Report No. 70

REPUBLIC OF KENYA

MINISTRY OF NATURAL RESOURCES AND WILDLIFE
GEOLOGICAL SURVEY OF KENYA

GEOLOGY OF THE KAJIADO AREA

DEGREE SHEET 51, S.E. QUARTER
(with coloured geological map)

by
F. J. MATHESON, B Sc.. Ph.D., F.G.S.
Geologist

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FOREWORD

The publication of this report on the geology of the Kajiado area fills one of the few remaining gaps in the geological mapping of the southern part of Kenya. The southern part of the area is an extension of the Basement System described in Report No. 39 "The Geology of the Namanga-Bissel Area", and the eastern part of the Kajiado area is an extension of the Cenozoic volcanics and sediments of the Magadi area of the Rift Valley (Report No. 42) whose eastern wall traverses the map area.

Dr. Matheson gives an interesting interpretation of the structure of the area, based mainly on the evidence of minor fold features, which differs somewhat from the views of Joubert who mapped the Namanga-Bissel area.

The Kenya Marble Quarries Co. Ltd. have for over 40 years worked the Basement System limestones near Turoka for agricultural lime and statuary marble, and a concise but complete account is given of the workings and their history. Further summaries are given of other economic minerals and water supplies, but it appears that valuable mineral deposits are unlikely to be found in this area.

Nairobi,
22nd December 1964.

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

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ABSTRACT

The report describes an area of approximately 1,200 square miles in the Kajiado District of the Southern Province, bounded by latitudes 1° 30′ and 2° 00′ S. and longitudes 36° 30′ and 37° 00′ E. Physiographically the area may be divided into three units: (1) The hills and plains formed of the Basement System rocks, (2) The volcanic plateaux, and (3) The Rift Valley.

The rocks of the Basement System, which outcrop in the southern and south-eastern parts of the area, consist of crystalline limestones, quartzites, gneisses and granulites. They are cut by minor acid and basic intrusions. Tertiary and Pleistocene volcanics cover the remaining two-thirds of the area, and superficial deposits are represented by soils, sands and gravels of Pleistocene to Recent age.

The petrography and metamorphism of the rocks are discussed and an account given of the minor and major structures of the area. The workings of the Kenya Marble Quarries Co. Ltd. are described and other economic prospects are considered.

I—INTRODUCTION

The Kajiado area, as defined for the purpose of this report, is the south-east quarter of Degree Sheet 51 (Kenya); it is bounded by latitudes 1° 30′ and 2° 00′ S., and longitudes 36° 30′ and 37° 00′ E., and has an area of approximately 1,200 sq. miles. The region falls within the Southern Province, and the greater part of it is administered by the District Commissioner, Kajiado. The north-eastern corner, beyond the Nairobi–Mombasa railway, is occupied by European farms belonging to the Machakos District.

Reconnaissance geological mapping was carried out between the 13th December 1957 and the 6th June 1958.

Maps.—The topography of the geological map is based on aerial photographs on an approximate scale of 1:29,000, taken by the R.A.F. in 1948 and 1952. For map production these were controlled by the Survey of Kenya Main Triangulation Chart No. 284D, and by triangulation carried out by 89 Field Survey Squadron R.E. in 1955. The use of these fixed points revealed errors in the topographical mapping of the south-western part of the Magadi sheet (Baker, 1958), which necessitated the extension of the Kajiado sheet to 36° 27′ 32″ E. to cover the Magadi railway. Some place names and form-lines were taken from G.S.G.S. No. 1764 Magadi District (1:250,000) published in 1916, but this map had to be considerably modified and much detail added. The north-western corner of the area is covered by the 1:50,000 map of the Ngong Training Area, E.A.F. No. 1180 which proved to be very accurate.

Gaps in the aerial photographic cover were mapped on a scale of 1:30,000 by plane-table and cyclometer.

Both the configuration and vertical interval of form-lines are approximate only, since they are controlled by barometric spot heights.

Communications.—The Nairobi–Mombasa railway passes through the north-eastern corner of the area but no stations were built on this stretch of track. The Magadi railway which leaves the Nairobi–Mombasa line farther east at Konza, links Kajiado with the Turoka valley and the floor of the Rift Valley.

The main Cape to Cairo road (A 104) which traverses the area from south to north-east is usually in good condition, but is sometimes closed to heavy traffic during periods of excessive rainfall. The road to the Kenya Marble Quarries is in quite good condition, becoming impassable when the crossing of the river Turoka is flooded. It deteriorates, however, when continued to Mile 46. The Magadi road in the north-western corner of the area is not so well maintained as formerly because of the introduction of a weekly air service to Magadi; but is passable, except when the Lodo Ariak river floods. The other minor roads and tracks become waterlogged in wet weather. Since the time of survey, Mr. M. Cooper of the Veterinary Department has extended the track from Mile 46 to Singaraini, to connect with the Nairobi–Magadi road near Magadi, but it is only passable to field-cars and lorries.

Climate and Vegetation.—Rainfall is concentrated in the months March–May and October–December. Records have been kept in Kajiado District Office for 27 years, but other stations have started keeping records only recently and intermittently. Of the stations outside the area, the figures for Magadi show the arid climate of the Rift Valley, those from Stony Athi that of the Kapiti plains in the north-east, and information from Bissel depicts the effect of the Lemilebbu hills.

