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MINISTRY OF NATURAL RESOURCES, WILDLIFE AND TOURISM

GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE KARASUK AREA

DEGREE SHEET 18, S.W. QUARTER, AND PART OF
DEGREE SHEET 17, S.E. QUARTER

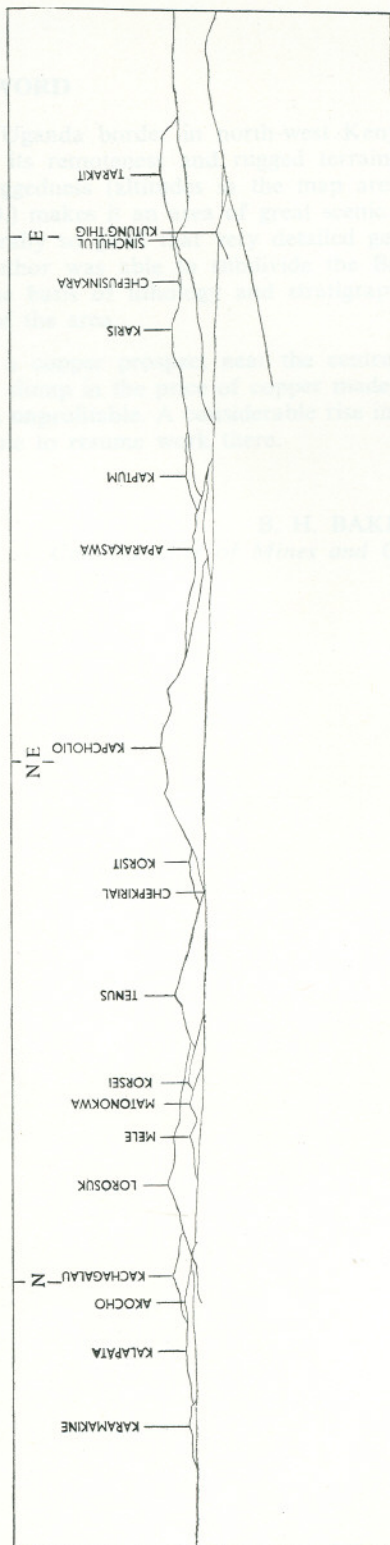
(with coloured geological map)

by

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Fifteen Shillings - 1966



Frontispiece

Panorama of the Karasuk mountains, looking north and east from Katapoi. The plain in the foreground is the 5,100 feet peneplain

FOREWORD

The Karasuk area, which adjoins the Uganda border in north-west Kenya, is a little-known part of the country owing to its remoteness and rugged terrain, which make access difficult. However, its very ruggedness (altitudes in the map area range from below 2,500 ft. to above 9,000 ft. O.D.) makes it an area of great scenic beauty, and one in which rock exposures are generally so good that very detailed geological and structural mapping is possible. The author was able to subdivide the Basement System rocks into four main groups on the basis of lithology and stratigraphy, and to give a detailed account of the structure of the area.

The main economic possibility lies in a copper prospect near the centre of the area, which was abandoned in 1958 when a slump in the price of copper made further prospecting or mining in such a remote area unprofitable. A considerable rise in copper prices in recent months may make it possible to resume work there.

Nairobi,
30th December 1964.

B. H. BAKER,
Commissioner of Mines and Geology.

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Geological map of the Karasuk Area (degree sheet 18, N.W. quarter, and part of degree sheet 17, N.E. quarter)—Scale 1:125,000	at end
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ABSTRACT

The report describes an area of approximately 1,400 square miles in the Turkana District of the Northern Province of Kenya, including much of Karasuk, which for many years has been administered by the Uganda Government while remaining part of Kenya. The area is bounded by parallels 2° and $2^{\circ} 30' N.$, meridian $35^{\circ} 30' E.$ and the Kenya-Uganda border. It is divided into four main physical units, (1) the Uganda plain in the extreme south-west, (2) the Karasuk hills with isolated summits reaching elevations of more than 9,000 ft., (3) a dissected plateau of altitude about 5,100 ft. lying between the Uganda plain and the Karasuk hills, and (4) the Turkwel plain lying at approximately 2,500 ft. and separated from the Karasuk hills by the eastward facing Turkwel escarpment. The relationship of these physical units to the erosion surfaces of the area is discussed and a correlation suggested with erosion surfaces identified in neighbouring areas.

A metamorphic and igneous complex containing recrystallized sedimentary and volcanic rocks of late Precambrian age is extensively exposed in the western half of the area; it includes a body of olivine norite and minor intrusions ranging from alkaline and acid to ultrabasic. Superficial deposits of Pleistocene to Recent age occupy most of the Turkwel plain in the eastern half of the area.

Two major periods of folding have affected the Precambrian rocks; the first fold axes trend east-west, and the second fold axes north-south. A third episode of less intense folding is indicated about east-west axes.

The economic geology of the area is reviewed and a description is given of the mineral deposits and available water resources.

GEOLOGY OF THE KARASUK AREA

I—INTRODUCTION

General.—The area described in this report is approximately 1,400 square miles in area, and is bounded by latitudes 2° N. and $2^{\circ} 30'$ N., longitude $35^{\circ} 30'$ E. and the Kenya-Uganda border. It is covered by Directorate of Overseas Surveys sheet No. 50 (Kenya) and part of sheet No. 36 (Uganda) and lies partly in Turkana District of the Northern Province and partly in the Karasuk District which embraces all the mountainous country in the west of the area. Karasuk District has for many years been administered by Uganda, and comes under the authority of the District Commissioner at Moroto and the Assistant District Commissioner at Amudat, situated three miles south-west of the south-west corner of the area. The Turkwel plain and a few embayments along the northern boundary are administered from Lodwar. The area is sparsely populated, and contains neither town nor village, though Alale in Karasuk and Kaputir in Turkana can be considered as focal points, each having a single African shop which opens at intervals during the year. Kaputir was for some years a District Officer's post, but the post was abandoned between the two World Wars.

Two tribes inhabit the area, the Suk (or Pokot) in the Karasuk hills, and the Turkana in the Turkwel plain. Some intermingling of the two tribes occurs along the marginal areas, the Suk moving down on to the plains and the Turkana moving up on to the hills according to the availability of water and grazing. Both tribes live almost entirely by their livestock, and are semi-nomadic, moving from place to place as grazing becomes exhausted. Their food is mainly milk, blood and meat with occasional store-bought maize-meal. Around Tarakit and Kapcholio, and on the western slopes of Lorosuk and Kachagalau, where rainfall is good or surface water occurs, some of the Suk are settled permanently growing maize and keeping a handful of stock for milk. Land under permanent cultivation comprises less than a half of one per cent of the whole area.

The Turkana and Suk are little influenced by Western civilization, and have little need for imported goods other than iron for their spears and knives (which up to about a hundred years ago was smelted locally from laterite) and cotton cloth for the men's dress which is a simple square of black material thrown over the shoulders. The women's clothes, which are of leather made from the skins of their own animals, are often well decorated with coloured leather interlacing and beadwork. Animal skins also serve for sandals, which are very necessary in this rough and rugged terrain. Hats are unknown, but the men wear decorated skull-caps of clay mixed into their own short hair, usually crowned with ostrich feathers. Lip ornaments are common among the men, usually consisting of a disc of ivory or aluminium about the size of a penny let into the lower lip, the influence of the West sometimes showing itself in odd forms of lip ornaments such as a discarded benzedrine plastic inhaler or a screw-type bottle top.

Climate and Vegetation.—No rainfall statistics are available for the area but at Amudat records are as follows:—

Year	Annual rainfall (inches)				Average annual rainfall for 10 years			
1955	..	..	..	23.86	..	..	..	23.94
1956	..	..	..	23.27				
1957	..	..	..	18.06				

Rainfall at Kaputir in the south-east was measured for a few years, and Champion (1937, p. 108)* gives the annual average rainfall as about 12 inches. At Lodwar, situated on the Turkwel river about 45 miles north-north-east of the area, the average annual rainfall is under six inches. At Amudat some rain falls in every month of the year, with a maximum in August and a lesser peak in April, while at Lodwar and Kaputir all the rain normally falls between March and August, with a maximum in April.

On almost every day throughout the year hot, dry south-easterly winds often reaching gale force are experienced from early afternoon to sunrise.

No rainfall figures have ever been measured in the mountains of Karasuk, but the vegetation of much of the land above 5,500 feet suggests an annual average of up to 50 inches. Above 7,000 feet *Podocarpus* forests exist on Lorosuk, Kachagalau and Kapiltugei, and remnants still exist on Tarakit. In these areas the relatively high rainfall is augmented by mist which sometimes persists for many hours after sunrise. On all of these mountains and on Chemorongit small streams flow for all but the driest period of the year; the water only flows below the 6,000 feet contour during the rains.

Of the larger rivers in the area only the Turkwel maintains a surface flow for more than a day or two after heavy rains, and that river is usually dry a few miles north of Kaputir. Nevertheless along the whole length of the Turkwel and at certain places along most of the other larger rivers water can be obtained by digging a few feet into the river bed, usually where rock outcrops form natural dams. At such places the water soon becomes fouled by the large numbers of stock which water there, and however carefully treated by boiling and filtration the water is most unpleasant to the taste.

Succulents, mostly aloes, crassula and euphorbia, are common up to a height of 6,500 feet. Aloes, which have a life-span of about five years, are often found growing on pedestals of soil or subsoil that rise up to two feet above the level of the surrounding land, indicating the extreme rate of soil erosion. The uphill spread of the succulents, which normally indicate an average annual rainfall of under 20 inches, is due to the removal of grass cover by over-grazing on the steeper slopes, allowing the topsoil and often much of the subsoil to wash away in the torrential rainstorms that commonly occur. A high percentage of rainfall is lost by run-off, and the high-rainfall vegetation only survives where topography or remnants of grass cover retain appreciable moisture.

On the lower ground to the west of the main mountain ridge the ground cover is an almost continuous stone-mantle, which supports a poor thorn-scrub of varieties of acacia, though good grass grows where soil exists below the stone-mantle and is protected by it from erosion. Just across the Uganda border, along the Kenyangareng river, a broad stretch of badly eroded land has been fenced in and closed to grazing, and in only two years has grown an almost continuous grass cover. In times of drought, when near-by grazing becomes exhausted, parts of the fenced area are opened to grazing to save stock from almost certain starvation. But for overgrazing it seems certain that in a very few years the land would revert to the natural lush grassland described by travellers in the early years of the century. The whole problem is one of overstocking, much of which, ironically enough, owes its origin to the efforts of the officers of the administration to improve the health and life-expectancy of the animals, and in their labours, not yet wholly successful, to prevent cattle-raiding and consequent minor yet bloody forays between the Suk and Uganda Karamojong. In the arid Turkana plains, which support a much lower density of stock, the grazing problem is much more acute, and it is difficult to see how conditions can be improved except by closing the whole area to grazing for a number of years, a seemingly impossible solution.

Game animals are now rare over the whole of the area, though elephant and buffalo are occasionally encountered in the thick riverine forests that cover the alluvium of the Turkwel river. Buffalo are also found on Lorosuk and Kachagalau. A small herd of Greater Kudu, thought to be long extinct in the area, was met on the

* References are quoted on p. 34.

summit of one of the lesser Karasuk peaks and a few Grant's gazelles, ostriches and giraffes are to be seen on the plains. Lion, leopard and cheetah exist in small numbers, often preying on the domestic stock.

Communications.—Communications are poor, the only well-maintained road being that between Kitale and Lodwar which cuts the north-west corner of the area, and the branch road west to Moroto. A good secondary road branches east from the Kitale-Lodwar road at Amudat and rejoins it south of Lokitanyala. Locally known as the Bore-holes Road, it was built for heavy lorries to drill and maintain the many bore-holes in its vicinity. The bore-holes are all fitted with hand-pumps and used mainly for watering of stock. An unfinished motor-track branches off this road to the flanks of Kapcholio, and was intended to reach the now abandoned copper prospects north-east of that mountain. Another track runs north-east from Alale to the col between Lorosuk and Kachagalau, to give access to the forests on those mountains. It is intended to continue this track downhill to the north-east to reach the water-holes at Kordei. On the west of the Turkwel river are two poor tracks, seldom used, and not maintained. The more westerly, built for Locust Control purposes, ends at Kotulol, and the other reaches the Turkwel opposite Kaputir, where a four-wheel drive vehicle can cross the river during dry seasons. East of the Turkwel two roads enter the area, both running via Lokichar to Lodwar, that in the south-east leading southwards to Lotongot and the Marich Pass, giving access to Kitale in dry weather. Older maps of the area show the northernmost of these two roads to cross the Turkwel by a ford, but the road now ends in a swamp and is impassable.

Foot safaris with porters and donkeys of up to three weeks' duration were made to reach less accessible parts of the mountains.

Maps.—Royal Air Force air photographs on a scale of about 1:35,000 cover all the area with the exception of a small part east of the Turkwel. Uncontoured Preliminary

Plots at a scale of 1:50,000 prepared from the photos are Kenya $\frac{\text{NA-36}}{\text{L-III}}$ (four sheets), and parts of Uganda $\frac{\text{NA-36}}{\text{K-IV-NE}}$ and $\frac{\text{KA-36}}{\text{K-IV-SE}}$. Where necessary place names

shown on these sheets have been amended, both as regards spelling and position. Mapping in the field was made with the assistance of the air photographs and geological information plotted on to the 1:50,000 sheets, the draft of the final map being made at a scale of 1:83,333 for reduction to the printed 1:125,000 map. Form lines at 500 feet vertical intervals are based on suitably corrected spot heights obtained by a single aneroid barometer, and must be considered as approximate.

Officers of the Turkana District administration, and those of the Uganda administration stationed at Moroto, are thanked for their assistance during the survey. Thanks are also due to Mr. and Mrs. Andrew Mortimer of Amudat, and Dr. J. Kenyon and Mr. D. Crossley of R. T. Mines Ltd., for generous hospitality. The valuable assistance of Mrs. A. G. Totty of Nasokol Mission, who checked and corrected the spelling of many Suk place-names, is also acknowledged.

II—PREVIOUS GEOLOGICAL WORK

J. W. Gregory (1896 and 1921) briefly refers to the Turquel (Turkwel) river in discussions on the northern extension of the Rift Valley, though he did not visit the area. Two papers were written by V. G. Glenday and J. Parkinson on their visit to the Suk Hills. The first (1926) only briefly mentions the present area, but the later paper (1927) deals with parts of the Karasuk in detail, and are referred to at greater length in a later chapter.

Murray-Hughes (1933) deals with the area in broad detail, and his geological sketch plan shows only undifferentiated Basement Complex there.

Two expeditions to Lake Rudolf were led by V. E. (now Sir Vivian) Fuchs: the first, in 1930, was cut short by illness. The second expedition made in 1934 is covered by two papers: one deals with the expedition in general terms, and includes a description of a journey down the east side of the Turkwel to Kaputir and thence along the foot of the Turkwel escarpment northwards and westwards to rejoin the Kitale-Lodwar road (1935). A further paper (1939) deals in more detail with the geology and tectonics of the area.

