..

Plate III—(*a*) Plates of gypsum (selenite) north of Lomenyangaparat Gorge ..

(*b*) Kamutile Peak, a microfoyaite plug .. ..

Plate IV—Typical textures in hornblende migmatites near Emurualigui ..

MAPS

Geological map of the area south of Lodwar (Degree Sheet 18, N.E. quarter). Scale 1:125,000 ..... at end

ABSTRACT

The report describes an area of approximately 1,188 square miles in the Turkana District, bounded by latitudes 2° 30′ N, and 3° 00′ N, and meridians 35° 30′ E, and 36° 00′ E. The topography of the area is divisible into the following regions: (1) the hills composed of Precambrian rocks, surrounded by plains covered by gravels derived from those rocks; (2) the central alluvial flats, bounded on the west by an approximately north-south aligned erosional terrace; (3) the Kamutile and Napedet hills composed of volcanic rocks; (4) the sandy desert in the north-eastern corner of the area.

Rocks of the area are classified as follows:—

(1) Basement System (Precambrian) gneisses, granulites, quartzites and limestones with metamorphosed intrusive rocks, anatectic rocks, and post-Basement System norites and gabbros; (2) Tertiary sediments of the Turkana Grits series; (3) Tertiary lavas comprising basalts with an itercalated magnesian limestone horizon, pyroclastic volcanic rocks, phonolites, trachyandesites and nephelinites, with numerous intrusive rocks of nephelinite, dolerite, teschenite, lamphrophyre and microfoyaite compositions; (4) Pleistocene lake sediments of the Lake Rudolf Basin; (5) Pleistocene to Recent superficial deposits, which cover most of the central and north-eastern parts of the area.

An account is given of the petrography of the various rock types, the structures, and the metamorphism of the Precambrian rocks.

I—INTRODUCTION

The area described in this report is approximately 1,188 square miles in extent, and is bounded by latitude 2° 30′ N, and 3° 00′ and by meridians 35° 30′ E, and 36° 00′ E. The area comprises the north-east quarter of degree sheet 18, Kenya (D.O.S. sheet No. 39) and lies in the central part of the Turkana District, Rift Valley Province, which is administered by the District Commissioner, Lodwar. There are no villages or administrative posts in the area.

Population

The region is populated entirely by Turkana tribesmen. The Turkana are nomadic and rarely remain in one locality for more than a few months at a time, their movements being influenced both by the state of grazing for their stock and the availability of water in various parts of the area throughout the year. Permanent water supplies are obtainable at the waterholes of Loichangamatak and Kaetako, and at springs in the Kanigium and Lomenyangaparat valleys in the central part of the Kamutile Hills. To the north, west and east of the area the Turkwel River and Lake Rudolf provide additional sources of permanent water. As is the habit of all nomadic tribes in northern Kenya, the Turkana tend to scatter after the onset of rains in search of better grazing for their cattle, camels, goats and sheep, obtaining water from numerous temporary sources such as normally dry river beds and minor pools.

No attempts at crop cultivation are made in the area. Due to the low rainfall and poor fertility of the sandy soils it is doubtful if even the most hardy crops could be grown in the arid region south of Lodwar.

Climate and Vegetation

The area lies in one of the most arid parts of East Africa. No rainfall statistics are available for the area but the recorded figures for Lodwar, situated about ten miles to the north, may be considered as representative of the area as a whole.

ANNUAL TOTAL

Station	Altitude in feet	1957 inches	1958 inches	1959 inches	Average inches	Number of Years recorded
Lodwar	1,660	6·66	15·96	12·05	5·99	34

Maximum shade temperatures taken in the Luterere Valley, near Loichangamatak waterhole, and in the Kamutile Hills, between November 1959 and March 1960, varied from 89° F. (32° C.) to 104.5° F. (40.5° C.).

Vegetation in the area is scanty. In the western half of the area acacia thorn trees are patchily scattered along the banks of the numerous sandy river bends, while the interfluves are either barren or support sparse thorn scrub. The thorn scrub becomes slightly denser on the slopes of the higher hills. The upper part of Emurualigui Peak, the highest point of the area, is covered by a dense mat of euphorbia bush. Doum palms grow profusely in the sandy river beds of the larger valleys such as the Lomenyangaparat, Orengaloup, Kaetako and Kanigium. The lava hills of Napedet and Kamutile in the eastern part of the area support a sparse growth of thorn scrub and xerophyte succulents. The sandy desert east of the lava hills is almost completely free of vegetation. Grass is found in sheltered valleys of the Emurualigui Hills, in the Ngyungyung Basin, and in other small patches immediately after the seasonal rains.

Communications

Being a somewhat remote region without administration posts or trading centres, the area is poorly supplied with roads. A single motorable track, which connects Lodwar with Lokichar to the south, passes through the western part of the area more or less following cattle tracks leading to Loichangamatak waterhole from the north and south. Due to the sandiness of numerous gullies and minor river courses through which the track passes it is only just passable to vehicles not equipped with four-wheel drive. General accessibility off the single motor track is fairly good however, and the central part of the area can be traversed by motor vehicle with little difficulty, the interfluve slopes forming gently inclined flat surfaces passable to most vehicles.

Maps

Although no suitable maps of the area were available as a base for the geological survey, air photographs cover the area with the exception of the south-western corner and small gaps along the northern boundary. Geological data was plotted both on tracings of air photographs, later reduced to suitable scale, and directly on to the topographical detail surveyed by plane table. The draft of the final map was made at a scale of 1:83,333, one third larger than the scale of the final printed map of 1:125,000. Form lines at 200-foot intervals are based on a number of spot heights taken from aneroid barometer readings, or calculated from sightings taken by clinometer.

II—PREVIOUS GEOLOGICAL WORK

The area south of Lodwar has received scant geological attention in the past. Early travellers such as Count Teleki and H. S. H. Cavendish may have passed within a few miles of the area, but did not describe any geological or geographical features of that region. A. M. Champion carried out a number of survey traverses in the Turkana District, during which he recorded geological data. His work in the present area included fixing the positions of the two peaks, Emurualigui and Loichangamatak in the northern half of the area, and Kaureta Authrui in the south-eastern corner.

In his discussion of the physiography of Turkana, Champion (1937)* makes little mention of the area south of Lodwar, but rock specimens which he collected during his traverses were later described by W. Campbell Smith (1938). Seven of these rock specimens originated from the present area.

In 1932-1933 C. Arambourg (1933, 1935, 1943) led a part geological, part anthropological expedition to the Omo delta on the northern shores of Lake Rudolf. While he did not visit the present area, the results of his work have a bearing on the geology of the Lake Rudolf basin as a whole. In his opinion the structures of the Lake Rudolf basin follow a general north-south trend, superimposed on a fold-pattern of the same trend in the Basement System. Dealing with Tertiary sedimentary rocks he suggested that the series known as Turkana Grits should be renamed the Lubur Series, pointing out that the sediments are best exposed at Lubur, a mountain range on the north-western side of Lake Rudolf. Arambourg originally correlated his Lubur Series with the Adigrat Sandstones of Ethiopia. He later considered the age to be between the Cretaceous and the mid-Tertiary period.

V. E. Fuchs (now Sir Vivian Fuchs) took part in two expeditions to Lake Rudolf. He did not visit the area south of Lodwar but his discussions (1935, 1939) of the geological history of the Lake Rudolf basin are relevant to the geology of the present area. He recognized three periods of tectonic movements: first, late Oligocene movements with a NW-SE trend; secondly, Pliocene movement which produced branches from the pre-existing fractures and thirdly, minor faulting at the close of the Middle Pleistocene. F. Dixey (1948) reported on the geology of northern Kenya, briefly describing the physiography, geological succession and structures of Turkana. He commented on the terrace which extends from south of Lodwar through the present area in a roughly north-south alignment, considering it to be the product of sub-aerial erosion of a plain surface, consequent upon the falling of the Lake Rudolf base level.

P. Joubert (1966) mapped the Loperot area, to the south of the present area. He considered the Basement System to be divisible into two groups, a lower gneiss series composed predominantly of hornblende-rich rocks, with an upper pelitic gneiss series typically containing an abundance of crystalline limestones and quartzites. He recognized Turkana Grits with interbedded tuffs as the oldest of a series of sedimentary and volcanic Tertiary rocks, the youngest being intrusive microfoyaites. Joubert described the Basement System structures in the Loperot area as typically striking at about N. 25° E. Of the post-Basement System tectonics he recognized sub-Miocene warping and faulting, and mid-Pleistocene faulting.

To the west of the present area W. A. Fairburn and F. J. Matheson (1970) mapped the Loiya-Lorugumu area. They described a succession of metamorphosed Basement System rocks, Turkana Grits and Tertiary lavas. Fairburn and Matheson concluded that the predominant structural trend over most of the area is north-north-westerly, the trend east of the Turkwel River and in the north-western corner of the Loiya sheet being however, north-north-easterly. They considered that most of the Basement System rocks belong to the almandine-amphibolite metamorphic facies as described by Fyfe, Turner and Verhoogen (1958).

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* References are quoted on page 35 and 36.

III—PHYSIOGRAPHY

1. Topography and Drainage

The area consists of four physiographic regions each with distinct topography and drainage:

The western region, including the numerous hills composed of Basement System rocks.

The alluvial plains in the central part of the area.

The lava fields which make up the Kamutile and Napedet hills.

The sandy desert in the north-eastern corner of the area.

The topography of the western part of the area is typified by gently undulating country with rounded hills and well-defined valleys. The hills such as Lochereesokon (also known as Luterere), Emuruanuk and Loichangamatak (the writer considers Loichangamatak a more correct spelling for Ngamatak used by earlier writers) are somewhat eroded with rounded, convex profiles, their slopes covered with sandy or rocky debris. The plains in this region are covered by a mantle of coarse, angular quartz and felspar rubble derived from the underlying Basement System rocks (*see* Plate 1 (*a*)).

The western part of the area is separated from the central alluvial flats by a low scarp described by Dixey (1948, p. 24). Fuchs (1939, p. 247) and Joubert (1966, p. 4). East of the Lochereesokon Hills the scarp is well-defined, forming an abrupt terrace between ten and 16 feet high (*see* Plate I (*b*)). Southwards the scarp becomes progressively less well defined, forming a gentle slope rather than a bluff terrace. Dixey considered the scarp to be the result of sub-aerial erosion of the westerly plains, consequent upon the falling of the Lake Rudolf base level. Fuchs described a 330-foot lake level, recognizable at the foot of the Lodwar Hills, adding: "These distinct shorelines can be traced south, past the Ngamatak Hills." It is not clear whether Fuchs considered the scarp to be a southerly extension of the 330-foot lake level, but as there is no other terrace, scarp or level in the vicinity of the Loichangamatak Hills it must be assumed that he did relate this scarp to a former level of Lake Rudolf. There is little doubt that the scarp does not constitute part of a former lake level as it varies in altitude from about 300 feet to about 1,000 feet above the accepted present-day level of Lake Rudolf, and there is no sign of tilting in the area. Joubert (*op. cit.*) considered the scarp to be a terrace cut by the Lomenyangaparat River, which he believed originally flowed due northwards as a tributary of the Turkwel River. The writer is in general agreement with this explanation as it would account for two important features of the scarp. First, the scarp slopes to the north at about 20 feet per mile and secondly, in plan, the shape of the scarp conforms fairly well with the present course of the Lomenyangaparat River and what is believed to have been the northerly extension of the original river course. The sequence of events leading to the formation of the scarp is believed to have been as follows: Following the Tertiary lava outpourings responsible for the formation of the Napedet and Kamutile hills the drainage to the west of the volcanic rocks was diverted northwards towards the Turkwel River. The alignment of the original Lomenyangaparat Valley is indicated by a well-developed north-south-aligned relic drainage now choked with alluvium and wind-blown sands in the Ngyungyung Basin. A change in this drainage pattern took place through river capture, both along the northern edge of the Napedet Hills, now drained by the Orengaloup River course, and through the gorge now separating the Napedet and Kamutile hills. East of the present area the Lomenyangaparat and Orengaloup rivers join and flow into Lake Rudolf. The fall of the lake level with consequent lowering of the local base level, considered by Dixey as the principal cause of the

scarp development, undoubtedly exerted a strong influence on the evolution of the drainage system. It is considered probable that retreat of the lake eastwards away from the Kamutile Hills assisted in the river capture which changed the course of the Lomenyangaparat River from its north-south alignment to an east-west direction.

Alluvial flats extend from the low scarp to the western edge of the Kamutile and Napedet Hills. This featureless plain is covered by fine-grained alluvial soils which support a sparse, patchy grass covering with a few isolated stunted bushes. Locally the sandy soils have been affected by aeolian erosion, to form a few minor sand dunes in the north-eastern part of the Ngyungyung Basin. The drainage of the plain is indefinite, shallow sandy river courses frequently fading out, sometimes to reappear within a short distance. A striking feature of the eastern part of this plain is the presence of pebble beds, which are believed to have been derived from the basal beds of the Turkana Grits. These pebble beds are composed of a dense mat of sorted, well-rounded pebbles, forming a remarkably smooth level surface free of vegetation (*see* Plate II (*a*)). Most of the alluvial plain is passable to motor vehicles, the pebble beds forming a smooth firm surface.

The Kamutile and Napedet hills form the most prominent physical features in the area. They rise abruptly from the alluvial plains to form a chain of rugged steep-sided hills, with constructing deep cut valleys, narrow ridges and rocky plateaux. The hill slopes are practically devoid of vegetation but most of the valleys contain thorn bush and, rarely, tufts of grass. Some of the larger valleys such as Kanigium and Kaetako, like the Lomenyangaparat River, are lined with acacia trees and doum palms.

The north-eastern corner of the area consists of a featureless desert largely covered with sand dunes (*see* Plate II (*b*)). The topography of this region is a product of Pleistocene lacustrine coastal erosion during a peak level of Lake Rudolf, followed by a drop of the lake level and subsequent aeolian erosion. The sand dunes are typical barchan types, the orientation of their windward slopes being to eastward, facing the prevailing easterly winds. The average dimensions of 12 sand dunes measured were as follows:— Crest height 5 feet 4 inches, windward slope angle $\pm$ 5°. Drainage of this region centres around the Lomenyangaparat River but several minor valleys draining the lava hills form shallow indeterminate courses across the sandy plain. An interesting feature of these river courses is that most of them are straightened, exhibiting the characteristics of extended drainage on a raised coastal plain. This effect was undoubtedly caused by the final retreat of Lake Rudolf away from the hills.