Station	Annual Total—inches					Number of Years Recorded
	1954	1955	1956	1957	Average	
Kajiado D.O. ..	27·21	12·79*	16·82	21·34	19·52	27
Ngorika	—	15·95	12·20	—	14·05	2
Bissel	21·84	—	11·40	—	17·21	3
Magadi	17·64	17·92	16·87	23·69	14·69	32
Stony Athi ..	26·86	22·77	15·31	32·45	20·24	8

*January to November 1955 only.

The hottest part of the year is from January to March; at other times the temperatures are moderate.

No rivers flow perennially, but water can be obtained by digging in the bed of the Kajiado river. Apart from springs on the Ol Doinyo Narok plateau, the local population is dependent on boreholes and the old pipeline to Magadi, which brings water from the Ngong hills across the Kapiti plains to Kajiado, and then follows the railway. This pipeline is controlled by the Ministry of Works because the Magadi Company now obtains water from the Loita hills.

The vegetation of the Kapiti plains and other volcanic areas consists of rank grass and whistling thorn, but the river-courses are followed by lines of isolated trees. The area of Basement System rocks produces a much thicker growth of thorn trees, and thickets of evergreen forest occur in the valleys. In the Rift Valley vegetation is limited to stunted thorn bushes and small patches of grass. The eastern scarp of the Rift Valley, however, is thickly covered with thorn trees and evergreens.

Cultivation is carried out only by the non-indigenous peoples in small areas.

Population.—The Masai form the bulk of the population, but in many cases they have deserted their former nomadic way of life and settled near water supplies. They are still dependent on their cattle for a livelihood. The labouring population are Kamba, concentrated in Kajiado, but a settlement of them at Ngorika depends on agriculture. Most shops are kept by Asians or Somalis. The small European population is concentrated in the administrative headquarters at Kajiado.

The north-western part of the area lies within the Ngong game reserve, and it and the Kapiti plains are well-stocked with plains game. In the southern part of the area all kinds of game are plentiful although buffalo and elephant are rarely seen. Rhinoceros are usually found along the edge of the Rift Valley.

Acknowledgements.—Appreciation is expressed to the administrative officers of the District for assistance during the survey, and to Mr. P. W. Low, D.C. Kajiado, and Mr. Chadwick of the Kenya Marble Quarries, for hospitality. The Hydraulic Branch of the Ministry of Works kindly gave permission to use their map of the north-eastern part of this area.

II—PREVIOUS GEOLOGICAL WORK

Joseph Thomson passed through this region in 1885, on his way from Ol Doinyo Erok to Ngong, but made no particular reference to localities or geology (Loftus, 1951, p. 40).*

In his report on the East African Protectorate, H. B. Muff (Maufe) described the Kapiti plains, recognizing the phenocrysts of felspar and nepheline in the Kapiti Phonolite, and realized that younger lavas overlay it towards Nairobi (Muff, 1908, p. 33). He mentioned Ol Esakut as one of the main central volcanoes in the Rift Valley (*op. cit.*, p. 28), and attributed the Rift Valley scarps (*op. cit.*, p. 39) to a series of faults, two or three being

*References are quoted on page 50

parallel in the one scarp but none persisting for more than 80 or 90 miles. He thought the scarps must be due to faulting because they cut across lavas whereas erosion features would tend to follow horizons.

J. Parkinson (1913) proposed the name Turoka Series for a group of metamorphosed sediments, including marble, which he distinguished from the ortho-gneisses of the Basement System. He described a type section in a tributary of the river Turoka, about two miles above Turoka station and to the south of the old safari track, but it was not positively located during the present survey. His sequence could well be applied to many localities in the vicinity, and the term Turoka Series is used for much of the Basement System around Kajiado. He also found kyanite in a lower tributary of the Turoka but this again has not been relocated. In another paper Parkinson mentioned that the Kapiti Phonolite lapped against an eroded surface of gneisses near Kajiado where the lava is thin (Parkinson, 1914, p. 35). He also discussed the formation of the Turoka gorge (*op. cit.*, p. 43), attributing it to post-Kapiti Phonolite erosion. He thought that the alluvium along and west of the gorge was deposited when the river flowed into an ancient lake near the present Rift scarp, and renewed faulting led to the destruction of the lake and further downcutting by the river. He mentioned (*op. cit.*, p. 42) the diatomite deposit near mile 61 on the railway to Magadi. The same deposit was reported on by V. H. Kirkham (1917) during the search for suitable material for the manufacture of dynamite in the First World War, but the diatoms were of the wrong type. His work is summarized on p. 41 and his map reproduced in Fig. 11.

J. W. Gregory (1921, pp. 181–183) described the volcanic rocks of the Turoka–Magadi area, illustrating the relationship between the Basement System, the Kapiti Phonolite and the younger lavas with a section; he also commented on the grid faulting. He mentioned (*op. cit.*, p. 176) the twin volcanoes of Ol Esakut and Ol Esayeiti just to the north of this area but whose lavas extend into it.