C. Arambourg (1935) passed through the area from Kitale to Lodwar, and in his account (pp. 52-55) gives a brief description of some of the rocks of the Nepau pass. His references to other rocks are taken from Glenday and Parkinson.

A. M. Champion was for several years District Commissioner at Lodwar, and made the first triangulation survey of Turkana, making geological notes and collecting specimens as he worked. He wrote an account of the physiography of the area (1937), and W. Campbell Smith (1938) published a petrographical account of Champion's specimens. This work is devoted chiefly to the volcanic rocks to the north and east of Karasuk, but reference is made to rocks collected at Kaputir and in the Nepau pass (p. 545).

F. Dixey (1948) included the Karasuk in a reconnaissance survey of Northern Kenya, and made particular reference to erosion surfaces.

The Assistant Director of the Uganda Geological Survey, C. B. Bisset, wrote a short account of the Karasuk (1950), mentioning the geology in broad detail and making reference to graphite deposits, presumably those of Epeiyelel.

The geology of the adjoining area to the south was mapped between 1955 and 1956 by G. J. H. McCall (1964) and the area to the east by P. Joubert (at the press).

III—PHYSIOGRAPHY

The area can be divided into four physical units (Fig. 1). They are: (1) the Uganda plain found in the extreme south-west; (2) a dissected plateau lying between the Uganda plain and the Karasuk hills; (3) the main mountain mass of Karasuk terminating eastwards in the Turkwel escarpment, which overlooks (4) the Turkwel plain.

Embayments into the mountains in the north-west are part of the Turkana plain which forms a continuation of the Turkwel plain in the northern part of the area.

Drainage.—The principal watershed of the area runs from the Nepau Pass southwards to Kakes, thence south and west to the Kitale road south of Lokitanyala. Rivers north-west of this line drain to the Nile via Lake Kyoga, and the remainder to Lake Rudolf. A second watershed running south from Kakes through Karamakinei further divides the Lake Rudolf drainage, rivers west of the watershed flowing via the Turkwel Gorge which cuts the Turkwel Escarpment ten miles south of the area, and the remainder flowing to the Turkwel by more direct routes east or north-east.

The drainage south and west of the main mountain range flows either north or south of Tenus, uniting to form the Kopedo river which cuts through the range by a series of three spectacular gorges, at Chepkirial (Suk "Place of Lighting") Plate I, Chepkoi and Akiriameth, where it debouches on to the Turkwel plain where it is known as the Kateruk river. No major faulting exists at any of these gorges, and it appears that they have been formed by the headward erosion of the Kateruk river, the headwaters of which have captured a number of rivers that originally flowed from north to south, reversing the flow of the originally southern portions of these streams. Examples are now represented by the Akores-Kopedo-Kaparamatai, Lopotwa-Kopedo-Moinoi and the Kachar-Kopedo-Kamila rivers. Still further west, south of Akocho, the right-angled bend in the Kauriong river is suggestive of further river capture.

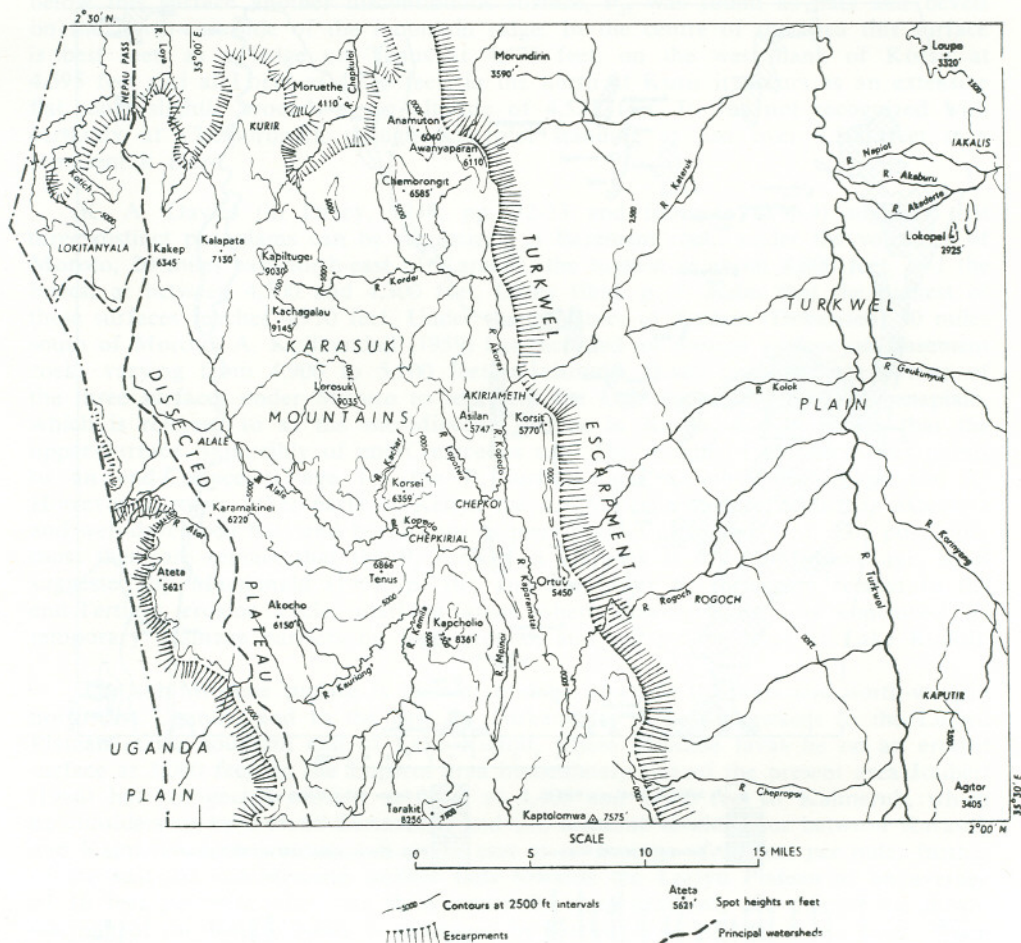


Fig. 1—Physiographical map of the Karasuk area

In the north-west the unusually straight portions of the Lokitanyala and Kotich rivers proved to be due not to fault lines as was expected but to incision of the rivers into a series of strong vertical joint planes resulting in sheer-sided canyons up to 200 feet in depth and averaging only 25 feet in width (Plate II).

The dendritic drainage in the Turkwel plain, which is largely a plain of aggradation, is unrelated to the underlying solid geology. At Rogoch on the west of the river and at several places north of Lokopel on the east side, uncompleted river captures are evident. At all these places one river has cut back and intersected a larger river without beheading the latter, so that surface water divides between the old and new courses. A mile and a half north of Lokopel the headwaters of the Akaburu river have cut into the valley of the Akederte river (Plate II) and when examined in December 1957 the width of the Akederte river was 150 feet and the capturing Akaburu 35 feet. The bed of the latter is four feet above that of the Akederte, and no water can be diverted from the main stream until the depth of water exceeds four feet. Two miles further up-stream, at Iakalis, the Akederte has again been intercepted, this time by headwaters of the Napiot river.

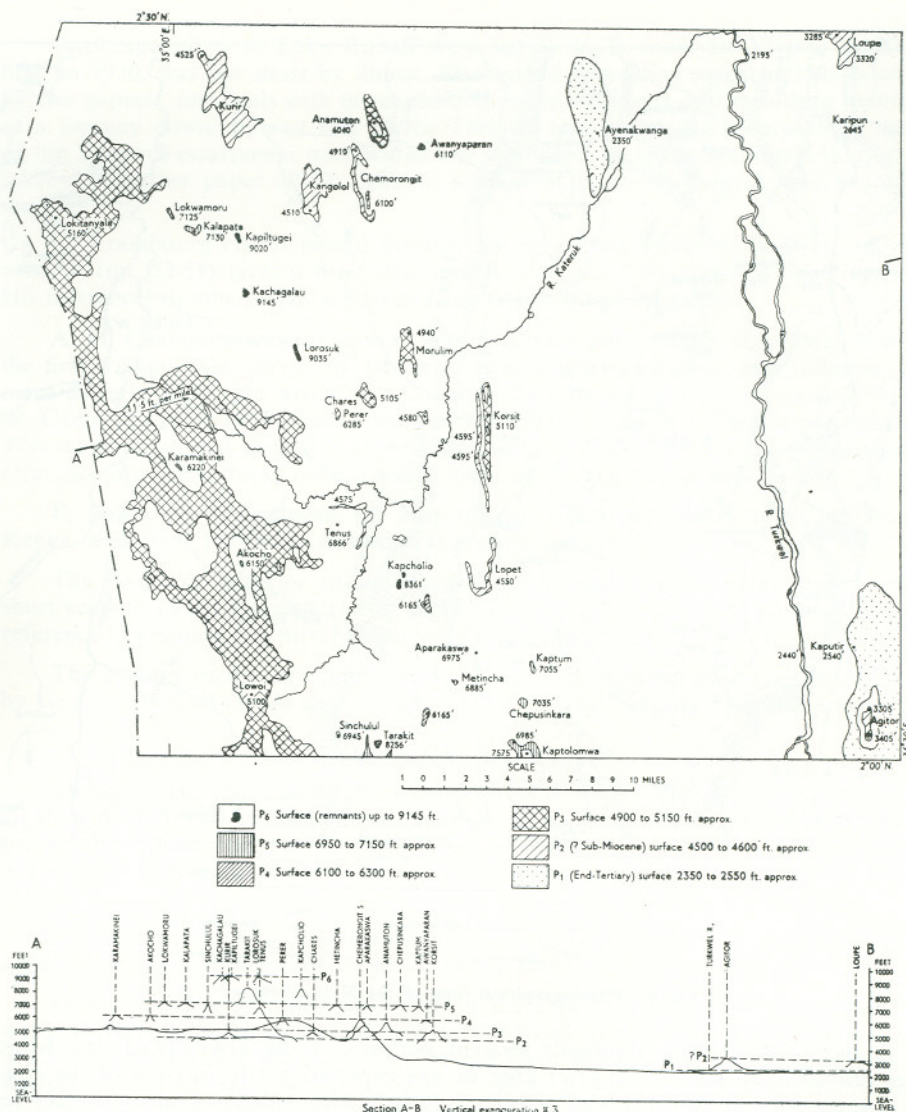


Fig. 2—Erosion surfaces in the Karasuk area

Erosion Surfaces.—Remnants of six erosion surfaces are recognized in the area and are shown in Fig. 2. The main erosion surface, P₃, in part dissected, can be recognized at an altitude of rather more than 5,000 feet over most of the western part of the area extending from the top of the escarpment which faces west over the Uganda plain to the foot of the main mountain ridge forming the central part of the area (Frontispiece). In the mountains themselves and to the east of them remnants of the surface can be found in a few places as ledges and ridges, as at Chares, Morulim and Korsit, all south-east of Lorosuk, and at Chemorongit and Anamuton. The main body of the surface varies in height from 5,160 feet at Lokitanyala in the north-west to 5,100 feet at Lowoi in the south-west. But outliers at Chemorongit and north of Morulim stand at only 4,910 feet and 4,940 feet respectively, indicating a down-warping of the surface towards the north-east at 11.5 feet per mile. About 600 feet

below this surface another discontinuous surface, P_2 , was found as flats and bevels on the north-east side of the mountain ridge. In the centre of the area this surface is best seen as a ledge on Tenus at 4,575 feet, on the west flank of Korsit at 4,595 feet and at Lopet at 4,550 feet; in the north at Kurir it occurs as an extensive flat, only slightly eroded, at an altitude of 4,525 feet. It was not recognized with certainty at Chemorongit, though Kangolol standing at just over 4,500 feet may represent it there.

K. A. Davies (in Dixey, 1948, pp. 32-33 and footnote to p.4) suggests that three distinct peneplains can be recognized in Basement rocks under the volcanics of Moroto, 20 miles east-north-east of Karasuk, the highest at about 4,800 feet, and the lowest at between 4,500 and 4,300 feet. Dixey (*ibid.* p. 5) states that the highest of these surfaces reaches 4,950 feet. Under the volcanics of Kadam (Debassien) 50 miles south of Moroto, A. K. Trendall (1959) has recorded an erosion surface on Basement rocks varying from 4,900 to 5,100 feet in altitude. Dixey considers the lowest of the three surfaces under Moroto to represent the Uganda or mid-Tertiary peneplain, which is referred to as the sub-Miocene surface in Kenya, and considers that the upper surface is possibly of end-Cretaceous age. The weight of evidence thus points to an end-Cretaceous age for the P_3 surface, and a sub-Miocene age for P_2 . However in many other parts of Kenya the sub-Miocene surface occurs as extensive and well-developed flats and bevels, not as mere shelves as in this area. The possibility must therefore remain that the P_3 surface in Karasuk is of sub-Miocene age, as is suggested by Macdonald (1961, p. 10), and the lower P_2 surface is related to the end-Tertiary erosion cycle, marking areas where down-grading was controlled by temporary drainage barriers on high ground, and not by the level of Lake Rudolf.

The sub-Miocene surface is known to slope down to the west and north-west in north-east Uganda, and to the east, in Turkana, to slope downwards to the Loriyu Plateau at the southern end of Lake Rudolf, where Miocene lavas lie on an eroded surface at 3,000 feet. In the Loperot area immediately east of the present area Joubert (1966) has recognized erosion surfaces at 4,400 and 3,800 feet at Kaimeruk, which he considers to be the end-Cretaceous and sub-Miocene levels. Thus between Karasuk and Kaimeruk both surfaces fall to the east at an average of 30 feet per mile; further to the east the sub-Miocene surface falls towards the Loriyu Plateau at an average of 16 feet per mile. How far these relatively steep gradients are due to the down-warping of the Rudolf basin as envisaged by Fuchs (1939, p. 266) is not clear. Much of the fall of 700 feet between Karasuk and Kaimeruk may be accounted for by the assumed continuation in the Turkwel plain of the Turkwel fault which McCall (1964, p. 58) considers to be of Miocene age.

The difference in elevation between the sub-Miocene surface and the end-Tertiary surface west of the Turkwel river is greater than 2,200 feet, whereas at Kaimeruk where the end-Tertiary surface occurs at 3,200 feet the difference is only 600 feet. East of the Turkwel the hills of Loupe in the north and Agitor in the south have fairly even surfaces, the former being 950 feet and the latter 850 feet above the level of the end-Tertiary surface. These two hills may, therefore, be further remnants of the sub-Miocene surface thrown down below the levels of Karasuk and Kaimeruk by faulting or warping. No traces of the sub-Miocene surface were found along the escarpment overlooking the Uganda plain in the south-west.