2. Erosion Surfaces

The area has been subjected to a series of structural and erosional phases which have either obscured or completely removed evidence of much of the early physiographic history. It is the writer's opinion that of the erosion surfaces recognized in Kenya by several writers, such as Shackleton (1945) and Dixey (1948), remnants of the sub-Miocene bevel alone can be identified in the area south of Lodwar.

The sub-Miocene erosion surface was the product of prolonged erosion after the dissection of the end-Cretaceous peneplain of which remnants are recognizable throughout East Africa. Sediments of Miocene age, locally known as Turkana Grits, were laid on the surface at a stage when little dissection had taken place. Consequently the presence of Turkana Grits is of great value in establishing the present-day profile of the sub-Miocene erosion surface. In addition to the presence of Miocene sediments, platforms identified as remnants of the original sub-Miocene bevel are present in the western part of the area around the Emuruanuk and Loichangamatak hills, at altitudes

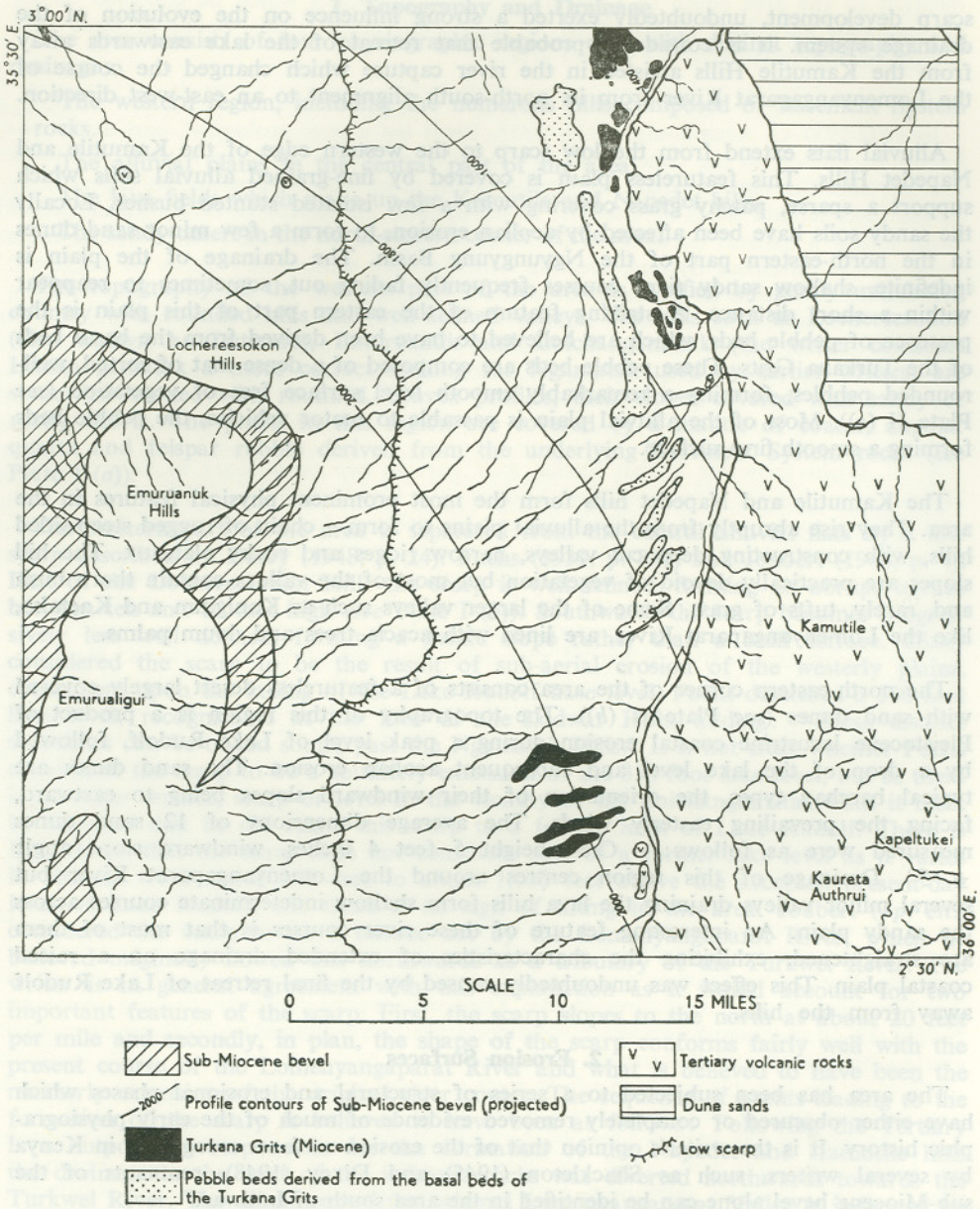


Fig.1—Physiographic sketch map of the area south of Lodwar.

varying from approximately 2,600 feet on the western edges of the hills to approximately 2,200 feet in the north-eastern margins of the hills. South of Loichangamatak a clearly defined platform-like remnant of the surface occurs at about 2,800 feet. Along the western margins of the Loichangamatak Hills, Fairburn and Matheson (1970, p. 9) recognized the westerly extensions of the platforms identified by the writer as remnants of the original sub-Miocene bevel. Walsh (1966, p. 7) described a bevel of the same age occurring about seven miles south-west of the Loichangamatak Hills. Joubert (1966, p. 5) considered that the sub-Miocene bevel is represented in only a few localities in the Loperot area to the south. He described remnants of the surface at between 3,800 ft. and 3,290 ft., with a slope down to the north. To the east and south-east of the Loichangamatak Hills indications of the former profile of the sub-Miocene bevel are provided by the presence of the lower horizons of Turkana Grits, together with pebble beds believed to have been derived from their basal beds. Most of the region between the Loichangamatak and Kamutile hills has undergone a marked degree of erosion, the early sub-Miocene erosion surface having been almost completely removed during a period of multicyclic erosion. In Fig. 1, contours of the sub-Miocene bevel were drawn from the recognizable remnant bevels in the Loichangamatak area and the altitudes of basal beds of the Turkana Grits.

The slope of the sub-Miocene bevel in the area south of Lodwar is estimated to be approximately 40 feet per mile down to the north-east. In the Kaureta Authrui region, at the southern end of the Kamutile Hills, the basal contact of the Turkana Grits occurs at about 2,000 ft., some two to four hundred feet above the estimated extension of the known sub-Miocene bevel contours shown in Fig. 1. This apparent anomaly is due to uplift along the western side of the Kanigium fault which extends from the eastern scarp of the Napedet Hills through the Kanigium Valley along a north-north-westerly alignment.

Pulfrey (1960) described the profile of the sub-Miocene bevel throughout Kenya. One of the characteristic features of the sub-Miocene surface is that it is raised ramp fashion to form the outermost shoulders of the Rift Valley. Locally, between the raised shoulders and the innermost down-faulted trough, the surface has been down-warped. An example of this down-warping, on the eastern side of the Suguta Valley south of Lake Rudolf, was described by Dodson (1963, p. 11). It is doubtful if down-warping took place in the present area. The sub-Miocene surface has however, been affected by a series of major step-like faults with easterly downthrows. To the west of the area the Turkana Fault described by McCall (1964, p. 57), Walsh (1966, p. 30) and Fairburn and Matheson (1970, p. 48) displaced the sub-Miocene surface, while in the eastern part of the area the Kanigium Fault repeats the easterly displacement. It is probable that immediately east of the Kanigium Fault the sub-Miocene bevel occurs below the level of Lake Rudolf. Farther eastward the hills on the western shores of Lake Rudolf area composed of a foundation of Basement System rocks capped by lavas. These hills must be considered either as remnants of older erosion surfaces or, more probably, as an up-faulted block.

The end-Tertiary erosion surface is one of the best known physiographic features of East Africa. It extends over most of Kenya as a well-preserved plain surface, little affected by erosion. In the present area the alluvial flats in the central part of the area and the sandy desert east of the Napedet Hills are likely to be mistaken for part of this surface, but their development in each case can be shown to be younger in age, and brought about by different physiographic conditions. It is therefore, the writer's belief that although the area was affected by erosion during the end-Tertiary era, true remnants of the end-Tertiary surface are not present in the area south of Lodwar.

Both the alluvial flats in the central part of the area and the sandy desert east of the Napedet Hills have been described earlier. Their surfaces are regarded as the product of erosion between the end-Tertiary and Recent period, their evolution being affected by the advance and retreat of Lake Rudolf. Both of these regions are plain surfaces of limited extent, forming part of the Lake Rudolf Basin. The alluvial flats were cut by the Lomenyangaparat River as a panplain, the process being hastened by the fall in level of Lake Rudolf.

There is ample evidence in the presence of fossiliferous Pleistocene sediments to prove that Lake Rudolf extended to the eastern and south-western margins of the Napedet and Kamutile hills. The sandy desert plain to the east of Napedet was therefore initially subjected to lacustrine erosion. When the lake level dropped the region reappeared with the features characteristic of a minor marine raised coastal plain. The final phase in the complex physiographic history of this region started with the onset of aeolian erosion following the most recent pluvial period. The plain, subjected to attack by westerly prevailing winds, was transformed into a typical sandy desert.

IV—SUMMARY OF GEOLOGY

The area is occupied by rocks of the Basement System with intrusive rocks, believed to be of Precambrian age, Miocene sediments, Tertiary volcanic rocks, Pleistocene lacustrine sediments, and Pleistocene to Recent superficial deposits. From evidence provided by the relationships between the metamorphic, sedimentary and volcanic rocks and the main physiographic features, it is possible to tabulate the following sequence of events in the history of the area:—

Age	*Geological Events*
Recent	Wind-blown sands.
Pleistocene	River capture through the Lomenyangaparat Gorge. *Faulting* Development of the low scarp east of Loichangamatak Hills. Lacustrine sedimentary deposition during peak level of Lake Rudolf
Pliocene	Pebble sheets derived from Turkana Grits.
Miocene to Pliocene	*Faulting* Intrusion of microfoyaites and nephelinite dykes. Intrusion of dolerites and lamprophyres. Tuffs, ashes and agglomerates. Trachyandesites.
Miocene	Basalts Intervolcanic sediments Basalts *Faulting Down-warping* (?) Turkana Grits
Oligocene (?)	Sub-Miocene peneplain maturation
Period for which there is no geological representation in the area	
Precambrian	Intrusions of norite, gabbro. Major intrusions of granite with minor intrusions of aplites, pegmatites. Folding, regional metamorphism, granitization. Fracturing, basic and ultrabasic igneous intrusion, geosynclinal sedimentation.

Rocks of the Basement System form a series of prominent hills in the western part of the area. They are also exposed in an inlier in the south-eastern part of the Kamutile volcanics. Numerous writers in East Africa have noted that the Basement System comprises a succession of metamorphosed sediments with related intrusive, and perhaps volcanic, rocks. The succession was subjected to orogenesis, the original sediments converted by successive compression, regional metamorphism and granitization to metamorphic gneisses, granulites, migmatites, quartzites and marbles, intrusive rocks of basic and ultrabasic composition being converted to amphibolites and talcose actinolitic rocks. The metamorphosed sediments were intruded by granites and numerous aplites and pegmatites. Minor basic intrusives of norite and gabbro composition, tentatively described as of Precambrian age, may belong to a younger intrusive phase.

The oldest sediments in the area are the Turkana Grits. They form low platforms along the western margins of the Napedet and Kamutile hills and are patchily exposed in the south-eastern corner of the area where they are in part overlain by lava and covered by gravels derived from the volcanic rocks.

Turkana Grits are in turn overlain by a series of volcanic rocks with an included horizon of sediments forming the chain of hills which extends from Napedet in the north of Kamutile, and southwards for a great distance beyond the limits of the present area. The oldest lavas are fine-grained basalts resting directly on the Turkana Grits, and are in turn overlain by a horizon of magnesian limestone. The basalts that overlie the magnesian limestone account for the upper part of the volcanic rock succession, forming plateaux several hundreds of feet high. The upper basalts are locally overlain by phonolites and two small flows of trachyandesite. Tuffs, ashes and agglomerates cover extensive parts of the Napedet Hills, and pale grey ash blankets the older lavas in a small area immediately west of Erakwait Hill. Dyke rocks of lamprophyre composition intrude both the lavas of the Kamutile Hills and the Basement System rocks outcropping in the western part of the area.

The youngest volcanic rocks in the area belong to an intrusive phase in which a number of microfoyaite plugs were emplaced, while nephelinite dykes were intruded into both the lavas of the Kamutile Hills and Basement System rocks forming the Loichangamatak Hills. The larger microfoyaite plugs such as Kamutile, Kanigium, Luchiriawor and Kapeltukei (Katheltege) account for the most prominent features of the volcanic region (Plate III (*b*)). In the eastern sector of the Kamutile Hills, a complex dyke-swarm of microfoyaite composition intrudes the plateau basalts. The dykes are arranged in linear and concentric patterns around a central microfoyaite plug.

Lacustrine sediments of the Lake Rudolf basin have been preserved in a few valleys in the eastern and north-western margins of the lavas fields. The sendiments are composed of shales, shelly limestones and coarse grits.

Superficial deposits cover large tracts of the area. The deposits include blocky waste derived from Basement System rocks, fine alluvial soils and gravels made up of the weathered products of the volcanic rocks, and wind-blown sands.

V—DETAILS OF GEOLOGY

1. Basement System

Rocks of the Basement System are sparsely exposed in the area. In the western sector they form a series of hills projecting through the superficial deposits, such as Lochereesokon, Kumaburi, Emuruanuk and Loichangamatak.

In the south-eastern corner of the area Basement System rocks are exposed as an inlier in the Kamutile volcanic rocks. Most of the exposed rock is highly weathered, the soft, friable nature of the outcrops often preventing detailed mapping. As an additional difficulty, many of the rock exposures are eroded and weathered to a condition in which their original constituents are almost completely altered.