F. Dixey (1930) suggested that the Turoka Series were the equivalent of the Nachipere Beds of Nyasaland but Parkinson (1930) disagreed, stating that the metamorphic histories of the two groups differ widely, and the Turoka Series lack the numerous plutonic intrusions found in the Nachipere Beds, which are coarser in lithology, mainly consisting of conglomerates and arkoses, with subsidiary argillaceous and calcareous members. It is of interest that Bloomfield (1958, pp. 40–47) restricted the term Nachipere Series to post-Basement System sediments which are slightly metamorphosed.

In his report on the soils of Kenya, D. S. Gracie (1930, p. 36), mentioned the grey soil overlying the black cotton soil on the Kapiti plains, near Machakos, east of the present area; similar grey soils occur near Kajiado. He thought the black soil is inherently more fertile than the grey, but the clay texture is difficult to break down.

Bailey Willis (1936, p. 267) noticed that the eastern scarp of the Rift Valley was low near the river Turoka but increased in height towards the Ngong hills. He believed the southern part of the eastern scarp of the Rift Valley was formed by a flexure with subsequent erosion.

In 1936, E. C. Bullard carried out a gravimetric survey of the Rift Valley, concluding that it was formed by compression rather than tension because those parts examined usually showed a gravity deficiency (Bullard, 1936, p. 531). He used the Kajiado rest-camp as a station obtaining a reading of 977·5766 milligals which gave corrected values for the anomalies shown on his Fig. 15 (*op. cit.*, p. 512).

During the Second World War the possibility of using the Turoka limestones for cement manufacture was investigated by the Mines and Geological Department, but the magnesia content was too high. Unpublished departmental reports were prepared by R. M. Shackleton (1943) and W. Pulfrey (1944), who discussed the possible use as a mix of the black-cotton soil on the Kapiti plains. In addition E. Parsons (1943) reported on the suitability of the kunkar limestones along the Athi River to Kajiado road. Numerous limestones analyses are held by the Mines and Geological Department, Nairobi.

When F. Dixey discussed the erosion surfaces of the Northern Province, he summarized the bevels in other parts of Kenya and gave a height of 5,500 feet for the contact of the Basement System with the Kapiti Phonolite near Kajiado, with no marked features (Dixey, 1948, p. 6). South-east of Kajiado, however, the Kapiti Phonolite does form a feature above the Basement System.

Parkinson's report of kyanite in the Turoka valley is mentioned by B. N. Temperley, then Senior Geologist in the Mines and Geological Department in his memoir on kyanite (Temperley, 1953, p. 63).

In 1956 L. E. Weiss carried out a structural survey in a small area near the Kenya Marble Quarries and postulated that rocks of the Basement System were folded about axes trending ENE.-WSW. (Weiss, 1958). Most of the minor structures are aligned along this trend but foliation and bedding strike NNW.-SSE.

E. Gevaerts of the Hydraulic Branch of the Ministry of Works, mapped the north-eastern part of the Kajiado area in 1956 for an unpublished report on the water supply of the Nairobi District (Gevaerts, 1957).

III—PHYSIOGRAPHY

The area has three main physiographical divisions; (1) ground occupied by the Basement System, displaying remnants of old erosion bevels; (2) the volcanic plains and plateaux; and (3) the Rift Valley. All three divisions can be further subdivided as shown on Fig. 1.