In the Turkwel plain remnants of a surface, P_1 , lower than those previously described can be seen at just above 2,500 feet at Kaputir, and at 2,350 feet on Ayenakwanga north of the Kateruk river. Both are characterized by an almost continuous sheet of angular quartz pebbles, and at Kaputir there are also deposits of secondary limestone sometimes reaching several feet in thickness on and near the underlying crystalline limestone outcrops. That part of the surface which faces the Kateruk

river shows an almost continuous scarp face approximately five feet in height cut in red-brown fine sandy soil derived either from alluvium of the earlier Turkwel river or its tributaries, or from outwash fans from streams draining the Turkwel escarpment. The downward slope between these two remnants is about seven feet per mile towards the north. They represent residuals of a peneplain comparable in age to the end-Tertiary surface in other parts of East Africa. The base level of erosion of this surface was Lake Rudolf, which in Middle Pleistocene times had risen to a level 330 feet above that at the present day (Fuchs, 1939, p. 266). The lowering of the water of the lake rejuvenated the Turkwel, which now flows 100 feet below the end-Tertiary surface at Kaputir and 150 feet below it in the north. The end-Tertiary surface to the west of the area is graded to Lake Kyoga, and lies about 4,000 feet at Amudat, three miles to the south-west of the area.

Features on residual hills above the 5,100 feet surface such as minor flats and bevels, saddles, and concordant summit heights, suggest that three older erosion surfaces may be present. The lowest, P_4 , occurs as bevels on the north and south flanks of Kapcholio, as a flat north-east of Tarakit, and as summits at Akocho, Karamakinei, Anamuton, Awanyaparan and Chemorongit, all of which lie between 6,100 and 6,220 feet above sea-level.

The next higher surface, P_5 , occurs as broad flats on Kaptolomwa at just below 7,000 feet, and its projection is possibly seen in the summits of Chepusinkara, Kaptum, Aparakaswa, Metincha and Sinchulul near by, and further to the north-east at Kalapata and Lokwamoru standing at just over 7,100 feet.

Finally the peaks of Lorosuk, Kachagalau and Kapiltugei, all just over 9,000 feet, and the lower peaks of Kapcholio and Tarakit, are thought to represent remnants of a yet higher surface, P_6 .

There is no evidence as to the age of these three highest surfaces. In the Kitale-Cherangani Hills area Miller (1956, Fig. 2) maps the sub-Miocene surface at 4,500 feet, followed upwards by the Kitale plain at 6,200 to 6,500 feet (Dixey's "6,200-foot" peneplain) which by its position under the lavas of Mount Elgon can be correlated to the 4,800-foot surface under Moroto, and therefore with the 5,100-foot surface in Karasuk. Miller further shows three surfaces above the 6,500-foot peneplain, at 7,600 and 10,800 feet. The interval of 1,100 feet between the Kitale surface and the next higher level in both the Kitale and Karasuk areas suggests that the Karasuk P_4 surface is the equivalent of Miller's 7,600-foot surface, which he presumes to be of Cretaceous age, after Shackleton (1951, p. 379). The next two higher surfaces Miller defines at 9,600 and 10,800 feet, both occurring in the Cherangani Hills. Vertical intervals between these two surfaces and the Kitale surface are 3,100 feet and 4,300 feet, as against 1,900 feet and 4,050 feet between the equivalent of the Kitale surface and the two highest surfaces in Karasuk. It seems, therefore, that the eroded P_6 surface in Karasuk is of equivalent age to Miller's 9,600-foot surface, and that the Karasuk P_5 surface is of intermediate age.

IV—SUMMARY OF GEOLOGY

The solid rocks of the area are all referred to the Basement System, a crystalline complex of late Precambrian age, including one major basic intrusion and a number of minor intrusions ranging from acid to ultra-basic in composition. They are in many places covered by superficial deposits of Pleistocene and Recent age. Turkana Grits, sediments of Miocene age, were not found in the area, though they might be expected to occur along the Turkwel escarpment. The writer agrees with Fuchs (1939, p. 245) that such deposits would have been scoured away by the Turkwel and its tributaries.

1. Basement System

The Basement System rocks can be divided into four main groups, as outlined in Fig. 3. The broad succession is as follows:—

- (4) Biotitic and granitoid gneisses, with kyanite important in the north, with one major and several minor bands of plagioclase amphibolite and rare thin crystalline limestones. Typical localities Korsit and Morundirin.
- (3) Plagioclase amphibolites with intercalations of acid gneisses, including granitoid gneisses and granite, minor talcose schists and very thin crystalline limestones. Typical localities Tarakit and Kachagalau. Equivalent to the Marich-Korpu Schist group (McCall, 1964, p. 16).

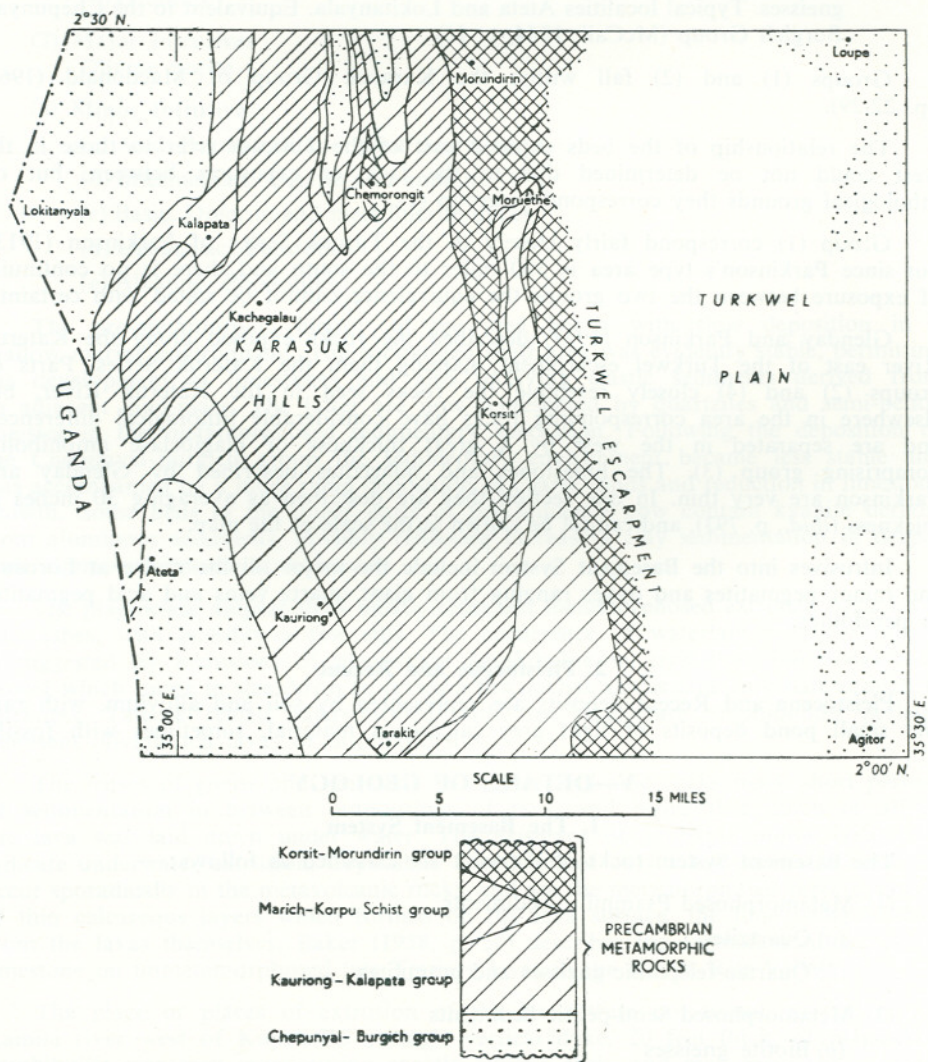


Fig. 3—Rock groups of the Basement System in the Karasuk area

- (2) Biotite gneisses with hornblende becoming more abundant towards the east; locally granitoid at the contact with overlying plagioclase amphibolites of the Marich-Korpu Schist groups. Graphitic gneisses important in the west, and minor intercalations of plagioclase amphibolite throughout. Thin impersistent limestones towards the top of the series at Akumait in the north and near Tarakit in the south, and one thin quartzite near Tarakit. Typical localities Kauriong' and Kalapata.
- (1) Alternation of crystalline limestones, siliceous gneisses (biotitic and quartzofelspathic) and quartzites, with major and minor intercalations of plagioclase amphibolite, increasing in thickness towards the top. Four major limestones are distinguishable near Ateta and south-east of Lokitanyala. The top of the uppermost limestone is taken as the top of the group. One major lens of graphitic gneiss in the upper part of the group. In the north-west no quartzites are found, their place being taken by leucocratic biotite gneisses. Typical localities Ateta and Lokitanyala. Equivalent to the Chepunyal-Burgich Group (McCall, 1964, p. 16).

Groups (1) and (2) fall within the Karasuk Group of Macdonald (1961, pp. 22-29).

The relationship of the beds exposed east of the Turkwel river to those in the west could not be determined due to the lack of exposures between, but on lithological grounds they correspond to group (1).

Group (1) correspond fairly closely to the Turoka Series of Parkinson (1913), but since Parkinson's type area is 300 miles to the south and there is no continuity of exposure between the two groups the equivalence cannot be stated with certainty.

Glenday and Parkinson (1927) described the rocks exposed along the Kateruk River east of the Turkwel escarpment, naming them the Kateruk Series. Parts of groups (2) and (4) closely resemble the rocks seen in the Kateruk River, but elsewhere in the area corresponding rocks have considerable lithological differences, and are separated in the west by a great thickness of plagioclase amphibolite comprising group (3). The limestones and quartzites described by Glenday and Parkinson are very thin. In one section they are described as averaging 30 inches in thickness (*ibid.*, p. 793), and cannot be shown at the scale of the map.

Intrusives into the Basement System include the major olivine norite at Lorosuk, and minor pegmatites and dykes ranging from giant quartz veins and acid pegmatites to peridotites.

2. Pleistocene and Recent

Pleistocene and Recent deposits are represented by soil and alluvium, with rare and small pond deposits of light grey calcareous material, sometimes with fossils.

V—DETAILS OF GEOLOGY

1. The Basement System

The Basement System rocks of Karasuk are classified as follows:—

- (1) Metamorphosed Psammitic Sediments
 - (a) Quartzites
 - (b) Quartzofelspathic gneisses and granulites
- (2) Metamorphosed Semi-pelitic Sediments
 - (a) Biotite gneisses
 - (b) Muscovite-biotite gneisses

- (3) Metamorphosed Pelitic Sediments
Graphitic gneisses
- (4) Metamorphosed Calcareous Sediments
Crystalline limestones.
- (5) Metamorphosed Volcanic Rocks
 - (a) Plagioclase amphibolites
 - (b) Talc schists
- (6) Metasomatic Rocks
 - (a) Granitoid gneisses
 - (b) Granites
- (7) Major Intrusives
Olivine norite
- (8) Minor Intrusives
 - (a) Acid. Pegmatites and giant quartz veins
 - (b) Intermediate. Diorite and andesite
 - (c) Basic. Dolerite and metadolerite dykes
 - (d) Ultrabasic. Peridotite
 - (e) Alkaline. Phonolites.

The pre-metamorphic history of the area began with slow deposition in a shallow marine environment. The submerged shelf area was evidently stable, permitting the development of limestones and also receiving clastic sediments derived from an adjacent land-mass. The latter are now represented by quartzites and semi-pelitic gneisses in the metamorphosed sedimentary succession. Following the deposition of the Chepunyal-Burgich group the sedimentary environment became less stable and was accompanied by a more rapid deposition of coarse sands and reduction in limestone growth. Some beds in the upper parts of the sequence now contain kyanite derived from aluminous sediments, possibly reflecting increasing clay sedimentation in deeper waters remote from the littoral zone.

The plagioclase amphibolites mostly represent metamorphosed extruded basic lavas and ashes, with possibly a few sills. The occurrence of waterlain ashes or bombs is suggested by inclusions of plagioclase amphibolite in crystalline limestones near Lowoi which range in size down to lenses a few inches across and only half-an-inch in thickness. Talcose schists interstratified with the plagioclase amphibolites perhaps represent olivine-rich lavas or ultrabasic sills.

The lenses of gneiss and limestone in the metavolcanic rocks mark short periods of sedimentation in between outpourings of lava, and prove that much or all of the lava was laid down under water. The existence of probable pillow lavas also indicate underwater extrusion. Crystalline limestones of only a few inches in thickness occur sporadically in the metavolcanic rocks, and are the metamorphosed representatives of thin calcareous layers which formed on the lava surface, the lime being leached from the lavas themselves. Baker (1958, p. 50) describes the formation of secondary limestone on unmetamorphosed late Tertiary lavas in the Kenya Rift Valley.

The place or places of extrusion of the lavas were not found, though in the Kamila river west of Kapcholio a single vertical dyke, 20 feet thick, of plagioclase amphibolite was seen cross-cutting exactly similar rock, and may represent a feeder dyke of lava extruded at a higher level. The great boss of olivine norite at Lorosuk may also mark the site of an original volcano.

Vulcanicity was fairly active in Chepunyal-Burgich times, rare in Kauriong'-Kalapata, and reached a maximum with the Marich-Korpu Schists. At least one major outburst is recorded in the Korsit-Morundirin group.

The approximate succession and thickness along the line of section of the map is as follows:—

		Average thickness (feet)
Korsit-Morundirin group	Top not seen	
	Biotite gneiss with kyanite locally	500
	Plagioclase amphibolite	1,000
	Biotite gneiss	3,500
		5,000
Marich-Korpu Schist group	Plagioclase amphibolite with minor intercalations of talcose schists, siliceous gneisses and crystalline limestones	10,500
	Metasomatic granite	3,000
	Plagioclase amphibolite with minor intercalations of talcose schists, siliceous gneisses and crystalline limestones	2,000
		15,500
Kauriong'-Kalapata group	Biotite gneiss, locally granitoid	10,500
	Graphitic gneiss	300
	Biotite gneiss	3,000
	Plagioclase amphibolite	700
		14,500
Chepunyal-Burgich group	4th crystalline limestone	200
	Graphitic gneiss	1,200
	Plagioclase amphibolite	1,800
	Quartzite	250
	3rd crystalline limestone	350
	Plagioclase amphibolite	900
	2nd crystalline limestone with quartzite lens	400
	Biotite gneiss with quartzite and plagioclase amphibolite	2,000
	1st crystalline limestone	300
	Quartzite	50
	Biotite gneiss	350
	Base not seen	
		7,800

(1) METAMORPHOSED PSAMMITIC SEDIMENTS

The rocks included in this section had their origin in orthoquartzites and feldspathic sandstones containing only minor amounts of ferruginous or calcareous material. All the quartzo-feldspathic gneisses contain some biotite, and the division between them and the biotite gneisses has been made where biotite content of the rock does not exceed two per cent by volume.