Due to the restricted limits of the rock exposures measurement of the complete succession of Basement System rocks in the area is impossible. The following sequence was measured along the vertical section line A—A_1 on the coloured geological map:—

Formation	*Approx. thickness (ft.)*
Biotite gneisses with intercalated amphibolite bands	1,400
Hornblende migmatites	500
Biotite migmatites with semi-pelitic host	800
Amphibolites	600
Biotite migmatites with semi-pelitic host	700
Biotite gneisses with intercalated bands of amphibolite ...	2,800
Amphibolites	400
Biotite gneisses	600
Biotite migmatites with semi-pelitic host	3,200

In the South Horr area Dodson (1963) noted a possible disconformity between two lithological groups in the Basement System, the lower member being typified by a slight enrichment of calcium, the upper member being composed of pelitic to psammitic gneisses and migmatites, with bands of amphibolite intercalated in some of the gneiss horizons. In the Loperot area to the south, Joubert (1966) considered the Basement System to be divisible into two series: the Turoka series composed of fine-grained pelitic gneisses with crystalline limestones and quartzites, and the underlying Kaimeruk series composed of coarse-grained granulites and migmatites, with abundant amphibolite and ultrabasic intrusive horizons, and occasional small bands of crystalline limestone. If Joubert's subdivision can be applied to the present area it would appear that most of the Basement System rocks exposed in the western part of the area must be classified as members of the Kaimeruk series, the only possible exception being the small outcrops of rock known collectively as the Kajalaite Hills, which consist mainly of quartzites and crystalline limestones, indicating that they may be members of the Turoka series. If Dodson's tentative division of rock types in the South Horr area applies in the area south of Lodwar, the Basement System rocks in the western part of the area belong to the upper division, while rocks exposed in the Basement System inlier of the south-eastern corner of the area, composed mainly of hornblende and garnet-rich granulites, belong to the lower hornblende division. In nearby areas Walsh (1966, p. 9) and McCall (1964, p. 16) have subdivided the Basement System into separate lithological groups. In the subdivision adopted by Walsh, he considered the lowermost group to be equivalent to the Turoka series. If this is the case the other three groups described by Walsh overlie the Turoka series, thus extending subdivision of the Basement System to six lithological groups. It must be emphasized however, that the subdivision outlined above is based entirely on lithological grounds and lacks confirmatory evidence such as proof of disconformable or unconformable contacts, or variance of tectonic styles between the groups.

For purpose of description, the following is considered the most satisfactory classification of the Basement System rocks and intrusive rocks believed to be of Precambrian age:—

1. Metasedimentary rocks
   (*a*) Crystalline limestones
   (*b*) Calc-silicate granulites
   (*c*) Hornblende-diopside gneisses
   (*d*) Hornblende-biotite gneisses
   (*e*) Biotite-garnet gneisses
   (*f*) Sillimanite gneisses
   (*g*) Muscovite schists
   (*h*) Biotite gneisses
   (*i*) Quartzites
   (*j*) Quartzo-felspathic granulites
2. Migmatites
   (*a*) Biotite migmatites
   (*b*) Hornblende migmatites
3. Cataclastic rocks
4. Premetamorphic intrusive rocks
   (*a*) Amphibolites
   (*b*) Intrusive rocks of ultrabasic composition
5. Anatectic rocks
   (*a*) Granites
   (*b*) Aplites
   (*c*) Pegmatites
   (*d*) Quartz veins
6. Postmetamorphic intrusive rocks
   (*a*) Norite
   (*b*) Gabbro

(1) Metasedimentary Rocks

(*a*) *Crystalline limestones*

A few isolated bands of marble occur in the outcropping Basement System rocks as insignificant, narrow, impersistent lenses in the succession exposed in the Loichangamatak Hills, and as thick bands forming low ridges in the Kajalaite group of hills. The limestones in the Kajalaite area are typically coarse-textured white to salmon-coloured marbles, free of visible impurities but containing lenses or minor bands composed almost entirely of calc-silicate minerals. The limestones exposed in the Loichangamatak Hills are fine-grained, grey to bluish-coloured types usually containing abundant evenly distributed calc-silicate minerals.

Specimens 18/652* and 18/657 are typical of the coarse-grained marbles outcropping in the Kajalaite Hills. They are coarse-textured rocks containing only rare megascopic non-calcareous accessory minerals. They vary from white (18/657) to a pale salmon colour (18/652), the discoloration being due to interstitial staining by iron oxide. In

*Numbers 18/652 etc. refer to specimens in the regional collection in the Mines and Geological Department, Nairobi.

thin section the limestones are seen to be composed of large grains of calcite with small amounts of accessory serpentine in 18/657, and apatite in 18/652. As an example of the more impure limestones occurring in the Loichangamatak Hills specimen 18/694, a dark greenish to red mottled limestone outcropping immediately south-east of Emurualigui Peak, is composed of calcite with abundant roughly equidimensional grains of diopside and calcic garnet. Accessory minerals identified in heavy mineral concentrates of this rock are hornblende, sphene, apatite and rare tremolite.

(b) Calc-silicate granulites

A single band of calc-silicate granulite is exposed in the valley about three miles north of Loichangamatak Peak. In addition, rocks composed predominantly of calc-silicate minerals occur as inclusions or minor bands in crystalline limestones, and also as small segregations in migmatites or biotite gneisses. The occurrence of calc-silicate granulite segregations in Basement System rocks has been described in the Nanyuki-Maralal area by Shackleton (1946, p. 8) and in the South Horr area by Dodson (1963, p. 15).

Typically the granulites are grey to greenish rocks, sometimes including patches or veinlets of free calcite. Specimen 18/651, from the hydridized margin of a crystalline limestone horizon in the Kajalaite Hills, is a medium-grained granulitic textured rock composed of partly intergrown grains of diopside and clinozoisite with much altered andesine. Specimen 18/579, from a small segregation of calcium enrichment in biotite migmatite on the south-eastern slopes of the Lochereesokon Hills, is green to brownish in colour, with an even-grained granulitic texture and is composed of epidote, scapolite, calcite, garnet and diopside. Some of the smaller calc-silicate segregations are of nearly monomineralic composition, the most common constituent minerals being garnet, diopside, epidote or hornblende.

(c) Hornblende-diopside gneisses

The inlier of Basement System rocks south of Kaureta Authrui includes a horizon of hornblende-diopside gneisses. As the rocks of that region are generally weathered to a high degree, the hornblende-diopside gneiss is exposed as a series of low, rounded, stumpy mounds of coarse-grained, grey to greenish rock, seldom retaining recognizable foliation. The hornblende-diopside gneisses are green to greyish coloured, even-grained rocks showing slight banding through enrichment of diopside in narrow layers. As it was not possible, due to their friable nature, to prepare thin sections from any of the exposed rocks examined, concentrates of heavy minerals were collected. Heavy minerals identified in the concentrates, in order of their abundance, are hornblende, diopside, garnet, sphene, iron ore and apatite.

(d) Hornblende-biotite gneisses

Adjacent to the hornblende-diopside gneisses are bands of hornblende-biotite gneisses which can be distinguished in the field by their darker colour, schistose texture and an even more deeply weathered condition. In hand specimen biotite is easily identified, both as individual flakes scattered through the rock and as concentrations in narrow partings of the foliation planes. Examination of heavy mineral concentrates showed that diopside is present in small amounts only.

(e) Biotite-garnet gneisses

The biotite-garnet gneisses of the area are medium to coarse-textured, granulitic, pale grey to reddish coloured rocks exhibiting marked preferred orientation in field exposures but little gneissosity in the hand specimen. Both garnet and biotite tend to be concentrated in narrow seams. The biotite-garnet gneisses occur in sequence with

the hornblende-biotite gneisses in the south-eastern corner of the area. Due to the compactness of their texture and quartzose nature of their composition the biotite-garnet gneisses, unlike the other rocks exposed in that region, form extensive outcrops of relatively unaltered rock.

Specimen 18/725 from the valley south of Kaureta Authrui is a medium-textured, granulitic rock composed of orthoclase, oligoclase, microcline, quartz, biotite and garnet as the primary constituent minerals. The biotite occurs as variable shaped green flakes, some of which are slightly altered. The garnet, a pale pink type, is present as medium-sized idiomorphic grains. Accessory minerals are pyrite, zircon and rare apatite.

(*f*) *Sillimanite Gneisses*

Sillimanite-bearing gneiss is exposed in the Loichangamatak Hills immediately south-west of Emurualigui Peak. The gneiss appears as a series of intermittent linear outcrops of streaky yellowish rock composed of felspar, most of which is kaolinized, ovoid segregations of quartz, and porcellaneous stringers of sillimanite. In thin section specimen 18/695 from Emurualigui is seen to consist primarily of quartz, orthoclase and sillimanite. The sillimanite needles are concentrated in seams which curve around the quartz and felspar grains, in radiating tufts, and as scattered prisms penetrating the quartz and felspar grains. Included in the specimen are amorphous, opaque, yellowish grains, believed to be the alteration product of muscovite stained with iron oxides.

(*g*) *Muscovite Schists*

Outcrops of muscovite schists occur in the succession of rocks forming the Loichangamatak Hills and also in the north-western corner of the area between the two hills Luleliam and Sopel, where Basement System rocks are exposed between layers of basic and ultrabasic intrusive rocks.

Specimen 18/591 from near Luleliam and 18/695, representative of the outcropping muscovite schist to the immediate south-west of Emurualigui Peak, bear close resemblance to each other. In hand specimen they are medium-textured, schistose, whitish to pale grey rocks, containing a sufficiently high mica content to impart a vitreous lustre to the rock exposures. The muscovite schists are composed mainly of quartz, felspar and muscovite, the mica flakes attaining a maximum length of 5mm. They tend to be concentrated in narrow partings, emphasizing the schistose texture of the rock. The felspars present are orthoclase and microcline, the latter patchily forming intergrowths with quartz. While not apparent in the thin section, specimen 18/591 contains a few medium-sized garnets, sparsely distributed through the schist.

Considering the close proximity of the muscovite schists and sillimanite gneisses near Emurualigui, and the similarity of their mineral assemblages, it is possible that the muscovite was formed by retrogressive metamorphism at the expense of sillimanite.

(*h*) *Biotite Gneisses*

Biotite gneisses account for an appreciable proportion of the Basement System succession exposed in the area. Like most other rocks of the succession they are somewhat weathered, forming rounded outcrops of friable grey rock, frequently stained reddish to yellowish by iron oxides. They vary from leucocratic types with a low biotite content to melanocratic biotite-rich gneisses of pelitic composition. While they grade into adjacent migmatites and quartzo-felspathic granulites, the biotite gneisses are typically homogeneous, pale grey, strongly gneissose rocks. The most common of the slight mineral and textural variations seen in these rocks are: a slight banding effect produced by the contrast between the gneiss and lenticles of felspar enrichment;

concentrations of biotite and sometimes magnetite grains to form glomero-plasmatic clusters; and the spotted effect given by the growth of augen porphyroblasts of felspar. The growth of felspar augen and lenticles is nearly always confined to transitional zones between the biotite gneisses and migmatites.

Specimens 18/598 and 18/599, from a small rocky outcrop roughly halfway between the Kajalaite Hills and Locheriamoit Hill and too small to be shown at the scale of the map, are representative of the most common forms of biotite gneisses and pelitic biotite gneisses. Specimen 18/598 is an allotriomorphic textured rock composed of quartz, felspar, biotite and muscovite, with accessory pyrite, iron ore, apatite and zircon. The felspars are large grains of microcline, better preserved than the other felspars but nevertheless in parts turbid and patchily replaced by sericite, turbid grains of altered orthoclase, and plagioclase, which is present as medium-sized grains more or less saussuritized and lightly stained with iron oxide. Some of the plagioclase forms myrmekite intergrowths. The biotite is a greenish brown variety, patchily altered to chlorite. Apart from the small flakes of sericite derived from potash felspar, muscovite occurs as medium-sized flakes formed at the expense of biotite. Pyrite occurs as subhedral grains of about 2mm. diameter. The iron oxide is mainly secondary, occurring as interstitial staining. Both apatite and zircon are abundant, apatite as medium-sized subhedral grains, and zircon as minute euhedral prisms, which when included in biotite are surrounded by pleochroic haloes. Owing to the soft friable condition of specimen 19/599 microscopic examination of this rock was mostly directed at examination of heavy and light mineral separations of crushed rock. Biotite is far more abundant than in specimen 18/598. The felspar content is correspondingly different, oligoclase is abundant, orthoclase less common, while microcline is rare. The accessory mineral content remains constant for the two types of biotite gneiss.

(*i*) *Quartzites*

Quartzites are not common in the area. They are confined to the region between Loichangamatak waterhole and Koloi Hills, where quartzite bands form a few low-lying rocky ridges, free of vegetation. As the quartzite shows unusual resistance to weathering, forming conspicuous hills rising above the debris-strewn plains, it is likely that these exposures represent the only quartzite horizons in the local Basement System succession.

In hand specimen the quartzites are coarse-grained, compact, vitreous rocks, speckled with inclusions or, as in specimen 18/720 from immediately north-west of Loichangamatak waterhole, spotted with small pits where the inclusions have been removed by erosion. The small pits are lined with iron oxides or hydroxides, and sometimes contain fine yellowish kaolin indicating that the original inclusions were probably felspars. The quartzites are typically translucent and whitish-coloured, strongly resembling massive quartz at a distance. The outcrops are well jointed, their joint partings usually being coated with reddish brown iron oxide.

Specimen 18/595 from the Emuruaring Hills is a compact coarse-textured quartzite composed of an interlocking mosaic of quartz, medium-sized, rounded grains of somewhat altered felspar, muscovite and pyrite. The quartz grains often have narrow margins of interstitial iron oxide staining which also penetrates cracks in some of the larger crystals. The felspar grains are sodic-oligoclase and orthoclase, the latter patchily replaced by sericite. Muscovite appears to have formed at the expense of biotite, as the edges of some muscovite flakes retain relic shreds of biotite. The pyrite occurs as euhedral to subhedral medium-sized crystals scattered through the rock. Specimen 18/730, a coarse-grained quartzite from a small hill near Loichangamatak waterhole, is composed almost entirely of quartz with specks of magnetite.

(j) Quartzo-felspathic Granulites

Although quartzo-felspathic granulites account for only a small proportion of the Basement System succession exposed in the area south of Lodwar, outcrops are usually well preserved and, like the quartzite exposures, exposures of granulite often protrude through superficial deposits to form rocky ridges.