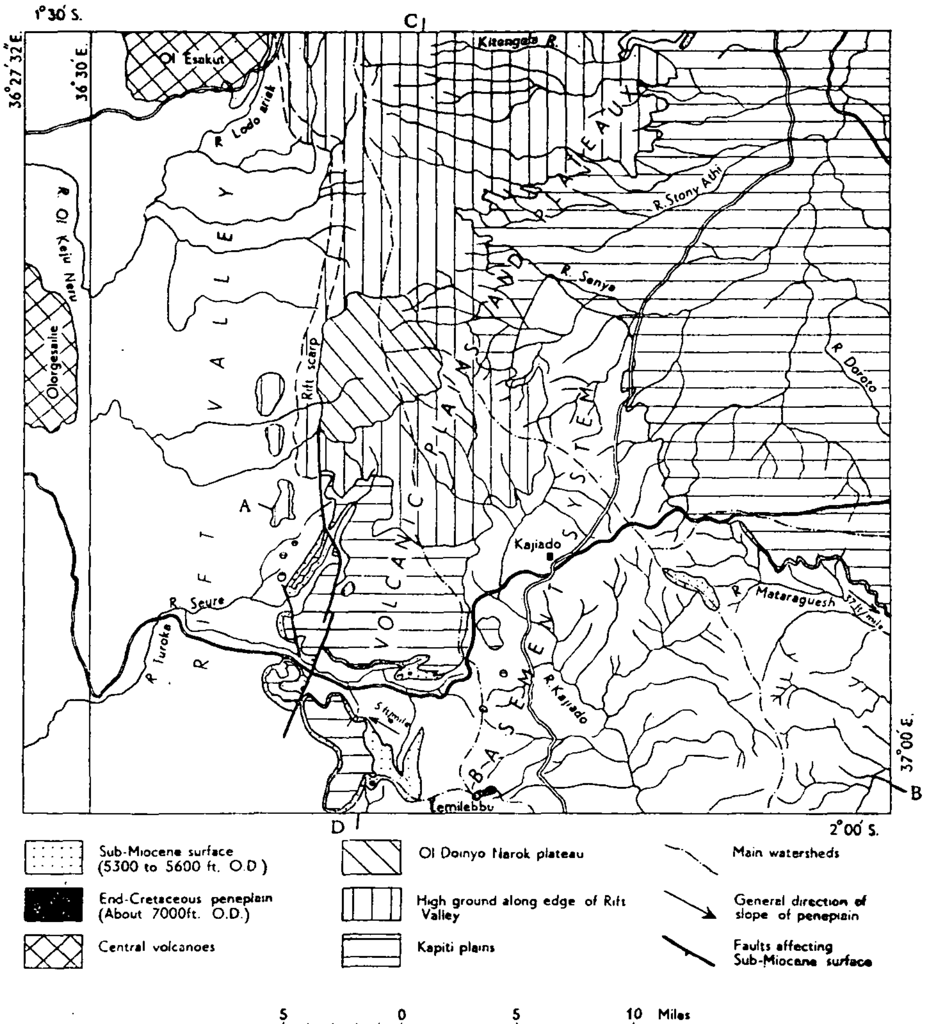

Fig. 1—Physiographical map of the Kajiado area

The physiographical history of the ground occupied by the Basement System is displayed by bevels on the highest hills and by the remains of a peneplain on the lower ground. The oldest peneplain is represented only by the flat tops of the Lemilebbu hills round the trigonometrical beacon of Lemilebbu. This surface lies at about 7,000 feet and is thought to be a remnant of the end-Cretaceous peneplain. The slightly lower peaks of the Lemilebbu and Ngoragaishi hills are residuals from this peneplain. The remnants of the peneplain in the area mapped are too few and of too small extent to permit calculation of its slope.

The most important bevel in the area can be seen underlying the Kapiti Phonolite along the Turoka valley and on the north bank of the river Mataraguesh. Extensions of the bevel on the Basement System where the lava is no longer preserved were recognized south of both these river valleys. Further north the mapped boundary of the Kapiti Phonolite against the Basement System cannot be used for determining the height of the bevel, because a low ridge extended northwards from the Lemilebbu hills through Kajiado in sub-Miocene times. The Kapiti Phonolite lapped against the ridge and in places was overlapped by younger flows. North of Kajiado the ridge reaches a height of 5,700 feet.

The slope of the bevel is shown on Fig. 2, which illustrates the extent of the ridge against which the lava flowed and the fact that the bevel is only meagrely represented in the area. The writer considers that the bevel as mapped in the Turoka valley slopes down gently westwards away from the ridge as at other parts of the shoulder of the Rift Valley. The projection of the base of the phonolite on the ridge shows that it is an irregular surface which is too high to represent the bevel. East of the ridge the bevel slopes downwards to the ESE. with a gradient of 37 feet per mile to a height of 5,200 feet at the eastern boundary of the area.

The three physiographical subdivisions of the volcanic plains reflect the rock types of which they are composed. The Kapiti plains (*see* Fig. 1) are formed by the Kapiti Phonolite and the overlying soft Upper Athi Tuffs where they form a thin capping to the phonolite. The surface of the plains is flat, sloping up gently westwards; it consists of black-cotton soil, while boulder fields often overlie the Kapiti Phonolite. The rivers, marked by lines of trees, have not dissected deeply into these rocks.

The line of hills along the edge of the Rift Valley are formed of younger lavas which did not flow far from their source volcanoes on the floor of the Rift Valley. The pile of agglomerates which form the highest part of the scarp built the Ol Doinyo Narok plateau to the east. They die out to the south and thin to the north, passing into the Kerichwa Valley Tuff.

The Rift Valley can be divided physiographically into three parts:—

(*a*) The soil-covered plain next to the eastern wall of the Rift Valley. In its southern part, this consists of grey sandy soil in the east and black-cotton soil to the west. The eastern part of the grey sandy soil overlies rocks of the Basement System and forms part of the sub-Miocene surface near down-faulted Kapiti Phonolite. The western part, especially near the river Turoka, is thought to be hill-wash overlying volcanic rocks, because bore-hole No. C1390 at mile 45 on the Magadi railway passes through a considerable thickness of lava. The black-cotton soil in the west presumably overlies the same olivine basalts that are found still further west. In the north, however, the strip consists entirely of red soil formed from the volcanic rocks of the rift scarp.

(*b*) The area of grid-faulting in the central part of the Rift Valley (*see* Fig. 4) consists of a series of north–south scarps bounding ridges and troughs, which are often partially filled with sediments. The tops of the ridges are flat, covered with boulders, and have sparse soil cover.

(*c*) The central volcanoes of Olorgesailie and Ol Esakut stand above the other two areas; their slopes are broken by scarps and covered with boulders.