(a) Quartzites

These are all of coarse grain, usually white or pink in colour, the pink colouring being due to traces of iron oxide in intergranular films. A typical example, specimen 18/4* from Lowoi in the south-west was sectioned, and has the following

*Numbers prefixed 17/ and 18/ refer to specimens in the regional collection for Degree Sheets 17 and 18 in the Mines and Geological Department, Nairobi.

PLATE I



Fig. 1—Chepkirial Gorge



Fig. 2—Chepkirial Gorge

PLATE II

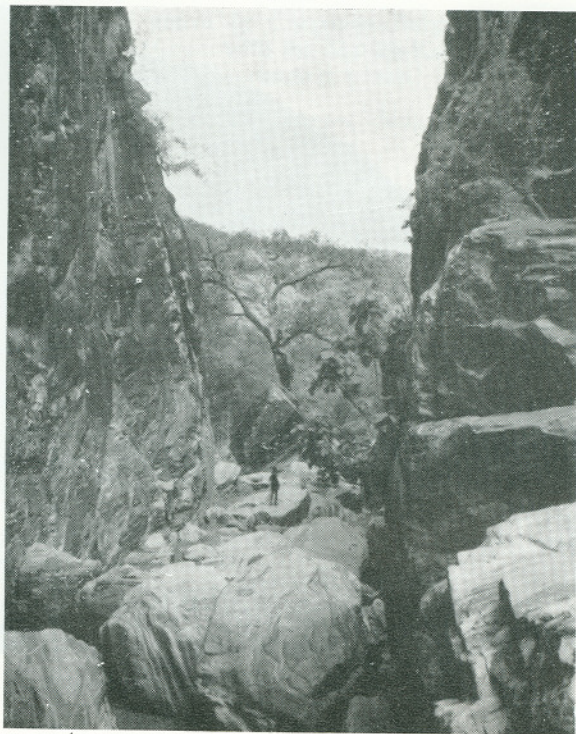


Fig. 1—Lokitanyala river following joint planes



Fig. 2—River capture north of Lokopel

PLATE III



Fig. 1—Pillow lava at Song'wet



Fig. 2—Pillow lava at Song'wet

PLATE IV



Fig. 1—Pillow lava at Kois



Fig. 2—Minor structures and faults in Chepkirial Gorge

mode*: Quartz 97 per cent, colourless tremolite 2 per cent, microcline 1 per cent, sillimanite, graphite and iron ore in trace amounts. One large crystal of quartz is seen to be partly replaced by microcline, as a result of potash metasomatism. Specimen 18/16 from Turutur, four miles north-west of Lowoi, contains only quartz and colourless diopside, the latter making up 18 per cent of the rock.

(b) *Quartzo-felspathic gneisses and granulites*

These grade in colour from off-white to cream, and their texture varies from fine (the granulites) to coarse, sometimes very coarse where recrystallization has occurred. A thin section of a typical specimen, 18/60 from Kapcholio, shows quartz, microcline, oligoclase and muscovite, with a small amount of iron ore. Quartz occurs in lenses and layers aligned along the foliation, individual grains showing no strain effects, whereas an older generation of quartz and cloudy feldspar often shows strain shadows.

Specimen 18/110 from Okial in the centre of the area is a local variation of the biotite gneiss, which is semi-granitoid at that place. The feldspars in the specimen are sodic andesine and microcline; muscovite occurs in addition to biotite, with trace amounts of opaque iron ore.

(2) METAMORPHOSED SEMI-PELITIC SEDIMENTS

The metamorphosed semi-pelitic sediments comprise two groups, the biotite gneisses and the muscovite-biotite gneisses. Many exposures of biotite gneiss contain muscovite locally as a second mica, but only where muscovite is an important constituent throughout the outcrop was the rock mapped as muscovite-biotite gneiss.

(a) *Biotite gneisses*

The biotite gneisses are generally of fine to medium grain, sometimes granulitic, and always show marked foliation due to the tendency of the mica flakes to align themselves in discrete layers, alternating with leucocratic layers. Where layering is well-marked the rocks locally become clearly banded on a fine scale. With increased coarseness of grain and consequent lessening of foliation they grade into granitoid gneisses.

In thin section the biotite is usually strongly dichroic from yellow-brown or yellow-green to dark brown or dark olive, sometimes black. Quartz is always an important constituent, and orthoclase occurs in several of the samples, notably specimen 17/19 from Kataier in the north-west, where it occurs with microcline, though in all the other slides in which microcline occurs orthoclase is absent. Plagioclase feldspar ranges in composition from oligoclase to andesine, the rocks with the more calcic plagioclase usually containing free calcite. In the south centre of the area, around Kasei and Chepurwa, hornblende becomes an important constituent, sometimes equalling biotite in volume, as in specimen 18/52, which also contains a small proportion of diopside. Glenday and Parkinson (1927, p. 793) suggest that the occurrence of hornblende in an acid gneiss in the Kateruk river may be due to ash material incorporated in a grit, an explanation which is given added weight in this case by the occurrence of diopside.

In the north and centre of the area, in the uppermost biotite gneisses of the Korsit-Morundirin group, kyanite is important locally, occurring as blue or blue-green bladed crystals which sometimes reach a length of 3 cm. The kyanite is usually associated with muscovite as well as biotite, and in the specimens examined was never seen to exceed 5 per cent of the total volume of the rock. In view of the high grade of regional metamorphism throughout the area the existence of kyanite in a fairly restricted locality is attributed to an excess of alumina present in the original sediments rather than to a difference in metamorphic grade. No garnet was found in any of the exposures of biotite gneiss.

* All modes quoted are volumetric and estimated.

Other accessory minerals are calcite, epidote, sphene, apatite and iron ores. West of Agitor scattered fragments of grey, well-crystallized corundum (specimen 18/124) were found, individual crystals reaching 8 cm. in length. The host rock from which the crystals were derived could not be located, but was almost certainly the underlying biotite gneiss.

Some estimated modes for the biotite gneisses, listed in order of decreasing biotite content, are as follows:—

	18/72	17/19	18/34	18/52
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Quartz	48	20	12	37
Orthoclase	12	15	—	27
Microcline	—	48	48	—
Plagioclase	18	7	27	22
Biotite	12	8	8	6
Hornblende	—	—	—	6
Calcite	6	2	+	—
Epidote	3	—	—	+
Other minerals	1	+	5*	2†

*Mainly apatite and iron ore.

†Mainly diopside.

Specimen 18/72 Apuke.

Specimen 17/19 Kataier.

Specimen 18/34 Lowoi.

Specimen 18/52 Chepurwa.

(b) *Muscovite-biotite gneisses*

Only three bands of muscovite-biotite gneiss large enough to map were found in the area. All are of medium grain, and vary in colour from cream to grey. Foliation is well marked by alignment of mica flakes. In all the slides examined the muscovite appears to be a replacement of biotite. Specimen 18/71 from the Kopedo river north-west of Kapcholio is typical, showing muscovite replacing biotite, dichroic from yellow-brown to black, with grains of opaque iron ore. Quartz makes up 46 per cent of the rock, and feldspars are microcline and cloudy and altered plagioclase of the composition of oligoclase-andesine. Of the other two outcrops, at Chepkuloi and Akwang'a (specimens 18/76 and 18/101 respectively) only that at Akwang'a shows microcline, though both show oligoclase-andesine feldspar. Accessory minerals, all in trace amounts, are epidote, apatite and calcite and, in 18/101 only, garnet.

(3) METAMORPHOSED PELITIC SEDIMENTS

The only representatives of this class of rock shown on the map are the graphitic gneisses, which are well developed in the south-west, with a very small band near Agitor in the south-east, the outcrop of which has been somewhat exaggerated on the map. A second metamorphosed pelitic rock type was found in an exposure a few feet wide in the Napiot river in the north-east, marginal to a fairly wide exposure of biotite gneiss. This rock could not be seen elsewhere along the margin of the biotite gneiss. In hand specimen No. 18/89 it is coarsely granular and dark red-brown in colour. Under the microscope its mode was estimated as quartz 46 per cent, hornblende 7 per cent, garnet 43 per cent, opaque iron ore 4 per cent, plus trace amounts of zircon, sphene and apatite.

Graphitic gneisses

In hand-specimen these rocks are of medium to coarse grain, friable where graphite content exceeds 7 or 8 per cent but otherwise hard and compact, grey in colour, and streaked with red-brown hydrated iron oxides. Mechanical separation of samples from the Epeiyel and Moruankoch areas averaged 10 and 16 per cent graphite, and a single sample from the Agitor outcrop showed a graphite content of 26 per cent. In thin section, Specimen 18/12 from Moruankoch shows an intergrowth of graphite with goethite and trace amounts of biotite, dichroic from colourless to light brown. The only other minerals seen were quartz and oligoclase.

(4) METAMORPHOSED CALCAREOUS SEDIMENTS

The only metamorphosed calcareous sediments with outcrops large enough to map are crystalline limestones, but small and impersistent calc-silicate gneisses occur in and marginal to the crystalline limestones.

Crystalline limestones

The limestones and marbles show wide variations in colour, texture and mineral content even between parts of the same outcrop. Their colour is usually white, speckled with small flakes of graphite, though many of the thin limestones associated with the main outcrop of plagioclase amphibolite are grey, and bright pink marble is found at Lokopel and near Kalapata, the latter (specimen 17/15) being chocolate-brown in patches, some individual crystals being partly brown and partly pink. All are holocrystalline, individual grains ranging from one to ten millimetres in diameter. The most common impurity after graphite is tremolite, which in hand-specimen varies from colourless to bright green, and sometimes, as in specimen 18/68 from Chepkoi, north of Kapcholio, is partly altered to pale green talc. Quartz is common in grains and knots intergrown with calcite. The very thin limestone west of Lokitanyala carries rare and scattered cubes of iron pyrites.

Thin sections were cut of two of the grey limestones, specimens 18/70 from Korsit and 18/95 from Pulichon river, north-west of Morulim. The first showed calcite and quartz with trace amounts of magnetite and haematite, and the latter showed in addition both muscovite and pale brown phlogopite. No graphite was found in either specimen.

Forsterite occurs in specimen 18/82 from Kaputir, where it is seen only as relics, the bulk of the mineral having changed to opicalcite, a mixture of serpophite and antigorite. Specimen 18/84, taken from an outcrop two miles further east, showed in addition to calcite only opicalcite, which has completely replaced the earlier forsterite.

The highest index mineral of metamorphic grade in the limestones is diopside, which was seen in specimen 18/33 from Lowoi. In the limestone outcrop knots of diopside measuring up to 3 feet in diameter were observed, individual crystals sometimes reaching several inches in length. The diopside is pale grey in colour; the limestone itself is pure white, with a grain size averaging two to three millimetres.

Specimen 17/9 was taken from a thin dark green calc-silicate lens in the marble at Kataier, south-east of Lokitanyala. Its thin section shows, in addition to calcite, diopside altering marginally to common green hornblende, quartz, andesine, sphene, scapolite, pale pink garnet and opaque iron ore. A further calc-silicate in the form of a thin band marginal to crystalline limestone occurs at Epeiyel, and was exposed in a shallow drain beside the road. In hand-specimen (18/44) it is of medium grain, pale pink in colour and speckled with dark green patches. Under the microscope calcite is seen to be only a minor constituent, the main minerals being blue-green diopside and scapolite. Quartz was not found, but a small amount of orthoclase is present, together with garnet and sphene. The mode of this specimen was estimated as diopside 55 per cent, scapolite 23 per cent, garnet 12 per cent, calcite 6 per cent, orthoclase 2 per cent and sphene 2 per cent.

The origin of the calc-silicate gneisses appears to be connected with the early vulcanicity of the area. Volcanic material in finely divided form such as ashes or dust falling into the sea in which limestones were being deposited would result in contaminated limestones which, after metamorphism, would become calc-silicate gneisses. Where the accession of volcanic material to the slowly forming limestone was more rapid, as in the case of flows or the falling in of bombs, there has been little or no interaction on metamorphism, so that sharply margined lenses or knots of plagioclase amphibolite are interbedded with the crystalline limestones.

(5) METAMORPHOSED VOLCANIC ROCKS

The metamorphosed volcanic rocks which outcrop over a large part of the Karasuk area are considered to be metamorphosed lavas and ashes. They are divided into two main groups, the plagioclase amphibolites and the talc schists, the latter arising from lavas of different composition to those which gave rise to the plagioclase amphibolites, probably a more basic type. This is deduced from the field relationships, the talc schists being always perfectly conformable with the plagioclase amphibolites, and often traceable as continuous outcrops over a strike of many miles. Retrograde metamorphism of the plagioclase amphibolites produced by shearing has led to the alteration in whole or in part of hornblende to biotite and epidote and sometimes actinolite, but not to talc. The plagioclase amphibolites are more resistant to weathering than the biotite gneisses, and form escarpments or ridges and underlie much of the high ground of the area. The talc schists generally make negative features.

It can be deduced that most of the original lava was laid down under water; lenses and bands of limestone and gneiss of sedimentary origin lie conformably in the plagioclase amphibolite, and thick bands of plagioclase amphibolite are also intercalated with the metasediments. It is possible that some extrusions rose above the surface of the sea, but no unconformity was found to indicate the deposition of new lava on an eroded surface of older lava. It is, however, likely that unconformity of this kind would be difficult if not impossible to detect. A possible submarine origin for the metamorphosed lavas is also supported by the presence in them of curved structures resembling pillows. The structures were observed in the extreme south-west of the area at Kois and Song'wet (Plates III and IV) where the supposed pillow lavas are aligned along the strike and apparently occupy a common stratigraphical position in the metamorphic succession. Individual pillows range in size from a few inches to several feet across and their convex upper and concave lower surfaces parallel the dip of foliation in the surrounding rocks. The interstices of adjacent pillows are filled with similar material to the pillows themselves, not with chert as often occurs in pillow lavas. The foliation of the rock continues through the pillows, but becomes indistinct towards their outer surfaces, where spalling of the curved surfaces gives the appearance of "onion-skin" weathering. The internal foliation is a result of regional metamorphism; the original lava must have been unfoliated. Only one other occurrence of pillow structure was noted, at Ateta, north of the exposures just described.