The granulites vary from medium-grained, saccharoidal-textured, pinkish rocks to coarse-textured grey types, but retain certain common characteristics such as an even-grained granulitic texture and predominantly quartzo-felspathic composition. Specimen 18/587, from a narrow band adjacent to the quartzite of the Emuruaring Hills, is a typical medium-grained granulite composed of quartz, felspar and small amounts of accessory minerals. The felspar content includes orthoclase, microcline and plagioclase, all of which are somewhat altered. Most of the orthoclase grains are patchily converted to small flakes of sericite, while one large grain of potash felspar is partly replaced by a ragged flake of muscovite. Microcline locally replaces orthoclase, quartz and the plagioclase, which approximates to a composition of sodic oligoclase. Green biotite is present as an accessory mineral, the other accessories being magnetite and small prisms of zircon.

(2) Migmatites

(a) Biotite Migmatites

Biotite migmatites form the Lochereesokon Hills, Kumaburi, and an appreciable portion of the Emuruanuk and Loichangamatak Hills. The migmatites are mixed rocks in which the original host rock, usually a pelitic or semi-pelitic biotite gneiss, is invaded by veins, stringers or lamellae of granitic and aplitic material. Because of their heterogeneous composition and variable texture, migmatites are best studied as massive rocks *in situ,* rather than in simple hand specimens which at best can show only part of the textural or mineral variations apparent in field exposures.

Specimen 18/708, from the Kauthrui Hills, exhibits most of the features typical of migmatites. It is a streaky grey rock, consisting of biotite-rich layers alternating with potash-rich lamellae, minor lenses, augen and veins. In thin section the rock is seen to be medium-grained and composed of microcline, orthoclase, plagioclase, quartz, biotite and iron ore. There appear to be two generations of microcline in the rock, the early crystallized microcline forming large coarse grains, sometimes including narrow perthite streaks. Second-generation replacive microcline tends to be concentrated in elongated vein-like channels penetrating the rock, replacing orthoclase, quartz, plagioclase and the older microcline. Quartz occurs as variable-sized irregular grains, and as patchy intergrowths with microcline. Examination of the small augen apparent in the hand specimen proved that they are invariably composed of microcline, frequently surrounded by a layer of smaller grains of microcline which in turn is sometimes surrounded by microcline-quartz intergrowths. The minor lenses in the rock are composed predominantly of microcline, with orthoclase, sodic-plagioclase and large quartz grains. Although ferromagnesian minerals are rare in the lenses, flakes of biotite are usually concentrated around their margins, this mineral distribution suggesting that the lenses are the products of segregation by migration of felsic constituents.

(b) Hornblende Migmatites

The hornblende migmatites, like the biotite migmatites, are mixed rocks in which the two components representing the original host rock and the later-introduced felsic material remain distinct. There is however, little similarity between the two types. The hornblende migmatites are typically composed of a melanocratic even-grained amphibolite host rock, intruded by anastomosing veins of felsic composition. The general

character of the rock is dependent on the degree of migmatization. In the least migmatized types the host rock frequently retains a fissile schistose character, typical of the hornblende-rich rocks, while the hybrid product of advanced migmatization is typified by a blocky uneven texture, made up of homogeneous biotite and hornblende-bearing gneiss, with contrasting undigested patches of a melanocratic hornblendic character (Plate IV).

Specimen 18/674, from a hornblende migmatite exposed in a steep-sided valley north of Emurualigui Peak, is representative of portions of the original hornblendic host-rock, which occurs as undigested blocks surrounded by felsic veins, and hybrid gradations between the host rock and the felsic veins. In thin section it is allotriomorphic textured and composed of hornblende, plagioclase, biotite, quartz and the accessory minerals sphene and apatite. The plagioclase is andesine (An_{45}). The biotite, a greenish brown variety, is present as small shred-like flakes, apparently replacing hornblende. Specimen 18/676 from the same exposure of migmatite is an example of patchy, roughly banded, gradational rock between the blocks of hornblendic material and the zone of completely digested gneiss. Thin section 18/676, prepared from the felsic portion of the specimen, exhibits an aplitic texture composed of orthoclase, oligoclase, quartz, biotite and muscovite. Thin section 18/676A, from the melanocratic layers, is composed of biotite, hornblende, oligoclase, potash felspar and quartz. The biotite is probably a replacement of hornblende, following the introduction of potash by the felsic veins. The oligoclase has a composition of about An_{30}, as compared with the slightly more sodic variety in specimen 18/676, An_{25}. The potash felspar occurs as small discrete lenticular grains replacing plagioclase.

(3) Cataclastic Rocks

The western portion of the area is cut by numerous faults which are often indicated by the presence of well-defined hills or ridges composed of fault breccia. The breccias outcrop over most of the western part of the area, the more prominent ridges being north of Kumaburi, north-west of the Emuruanuk Hills, in the Kajalaite Hills region, and between Loichangamatak waterhole and the Loichangamatak Hills. In hand specimen the breccias vary from extremely fine-grained, porcellaneous, mylonitic types to coarse, blocky rock, composed of angular fragments of quartz and other resistant minerals set in a fine-grained matrix composed of the pulverized remains of the least resistant minerals. In some of the fault lines polished slickensided surfaces can be observed. Secondary mineralization is widespread in the breccias, as infillings of cracks along shear planes and as later veining. Typical secondary minerals are quartz, limonitic staining, and less common pyrite. Assays of grab samples taken from the crush breccias of Kumaburi Hill, Koloi Hill and the fault lines between Loichangamatak waterhole and the Loichangamatak Hills, showed only slight traces of gold.

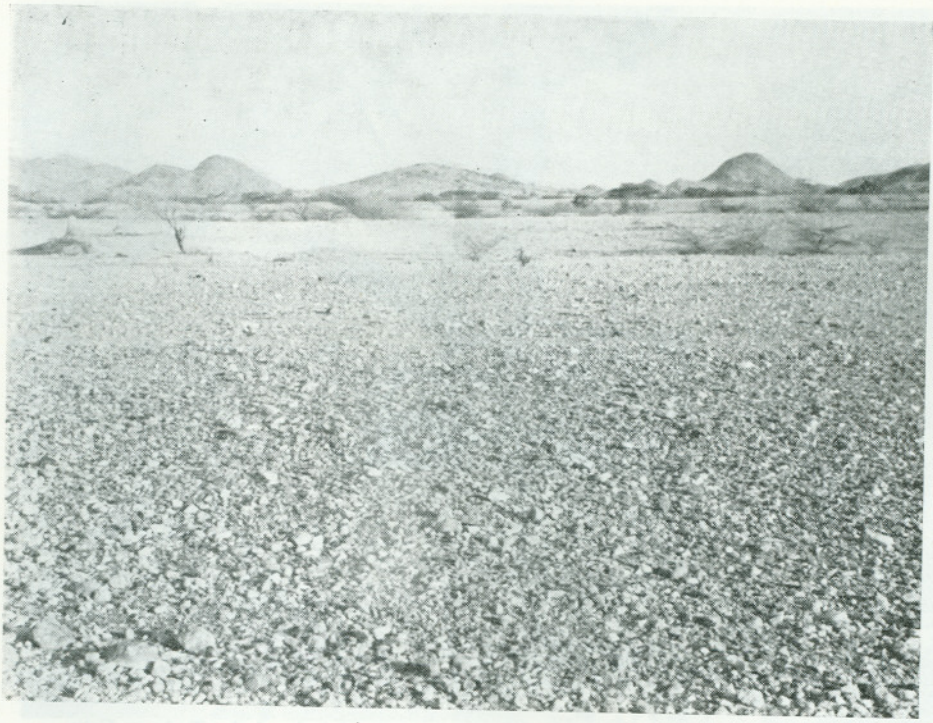
(4) Pre-metamorphic Intrusives

(*a*) *Amphibolites*

Amphibolites are found throughout the Basement System rocks in the area. They occur as variable-sized lensoid intercalations in the gneisses, the contacts between the amphibolite and gneiss being well defined. Owing to their superior resistance to weathering, amphibolites frequently form rocky outcrops in regions where contiguous rock types have already been reduced to rock waste by erosion. The amphibolites are believed to be metamorphosed basic rocks, possibly introduced during an intrusive phase of the orogenic cycle.

They are medium-grained, pale greenish grey to nearly black rocks forming fissile slabs or schistose blocks with well-defined preferred orientation, emphasized by the common alignment of hornblende grains. Specimens 18/653 from the Kajalaite Hills

PLATE I

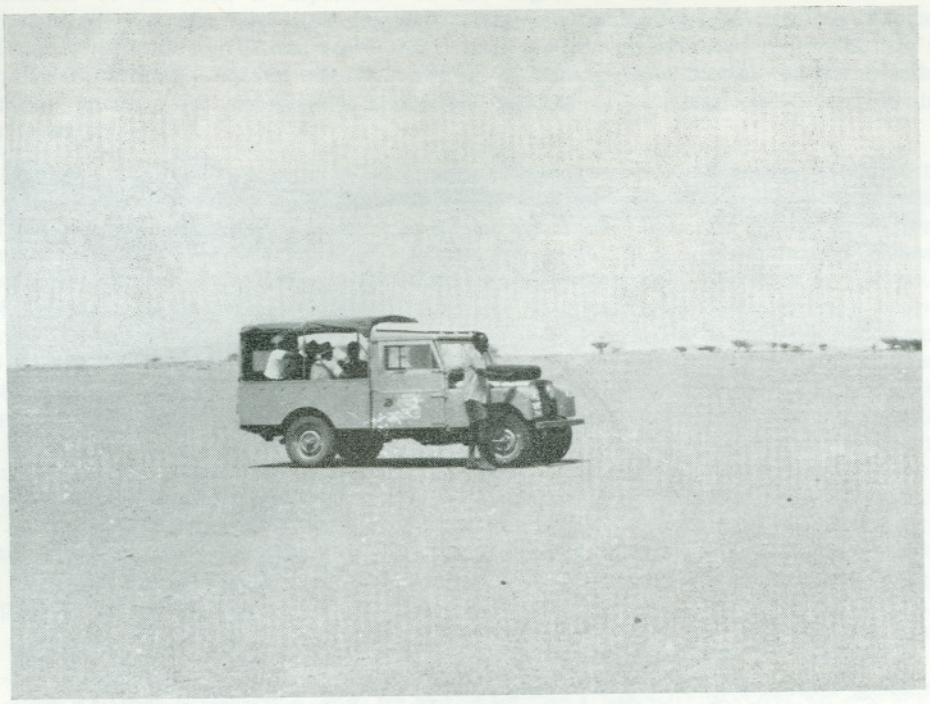


(a) Gravels of rock waste near the Emuruanuk hills



(b) Erosional bluff terrace east of Lochereesokon

PLATE II

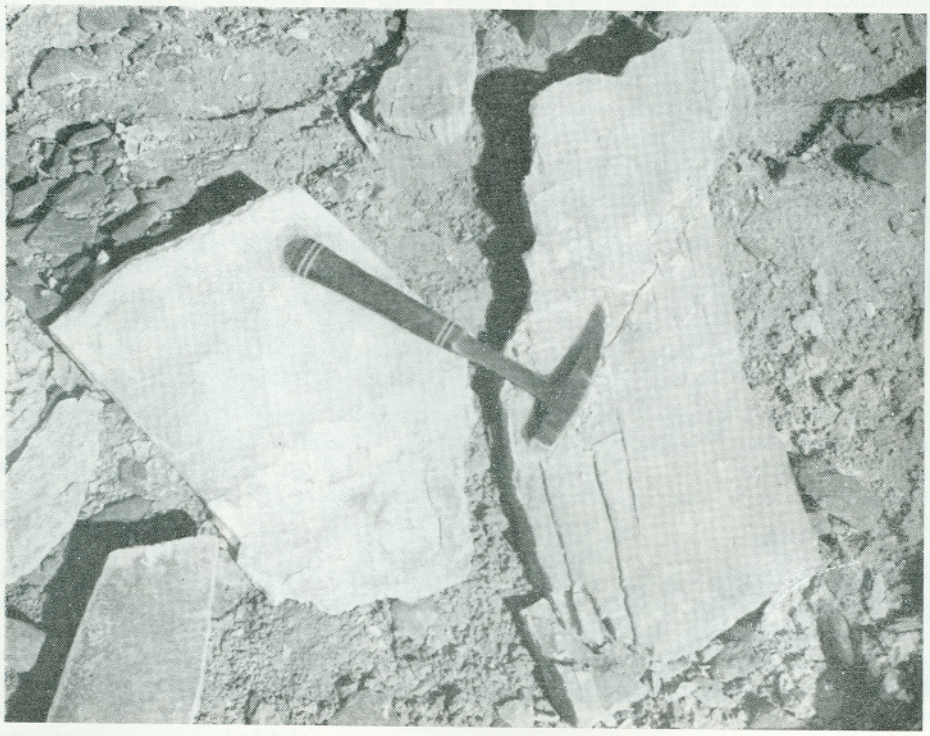


(a) Pebble sheets west of Napedet derived from basal beds of the Turkana Grits



(b) Barchan dunes east of the Napedet hills

PLATE III



(a) Plates of gypsum (selenite) north of Lomenyangaparat gorge



(b) Kamutile peak, a microfayaite plug

PLATE IV





(a) and (b) Typical textures in hornblende migmatites, near Emurualigui

and 18/660 from an exposure four miles south of Emurualigui Peak in the Loichangamatak Hills are typical of the common types of amphibolite. In thin section they are medium-grained schistose rocks, composed essentially of roughly equidimensional grains of green hornblende, often containing poikilitic inclusions, plagioclase and accessory minerals, frequently of calcic composition. Other primary minerals found in the amphibolites are pale green diopside, scapolite, usually present as the calcic member meionite, biotite, and less commonly garnet. The most common accessory minerals are sphene, calcite, quartz, apatite and zircon. Specimen 18/724, from a narrow rocky outcrop in the Basement System inlier south-east of Kaureta Authrui, is an example of plagioclase amphibolite, distinguishable from the other amphibolites by the increase in plagioclase content, which in this specimen amounts to just over 60 per cent of the total mineral composition. The plagioclase, andesine, is slightly more sodic than the andesine of the melanocratic amphibolites.

(b) Intrusive rocks of ultrabasic composition

A variety of rocks of ultrabasic composition, occurring as small dyke-like intrusive bodies, are sparsely distributed through the exposed Basement System rocks in the area. There is little similarity between the various ultrabasic rock types, each having been metamorphosed to the extent that many of the original component minerals have been replaced.