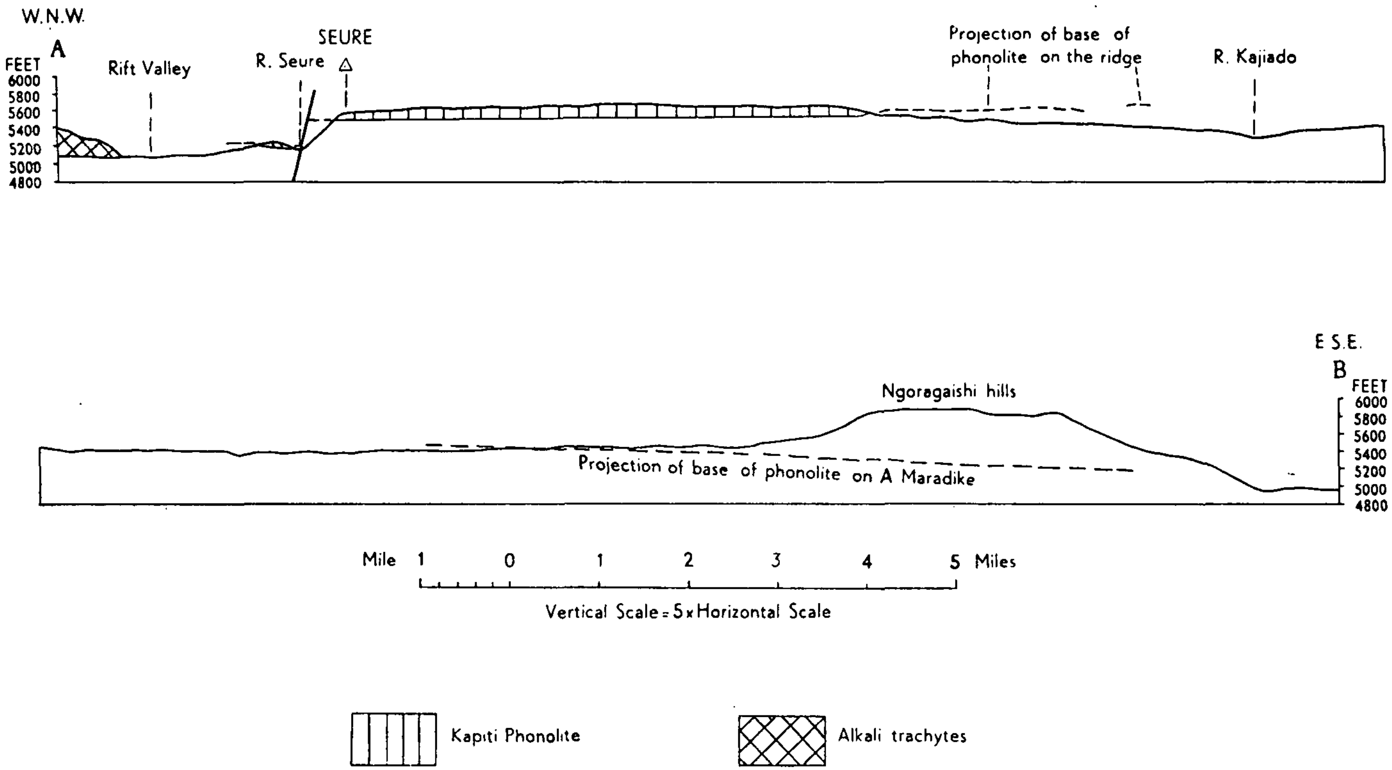

Fig. 2—Section along A-B on Fig. 1 showing the slope of the sub-Miocene surface in the Kajiado area

The drainage of the area is controlled by the pre-volcanic high ground and the high ground along the edge of the Rift Valley. The headwaters of the Kajiado river lie north-west of Kajiado, while their western watershed is formed by the Kapiti Phonolite and the Ol Doinyo Narok plateau. The river then cuts through the ridge south-west of Kajiado to drain the eastern side of the Lemilebbu hills and the western side of the Ngoragaishi hills. The eastern side of the latter is drained by the river Mataraguesh and its tributaries, whose basin is bounded to the north by the Kapiti Phonolite. The Stony Athi river, most of whose tributaries originate in hills along the edge of the Rift Valley, drains the Kapiti plains and flows north to join the Athi River.

The drainage of the Rift Valley is effected by small streams originating in the scarp and terminating in enclosed basins. The Turoka river has cut back through the scarp to the north end of the Lemilebbu hills, and terminates in Lake Kabongo in the area to the south-west. Its tributary, the Seure, drains the southern side of the Ol Doinyo Narok plateau before descending into the Rift Valley. The other major river in the Rift Valley, the Ol Keju Nero, flows into the depression west of Olorgesailie.