(a) *Plagioclase amphibolites*

In the majority of exposures the plagioclase amphibolites are of medium grain, varying in colour from dark grey to black according to the amount of contained felspar and quartz. The tendency for quartz and felspar to be aligned in discontinuous thin layers gives a marked foliation to the rock. East and south-east of Kapcholio and at a few localities in the west foliation is strong, and the rocks are locally fissile, and greenish grey in colour. The change in colour is reflected in the mineral composition of the rocks, much of the hornblende showing alteration to actinolite and biotite accompanied by an increase in epidote. Garnets are generally rare, although in specimen 18/7 from Lowoi they are seen to constitute 40 per cent of the rock. The amphibole content, except in the schistose varieties, is usually hornblende, strongly pleochroic in shades of yellow-green and olive, sometimes with a markedly bluish tinge. Where diopside is

present it is of a pale green or blue-green colour, and usually forms relict cores to hornblende, showing conversion to the latter. In specimen 17/17 from Lokitanyala no hornblende was found in thin section, only diopside intergrown with granular epidote and a small proportion of garnet. The hand-specimen shows small amounts of two secondary copper minerals, malachite and azurite, emplaced on joints and fractures. Quartz occurs in about half the slides examined, reaching 13 per cent in specimen 18/9 from Kutung'thig in the south-west. It is unlikely that quartz was a constituent of the original lava. A small amount would have resulted from the change of diopside to hornblende but an influx of silica seems to be indicated. It is noteworthy that no free quartz occurs in any of the rocks which still contain diopside. Plagioclase felspar occurs in all the specimens, reaching 46 per cent in 18/35 from Kauriong', and varies in composition from oligoclase-andesine (rare) to labradorite, being most commonly andesine-labradorite. No orthoclase or microcline feldspars were found. Iron ores, apatite and sphene occur as accessories in most of the slides, and rutile was found in specimen 18/48 from Matonokwa, west of Kapcholio.

Some estimated modes of the plagioclase amphibolites, listed in order of decreasing hornblende content, are as follows:—

	18/80	17/5	18/9	18/35	18/7	17/17
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Quartz	4	—	13	—	12	—
Plagioclase ..	31	23	25	46	8	3
Hornblende ..	65	64	60	48	26	—
Diopside	—	6	—	4	—	46
Epidote	—	2	2	—	12	48
Garnet	—	—	—	—	40	2
Other minerals ..	—	5*	+	2	2	1

*Sphene 3 per cent and apatite 2 per cent.

Specimen 18/80, Agitor.

Specimen 17/5, north-west of Lokitanyala.

Specimen 18/9, Kutung'thig.

Specimen 18/35, Kauriong'.

Specimen 18/7, Lowoi.

Specimen 17/17, Lokitanyala.

The more schistose amphibolites vary widely in mineral composition. The proportion of quartz and felspar combined varies from a maximum of 68 per cent in specimen 17/12 to nil in specimen 17/7; the plagioclase is rather more sodic than in the gneissose amphibolites, varying in composition from oligoclase to andesine. The combination of sodic plagioclase and a high proportion of quartz suggests an influx of sodium and silica. The lime content remains high, as evidenced by the abundance of epidote, and the frequent derivation of biotite from hornblende points to an influx of water vapour at a late stage in the metamorphic cycle. Extreme cases of alteration of the original lava are specimens 18/65 from Ortu, east of Kapcholio, and 17/7 from north-east of Kolewilewi. The former is an epidosite which forms a conformable lens a hundred feet long and up to twenty feet wide in the plagioclase amphibolites. In hand specimen it is pale grey-green in colour, finely granular, and cut by thin layers of quartz which frequently show slickensided surfaces indicative of shearing. Its mode was estimated as quartz 11 per cent (mainly in layers, but also in granules intergrown with epidote), epidote 87 per cent, and euhedral magnetite 2 per cent. Specimen 17/7 was taken from one of the few occurrences of schistose amphibolite in the west of the area, though in approximately the same horizon as most of the other schistose types. In the

field it appears as a local variation of the gneissose plagioclase amphibolite and was seen over a width of outcrop of about 400 ft. In hand specimen it is of medium to fine grain, in colour dark greenish grey with small patches and films of brown iron oxide. Under the microscope it consists only of pale green faintly pleochroic fibrous actinolite and granular opaque iron ore, with films of yellow-brown iron oxide. Its mode is actinolite 98 per cent and iron ores 2 per cent.

Modes of some of the schistose amphibolites, again listed in order of decreasing hornblende content, are as follows:—

	18/73	18/64	18/45	18/49
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Quartz	3	18	8	50
Plagioclase	—	32	47	—
Biotite	—	18	15	—
Hornblende	62	23	22	—
Actinolite	—	2	—	12
Hypersthene	—	—	8	—
Epidote	35	7	—	37
Other minerals	—	+	+	1

Specimen 18/73, Lopotwa river.

Specimen 18/64, Ortu.

Specimen 18/45, Epeiyelel.

Specimen 18/49, Chepkirial.

Glenday and Parkinson (1927, p. 795) quote an analysis of schistose hornblendite from the Akorre (Akores) river, a tributary of the Kateruk. Its analysis, together with its norm calculated by the writer, is as follows:—

	I		II	
	<i>per cent</i>	<i>norm</i>	<i>per cent</i>	<i>norm</i>
SiO ₂	40.40	or 0.56	41.03	or 5.56
Al ₂ O ₃	13.45	ab 13.08	11.07	ab 6.29
Fe ₂ O ₃	5.68	an 29.50	4.65	an 21.13
FeO	12.24	di 19.21	7.05	ne 4.26
MgO	9.40	hy 0.48	15.75	di 22.54
CaO	11.55	ol 20.67	10.59	ol 24.06
Na ₂ O	1.54	mt 8.10	1.71	mt 6.73
K ₂ O	0.12	il 3.78	0.94	il 4.56
H ₂ O+	1.80	ap 0.17	2.85	ap 1.01
H ₂ O—	0.55	cc 1.30	1.36	
TiO ₂	2.00	py 0.48	2.43	
P ₂ O ₅	0.07		0.41	
MnO	0.32			
CO ₂	0.60			
S	0.14			
SO ₃	Tr.			
	99.86		99.84	

I—Hornblendite, Akores, Karasuk. Analyst, W. Herdsman.

II—Hornblende basalt, Platzerkuppe, Rhönegebirge. Analyst, M. Dittrich.

Analysis II is taken from H. S. Washington (1917, p. 652) and shows the relationship of the metamorphosed hornblendite to a fresh basaltic lava.

The plagioclase-amphibolites contain metastable relics of high-grade metamorphic assemblages which have been altered to hydrated minerals during adjustment to falling temperature and pressure, probably accelerated by shearing. The retrogressive changes suggested by the petrography of the rocks are as follows:—

- (i) Diopside → hornblende → epidote
- (ii) Diopside → hornblende → actinolite or biotite
- (iii) Plagioclase → quartz + epidote (zoisite)

Whether the pyroxene of the original lava was all diopside is doubtful. From the norm of the single chemical analysis quoted it seems likely that olivine was an important original constituent, with diopside or hypersthene or both.

(b) *Talc schists*

Most of the members of this division contain actinolite as well as talc, and with varying actinolite content the rocks vary in colour from light greenish grey to silver-grey, usually with iron oxide staining. Two typical modes are:—

					18/66	18/40
					<i>per cent</i>	<i>per cent</i>
Quartz	..	..	..	..	1	—
Actinolite		..	..	..	3	50
Talc	..	..	..	..	94	50
Iron ores	..	..	..	..	2	+

Specimen 18/66. Talc schist, Kaparamatai.

Specimen 18/40. Talc-actinolite schist, Kamila river.

In the West Suk area McCall records frequent occurrences of serpentine in the plagioclase amphibolites. No serpentines were found in Karasuk, but it is probable that some of the talcose schists have passed through serpentine in the course of metamorphism from ultra-basic rocks.

(6) METASOMATIC ROCKS

The metasomatic rocks are divided into two groups, the granitoid gneisses and the granites. Both had their origin in the same sediments that gave rise to the biotite gneisses, their classification being decided on their aspect in the field. The granitoid gneisses are generally of coarser grain than the biotite gneisses, sometimes with marked development of porphyroblastic feldspars and with only poorly defined foliation. In the granites foliation is generally poor or absent; if visible it is concordant with the foliation of neighbouring rocks, and is also sometimes expressed by dark biotitic layers suggesting that much of the granite has formed by replacement of original metasediments leaving only a "ghost stratigraphy" in the nearly homogeneous rock. On weathering both types lead to a rugged and broken topography, with crags and tors, in contrast to the smooth or rolling topography produced over the biotite gneisses.

The granitoid gneisses and granites have sharp contacts against the plagioclase amphibolites, suggesting that the latter effectively resisted the metasomatism producing the granitoid and granitic rocks; perhaps also the plagioclase amphibolites acted as barriers to the metasomatic emanations, since some enclosures of biotite gneisses in the plagioclase amphibolites show comparatively slight granitization.

The field evidence pointing to the non-intrusive nature of the Kapcholio granite is:—

- (1) The "ghost stratigraphy" of the original sediments contained in the granite.
- (2) The clean, conformable contact between the granite and plagioclase amphibolite, and a complete lack of contact metamorphism.
- (3) The enclosed lenses of plagioclase amphibolite in the south-east, which are closely parallel to the plagioclase amphibolite above and below in the sequence, and which show no sign of disturbance or fracturing as would be expected in rafts of country rock floated down into a magma. Local mobilization of the granite is indicated by a group of pegmatites located to the west of the mountain, which probably originated in the granite and rose through planes of weakness in the plagioclase amphibolite.

A second major granite exposure, that at Sinchulul, takes the form of an almost vertical sheet cutting across the foliation of the granitoid gneisses, and is evidently a locally mobilized phase of those gneisses.

(a) *Granitoid gneisses*

In hand specimen the granitoid gneisses are of medium or coarse grain, often with porphyroblasts of feldspar occurring in poorly defined layers parallel to the foliation; the porphyroblasts fail to disturb the alignment of mineral layers into which they have grown, showing that they have developed by replacement and not by mechanical injection of magmatic material. The granitoid gneisses with one exception are leucocratic, having a characteristic pink or fawn tinge. The exception is specimen 18/57 from Kalam, east of Tarakit, where a rather higher than usual content of mafic minerals darkens the gneisses. All the slides examined are rich in plagioclase feldspar, usually oligoclase, and sometimes andesine, as in specimen 18/110 from Okial in the centre of the area, where small patches of granitoid gneiss too small to map occur as local variations of the biotite gneisses. All the thin-sections with the exception of specimen 18/57 contain microcline and microcline-perthite. Orthoclase also occurs in this thin-section as well as in specimen 18/29 from Kalapata. The common ferromagnesian mineral is biotite, strongly dichroic from yellow-brown or greenish brown to almost black, accompanied by muscovite in specimens 18/110 and 18/102 (from Chemorongit), and in specimen 18/57 by hornblende, pleochroic from olive-green to deep blue-green. Accessory minerals identified are sphene, apatite, zircon, epidote, iron ores and, in 18/78 from Naruoro, garnet.

Some estimated modes for the granitoid gneisses are:—

				18/29	18/57	18/110
				<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Quartz	..	..	..	17	28	46
Orthoclase	..	..	..	28	8	—
Microcline	..	..	..	23	—	18
Plagioclase	..	..	..	22	48	34
Muscovite	..	..	..	—	—	2
Biotite	..	..	..	8	6	+
Hornblende	..	..	..	—	8	—
Accessories	..	..	..	2	2	+

Specimen 18/29, Kalapata.

Specimen 18/57, Kalam.

Specimen 18/110, Okial.

Comparison with modes of various specimens of biotite gneiss (page 14) shows their close petrographic relationship with the granitoid gneiss, and suggests that the differences between the two rock types are determined by more intense metasomatic effects apparent in the granitoid gneisses, rather than by differences in the original sediments.

(b) *Granites*

Two extensive areas of granite were mapped at Kapcholio and Sinchulul. The Kapcholio granite has an equigranular texture and is of medium to coarse grain; the Sinchulul granite exhibits a very coarse grain and is porphyroblastic in texture. Both granites are white or off-white in colour and sometimes contain irregular pink patches imparted by local concentrations of potash feldspar. The main constituents of the Kapcholio granite are quartz, microcline and oligoclase; no orthoclase was seen in the thin-sections. Specimen 18/50 shows examples of the growth of microperthitic microcline at the expense of plagioclase, sometimes accompanied by myrmekite. The only ferromagnesian present is biotite, seldom exceeding 5 per cent of the mineral composition and dichroic from brownish green to black. Biotite is sometimes accompanied by trace amounts of muscovite; accessory minerals are sphene, apatite, zircon and epidote.

The Sinchulul granite is more leucocratic than that at Kapcholio, biotite seldom exceeding 2 per cent. In thin-section the biotite is dichroic from olive-green to black and sometimes accompanied by red garnet. In hand specimens the garnets are large, some reaching 6 mm. in diameter, but in the thin-sections examined and in the granite as a whole, garnet is only present in trace amounts. The leucocratic portion of the rock is made up of quartz, microcline and clouded albite, sometimes showing replacement by microcline. Accessory minerals, in addition to garnet already mentioned, are apatite and magnetite. The mode of a typical specimen, 18/41, was estimated as quartz 33 per cent, microcline 8 per cent, plagioclase 57 per cent, biotite 1 per cent, magnetite 1 per cent and garnet and apatite in trace amounts.

(7) MAJOR INTRUSIVES

Olivine Norite

The outcrop of this single distinctive major intrusion is roughly circular measuring five and a half miles across, and forms the mountain of Lorosuk whose altitude is 9,035 feet. There is no clear evidence as to its age, but the fresh appearance of the olivine norite suggests that it is younger than the surrounding plagioclase amphibolites. It is dark grey in colour, of coarse grain, with no trace of foliation. It gives a dark red-brown fertile soil on weathering, which is usually deep, so that even on steep gradients outcrops are few. Examples of the underlying rock are commonly seen in well rounded boulders which due to their shape and hardness are carried great distances in stream beds. Boulders of Lorosuk norite up to ten inches in diameter can be found in great numbers in the Kateruk river as far down-stream as Kaabwa. Specimens taken at various places over the outcrop showed little variation. A typical thin-section from specimen 18/91 contains rounded and fractured olivine with yellow serpentine infilling the cracks, the olivine being surrounded by successive coronas of opaque iron ore, pale brown to colourless cummingtonite (usually in a discontinuous corona) and pale green antigorite, sometimes showing symplectic texture. Strongly schillerised hypersthene occurs in ophitic relationship to labradorite. The mode of the rock, averaged from specimens taken from three widely spaced localities, is labradorite 43 per cent, olivine 15 per cent, hypersthene 21 per cent, cummingtonite 8 per cent, antigorite 11 per cent, yellow serpentine 1 per cent, iron ore 1 per cent and calcite a trace.

At Kapiemit the norite is locally altered to a coarse, hard, green and white speckled rock. It occurs in patches sometimes a hundred feet across in unaltered norite, the transition between the two being over a distance of only a few inches. Exposures in steep gullies show the alteration to extend more than 30 feet in depth (the base was never seen) suggesting hydrothermal alteration from below. Under the microscope only three minerals were seen in the altered norite, specimen 18/99, plagioclase, antigorite

and tremolite. The plagioclase feldspar is labradorite, now much fractured and with more pericline twinning than is seen in the unaltered rock. All the olivine and associated minerals of the original rock have been altered to antigorite, and the hypersthene to tremolite.