Pyroxenites are intermittently exposed in the compactly folded rocks between Luleliam and Sopel hills, where they form heaps of soft, friable rubble. Specimen 18/584, from an outcrop about one mile west of Kakenye Hill, is a coarse grained greenish, waxy-looking, fibrous rock composed of pale green actinolite, partly altered to talc, with a few small specks of black iron ore. Where replacement of actinolite by talc has proceeded to a great extent the rock is reduced to a pale grey colour and has the characteristic soapy feel of talc.

Two occurrences of *serpentinite* were mapped, the smaller of the two being a narrow band contiguous with a crystalline limestone horizon in the Kajalaite Hills, and the larger body forming a low rocky hill situated between the Loichangamatak and Emuruanuk Hills. In thin sections, specimens 18/682 from about two miles south of Emuruanuk Peak and 18/655 from the Kajalaite Hills, the serpentinites are seen to consists almost entirely of serpentine with a skeletal network of iron ore and rare patches of calcite. Much of the serpentine is pseudomorphous after olivine.

A single band of *peridotite* is exposed in a shallow valley two-and-a-half miles north-west of Loichangamatak Peak. In the hand specimen (18/671) it is a fine-grained, grey rock with a distinctive greenish tinge. The thin section shows olivine, which occurs as separate grains surrounded by pale green replacive serpentine, tremolite which appears to be a replacement of enstatite, and iron ore both as individual grains and concentrations of minute grains into seams, or coalesced to form elongated feathery patches along the veins of serpentine.

(5) Anatectic Rocks

(a) Granite

The north-western part of the Loichangamatak Hills and the western side of Emuruanuk are composed of medium-grained granite. The granite intrudes the Basement System rocks, but where visible the contact is often gradational, from the normal country rock, through a zone rich in potash felspar augen, to the granite which is distinctly coarser-grained than the gneisses. It is therefore considered that the granite is derived directly from the Basement System rocks, a localized intensification of

granitization having induced the state of mobilization responsible for the intrusive nature of the granite. Dodson (1963, p. 25) and Baker (1963, p. 29) described similar granites in the South Horr and Baragoi areas.

Field exposures of the granite consist of variable-sized boulders heaped up to form conspicuous rocky hills, typical of most granite areas in Africa. The rounded shape of granite boulders is caused by the effects of spheroidal weathering of blocks separated by the predominant sets of jointing. Specimens 18/668 from three miles north of Emurualigui and 18/687 from the central western slopes of the Emuruanuk Hills are typical of these granites. They are medium to coarse-grained non-porphyritic granitic-textured rocks composed of quartz, potash felspar, oligoclase, biotite, muscovite and accessory apatite and zircon. Microcline replaces orthoclase and plagioclase, and locally forms intergrowths with quartz. The minerals of the granites do not show preferred orientation in field exposures or in thin section.

(*b*) *Aplites*

Aplites occur abundantly in most of the Basement System rocks, but tend to be concentrated in the well-jointed rocks such as granites and quartzo-felspathic granulites. They are also common in the migmatites. The aplites are found as veinlets varying from about an inch in thickness to large bodies over 100 feet wide. Unlike pegmatites, which occur in a variety of shapes, aplites are invariably vein-like, with more or less parallel sides. The aplites are usually discordant with the country rock. Contacts are sharp, with no apparent hybridization between the two rock types. In the largest aplites there is a distinct increase in the coarseness of the texture from a fine-grained chilled marginal contact towards the centre of the body.

Typically the aplites are even-grained, dull pink to off-white rocks of predominantly felsic composition. Locally they are sprinkled with specks of hornblende, biotite, muscovite or magnetite, but they seldom include even patchy enrichment of the non-felsic minerals. Specimens 18/661 and 18/680 from about three miles north of Loichangamatak Peak and 18/685 from the large vein on the northern side of the Emuruanuk Hills, are typical aplites, and in thin section reveal strong textural and mineral uniformity. They are aplitic-textured and composed of microcline, quartz, orthoclase, plagioclase, biotite, magnetite, muscovite and the accessory minerals zircon and apatite. The quartz sometimes exhibits preferred orientation, parallel with the margins of the aplite vein. Most of the muscovite present is a replacement of orthoclase. In a heavy mineral concentrate from specimen 18/685 a feebly radioactive grain was tentatively identified as orthite. Other heavy minerals identified in the concentrate but not seen in the thin sections were pyrite, sphene, ilmenite and epidote.

(*c*) *Pegmatites*

Pegmatites occur in a variety of types and vary widely in dimensions, but conform roughly with the three types of pegmatites described by Dodson (1957, p. 89). In the present area, the distribution and field relationships of segregation, permeation and intrusive pegmatites, are similar to those of the South Horr area described by Dodson (1963, p. 26) and those of the Baragoi area, described by Baker (1963, p. 33).

The *segregation pegmatites* are mainly concentrated in the migmatites, and generally show an affinity to the composition and mineralization of the host rock from which they are derived. Despite the fact that most of these pegmatites are eroded to a soft friable condition, it was possible to establish the fact that in the semi-pelitic biotite migmatites they are composed manly of potash felspar and sodic plagioclase with a composition of approximately An_{10}, the potash felspar being slightly in excess of the plagioclase. On the other hand, in the hornblende migmatites, potash felspar is distinctly subordinate to plagioclase of slightly more calcic composition (An_{20} to An_{35}).

Permeation pegmatites are rare in the area. In the quartzo-felspathic granulite horizons they form ovoid lenticles, seldom more than a few feet long, composed of blocky crystals of potash felspar, quartz and small amounts of iron ore or biotite.

Intrusive pegmatites are divisible into simple and complex types, both characterized by well-defined sharp contacts, and parallel sided vein-like forms. Simple intrusive pegmatites are white to pinkish veins composed of coarse-grained potash felspar phenocrysts set in a finer-grained matrix of potash felspar, sodic plagioclase, quartz and biotite. In specimen 18/729, from a pegmatite intruding hornblende migmatite immediately west of Loichangamatak waterhole, orthoclase is the predominant potash felspar, microcline occurring as small isolated grains. The plagioclase is a sodic oligoclase and accounts for about 30 per cent of the total rock composition.

The *complex pegmatites* are composed of zones of different mineral composition, frequently with a central core of quartz. A complex pegmatite outcropping about two miles north-east of Loichangamatak Peak may be considered as typical of the pegmatites. It is composed of the following mineral units: an outer zone of quartz-albite intergrowth, the latter patchily replaced by microcline, an inner zone of coarse microcline, albite and quartz, with garnets and books of muscovite, the mica concentrated around an innermost core of quartz. The quartz core includes isolated idiomorphic crystals of pink microcline and a few small flakes of muscovite.

None of the pegmatites examined contained mineralization of potential economic value.

(*d*) *Quartz veins*

Although small quartz veins are fairly common in the psammitic rocks, no veins longer than about a hundred feet were discovered. The veins are lenticular or roughly parallel-sided and are usually composed of massive clear quartz with small grains of iron ore, or less commonly a few crystals of felspar. Examination of heavy mineral concentrates from five quartz veins in the Loichangamatak and Emuruanuk hills revealed the presence of small quantities of hornblende, muscovite and, less commonly, pyrite.

(6) Postmetamorphic Intrusives

(*a*) *Norites*

In the north-western corner of the area norite is exposed as a series of low-lying rocky outcrops, the most prominent being Luleliam Hill. The outcrops of norite consist of heaps of spheroidally weathered boulders up to five feet in diameter, usually covered by a chocolate-coloured crust of oxidation. Specimen 18/588 from Luleliam Hill is a medium-grained, grey coloured rock composed of hypersthene, plagioclase, hornblende and olivine. The hypersthene occurs as large faintly pleochroic grains with minute schiller inclusions either distributed through the pyroxene in well-defined orientations, or coalesced to form fine feathery-textured elongated stringers. The plagioclase was identified as labradorite (An_{65}). The hornblende is a dull brown variety, and is present mainly as a marginal replacement of pyroxene. Olivine is relatively fresh, although the grains are rimmed by kelyphitic intergrowths where in contact with plagioclase.

(*b*) *Gabbros*

While it is probable that the exposures of norite belong to the same intrusive body, it is clear that the four widely separated outcrops of gabbro in the area are not connected with each other. The largest of these outcrops forms the low-lying plateau of Sopel in the north-western corner of the map. Smaller concordant bodies of gabbro outcrop just north of the Loperot-Lodwar road crossing of the Luterere Valley, in the plains north-north-west of Emuruanuk Peak, and about three miles north-west of

Emurualigui Peak. The gabbro of Sopel forms massive spheroidal boulders up to six feet in diameter. The boulders are coated with a dark grey skin of oxidation, their appearance being remarkably similar to lava boulders of Kakenye Hill and several other smaller lava plateaux just north of the present area. The other gabbros are free of weathered crusts.

The gabbros are typically coarse-textured mesocratic rocks, much lighter coloured than the norites and are of bojitic composition. Specimen 18/731 from Sopel, typical of all the gabbros, is a medium-grained, granitic-textured rock composed of well-twinned labradorite, pale green hornblende, and a few grains of clinozoisite. The other gabbros exposed show only slight variations of texture and composition.

2. Tertiary Rocks

(1) Turkana Grits

The name Turkana Grits was first used by Murray-Hughes (1933) for a succession of sediments shown in his geological sketch map of western Kenya. He considered them to be of Jurassic age. Arambourg (1935, p. 10) referred to these sediments as the Lubur Series after what he considered to be the best type locality, Lubur (Labur) mountain on the north-western shores of Lake Rudolf. He originally correlated the Lubur Series with the Adigrat Sandstones of Ethiopia, which are believed to be Triassic in age, but later modified his views, concluding on the basis of fossil evidence (1943, p. 165) that the age of the series was between Cretaceous and Mid-Tertiary. Fuchs (1939, p. 228), on the strength of palaeobotanical evidence provided by Dr. M. Bancroft of the Imperial Forestry Institute, Oxford, from fossil wood in the Turkana Grits, pointed out that the sediments are not older than the Cretaceous, stating the belief that they were of Miocene age. Dixey (1944, p. 13) mentioned the presence of the fossil *Deinotherium hobleyi* in the Turkana Grits of the Loperot area. As Shackleton (1946, p. 27) also reported this fossil in the sub-volcanic sediments of the Maralal area it is likely that the Turkana Grits were laid down during Miocene sedimentation which covered most of northern Kenya.

In the present area Turkana Grits are exposed near the western margins of the Napedet and Kamutile lava fields, and in the north-western corner of the area. Along the edges of the lava flows and in the Basement System inlier south of Kaureta Authrui exposures of Turkana Grits are either obscured or completely covered by gravels derived from the volcanic rocks. By comparison with the Turkana Grits succession described by Joubert (1966, p. 26) the sediments exposed in the present area belong to the lower members of the series. This is confirmed by the relationship between the exposed sediments and the pebble sheets shown on the geological map. The pebble sheets consist of layers of well-sorted rounded pebbles situated immediately west of the easterly dipping sediments, that is in a position which would be occupied by the basal conglomerate of the Turkana Grits.

The bulk of the exposed sediments are calcareous gritty sandstones. Specimens 18/614 and 18/637, from the Turkana Grits west of Napedet Hills, consist of angular to sub-angular mineral fragments derived from the Basement System rocks, set in a calcareous matrix. At the base of the exposed calcareous sandstones they are slightly more conglomeratic, with rounded pebbles of quartz, felspar and gneiss up to four inches in diameter. A layer of gypsiferous shaley mudstones overlying the sandstones is patchily exposed in some of the gullies eroded through the gravels covering the western slopes of the Napedet Hills. The shales occur about 90 feet above the exposed calcareous sandstones, a figure corresponding with the thicknesses of the lower parts of the succession described by Joubert between a layer of "... calcareous sandstones and

some grits . . ." and ". . . silts and tuffs with gypsum and trona . . ." (Joubert 1966, p. 26). The maximum thickness of the exposed mudstones is about 15 feet. Throughout the exposures the rock is completely homogeneous and is free of recognizable fossils. The exposures usually have a well-developed vertical joint system, while in the horizontal plane the sediments form thin, flaggy, slate-like slabs seldom more than a quarter of an inch thick. The mudstone is pale greenish to grey in colour when fresh, turning to dull brownish grey when exposed to sunlight for a few days. As exposure to sunlight also increases friability it is probable that the mudstone contains a relatively high water content, which is driven off by prolonged exposure to the sun. Similar effects can be artificially induced by heating slabs of the sediment in an oven. The mudstone is extremely fine-grained and of argillaceous composition, surfaces having a distinctive soapy feel. Highly altered clay-like pellets are sparsely included in the mudstones, but as a whole the rock remains homogeneous in texture. The composition of these rocks is difficult to establish, but from their texture it is apparent that they are fine-grained lacustrine sediments made up of clay minerals, possibly originally derived from pyroclastic material.

The gypsum is present mainly as discontinuous seams, although isolated crystals and rosette-like structures are also found. The seams vary from minute veinlets to more extensive veins up to two inches thick, usually cutting across the stratification of the mudstones. The rosettes are scattered through the mudstones, usually in close proximity to the gypsum seams. The gypsum is mostly pure white, but changes locally to pale greenish or yellow. Where the seams are parallel with the sedimentary bedding, lenses of mudstone in crude stratiform arrangement are sometimes included in the gypsum. The rosettes of gypsum consist of concentrically arranged disc-like slabs around a central nucleus of mudstone or clay. About four miles north of the western mouth of the Lomenyangaparat Gorge a small exposure of mudstone is littered with plates of gypsum. From a distance the gypsum looks like a mica occurrence, the plates of transparent to opaque gypsum, up to three feet across, presenting a striking spectacle from distances up to a mile away (Plate III (*a*)). As this mudstone is some 50 feet higher than the sediments exposed in gullies to the north it is probable that it occurs slightly higher in the succession.

Trona occurs as small acicular crystals lining cavities, or in narrow veinlets parallel with the stratification.

In the south-eastern corner of the area Turkana Grits are intermittently exposed along the gravel-strewn slopes between the lava flows of the Kaureta Authrui region and the low-lying Basement System rocks. These sediments probably represent a higher horizon than the mudstone. At the base of one of the exposures of sandstones in this region, buff coloured mudstones similar to the rock described above are just discernible beneath the covering gravels. The sandstones vary from yellow to reddish coarse-grained calcareous types, to fine yellow grits.