IV—SUMMARY OF GEOLOGY

The geological succession found in the area is:—

Age	*Formation*	*Tectonics*
Recent	Soils	
Pleistocene	Olorgesailie Lake Beds Orthophyre-trachyte Alkali Trachytes	Minor Grid Faulting Grid Faulting
Pliocene to Miocene	Ol Keju Nero Basalts Ol Esayeiti Volcanics Ol Doinyo Narok Agglomerate and Kerichwa Valley Tuff Olorgesailie Volcanic Series Mbagathi Trachyte Upper Athi Tuffs Kapiti Phonolite	Rift Faulting
		Erosion and formation of peneplains
Archaean	Basement System	Folding and metamorphism of Basement System

The oldest rocks in the area are the gneisses, limestones and quartzites of the Basement System, known to be of Precambrian age. They are almost entirely of sedimentary origin and presumably were laid down in a geosyncline since they cover a large part of East Africa. The lower succession consists of psammitic gneisses, probably produced by rapid deposition in relatively deep water. The upper part, the Turoka Series, is mainly pelitic in character, and numerous limestones and quartzites indicate quieter deposition in a relatively shallow basin. Minor igneous activity following the deposition of the sediments is represented by amphibolites which are thin and concordant.

Orogenic folding then produced the structures of the Basement System. Although the dominant trend of the foliation is NNW.–SSE., the main folds are believed to plunge ENE., for the most abundant minor folds and their accompanying *b*-lineations plunge to the ENE. at angles between 20 and 30 degrees. Along the river Kajiado, however, NNW.-SSE. minor folds are abundant, so there major folds are probably aligned in the same direction. As both sets of folds are mutually perpendicular it is thought that they developed contemporaneously.

The metamorphism accompanying the folding consisted of recrystallization and *lit-par-lit* injection, which produced many migmatites and concordant pegmatites. The quartzites and limestones, however, proved resistant to felspathization. In the west, the process approached the stage of granitization forming the augen gneisses of the Ngoragaishi hills. Discordant pegmatites formed the last phase of the metamorphism.

The compression and folding of the Basement System rocks led, by the process of isostasy, to the formation of mountain chains which were intensely eroded. As a result, the rocks now exposed represent the more highly altered cores of the mountains. At the end of the Cretaceous period the area was reduced to a peneplain, of which only the flat top of Lemilebbu at 7,000 feet now remains. There is no evidence of earlier peneplanation. Further uplift and erosion resulted in the formation of the sub-Miocene peneplain, upon which the Tertiary volcanics were extruded.

The oldest of these rocks is the Kapiti Phonolite which covers a vast area to the east and north-east of Kajiado. No central volcanoes from which the phonolite could have been extruded were found, so it is assumed to be the result of eruption from fissures or small vents. No underlying fossiliferous sediments were located in the Kajiado area, but by analogy with similar lavas in other parts of Kenya, it is considered to be probably of Miocene age (Kent 1944, p. 19).

A period of explosive vulcanism followed, during which the Upper Athi Tuffs were deposited, but these did not extend as far south as the Kapiti Phonolite. In the north, the Mbagathi Trachyte flowed over the tuffs but thins rapidly towards the south.

The building of the central volcano of Olorgesailie was the next event in the volcanic history. The mountain itself consists of agglomerates, augitites and trachytes with a capping of nephelinite, but the base on which these rest is not exposed. On the volcanic plains east of the Rift Valley the lower part of the sequence is represented by the Olorgesailie biotite phonolite which rests on Kapiti Phonolite and Upper Athi Tuffs. In the northern part of the area a tongue of Olorgesailie phonolitic nephelinite, equivalent petrographically to the nephelinite capping of the volcano, rests on the Olorgesailie biotite phonolite and overlaps it onto the Upper Athi Tuffs and the Mbagathi Trachyte.

The Olorgesailie volcanics on the edge of the Rift Valley are overlain by the Ol Doinyo Narok Agglomerate, which thins to the north before passing into the Kerichwa Valley Tuff. The formations represent a return to explosive activity.

Another central volcano, composed of two centres, Ol Esakut and Ol Esayeiti, the latter being located just outside the region mapped, then formed to the north-west, but lavas from it did not flow far, although they do overlie the Kerichwa Valley Tuff on the eastern side of the Rift Valley.

The first episode of rift faulting then followed, bringing the central volcanoes down to the floor of the Rift Valley. The throw of the faults in the northerly volcanic rocks is much greater than in the Basement System to the south.

The succeeding vulcanicity was confined to the floor of the Rift Valley. The Ol Keju Nero Basalts probably represented the last phases of the central volcanic activity since patches of basalt on Ol Esakut overlap the older lavas. They are succeeded by the Pleistocene alkali trachyte and orthophyre-trachytes to the west. Both the basalts and trachytes are cut by grid faults although some faulting may have originated before the formation of the trachytes.

Middle and Upper Pleistocene sediments, notably the Olorgesailie Lake Beds, were deposited in the troughs between the fault-scarps. These beds were cut by renewed movement along some faults, but the amount of throw was slight.

The final event was the formation of soils. On the Basement System these are usually reddish brown and sandy, with kunkar deposits on calcareous bands and black-cotton soil in areas of poor drainage. The Basement System in the Rift Valley yields a grey sandy soil. Black-cotton soil is formed on most of the volcanic rocks, but the Upper Athi Tuffs sometimes grade into a yellow clay. The Ol Doinyo Narok Agglomerate and alkali trachytes produce a red volcanic soil.