(8) MINOR INTRUSIVES

(a) *Acid. Pegmatites and Giant Quartz Veins*

Typical of the acid pegmatites of the area are those at Lokopel in the north-east of the area. Individual pegmatites reach about 100 feet in width, and are usually conformable to the strike of the country rocks or crosscut them at a very low angle. They are composed mainly of white cloudy quartz and pink feldspar, some crystals of the latter reach 30 cm. across and often contain small blebs of quartz in discontinuous lines and layers. The feldspar was microscopically determined as microcline in specimen 18/85; the only other minerals noted were muscovite in flakes seldom exceeding 3 cm. across, and needles and prisms of rare black tourmaline. A similar pegmatite, specimen 17/16, occurs at Lokitanyala. It averages only 25 cm. in width, and crosscuts the strike of biotite gneisses and plagioclase amphibolites at a low angle over a length of outcrop of several hundreds of feet. It is shown to be a replacement pegmatite by the preservation in it of undisturbed inclusions of biotite gneiss. Similar inclusions of amphibolite or basic hybrids derived from amphibolite were not observed. The pink feldspar in this pegmatite was determined as albite, with minor amounts of microcline. The remaining minerals seen were biotite and muscovite, both in small flakes in trace amounts.

Specimen 18/97 was taken from a pegmatite 20 feet in width on the Embasos river north-east of Lorosuk. It is of coarse grain, individual crystals measuring up to 10 cm., and is composed of colourless quartz, white albite and small books (up to 3 cm. across) of muscovite. In the slide of this rock there is one small pale pink garnet, but none was seen in the outcrop. This pegmatite cuts the foliation of plagioclase amphibolite at a high angle, and is clearly intrusive in origin.

Specimens 18/37 and 18/38 were taken from the group of pegmatites west of Kapcholio. Both are of fine to medium grain, cream in colour and speckled with flakes of black mica. The widest of the pegmatites occurs as a multiple band covering a width of nearly 200 feet, individual bands reaching 50 feet in width. The thin-section of specimen 18/37, the more leucocratic of the two pegmatites, shows the main constituents to be microcline and quartz, with lesser amounts of oligoclase, together with biotite and iron ore. Specimen 18/38 is very similar, with a biotite content approaching 5 per cent, and plagioclase feldspar slightly more calcic (oligoclase-andesine). Sphene and apatite occur in trace amounts. The similarity of these pegmatites to the Kapcholio granite, both in appearance and mineral content, suggests a common origin. It is probable that they were intruded from the underlying granite, in which metasomatism was sufficiently intense to mobilize the rock.

Giant quartz veins are few, a typical one being that near the summit of Tenus, which approaches 50 feet at its widest and is composed entirely of white translucent quartz which cuts gneissose plagioclase amphibolites. Lesser quartz veins ranging from a fraction of an inch to several feet in thickness are common throughout the area, and where erosion has removed much of the topsoil, especially over the biotite gneiss outcrops, fragments of iron-stained vein quartz locally form a continuous stone-mantle. In the plagioclase amphibolites quartz stringers often reveal minor fractures and folds which would otherwise go unnoticed in such structureless rocks. Plate IV Fig. 2 shows quartz stringers picking out minor faults and puckers in plagioclase amphibolite in the Chepkirial gorge. East and north-east of Kapcholio most of the quartz veins carry copper minerals and gold. These veins are described more fully on p.30.

(b) *Intermediate. Diorite and Andesite*

A vertical dyke of diorite averaging 30 feet in width and just over half a mile in length is well exposed in a waterworn platform at the top of a 150-foot waterfall at Kotich, north of Lokitanyala, where it cuts plagioclase amphibolite at an angle of 40°.

The country rock has been slightly disturbed by the intrusion and angular blocks of it are enclosed in the dyke. The dyke contacts are obscured by thin quartz stringers which ramify through both the dyke and country rock, and are apparently younger than both, having followed lines of weakness caused by the intrusion. No thermal metamorphism of the plagioclase amphibolite nor marginal chilling of the dyke was seen. The rock is of medium grain, speckled black and white, and non-foliated. Under the microscope the thin-section from specimen 17/13 shows an equigranular mixture of oligoclase with lesser amounts of orthoclase and quartz. The main mafic mineral is hornblende, pleochroic from yellow-green to blue-green, frequently intergrown with straw-yellow to dark grey-brown biotite. Accessory minerals are rounded or subhedral grains of sphene and anhedral iron ore. The mode of the diorite was estimated as quartz 10 per cent, orthoclase 12 per cent, plagioclase 49 per cent, hornblende 16 per cent, biotite 9 per cent, sphene 2 per cent and iron ore 2 per cent.

The andesite, a hornblende variety, occurs near Nyang'a in the south-west where it was traced over a distance of nearly two miles, in a vertical dyke of width averaging 15 feet. It is almost black in hand specimen, stained with films of hydrated iron oxide, and so fine-grained that the texture can only be distinguished with difficulty by the unaided eye. A typical thin-section from specimen 18/11 shows porphyritic felspar laths set in a fine-grained holocrystalline matrix of hornblende, felspar and quartz. The felspar is andesine, and sometimes encloses small grains of zircon. The hornblende is pleochroic from light to medium olive-green. Accessory minerals in addition to zircon are iron ore and calcite. A modal analysis of the andesite was estimated as quartz 7 per cent, plagioclase 52 per cent, hornblende 36 per cent, zircon 2 per cent, iron ore 3 per cent and calcite a trace.

(c) *Basic. Dolerite and Metadolerite*

Dolerite dykes were found at two places, at Kaputir in the south-east and Karkor south-east of Kapcholio, the latter occurrence showing two parallel dykes displaced by a fault. The more westerly dyke, approximately 150 feet in width, was found on both sides of the fault, displaced by a distance of 400 feet in a horizontal direction, but the continuation of the remaining dyke was not located. The dykes weather into rounded boulders from which the outer layers flake off and alter to a soft brown aggregate similar in appearance to laterite. Both dolerite dykes are similar in appearance, being almost black in colour with a grain barely distinguishable to the unaided eye, and speckled with white zeolites infilling cavities which sometimes reach 8 mm. across, but average only 2 to 3 mm. A thin-section, specimen 18/53, contains a fine-grained aggregate of purple-brown titanite and andesine-labradorite, much of it altered to a greenish brown chloritic aggregate. Opaque iron ore is an important accessory. The zeolites were identified as analcime, with lesser amounts of calcite.

The dolerite outcropping at Kaputir, specimen 18/83, is slightly coarser in grain than the Karkor dykes, and contains only rare zeolite-filled cavities. Under the microscope the rock is seen to have a holocrystalline ophitic texture, with a few felspar phenocrysts set in a felted groundmass of feldspars and pyroxene; the latter is an anhedral brown pigeonite, accompanied by lesser amounts of almost colourless orthopyroxene identified as hypersthene. The felspar is labradorite, and quartz is absent from the thin-section. Iron minerals occur as opaque grains and as yellow oxide staining. The estimated mode of this dolerite is plagioclase 40 per cent, pigeonite 48 per cent, hypersthene 5 per cent and iron minerals 7 per cent.

A metadolerite, specimen 18/134, was found at Ogwagwat in the south of the area. It is of medium to coarse grain, and consists of an intergrowth of plagioclase felspar of the composition of andesine, and pale green augite altering marginally to common green hornblende, which in turn shows alteration to biotite. Almost colourless euhedral garnets have formed incomplete coronas between hornblende and plagioclase.

(d) Ultrabasic. Peridotite

Also at Ogwagwat there is a single small outcrop of peridotite, specimen 18/133, which is of medium grain and in thin-section shows fractured anhedral grains of olivine altering marginally to serpentine, with orthopyroxene (enstatite) patchily coloured from purple-brown to almost colourless, and a pale grey-green clinopyroxene (augite). Strongly pleochroic red-brown lepidomelane also occurs, usually associated with opaque iron ore. The rock contains no feldspar or quartz.

(e) Alkaline. Phonolites

Two phonolite dykes were mapped, at Moruankoch and Nakut, both in the north. The former is over ten miles in length and varies in width from five feet to over eighty feet. In hand specimen, 18/107, the rock is blue-grey in colour, with rare laths of anorthoclase set in a fine-grained groundmass. Small spheroidal vesicles are common, sometimes with an infilling of analcime. In thin-section the groundmass is seen as a fine-grained felted intergrowth of anorthoclase with minor amounts of nepheline and analcime. The main ferromagnesian is green aegirine-augite with lesser amounts of greenish brown kataphorite and strongly pleochroic brown cossyrite. Grains of opaque iron ore are scattered throughout the slide.

The phonolite at Nakut, specimen 18/114, takes the form of a small vertical dyke up to 30 feet in width. The rock consists of a fine-grained dark green groundmass set with white phenocrysts of sanidine up to 12 mm. in length and smaller colourless and black phenocrysts identified in thin-section as sodalite, marginally altered to stilbite, plus biotite and occasionally aegirine-augite. The groundmass consists of euhedral or subhedral nepheline, sodalite and sanidine, with laths of aegirine-augite and rare kataphorite.

(9) METAMORPHISM AND GRANITIZATION

The following sequence of events is deduced to have taken place during the evolution of the metamorphic rocks exposed in the area:—

- (a) Deposition of sediments interspersed with lavas and pyroclastic rocks.
- (b) Folding of the sedimentary and volcanic rocks, accompanied by regional metamorphism.
- (c) Granitization of the deformed and metamorphosed rocks.

Granitization was probably initiated during phase (b) and evidently continued to a late stage of the regional deformation since fresh unstrained quartz and feldspar of late growth are common as layers in rocks containing abundant relics of strained quartz and deformed feldspars which were not recrystallized during earlier stages of deformation. The abundance of microcline feldspars in these later layers as compared with the feldspars in the older portions of the rock show the metasomatizing agents to have been largely potassic. Where granitization has been locally more intense feldspar porphyroblasts have developed, growing laterally into the minerals of the surrounding rock without displacing them, showing that the porphyroblasts grew by assimilation of the existing minerals without significant addition to the rock mass. At the highest degree of granitization granites were formed, and locally attained a degree of mobility leading to the intrusion of crosscutting sheets and pegmatites.

The metamorphic grade of the area is high, and is characteristic of the almandine-diopside-hornblende subfacies of the amphibolite facies (Turner, 1948, pp. 87-88), typical mineral assemblages being hornblende-diopside-epidote, and oligoclase-biotite-quartz, and in calcareous rocks epidote-diopside-hornblende-scapolite-andesine-quartz. Hornblende is sometimes clearly secondary to pyroxenes, but sometimes apparently in equilibrium with them. Much of the biotite is secondary after hornblende. Further evidence as to the high grade of regional metamorphism is given by the occurrence of kyanite in the biotite gneisses of the north-centre of the area, the alumina content of the original sediments

apparently being too small to allow that mineral to develop elsewhere. In the crystalline limestones tremolite, forsterite and diopside are common, and in one outcrop of quartzite sillimanite was found. These minerals are usually developed at temperatures and pressures appropriate to the amphibolite facies of regional metamorphism.

2. Pleistocene and Recent

(1) SUPERFICIAL DEPOSITS

Red sandy soils are of great extent in the area, the soils developed over the gneisses being generally coarser and with a higher content of angular quartz and felspar fragments than those covering the metavolcanic rocks. Large areas of black cotton soil occur immediately to the west of the area in Uganda, but similar soils fail to extend into the area mapped because of good drainage in the dissected highlands and very low rainfall in the flat Turkwel plain, both of which factors prevent the water-logging of soil and subsoil. Stone-mantles consisting of iron-stained angular fragments of vein quartz and country rock extend for many square miles over much of the higher ground and parts of the Turkwel plain. The stone layers are seen (a) lying directly on bedrock, (b) separated from bedrock by a layer of soil seldom more than a foot in thickness, and (c) with soil above and below the stone layer; only one layer of stone was seen in any exposure. No difference was detected between the soil above and that below the stone layer. Parizek and Woodruff (1957) have studied similar stone layers ("carpedoliths") in soil profiles underlain by crystalline rocks in Georgia and neighbouring states, and conclude that they are surface aggregations covered principally by sheet wash and colluvial action. They envisage the process in Georgia as being one of soil build-up followed by powerful erosion and deposition of the carpedolith, followed by a further period of soil accumulation to cover the carpedolith. The exposure of the stone layers at the present day in the south-eastern United States is due to a final period of erosion similar to that in which the layers were deposited, this later erosional stage has evidently been assisted by non-natural causes, principally bad husbandry. All the evidence in Karasuk points to a similar origin, the final erosional stage in this case being largely due to over-grazing. Where the stone-mantle is seen resting directly on bedrock, or with only a thin and discontinuous layer of soil between stone-mantle and bedrock, erosion has been sufficiently intense to remove the underlying soil horizon, lowering the stone layer to bedrock. Paradoxically this final stage of erosion is beneficial to grazing, since after rain good grass grows up between the stones, rooted in small pockets of soil which are protected from further erosion by the stone layer.

In the Turkwel plain, particularly within three or four miles of the river, the soil is lighter in colour and of finer grain than that on higher ground, due to an admixture of fine sandy alluvium laid down by the Turkwel in earlier changes of course across its floodplain.

(2) ALLUVIUM

Only the Turkwel river and a few of its larger tributaries such as the Korinyang and Kateruk have any notable amount of fine sandy alluvium, sand scrolls on the Turkwel itself sometimes extending for over a mile on either side of the river. The admixture of mud and silt in the Turkwel's alluvium together with the availability of water just below the surface have encouraged the development of thick riverine forest. West of Lokopel, at the end of the motor track, a wide expanse of forested swamp now extends across what was less than twenty years ago a road-crossing of the river. In November 1957, when the Turkwel was dry for many miles above this point, water lay to a depth of over three feet in the swamp.

None of the rivers draining the high ground deposit alluvium, and the river beds are covered with a mixture of coarse sand and rock rubble. Panned concentrates from various rivers showed only the minerals already identified in the rocks of the area, a typical assemblage being that from the Kateruk river at Napotimoru: magnetite,

ilmenite, hornblende, diopside, epidote, apatite, zircon, sphene, rutile and garnet. This pan concentrate surprisingly did not include kyanite, since the Kateruk drainage system is incised in some kyanite-bearing rocks.

At a few places on the Kauriong' and Alale rivers patches of light grey alluvium are exposed, varying from a few inches to six feet in depth, and often overlain by brown or red soil. It is almost wholly calcareous, with only a very small sand content, soft and friable, and sometimes with an oolitic texture. Gasteropod shells are locally plentiful, and species identified by the Coryndon Museum, Nairobi, are *Limicolaria martensia* (Sp.) probable race *catharia* (Ball), *Biomphalonia ?pfeifferi* (Moss) and *Lymnaea natalensis* (Moss), all of which range through Pleistocene to the present day. There is no concordance of altitude between any of the deposits, and they mark the sites of isolated ponds or small lakes.