No fossils were recognized in any of the Turkana Grits series rocks in the present area.

(2) Tertiary Basalts

Basalts occupy the greater part of the volcanic rock succession. They form the impressive plateaux between Emuruabahoi and Kaureta Authrui, and most of the larger hills in the Napedet and Kamutile ranges. Three miles north-west of the Kajalaite Hills a low hill composed of basalt may represent a much eroded outlier of the Kamutile basalts.

The plateau basalts in the Kaureta Authrui area are stratigraphically divided by an intercalated magnesian limestone horizon, separating the lower basalts which directly overlie the Turkana Grits and the upper plateau basalts. Apart from minor textural and lithological details, all the basalts in the area show marked similarities. The lowermost basalts, typified by specimen 18/719 from the valley south-east of Kaureta Authrui, are medium to fine-grained rocks composed of a fine-grained groundmass of analcite, plagioclase, augite, biotite, iron ore and secondary calcite, with phenocrysts, originally olivine, now almost completely replaced by antigorite. The plagioclase, identified as labradorite, An_{65}, is present as small laths with a tendency towards ophitic textural arrangement. The biotite occurs in rare small flakes with marked pleochroism from nearly colourless to reddish brown. Secondary calcite occurs both in concentrated patches in the groundmass and as narrow veinlets. It is likely that the weathered condition of this basalt with characteristic calcification is due largely to submersion beneath the lake responsible for the deposition of the intervolcanic sediments overlying this basalt.

Specimens 18/715 and 18/716, from the lowermost and uppermost lava flows forming the Emuruabahoi Plateau, are typical of the upper basalts overlying the sediments. Although collected from localities separated by a thickness of approximately 600 feet of lava, they show little difference from each other, both being porphyritic, medium-grained rocks composed of a groundmass of analcite, labradorite, iron ore and augite, with phenocrysts of titan-augite, olivine and iron ore. The augite phenocrysts are idiomorphic and vary from neutral to pale mauve in colour. Olivine phenocrysts are patchily replaced by iddingsite. Specimen 18/624, from the small hill to the north-east of Kajalaite, shows a greater affinity with the lowermost basalts. As this lava rests directly on Basement System rocks it either flowed out over an eroded surface free of Tertiary sediments or it might be the eroded remains of an intrusive basalt.

Campbell Smith (1938, p. 533) described nephelinite from near Kaureta Authrui Peak. The writer collected specimen 18/721 from this region, but considers the rock to be similar to the upper analcite basalts. In thin section it is composed of a fine-grained groundmass of analcite, labradorite, pyroxene and iron ore, with augite and much altered olivine phenocrysts. The original olivine now consists of cores of green antigorite surrounded by a margin of replacive iddingsite. No nepheline was identified in the rock.

(3) Intervolcanic Magnesian Limestones

The limestone dividing the lower and upper basalts is best exposed in the valley immediately north of Kaureta Authrui, and crops out in some of the nearby hill slopes along the same contour level. Since there is no trace of this limestone to the north of this exposure it is probable that it wedges out to the north. Where exposed, the band of limestone is slightly less than 30 feet thick. It is a fine-grained, yellowish or pinkish to grey mottled rock composed of fine carbonate matter with abundant lenticles of secondary quartz. The rock has an estimated hardness of about 7. The fact that this figure is much in excess of the theoretical hardness of dolomite must be attributed to the presence of colloidal silica. Partial analyses of samples from two miles west of Kaureta Authrui (Fuchs, 1939, p. 271) are as follows:

	(1)	(2)
CaO	31·71	27·92
MgO	19·04	18·70
Al_2O_3	2·02	0·82
Fe_2O_3	2·74	1·95
P_2O_5	0·0025	0·02

anal. S.E. Ellis.

Joubert (1966, p. 37) described the presence of gastropod fossils in horizons of the limestone exposed in the Loperot area. In the Kaureta Authrui area however, no fossils were found, but small fragments of limestone scattered about the gravels near Kapeltukei contained unidentifiable shell fragments.

(4) Tuffs, Ashes and Agglomerates

Pyroclastic material occurs in most parts of the lava fields. Tuffs are mainly confined to the northern part of the Napedet Hills, where they form flaggy, greenish grey outcrops in some of the larger valleys. Ashes are most abundant in the Kamutile Hills, the most extensive deposition being to the west of Erakwait. They underlie the oldest basalts, forming a discontinuous horizon between the basalt series and the Turkana Grits. The ashes vary in colour from pale grey to brownish, and are usually fine-grained. In the south-eastern sector of the Napedet Hills agglomerate forms a striking landscape of steep-sided hills and deep valleys. The agglomerate there is a bluish to grey compact rock, with inclusions of scoria, analcite basalt, and less commonly volcanic glass.

(5) Phonolites

Most of the phonolites in the area occur in the Napedet Hills where they are found as lava flows capping basalt, agglomerate and ash, and in one instance as a volcanic plug. Typically the phonolites are fine-grained, dark bluish grey rocks, sometimes dotted with microphenocrysts of felspar and nepheline. Specimen 18/600, from the small plug protruding through the gravels on the north-western slopes of the Napedet Hills, and 18/609 from the lava flows to the east of the plug, are composed of fine-grained groundmasses of nepheline, aegirine-augite, iron ore, the soda amphibole kataphorite, and anorthoclase. The phenocrysts are aegirine-augite, nepheline, hornblende, anorthoclase and iron ore. In thin section 18/600 most of the nepheline and anorthoclase phenocrysts are idiomorphic, and show a greater or lesser degree of marginal resorption corrosion. The hornblende phenocrysts have undergone a higher degree of resorption and have dense, nearly opaque, marginal reaction rims.

(6) Trachyandesites

Two minor lava flows of trachyandesitic composition overlie the basalts to the north and west of Kamutile. The relationships between these lavas and the other volcanic rocks are not clear, except that they are younger than the basalts and appear to have been extruded after a period sufficiently long to have allowed erosion of the upper surface of the basalts.

The trachyandesites are fine-grained, dark grey porphyritic rocks, distinguishable in the field from other lavas by the presence of abundant narrow felspar prisms arranged in common orientation.

Specimen 18/649, from three miles west of Kamutile, is a medium-grained, trachytic-textured porphyritic rock, composed of a groundmass of anorthoclase, aegirine-augite, iron ore and plagioclase, with plagioclase phenocrysts identified as andesine (An_{40}). The phenocrysts attain a maximum length of 20mm., the average length being about 9mm.

(7) Nephelinites

Nephelinite occurs both as lava flows and in dyke form. Since the dykes found in the western part of the area bear a close resemblance to the nephelinite lava flows, it is assumed that the dykes are contemporaneous with the lavas capping Kakenye Hill and a smaller hill about six miles to the east. The intrusive nephelinites may have been feeder dykes to a former lava flow that included the two isolated nephelinite-capped hills in the north-western part of the area. Further evidence of the existence of a single sheet of lava is provided by the general similarity of the lavas of each of

the two hills. It is also considered likely that these nephelinites are related to the nephelinites of the Lodwar region, described by Champion (1958, p. 534) and Walsh and Dodson (1969, p. 17).

Specimen 18/582 from Kakenye Hill is a compact bluish green lava, speckled with numerous small but recognizable nepheline crystals. In thin section it is seen to be composed of a groundmass of idiomorphic nepheline grains and pyroxene, with microphenocrysts of pyroxene, iron ore and biotite. The pyroxene is neutral to mauve in colour, and occurs as euhedral to subhedral prisms, sometimes with corroded margins. The biotite is strongly pleochroic in reddish brown, and is present as irregular skeletal flakes crowded with nepheline grains.

3. Tertiary Intrusive Rocks

(1) Nephelinites

Nephelinite dykes are found in three separate localities in the area, the nephelinite in each region being characterized by distinctive textures and widely differing appearances in the field. In the Emurualigui Hills the Basement System rocks are intruded by a series of north-south-aligned nephelinite dykes, which by their textures, composition and general appearance can be grouped with the nephelinite lava capping Kakenye Hill. These dykes are composed of greenish, medium-grained volcanic rock, speckled with waxy-looking nepheline phenocrysts. Specimen 18/666 from north-western Emurualigui consists of a nearly opaque groundmass composed of analcite, nepheline and slender prisms of pyroxene, with phenocrysts of pyroxene and idiomorphic nepheline grains. Some of the nepheline grains are replaced by calcite. The pyroxene phenocrysts are aegirine, some of the prisms being zoned, with an inner core of aegirine-augite. Several microxenoliths of the Basement System country rock are contained in the nephelinite, the inclusions being partly digested grains of microcline and sodic plagioclase, presumably incorporated during the intrusion.

A number of nephelinite dykes intrude an agglomerate pile on the eastern side of Napedet Hills. The dykes, aligned in a roughly north-south direction, present a striking feature in this region as they are considerably more resistant than the agglomerate, forming well-defined ridges which rise above the soft, easily weathered, pyroclastics. In hand specimen they are fine-grained, bluish grey rocks with sparsely distributed microphenocrysts. In thin section specimen 18/638, from the largest dyke in the eastern part of the Napedet Hills, consists of a fine-grained greenish groundmass with microphenocrysts of idiomorphic nepheline crystals. Detailed examination of the groundmass shows it to be composed of minute idiomorphic crystals of nepheline, with fine aggregates of pyroxene, iron ore, and patches of secondary calcite.

The most striking looking nephelinite in the area is an east-west aligned dyke about three miles north of Kanigium Hill in the north-eastern part of the Kamutile Hills. In hand specimen it is a dark grey rock, spotted with abundant off-white nepheline phenocrysts. In addition the rock includes equally abundant prisms of dark green pyroxene. In specimen 18/705 from this dyke the groundmass consists of much altered nepheline, specks of iron ore and aegirine-augite. The phenocrysts, estimated to account for 34 per cent of the total rock composition, are idiomorphic nepheline crystals, somewhat replaced by zeolites, subhedral to euhedral prisms of augite, less common octahedra of iron ore, and rare prisms of aegirine-augite. The nepheline phenocrysts attain a maximum length of 9mm. the average width of the rectangular and hexagonal sections being approximately 2.5mm. The augite is a pale neutral to mauve variety with zoning in some prisms. When zoned the outer shell is invariably of mauve-coloured titaniferous composition, the inner zone being neutral to pale grey in colour. The augite prisms attain a maximum length of 15 mm.

(2) Dolerites

In the western part of the area a small dolerite dyke with an approximate north-south alignment is exposed at the southern end of the Emuruanuk Hills. The dyke is somewhat obscured by talus on the hill slopes of that region. The dolerite forms medium-sized spheroidally weathered boulders coated with a thin chocolate-coloured crust of oxidation. In thin section (specimen 18/676) it is seen to be a typical dolerite with a medium-grained porphyritic texture, composed of ophitic laths of labradorite, iron ore, both as subhedral octahedra scattered through the rock and as skeletal aggregates derived from much-altered ferromagnesian grains, neutral coloured augite, and iddingsite replacement of olivine. No other dolerites were mapped in the area.

(3) Teschenites

In the central sector of the Napedet Hills several dykes intrude the basalts and pyroclastic rocks. These dyke rocks are unique in appearance, bearing no resemblance to either the nearby lavas or the other dyke rocks. Typically they are medium-grained, brown, greenish or grey porphyritic rocks, with abundant phenocrysts of felspar and dark coloured pyroxenes and amphiboles. In hand specimen the fine groundmass has a characteristic dull, waxy look. In thin section 18/619, a specimen from the most easterly of these dykes, the groundmass consists of analcite, sodic-orthoclase, pyroxene, iron ore, and rare nepheline. The phenocrysts are plagioclase, brown barkevikitic hornblende, brown biotite, augite, and octahedra of magnetite. The plagioclase, indentified as An_{15}, is somewhat altered.

(4) Lamprophyres

A number of dyke-like intrusives were mapped in the region between the Loichangamatak waterhole and the Kanathawaole Valley. Despite the eroded condition of the Basement System rock, the lamprophyres are easily recognizable as they form linear heaps of spheroidal boulders or pebbles just protruding through the rock waste. Even where lamprophyres are completely covered by the sandy soils and gravels derived from Basement System rocks, dark brown to reddish discoloration of the superficial deposits indicates the presence of the dykes. The lamprophyres are brownish to grey compact rocks usually covered with weathered shells of a slightly lighter colour. Specimen 18/707, from a dyke outcropping between two small hills immediately north of the Kanathawaole Valley, is composed of a compact, intergranular texture of plagioclase (An_{20}), iron ore and augite. Most of the plagioclase and pyroxene grains are altered. Veins of secondary calcite are scattered through the rock. The predominance of plagioclase and the presence of augite indicates a spessartite composition.

A small lamprophyre dyke with an east-west alignment intrudes the plateau basalts north of Kanigium Hill. The dyke rock is dark grey in colour and in the hand specimen is characterized by an abundance of felspar phenocrysts up to 16 mm. long. The groundmass has the waxy appearance typical of analcite-bearing volcanic rocks. Specimen 18/702 consists of a fine-grained groundmass composed almost entirely of analcite, with small prisms of pyroxene and abundant phenocrysts of hornblende, pyroxene, plagioclase and iron ore. The hornblende is a brown highly pleochroic, barkevikitic variety, and occurs as stout idiomorphic prisms. The pyroxene present is pale green aegirine-augite, exhibiting faint zoning in cross sections. The large plagioclase laths are andesine (An_{40}). In view of the analcite content of the groundmass and the presence of the barkevikitic hornblende, the lamprophyre can be classified as monchiquite.

(5) Microfoyaites

The term microfoyaite is used to describe the volcanic rock which forms a number of plug-like intrusive bodies in the Kamutile and Napedet lava fields. Use of the term follows the definition by Hatch, Wells and Wells (1949, p. 245), that is the micro-

foyaites are intermediate in texture between phonolite and the equivalent plutonic rock, nepheline-syenite. Microfoyaite plugs form some of the most prominent physical features of the lava fields, such as the conical peaks Kamutile, Luchiriawor and Kapeltukei. In addition to the intrusive plugs microfoyaite also occurs in dyke form, the best examples being the large dyke cutting the Lomenyangaparat Gorge at the Kakujukwok water-hole, and the dyke swarm in the Kanigium area.