V—DETAILS OF GEOLOGY

1. The Basement System

The gneisses, limestones and quartzites of the Basement System, which are thought to be sedimentary in origin because of their composition and layering, form part of the Mozambique belt (Holmes, 1951, p. 256). The regional foliation, which is most pronounced in the gneisses and only absent in the purest limestones and quartzites, is formed by layers of different mineralogical composition, and so parallels the bedding-planes. Close examination reveals that much of the foliation is lensoid, and marked by a preferred orientation of platy minerals, especially mica, but the folding and metamorphism may have only intensified original sedimentary features.

The Basement System in the Kajiado area can be divided into two main groups; the Turoka Series and the quartzo-felspathic gneisses. The term Turoka Series was first proposed by Parkinson (1913, p. 539) for the Basement System in the Turoka valley, although he described neither the succession nor the limits of the group. Joubert (1957, p. 30) in the Namanga–Bissel area to the south, separated the Turoka Series from the lower, banded and quartzo-felspathic gneisses, because of the variety of rock-types including crystalline limestones and quartzites. He also subdivided the Turoka Series into an upper limestone group and a lower quartzite group, since the majority of the limestones occur above the major quartzite horizon, while below it there is a marked increase in the granularity of the rocks.

The succession in the Basement System of the Kajiado area follows that envisaged by Joubert for the Namanga–Bissel area, but differs from it in one important respect, namely that in the Turoka Series the undifferentiated gneisses in which the migmatites invade semi-pelitic host rocks were not recognized to the west of the Lundiro limestone. In the Kajiado area this limestone forms an isoclinal fold which closes to the north, so the gneisses on both sides should be the same. This conclusion, however, does not affect Joubert's succession since only a small, isolated part of the Turoka Series in the Namanga–Bissel area adjoins the outcrop in question.

The relationship of the dominantly quartzo-felspathic gneisses which outcrop in the eastern part of the Kajiado area to the Turoka Series is open to question. They overlie the Turoka Series and so could be younger, but Joubert thinks they may be equated with the banded gneisses underlying the Turoka Series in the south-west of the Namanga–Bissel area. In the southern Machakos region to the east (report by Baker, 1954), pelitic and semi-pelitic gneisses and crystalline limestones outcrop east of the quartzo-felspathic gneisses. If these are equivalent to the Turoka Series, it would appear that the quartzo-felspathic gneisses are the older rocks, and their inverted position in the Kajiado area is due to isoclinal folding. This supposition is strengthened by the fact that much of the boundary between the two groups in the Namanga–Bissel area is occupied by a fault zone, which extends northwards into the Ngoragaishi hills. In addition a belt of augen gneisses outcrop along the southern part of the boundary between the two groups.

The lowest members of the Turoka Series appear to be the semi-pelitic gneisses, with many intercalated quartzo-felspathic gneisses and quartz-felspar-biotite gneisses found on the western sides of Martiolkimbai and the Lemilebbu hills. They are overlain in the Lemilebbu hills by graphitic gneisses which are in turn overlain by the major quartzite horizon. These two formations are often missing, for example the Turoka marble rests on the quartz-felspar-biotite gneisses. This outcrop is a representative of the lowest major crystalline limestone, forming the base of the upper part of the Turoka Series, which in the Kajiado area, normally overlies the major quartzite. In the Namanga–Bissel area, however, the limestone and quartzite are usually separated by semi-calcareous gneisses. The major crystalline limestone is followed by a series of pelitic gneisses with subordinate calcareous and semi-pelitic horizons.

The tentative succession proposed for the Kajiado area and its correlation with the general succession of the Namanga–Bissel area is as follows:—

		Namanga–Bissel area	Kajiado area
Upper (Limestone) Group	Turoka Series	Banded pelitic gneisses with prominent calcareous and subordinate semi-calcareous, semi-pelitic and psammitic types. Limestone (major)	Banded pelitic gneiss with prominent calcareous and subordinate, semi-calcareous, semi-pelitic and psammitic types. Limestone (major)
Middle (Quartzite) Group	Turoka Series	Quartzite (major) Semi-pelitic gneisses Quartzite Biotite Schists	Quartzite (major) Semi-pelitic gneisses with subordinate quartz-felspar-biotite gneisses
Lower (Banded Gneiss) Group		Banded gneisses with hornblende gneisses	Quartzo-felspathic gneiss with subordinate semi-pelitic gneisses

Estimated maximum thicknesses of these groups are:—

	Feet
Turoka Series above the major limestone	15,000
Major limestone	100–600
Major quartzite	100–600
Turoka Series below the major quartzite	5,000
Quartzo-felspathic gneisses	12,000

Isoclinal folding may have reduced the thicknesses given for the gneisses but was not recognized in areas of poor exposure and monotonous lithology.

The age of phlogopite enclosed in limestone from the Kenya Marble Quarries has recently been determined by Dr. N. J. Snelling of the University of Oxford, using the potassium-argon method. A result of 505 $\pm$ 25 million years was obtained, but, as Snelling points out, this figure indicates the age of metamorphism and not the date of sedimentation. The age of the metamorphism may differ somewhat in other parts of the country.