VI—STRUCTURE

The major structural features of the area are indicated on the structural map, Fig. 4. The main elements are a series of folds, overturned to the west in the north of the area but open elsewhere, the trace of whose axial planes trends roughly north-south. Lineations, marked by the alignment of elongated mineral grains and fine-scale puckering in

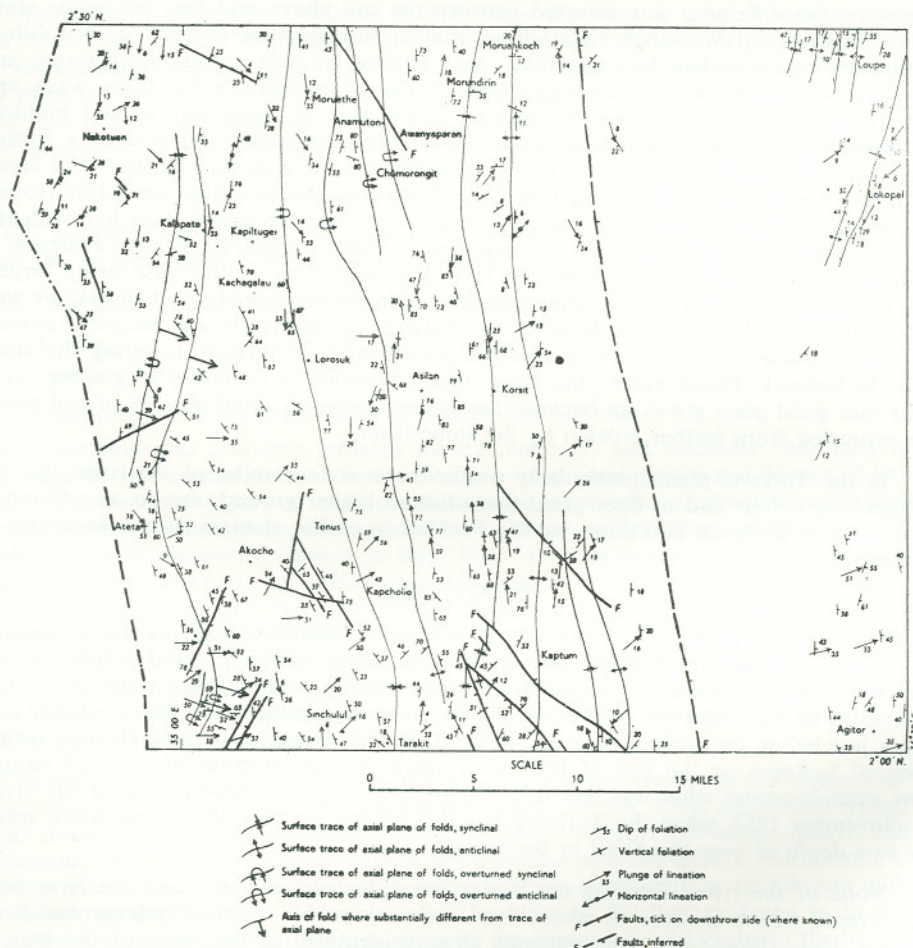


Fig. 4—Structures in the Karasuk area

the foliation planes of the rocks, are well marked in most of the outcrops, and range in direction from north to south through east, those with a westerly plunge being rare. The area was divided into seven sub-areas of relatively homogeneous lineation direction, and poles to foliation planes and lineation in each sub-area were plotted on a Schmidt equal-area stereographic net and contoured (Fig. 5). The plots of subdivisions 4 and 5

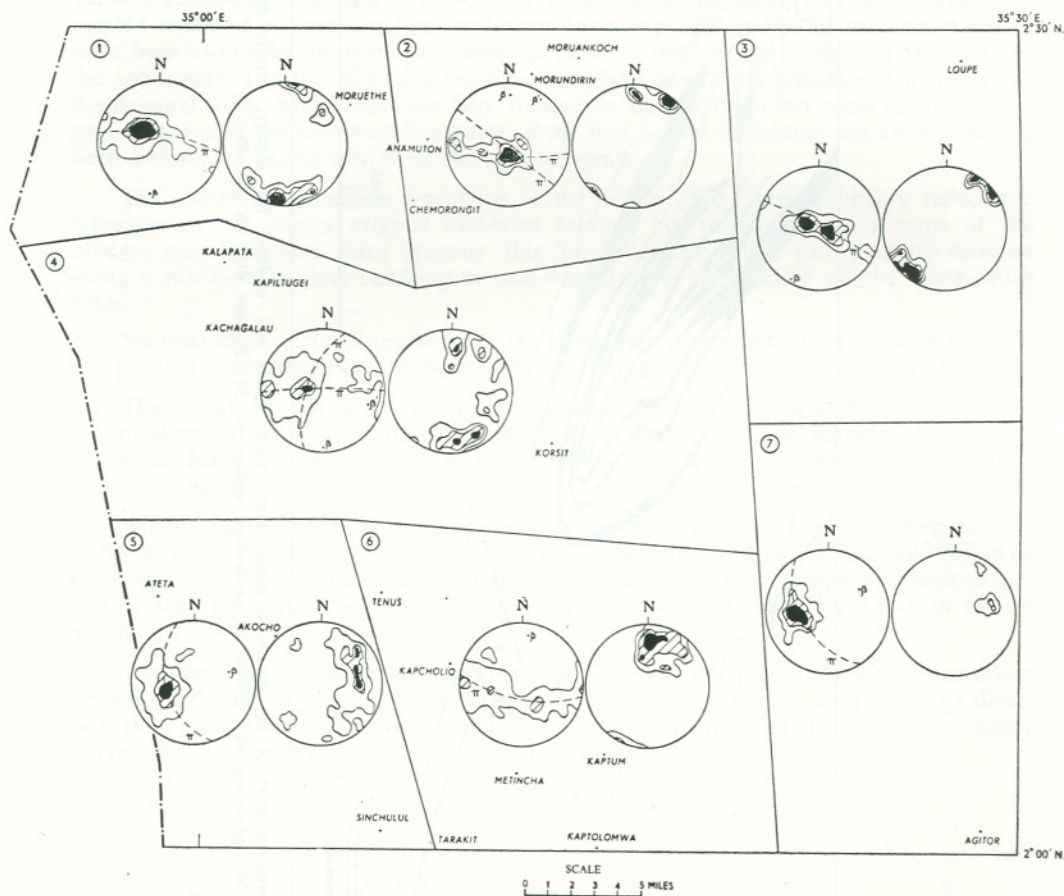


Fig. 5—Stereogram (Geographically orientated lower hemisphere projections) of poles to foliation planes (left), and lineations (right), in seven sub-areas of Karasuk. Contours in all cases at 1, 5 and 10 per cent, per one per cent area

show that the fold axes are roughly east-west. The average direction of lineations in the western part of subdivision 4 and the north of subdivision 5 is about 120° , with an average plunge of 30° . The tectonic profile of this part of the area, drawn along an axis of 120° , is as shown in Fig. 6, and establishes that the Ateta-Kalapata anticline is recumbent to the east-north-east, as is the parallel syncline to the west, both major folds having an axial direction of 120° . The central Tarakit-Tenus-Lorosuk syncline and the other folds west of the Turkwel plain have axes aligned from south to north or just east of north, with a generally northerly plunge except in the centre, where southerly plunges are common. North-east of the Turkwel plain, in sub-area 3, the stereograms show folds on axes trending south-west to north-east. No folds were recognized in the south-east in sub-area 7, and this part of the area appears monoclinical. Lineations trend west-south-west to east-north-east. All the evidence therefore suggests that the first axis of folding trends due east-west, and was probably produced by directed pressure from

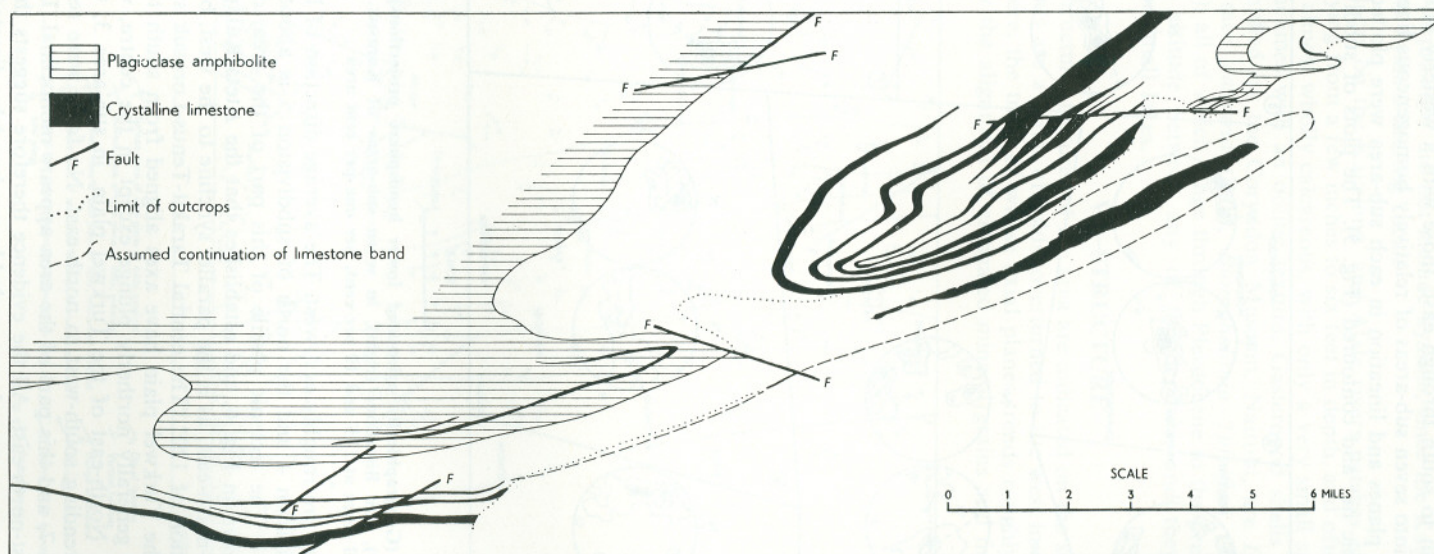


Fig. 6—Transverse profile of the western part of the Karasuk area. Some rock bands are omitted for clarity. Profile drawn along an axis of 120°, plunging 30°. (Plane of projection strikes N. 30° E. and dips 60° WNW.)

the south (*vide* the Ateta anticline recumbent towards the north), followed by later pressures acting east-west roughly perpendicular to the earlier pressures. The overturning of these later folds towards the west shows that pressure was applied from the east. The superposition of north-south folding with a northerly plunge on the original east-west folds has had the effect of rotating the axes of the original folds along an arc about the Tarakit-Tenus-Lorosuk fold axis, so that in the west the older fold axes have been rotated south of a west-east line, and now lies along 120° , while in the east the axes have been swung to the north and now lie between 040° in the north-east and 075° in the south-east. The two lineation maxima in subdivision 2 are considered to represent the original folds, whose axes are here rotated to about 030° . Over most of the central part of the area the east-west lineations of the first period of folding are absent, having been obliterated in the course of the later orogeny.

The southward plunging lineations in the centre of the area probably reflect the influence of the strong original east-west folding, but the steepness of some of the plunges may indicate a third orogeny, this time relatively slight, with pressure directed along a north-south line, resulting in east-west flexures superposed on the north-south folds.

Vertical cross-sections made from the large map of the area (not illustrated) show the gradual overturning of the north-south trending folds towards the north-west.

The Korsit-Morundirin syncline is interesting in that faulting at the southern end has produced three distinct noses to the fold, all very prominent features, the highest of which, Metincha, is bounded on the south by a slope which rises 1,200 feet with a gradient approaching 45° .

All the faults whose nature could be determined with certainty are steep normal faults. Erosion has been active everywhere along the faults and they are usually followed by river beds whose alluvium obscures the actual fault lines; where the fault-planes can be seen brecciation is confined to a narrow belt seldom exceeding a foot or two in width.

The frequency diagram of faulting, Fig. 7 (a), shows a marked strike maximum trending 40° west of north. The occurrence of faults concentrated along only one direction points to a lateral shearing effect, which could be produced in this case by either north-south or east-west compression.

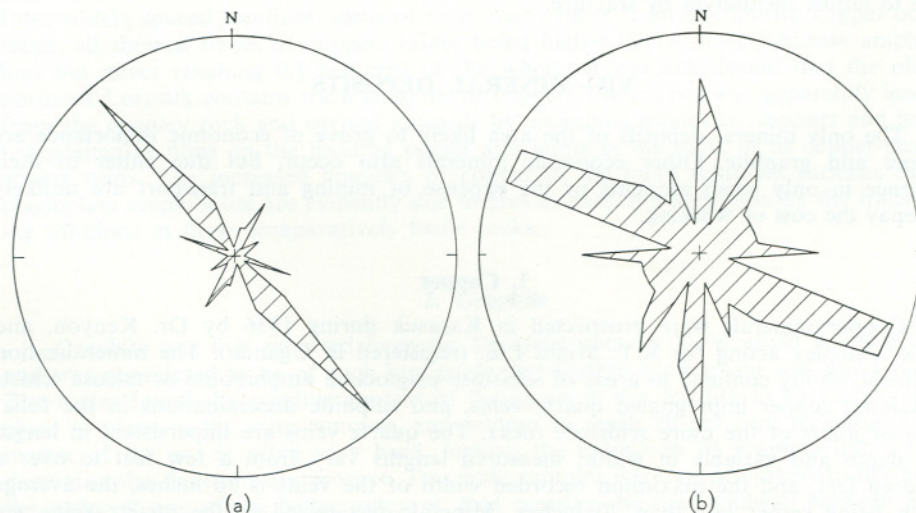


Fig. 7—Frequency diagrams of the strike of (a) faults, and (b) joints in the Karasuk area

The Turkwel escarpment, aligned a little west of north, is in appearance a fault-line or fault scarp, and a major fault was looked for at its foot. In the south exposures at the foot of the escarpment are rare or absent, but along the Kateruk river and further north exposures indicate that a major fault does not exist nearer than five miles from the foot of the escarpment. In the West Suk area farther south McCall has established the existence of a major fault extending towards the southern boundary of the Karasuk area, and in Fig. 4 a fault has been inferred continuing into the area parallel to the Turkwel escarpment. The position of the fault in the north of the area can be inferred with some precision, since it must lie close to the west of the remnant of the end-Tertiary surface north of the Kateruk river (Fig. 1); this position is based on the assumption that the Turkwel escarpment, in places several thousands of feet in height, has retreated westwards for a distance of over five miles from a fault-line originated earlier than the formation of the end-Tertiary peneplain. Fuchs (1939, p. 244) suggests that the Turkwel fault is Oligocene in age, and in an earlier paper (1935, p. 133) he considered the Turkwel escarpment to be the western wall of the Great Rift Valley. Joubert (1966) and Dodson (1963) mapped a series of faults trending north-north-east to south-south-west, and cutting post-Miocene lavas and tuffs in areas to the east of Karasuk. The trend of these faults differs considerably from that of the Turkwel fault which strikes west of north. Since Dodson considers these faults in the South Horr area to mark the eastern wall of the Rift, it is doubtful whether the Turkwel fault is a true rift fault.