Microfoyaites have been described from a number of localities in north-western Kenya. Campbell Smith (1938, p. 510) and Arambourg (1935, p. 26) described microfoyaites from the Muruanachok Hills area, some 30 miles south-west of the Napedet Hills. Joubert (1966, p. 39) described numerous microfoyaites in the southerly extension of the Kamutile Hills in the Loperot area, and Mason and Gibson (1957, p. 28) mentioned the occurrence of a single microfoyaite intrusion in the Kalossia-Tiati area, farther southwards. It would therefore appear that the microfoyaite intrusives are abundantly scattered through the north-south aligned chain of lava fields which extend down the western side of Lake Rudolf and which include the Napedet and Kamutile hills.

Even when they do not form prominent features the microfoyaite intrusives are easily recognizable in the field as they are considerably lighter in colour than the surrounding lavas. The compactness of their composition precludes their being mistaken for similarly coloured pyroclastic material. In hand specimen the microfoyaites are immediately distinguishable from both phonolite lavas and nepheline syenite, which occurs in the Napedet Hills as float blocks. They are medium to coarse-grained, pale greyish, pinkish, to brownish coloured rocks in which most of the constituent minerals can be recognized megascopically. The microfoyaites are generally trachytic-textured and nearly all are at least slightly porphyritic. In 14 specimens examined there is little variation of texture or composition. Specimens 18/643 from the north-eastern corner of the Napedet Hills, and 18/722 from Kapeltukei Hill, are representative of the microfoyaites examined. They are trachytic-textured and composed of laths of turbid anorthoclase, nepheline sometimes more or less replaced by analcite, aegirine-augite, and iron ore. Specimen 18/722 is porphyritic, with phenocrysts of anorthoclase up to 6mm. long.

Possibly the most impressive geological feature in the area is a swarm of microfoyaite dykes in the north-eastern part of the Kamutile Hills (Fig. 2). The dyke swarm occupies an area of over 30 square miles, the dykes being distributed around a central microfoyaite plug. The predominant directional trend of the dykes follows an approximate north-south alignment, with a concentric arrangement around the central volcanic boss. Due possibly to the fact that part of this region was submerged below Lake Rudolf for a period during the Pleistocene, most of the volcanic rocks are highly altered. The country rock, analcite basalt, is eroded to a dull brownish to dark grey colour, while the microfoyaite dykes are altered to a yellow or pale grey colour. From six rock specimens collected only one was sufficiently unaltered to allow preparation of a thin section. This specimen, 18/703, is a medium-grained rock with a distinctive felted texture, composed of anorthoclase laths with irregular aggregates of reddish iron oxide, apparently derived from altered ferromagnesian minerals. Patches of indeterminate turbid material may represent completely altered nepheline grains.

4. Nepheline Syenites

Float blocks of nepheline syenite are scattered about the southern part of the Napedet Hills. The blocks are concentrated in some valleys, their whitish colour contrasting with the sombre colours of the pyroclastic rocks and lavas of that region. In hand specimen the nepheline syenite is a whitish to greyish porcellaneous rock, with whitish coloured felspars and waxy greenish grey nepheline grains. Weathered surfaces

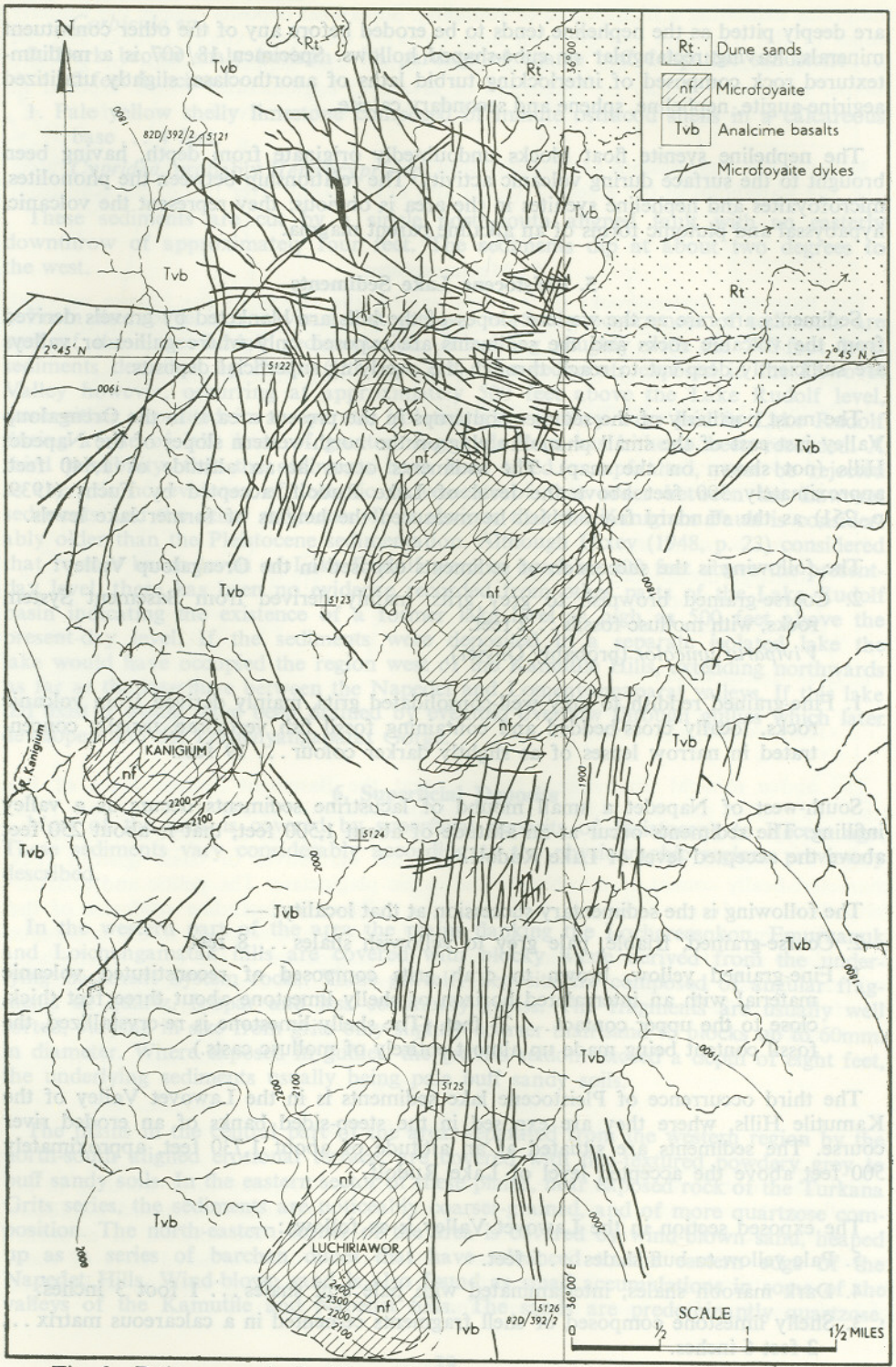


Fig. 2—Dyke swarm in the Kamutile Hills

are deeply pitted as the nepheline tends to be eroded before any of the other constituent minerals, leaving rectangular or cube-shaped hollows. Specimen 18/607 is a medium-textured rock composed of interlocking turbid laths of anorthoclase, slightly uralitized aegirine-augite, nepheline, sphene and secondary calcite.

The nepheline syenite float blocks undoubtedly originate from depth, having been brought to the surface during volcanic activity. The relationship between the phonolites, microfoyaites and nepheline syenites in the area is obvious; they represent the volcanic, hypabyssal and plutonic forms of an alkaline parent magma.

5. Pleistocene Lake Sediments

Sediments are rare as the western slopes of the hills are blanketed by gravels derived from the volcanic rocks and the sediments are exposed only where gullies or valleys are sufficiently deep-cut to reach through the overlying superficial deposits.

The most northerly of the sediment outcrops in the present area is in the Orengaloup Valley just east of the small phonolite plug on the north-western slopes of the Napedet Hills (not shown on the map). The sediments occur at an altitude of 1,540 feet, approximately 300 feet above the level of Lake Rudolf, accepted by Fuchs (1939, p. 251) as the standard from which he measured the heights of former lake levels.

The following is the succession of sediments exposed in the Orengaloup Valley:

2. Coarse-grained brownish to grey grits, mainly derived from Basement System rocks, with mollusc fossils . . .2 feet.
   Viviparus unicolor (probably Olivier).

1. Fine-grained reddish to grey well-consolidated grits, mainly derived from volcanic rocks, locally cross-bedded and containing fossil fish vertebrae, usually concentrated in narrow lenses of as slightly darker colour . . . 19 feet.

South-west of Napedet a small mound of lacustrine sediments occurs as a valley infilling. The sediments occur at an altitude of about 1,500 feet, that is about 250 feet above the accepted level of Lake Rudolf.

The following is the sedimentary succession at that locality:—

2. Coarse-grained, friable, pale grey to yellowish shales . . . 8 feet.
1. Fine-grained yellow, brown to drab grits composed of reconstituted volcanic material with an intercalated horizon of shelly limestone about three feet thick, close to the upper contact . . . 23 feet. (The shelly limestone is re-crystallized, the fossil content being made up almost entirely of mollusc casts.)

The third occurrence of Pleistocene lake sediments is in the Lawovet Valley of the Kamutile Hills, where they are exposed in the steep-sided banks of an eroded river course. The sediments are situated at an altitude of about 1,730 feet, approximately 500 feet above the accepted level of Lake Rudolf.

The exposed section in the Lawovet Valley is as follows:—

5. Pale yellow to buff shales . . . 5 feet.
4. Dark maroon shales, interlaminated with pale buff shales . . . 1 foot 3 inches.
3. Shelly limestone composed of shell fragments cemented in a calcareous matrix . . . 2 feet 6 inches.

Melanoides tuberculata

Corbicula sp.

2. Dark brown shaly horizon with partings of coarse buff felspathic sandstone... 2 feet 6 inches.

1. Pale yellow shelly limestone composed of minute ostracod shells in a calcareous base... 4 feet.

Cypridea, probably *Heterocypris* sp.

These sediments are cut by a single north-south aligned fault with an easterly downthrow of approximately four feet. The sediments dip at about two degrees to the west.

From the above it is obvious that the two northerly occurrences of sediments are part of the Lake Rudolf sedimentation, coinciding roughly with the 300-foot level sediments described by Fuchs (1939, p. 251). The sediments exposed in the Lawovet Valley however, occurring at approximately 500 feet above the Lake Rudolf level, were either deposited in a separate, isolated lake, or they were laid in Lake Rudolf during a rise of lake level of greater magnitude than has hitherto been recorded. A third possibility, that the sediments have been tilted or upfaulted, must be rejected as there is no evidence of tectonic movements of that order between the Lawovet sediments and the other sediments. It is obvious that the Kanigium Fault is considerably older than the Pleistocene sedimentation. Although Dixey (1948, p. 23) considered that former beach levels of Lake Rudolf were as much as 400 feet above the present-day level, there has been no evidence recorded from other parts of the Lake Rudolf basin indicating the existence of a former lake level as high as 500 feet above the present-day level. If the sediments were deposited in a separate isolated lake the lake would have occupied the region west of the Kamutile Hills, extending northwards as far as the interfluve between the Napedet and Lomenyangaparat valleys. If this lake did exist it would have been drained by eventual overflow through gullies which later developed into the Lomenyangaparat Gorge.

6. Superficial Deposits

Most of the area is covered by superficial deposits of Pleistocene to Recent age. These sediments vary considerably according to the physiographic regions previously described.

In the western part of the area the plains flanking the Lochereesokon, Emuruanuk and Loichangamatak hills are covered with blocky waste derived from the underlying Basement System rocks. These gravelly deposits are composed of angular fragments of quartz, felspar and less commonly gneiss. The fragments are usually well sorted, varying in size from grits only slightly coarser than sand to blocks up to 60mm. in diameter. Where exposed in gullies, the gravels seldom exceed a depth of eight feet, the underlying sediments usually being pale buff sandy soils.

The plains in the central part of the area, separated from the western region by the north-south aligned erosional terrace, are covered with fine-textured powdery grey to buff sandy soils. In the eastern sector of these plains, near exposed rock of the Turkana Grits series, the sediments are noticeably coarser-grained, and of more quartzose composition. The north-eastern corner of the area is covered by wind-blown sand, heaped up as a series of barchan dunes that have advanced to the eastern edge of the Napedet Hills. Wind-blown sand is also found as small accumulations in some of the valleys of the Kamutile and Napedet hills. The sands are predominantly quartzose,

the grains exhibiting a high degree of rounding. Superficial deposits mantle the westerly slopes of the Kamutile and Napedet hills, covering the lower volcanic rocks and the underlying sediments of the Turkana Grits series. The deposits consist of gravelly rubble, composed mainly of fragments of lava and agglomerate. Where exposed in eroded gulleys and valleys the gravels vary in thickness from five feet to 16 feet.

Minor saline incrustations are patchily distributed around the Loichangamatak waterhole, the waterholes in the Kaetako Valley and in the sandy river bed of the Kanigium Valley.

7. Metamorphism

The Basement System rocks in the area exhibit the effects of the intense regional metamorphism to which the original sediments and volcanic rocks comprising the system were subjected during orogenesis. The grade of metamorphism attained by the Basement System rocks is indicated by the following mineral assemblages:

1. Pelitic and quartzo-felspathic assemblages:—

   Sillimanite-quartz-orthoclase
   Muscovite-orthoclase-quartz
   Microcline-quartz-plagioclase-biotite.

2. Calcareous assemblages:—

   Calcite-garnet-epidote-scapolite-diopside
   Diopside-epidote-plagioclase
   Garnet-diopside-calcite.

3. Basic assemblages:—

   Hornblende-diopside-plagioclase-scapolite
   Hornblende-plagioclase.

The above mineral assemblages indicate that the Basement System rocks of the area fall within the almandine-amphibolite metamorphic facies described by Fyfe, Turner and Verhoogen (1958, p. 228). This facies is typical of high-grade zones of progressive regional metamorphism, in which the derivatives of basic igneous rock characteristically consist of hornblende and calcic plagioclase. The pelitic and quartzo-felspathic assemblages are fairly typical of the sillimanite-almandine subfacies of the almandine-amphibolite facies, but the presence of epidote and scapolite in the calcareous assemblage, and the andesine composition of the plagioclase in the basic assemblage, indicates a closer relationship with the staurolite-quartz subfacies. It must be concluded therefore that the Basement System rocks of the area are intermediate between these two subfacies.

VI—STRUCTURE

1. Basement System Structures

(1) Major Structures

The Basement System rocks are folded in a series of regular folds trending in an overall north-north-easterly direction. The axes of a folded succession of ultrabasic and basic rocks in the north-western corner of the area are aligned in a north-westerly orientation. The sparsity of rock outcrops and the weathered state of these rocks prevents recognition of their relationships with the folding exposed in the hills of Lochereesokon, Emuruanuk and Loichangamatak (*see* Fig. 3).

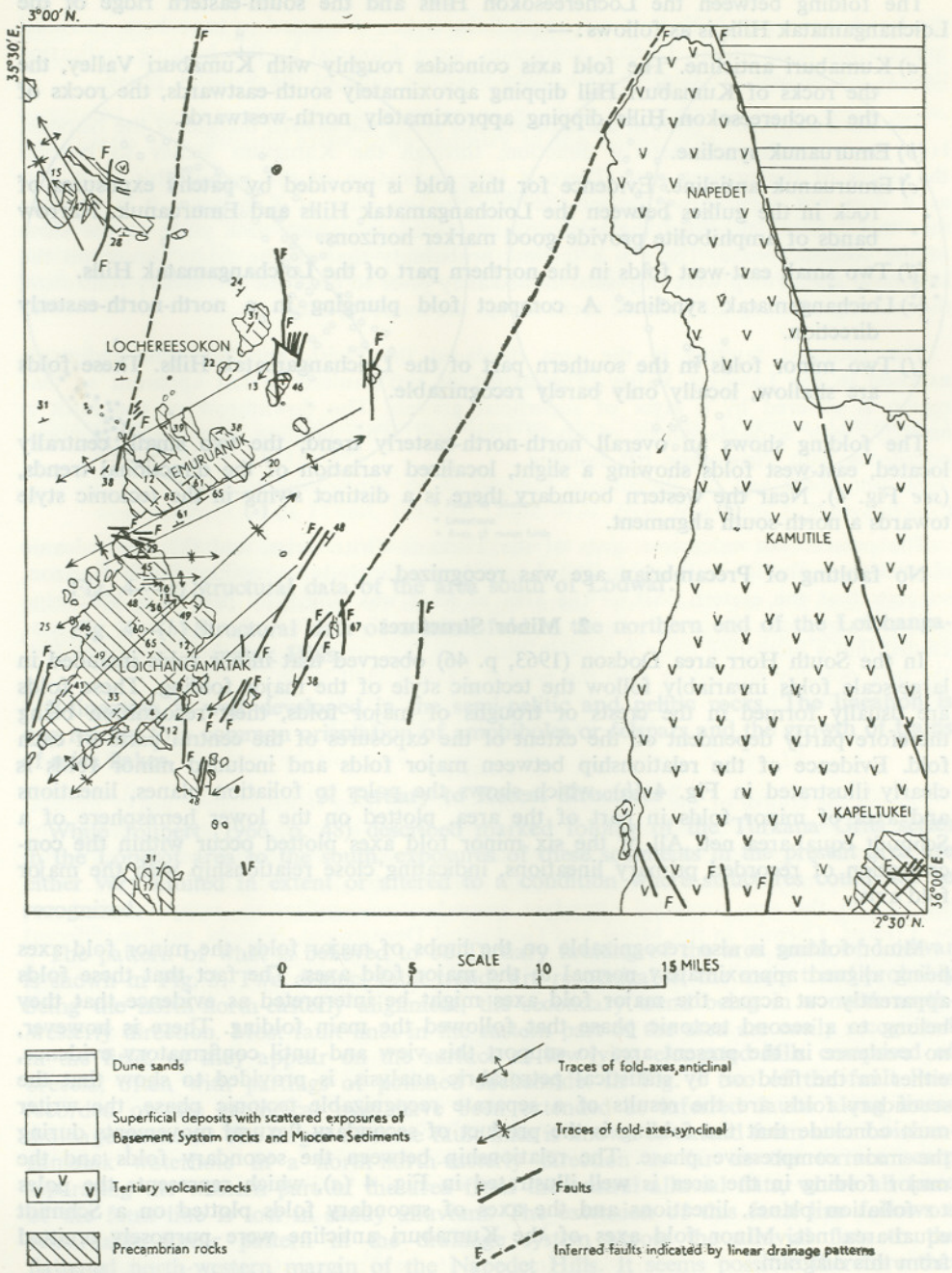


Fig. 3—Structural sketch-map of the area south of Lodwar.

The folding between the Lochereesokon Hills and the south-eastern ridge of the Loichangamatak Hills is as follows:—

(*a*) Kumaburi anticline. The fold axis coincides roughly with Kumaburi Valley, the the rocks of Kumaburi Hill dipping aproximately south-eastwards, the rocks of the Lochereesokon Hills dipping approximately north-westwards.

(*b*) Emuruanuk syncline.

(*c*) Emuruanuk anticline. Evidence for this fold is provided by patchy exposures of rock in the gullies between the Loichangamatak Hills and Emuruanuk. Narrow bands of amphibolite provide good marker horizons.

(*d*) Two small east-west folds in the northern part of the Loichangamatak Hills.

(*e*) Loichangamatak syncline. A compact fold plunging in a north-north-easterly direction.

(*f*) Two minor folds in the southern part of the Loichangamatak Hills. These folds are shallow, locally only barely recognizable.

The folding shows an overall north-north-easterly trend; the two small, centrally located, east-west folds showing a slight, localized variation of the directional trends, (*see* Fig. 4). Near the western boundary there is a distinct swing in the tectonic style towards a north-south alignment.

No faulting of Precambrian age was recognized.

2. Minor Structures

In the South Horr area Dodson (1963, p. 46) observed that minor folds included in large-scale folds invariably follow the tectonic style of the major folding. These folds are usually formed in the crests or troughs of major folds, their recognition being therefore partly dependent on the extent of the exposures of the central parts of each fold. Evidence of the relationship between major folds and included minor folds is clearly illustrated in Fig. 4 (*b*), which shows the poles to foliation planes, lineations and axes of minor folds in part of the area, plotted on the lower hemisphere of a Schmidt equal-area net. All of the six minor fold axes plotted occur within the concentration of recorded primary lineations, indicating close relationship with the major fold axis.

Minor folding is also recognizable on the limbs of major folds, the minor fold axes being aligned approximately normal to the major fold axes. The fact that these folds apparently cut across the major fold axes might be interpreted as evidence that they belong to a second tectonic phase that followed the main folding. There is however, no evidence in the present area to support this view and until confirmatory evidence, either in the field or by statistical petrofabric analysis, is provided to show that the secondary folds are the results of a separate recognizable tectonic phase, the writer must conclude that the folding is the product of secondary flexural movements during the main compressive phase. The relationship between the secondary folds and the major folding in the area is well illustrated in Fig. 4 (*a*), which represents the poles to foliation planes, lineations and the axes of secondary folds plotted on a Schmidt equal-area net. Minor fold axes of the Kumaburi anticline were purposely omitted from this diagram.

The smallest folds in the Basement System rocks are seldom more than of a few inches amplitude. They are best seen in the banded migmatite rocks, where the most common folds are asymmetric shear or slip-folds. Flexural slip-folds are confined almost entirely to the most finely banded migmatites.

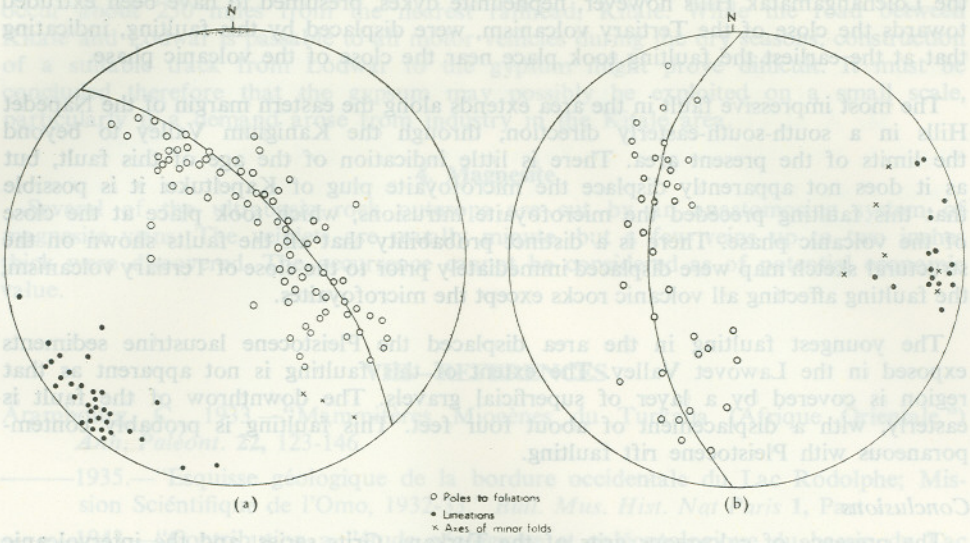


Fig. 4—(*a*) Structural data of the area south of Lodwar.

Fig. 4—(*b*) Structural data of a small fold in the northern end of the Loichangamatak Hills.

B-lineation is well developed in the semi-pelitic and pelitic rocks. The lineation is due mainly to a common orientation of amphiboles or felspars and the growth of trains of mica flakes.

3. Tertiary to Recent Structures

While Joubert (1966, p. 48) described marked folding of the Turkana Grits series in the Loperot area to the south, exposures of these sediments in the present area are either very limited in extent or altered to a condition where structures could not be recognized.

The pattern of what is believed to be Tertiary faulting of the area south of Lodwar is shown in Fig. 3. Two distinct fault trends are recognizable; the main trend probably being the north-north-easterly alignment, the secondary trend being in a north-north-westerly direction. Most fault lines in the eastern part of the area are easily recognized in the field, as they appear on the surface as low-lying elongated hills composed of breccia, often with partings of polished slickenside. In Fig. 3 two of the fault lines recorded on the geological map have been extended as inferred faults along linear drainage patterns. The larger of these fault lines is known to extend from near Loichangamatak waterhole in a north-north-easterly direction as far as the terrace scarp separating the western part of the area from the central alluvial flats, where all trace of the fault line is lost in sandy alluvium. The extension of this fault line follows a remarkable linear pattern in the drainage system across the alluvial flats to the flattened north-western margin of the Napedet Hills. It seems possible therefore that the volcanic rocks of the Napedet Hills were cut off by this fault. The other fault inferred from linear drainage extends from the north-western margin of the Emuruanuk Hills in a nearly northerly direction. It is significant that although the region north of the Emuruanuk Hills is covered by superficial deposits, isolated fragments of fault-breccia were found along most of this inferred fault line. The age of the faulting in the eastern part of the area cannot be dated with certainty. In the northern part of

the Loichangamatak Hills however, nephelinite dykes, presumed to have been extruded towards the close of the Tertiary volcanism, were displaced by this faulting, indicating that at the earliest the faulting took place near the close of the volcanic phase.

The most impressive fault in the area extends along the eastern margin of the Napedet Hills in a south-south-easterly direction, through the Kanigium Valley to beyond the limits of the present area. There is little indication of the age of this fault, but as it does not apparently displace the microfoyaite plug of Kapeltukei it is possible that this faulting preceded the microfoyaite intrusions, which took place at the close of the volcanic phase. There is a distinct probability that all the faults shown on the structural sketch map were displaced immediately prior to the close of Tertiary volcanism, the faulting affecting all volcanic rocks except the microfoyaites.

The youngest faulting in the area displaced the Pleistocene lacustrine sediments exposed in the Lawovet Valley. The extent of this faulting is not apparent as that region is covered by a layer of superficial gravels. The downthrow of the fault is easterly, with a displacement of about four feet. This faulting is probably contemporaneous with Pleistocene rift faulting.

Conclusions

The presence of calcareous grits of the Turkana Grits series, and the intervolcanic magnesian limestones, which in the Loperot area include a mollusc fossil horizon, suggests that the eastern part of the area at least was originally part of a lacustrine sedimentary basin. Since this basin antecedes the earliest rift faulting it must be concluded that a lucustrine basin or trough existed in this region during the Tertiary period, the lake possibly coinciding with the present Lake Rudolf basin.

VII—ECONOMIC GEOLOGY

1. General

During the course of the geological mapping of the area representative heavy mineral concentrations were collected from the main valleys draining the area occupied by Basement System rocks. Examination of these concentrates failed to reveal the presence of minerals of potential economic value. Despite the fact that most of the fault-breccias in the area included abundant secondary mineralization, assays carried out by J. Furst, Chemist in the Mines and Geological Department, Nairobi, on five different specimens proved equally disappointing as the breccias contained no more than a trace of gold. None of the pegmatites in the area contained mineralization of potential value.

2. Water

In comparison with most parts of northern Kenya water supplies are adequate for the amount of available grazing. The north-eastern part of the area is fairly close to Lake Rudolf, while the Turkwel River flows within a few miles of both the western and northern boundaries. Other sources of permanent water are the Loichangamatak and Kaetako waterholes and the Lomenyangaparat and Kanigium rivers.

3. Gypsum

The presence of gypsum in shaly horizons of the Turkana Grits series has already been mentioned. On the interfluve ridge between the Lomenyangaparat and Orengaloup valleys, gypsum is abundantly scattered about the surface as variable sized plates of selenite up to 18 inches long. The gypsum is opaque to nearly transparent, apparently free of impurities, and could easily be quarried, but after removal of the accessible surface supplies greater difficulty would be experienced in extracting isolated plates from the friable lake sediments in which gypsum is found. The gypsum deposits

occur about 230 miles from the nearest railhead, Kitale. While the road between Kitale and Lodwar is passable to all motor vehicles during the dry seasons, construction of a suitable track from Lodwar to the gypsum might prove difficult. It must be concluded therefore that the gypsum may possibly be exploited on a small scale, particularly if a demand arose from industry in the Kitale area.

4. Magnesite

Several of the ultrabasic rock outcrops are cut by an anastomosing system of magnesite veins. The veinlets are usually minute, but a few veins up to two inches thick were discovered. The occurrence cannot be considered as of potential economic value.

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