Joints are developed in most of the outcrops. They are usually vertical or near-vertical and parallel to the original bedding planes. Rivers tend to cut deeply along the vertical joints in the north-west where the Lokitanyala and Kotich rivers have cut narrow canyons, the vertical walls of which are formed by the falling away of rocks from successive parallel joint planes. At Napotimoru on the Kateruk river joints in the plagioclase amphibolites of the river bed have weathered into open fissures and are filled with rounded pebbles of alluvium cemented in place with calcareous material.

The joint frequency diagram Fig. 7 (b), shows a strong strike maximum between 110° and 120° , as compared with the fault frequency maximum at 140° , with lesser peaks at 360° , 030° and 090° . The maximum at 110° to 120° represents the *ac* or cross joints orientated sub-perpendicular to the later fold axes. They were produced by relief of stresses set up during folding, when the rocks had lost their plasticity, and were only able to adjust themselves by fracture.

VII—MINERAL DEPOSITS

The only mineral deposits of the area likely to prove of economic importance are copper and graphite. Other economic minerals also occur, but due either to their presence in only small amounts or the expense of mining and transport are unlikely to repay the cost of working.

1. Copper

Copper minerals were prospected in Karasuk during 1956 by Dr. Kenyon, and D. R. Crossley acting for R.T. Mines Ltd. (registered in Uganda). The mineralization is almost wholly confined to areas of schistose plagioclase amphibolite or talcose schists containing copper impregnated quartz veins, and sulphide disseminations in the foliations or joints of the more schistose rocks. The quartz veins are impersistent in length and depth and variable in width; measured lengths vary from a few feet to over a hundred feet, and the maximum recorded width of the veins is 30 inches, the average width being rather less than 20 inches. Minerals recognized in the quartz veins are bornite, cuprite, chalcopyrite, covellite, azurite and malachite, the latter being the most

common and frequently the only copper mineral present. Assays of samples taken systematically along and across the strike showed copper content to vary from a trace to 8 per cent; some picked specimens assayed very much higher copper values. Gold and silver occur in all the veins, the former being visible to the naked eye in rare specimens.

Copper values in the country rock itself are generally lower than in the quartz veins; the maximum was less than 3 per cent copper over a width of only 9 to 12 inches. Malachite is the principal copper mineral in the schists, accompanied by trace amounts of bornite. The only occurrence of copper recorded in a non-schistose plagioclase amphibolite is at Lokitanyala, where roughly equal amounts of malachite and azurite occur as films on joints in the rock. This occurrence was not assayed, and is unlikely to contain a higher proportion of copper than 1 per cent.

Exclusive Prospecting Licence No. 133 was granted to R.T. Mines on 1st January 1956. Trenches were cut across the more promising outcrops in the concession area and six shafts were put down. Shafts 1 and 2, north of Chowei, were sunk in a lens of mineralized quartz three feet thick at the surface, which pinched out at twenty-five feet below the surface in shaft 1, and at thirty feet below the surface in shaft 2. Shafts 3 and 4 were put down close to the river at Chowei, the former was stopped at nineteen feet and the latter followed the reef downwards at an inclination of 50°, until the vein petered out at an inclined depth of sixty-two feet. The remaining shafts, 5 and 6, were put down in a quartz vein at Chepkoi; the vein is two feet wide at the surface, conformable with the strike of the country rock, and dies out at a depth of twelve feet. The shafts were continued to depths of twenty-five and thirty-two feet respectively but no further quartz veins were met.

The Exclusive Prospecting Licence was surrendered on 1st January 1958 when a slump in the price of copper made further prospecting or mining unprofitable due to the inaccessibility of the region and the consequent high cost of transport of the ore or its concentrate.

The copper evidently originated in basic lavas now metamorphosed to amphibolites and talcose schists. Chemical tests on seven specimens of plagioclase amphibolite taken from widely spaced localities, some of them many miles from any known copper occurrence, all showed traces of copper, values being higher in the more schistose amphibolites but never reaching 0.1 per cent of the whole. It was also found that the olivine norite of Lorosuk contains trace amounts of copper. The copper was apparently leached from the country rock and carried upwards by ascending liquids or vapours and finally redeposited as films on the bedding planes and joints in the rock, or as copper-bearing quartz veins. The increased amounts of copper in the more schistose varieties of the plagioclase amphibolite are evidently due to greater ease of penetration by the transporting solutions in these comparatively fissile rocks.

2. Graphite

Graphite was first reported from the Epeiyel area by H. Wreford Smith in 1953 and was considered to be of such low grade that further prospection was unwarranted. The writer found the graphite content of the gneiss in this locality to be variable from place to place in the same outcrop, and seldom to reach 20 per cent by volume. The matrix of the ore is often very hard, making the extraction of graphite difficult and damaging the flakes in the process. Two bulk samples were taken systematically across the strike of one of the better outcrops, that crossing the road midway between Kases and Epeiyel (samples 18/123). The better of the two samples contained 16 per cent total graphite and 3 per cent crucible grade graphite. The second sample contained only

10 per cent total graphite, and 0.5 per cent crucible grade graphite. The fact that a graphite sample meets the screening requirements for crucible grade does not mean that it is automatically suitable for making crucibles. Other requirements such as toughness of flake and surface coefficient must be met. In fact, the final test is the quality of the finished crucible. A third sample, 18/121, taken from the outcrop one and a half miles east of the road at Epeiyel, possessed too hard a matrix to warrant laboratory testing.

The possibility of economic working of the Epeiyel graphite is small. Apart from the poor quality of the ore, lack of water in the area presents milling difficulties. The dryness of the region during most of the year should however permit concentration by dry winnowing prior to flotation at a suitable site on the Alale river to the north, or on the Kenyangareng river at Amudat on the main Lodwar-Kitale road, where water can be obtained throughout the year from shallow wells.

A further thin outcrop of graphitic gneiss was recorded near Agitor in the south-east. In 1959 S. A. Embleton of Kitale collected an 8 lb. sample from the outcrop for assay in the metallurgical laboratory of the Mines and Geological Department in Nairobi. The assay established a total flake content of 26 per cent, of which 40 per cent (i.e. a little over 10 per cent of the rock) met the screening requirements for crucible grade graphite. Commercial working of the deposit would be feasible if suitable ore reserves of this grade are proved, since a flotation plant for concentration of the ore could be sited on the Turkwel river, rather more than a mile to the west of the outcrop.

3. Limestone

Single specimens of crystalline limestone from all the major outcrops were tested for dolomite content, using a staining method with silver nitrate and potassium chromate. Only one limestone, that outcropping in the south-east at the junction of the Kaputir-Lotongot-Lokichar roads, contained dolomite (estimated at 10 per cent), and should more systematic sampling prove the lack of dolomite to persist throughout the other outcrops they could all provide a lime supply for cement manufacture, although the remoteness of their location and the general scarcity of water and total lack of clay or aluminous rock in the vicinity renders them of little importance.

4. Other Minerals

(1) GOLD

As mentioned on a previous page, the copper-bearing quartz veins emplaced to the north-east and east of Kapcholio contain gold, and most of the streams crossing that region are tributaries of the Kopedo and Kateruk rivers; the Kateruk descends to the Turkwel plain at Apuke, where the sudden decrease of gradient would be expected to concentrate alluvial gold carried down from the mountains. Several prospectors have panned there in the past, but, like the writer, found little or no traces of gold. S. A. Embleton informed the writer that in 1959 he had excavated the bouldery gravel of the river bed for a depth of 32 feet without reaching bedrock, and without panning a trace of gold. However, in such coarse alluvium any gold present would have worked down to bedrock itself, and Embleton considers that his work was insufficient to prove or disprove the occurrence of workable gold there. Many other rivers of the area were panned for gold, but without success.

(2) MICA, COLUMBITE AND BERYL

All of these minerals, plus samarskite, are being mined by Wreford Smith at Kenailmet, a few miles outside the southern margin of the area. In the Karasuk area itself, however, no mica larger than 3 to 4 cm. in diameter was found, and no trace of columbite or samarskite. A single crystal of green beryl was found in the bed of the Rogoch river south-west of Kamunono, and at Loupe in the extreme north-east a single small crystal of blue beryl accompanied by white mica and tourmaline was found in a thin pegmatite.

(3) CORUNDUM

At the western foot of Agitor situated in the south-eastern part of the area a patch of ground roughly 100 feet by 20 feet was abundantly strewn with barrel-shaped crystals of grey semi-opaque corundum, the largest of which reached 8 cm. in length. Several pounds weight of corundum (specimen 18/124) was collected in five minutes. The underlying rock is a coarse biotite gneiss, poorly exposed, which is probably the host rock to the corundum, though none could be found *in situ*.

5. Water

In the western part of the area boreholes have been drilled by the Uganda Administration. All are fitted with hand-pumps, and are used mainly for stock watering. Records in the Geological Survey Department of Uganda are as follows:—

No.	Location	Depth in Feet	Yield*
CD685	Lokitanyala west	301	1,365
CD691	Lokitanyala east	287	940
CD827	Kiwawa lower	180	270
CD834	Kiwawa upper	200	1,010
CD857	Alale north	168	160
CD870	Alale south	195	350
CD874	Amakuriat	220	300
CD889	Kamila I	160	152
CD894	Kamila II	130	1,500
CD902	Kauriong' I	183	1,130
CD914	Lowoi	192	810
CD922	Kauriong' II	267	400
CD961	Nyang'a	205	145
CD1314	Lokitanyala north	226	1,210
CD1320	Torikoi	278	270
CD1335	Kaimamosin	510	195

* Assumed to be gallons per hour.

In most of the larger rivers water is impounded below the surface of the alluvium by rock outcrops which form natural dams at intervals along the river. Subsurface dams to reinforce these rock barriers or to build up outcrops which do not reach the surface of the alluvium would increase water supplies in the larger rivers. In areas far from major rivers small earth dams might be constructed across the smaller rivers where gradients are low. These dams would soon silt up, but would still impound water which would be protected to a great extent from evaporation.

However, in the writer's opinion soil erosion due to overgrazing is so far advanced that any attempt to increase water supplies without a decrease in the number of stock in the area and a careful control on their future numbers would simply aggravate the problem. In the dry season the continual passage of herds of stock to and from the existing watering points rapidly leads to an ever-widening area of dust from which every blade of grass has been eaten or trampled in. The first rain on such areas, which have been seen to exceed half a mile across, can remove inches of soil in a few hours and initiate new gullying which in a short space of time will expose large areas of bedrock, soon removing the last vestiges of soil and subsoil. The problem is well appreciated by the administration, but until the local populace can be persuaded to adopt another form of currency and wealth than livestock it is difficult to see how conditions can be stabilized, much less improved.

VIII—REFERENCES

- Arambourg, C., 1943.—"Mission Scientifique de L'Omo, 1932-1933." Tome 1, Fasc. II.
- Baker, B. H., 1958.—"Geology of the Magadi area." Report No. 42, Geol. Surv., Kenya.
- Bisset, C. B., 1950.—"Geology of the Suk area, Karamoja District." Records. Geol. Surv. Uganda, pp. 13-14.
- Champion, A. M., 1937.—"Physiography of the Region to the West and South-West of Lake Rudolf." *Geog. Journ.*, Vol. 89, pp. 97-118.
- Dixey, F., 1948.—"Geology of Northern Kenya." Report No. 15, Geol. Surv., Kenya.
- Dodson, R. G., 1963.—"Geology of the South Horr Area." Report No. 60, Geol. Surv., Kenya.
- Fuchs, V. E., 1935.—"The Lake Rudolf Rift Valley Expedition, 1934." *Geog. Journ.*, Vol. 86, pp. 114-142.
- 1939.—"The Geological History of the Lake Rudolf Basin, Kenya Colony." *Phil. Trans. R. Soc.*, London, No. 560, Vol. 229, pp. 219-274.
- Glenday, V. G., and Parkinson, J., 1926.—"The Geology of the Suk Hills (Kenya Colony)." *Quart. Journ. Geol. Soc.*, Vol. 82, pp. 586-614.
- 1927.—"The Kateruk Series and Associated Rocks of the Northern Suk Hills (Kenya Colony)." *Quart. Journ. Geol. Soc.*, Vol. 83, pp. 790-800.
- Gregory, J. W., 1896.—"The Great Rift Valley."
- 1921.—"The Rift Valleys and Geology of East Africa."
- Joubert, P., 1966.—"Geology of the Loperot Area." Report No. 74, Geol. Surv., Kenya (at the press).
- Macdonald, R., 1961.—"Explanation of the geology of Sheet 36 (Nabilatuk)." Report No. 5, Geol. Surv., Uganda.
- McCall, G. J. H., 1964.—"Geology of the Sekerr Area." Report No. 65, Geol. Surv., Kenya.
- Miller, J. M., 1956.—"Geology of the Kitale-Cherangani Hills Area." Report No. 35, Geol. Surv., Kenya.
- Murray-Hughes, R., 1933.—"Notes on the Geological Succession, Tectonics and Economic Geology of the Western Half of Kenya Colony." Report No. 3, Geol. Surv., Kenya.
- Parizek, E. J., and Woodruff, J. F., 1957.—"Description and Origin of Stone Layers in Soils of the South-Eastern States." *Journ. Geol.*, Vol. 65, pp. 24-34.
- Parkinson, J., 1913.—"On a Group of Metamorphosed Sediments Situated Between Machakos and Lake Magadi in British East Africa." *Quart. Journ. Geol. Soc.*, Vol. 69, pp. 534-539.
- Shackleton, R. M., 1951.—"A Contribution to the Geology of the Kavirondo Rift Valley." *Quart. Journ. Geol. Soc.*, Vol. 106, pp. 345-392.
- Smith, W. Campbell, 1938.—"Petrographic Description of Volcanic Rocks from Turkana, Kenya Colony, with Notes on their Field Occurrence from the Manuscript of Mr. A. M. Champion." *Quart. Journ. Geol. Soc.*, Vol. 94, pp. 507-553.
- Trendall, A. F., 1959.—"The topography under the northern part of the Kadam volcanics and its bearing on the correlation of the peneplains of South-East Uganda and the adjacent parts of Kenya." Records 1955-56, Geol. Surv., Uganda.
- Turner, F. J., 1948.—"Mineralogical and Structural Evolution of the Metamorphic Rocks." *Geol. Soc. Amer.*, Mem. No. 30.
- Washington, H. S., 1917.—"Chemical Analyses of Igneous Rocks." U.S. Geol. Surv., Professional Paper 99.