For descriptive purposes the rocks of the Basement System in the Kajiado area may be classified into the following groups:—

(1) Metamorphosed calcareous sediments—
- (*a*) Crystalline limestones
- (*b*) Calc-silicate gneisses

(2) Metamorphosed pelitic and semi-pelitic sediments—
- (*a*) Graphite gneisses
- (*b*) Mica gneisses
- (*c*) Hornblende gneisses
- (*d*) Garnet gneisses

(3) Metamorphosed psammitic sediments—
- (*a*) Quartz-felspar-biotite gneisses
- (*b*) Quartz-felspar gneisses
- (*c*) Quartzites

(4) Migmatites—
- Augen gneisses

(5) Anatectic or palingenetic rocks—
- Pegmatites

(6) Metamorphosed intrusive rocks—
- Amphibolites

(1) Metamorphosed Calcareous Sediments

These rocks are found in the south-western part of the Basement System, where they form part of the Turoka Series (Parkinson, 1913).

(a) *Crystalline Limestones*

The limestones occur in four main areas; the Lemilebbu hills, Lundiro, the Turoka Valley where the Kenya Marble Quarries are situated, and the western side of Martiolkimbai. There are also smaller outcrops of limestone within the gneisses. Exposures of the smaller bands are usually poor, occurring only on the ridges and in rivers, but can be traced over intervening ground by surface or kunkar limestones. The latter, however, also develop on other calcareous bands which are not limestones, and as the kunkar limestones were deposited by surface waters they do not necessarily overlie their parent rock. The thinner limestone bands are thought to be lensoid in outcrop rather than continuous because they are sometimes missing in the rivers.

Below the Kenya Marble Quarries, the outcrop of kunkar descends a hundred feet further down the side of the Turoka valley than the limestone. In the Kenya Marble Quarries, the measured thickness of the Turoka marble is less than fifty feet but the width of outcrop is one thousand feet, which with a dip of 25° would give an estimated thickness of four hundred feet. This discrepancy is caused by numerous small folds and faults which are not apparent at the surface. The section in the Kenya Marble Quarries also reveals that major limestones are not formed by one thick band but by several bands of limestones with numerous siliceous and calc-silicate intervening layers.

Banding of the limestones parallel to the strike of the foliation in the surrounding gneisses is usually caused by the alternation of white and coloured layers, which vary in thickness from a fraction of an inch to several feet. The most frequent colours are grey and brownish-grey, while blue is less common. The banding looks sedimentary in origin but may have been formed by metamorphic differentiation; further banding is produced by variation in crystallinity, examples of which are given later.

The great majority of the limestones are composed of a calcite mosaic with some dolomite. In thin section the amounts of accessory minerals are seen to be very variable. Specimens 51/449*, 51/504, and 51/518 from the statuary marble quarry and the northern and central Lemilebbu hills respectively contain no appreciable impurities. The limestone band near Olkeloriti bore-hole (51/623) contains some muscovite flakes and a little zoisite, while 51/464 from the western side of Martiolkimbai has accessory magnetite. Specimen 51/532 from the south of Lundiro contains some albite in addition to flakes of muscovite. The addition of rounded quartz to the calcite mosaic is shown in specimen 51/570 from the Kenya Marble Quarries, but was probably introduced mechanically because few grains are enclosed in the calcite.

The slightly impure limestones are much more instructive than the purer ones because they develop a variety of minerals which show the grade of metamorphism reached. Specimens 51/574 from the Kenya Marble Quarries, and 51/458 from the western side of Martiolkimbai, have a few small tremolite crystals set in their calcite mosaics. Part of the Lundiro limestone is silica-poor, and in 51/482 developed forsterite and wollastonite, but specimen 51/481 from the same locality, has rounded quartz in association with diopside and wollastonite. The quartz was probably mechanically introduced.

Blue marble occurs sporadically throughout the area, but is best developed in the limestone bands on the western side of Martiolkimbai. Specimens 51/462 and 51/465 possess a pure calcite matrix with very few impurities, but the calcite crystals are either cracked or strained. When strained the calcite is biaxial and its cleavage and twinning planes are bent. J. L. Rosenhaltz and D. T. Smith (1950), investigated the Crestmore Blue Marble which has similar properties and attributed the blue colour to straining since it could not be caused by the impurities. X-ray examination by them revealed structural strain which was relieved by heating to 300° C. when the colour changed to white.

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*Numbers 51/449, etc., refer to specimens in the regional collection for Degree Sheet 51 in the Mines and Geological Department, Nairobi.

Very little pegmatitic material has been introduced into the limestones even when surrounded by intensely migmatized gneisses.

(*b*) *Calc-silicate Gneisses*

These rocks are widespread in the Turoka Series but exposures are always small. Generally they form lenticular segregations either in the limestones or along the strike continuation of the limestones, but some occurrences are far removed from limestone horizons. They are dark in colour, fine- to medium-grained, and banded due to the separation of melanocratic and leucocratic minerals.

Specimen 51/538, from the south-east of Martiolkimbai, is a transitional rock from the impure limestones to the calc-silicate gneisses and corresponds to Joubert's semi-calcareous gneisses (Joubert, 1957, pp. 11–13). The chief mineral, hornblende, is pleochroic from yellow to green, replacing a small amount of diopside. Calcite forms most of the remainder of the rock with a little sericitized plagioclase. Quartz is an accessory together with sphene and epidote. Both on the western side of Martiolkimbai and the eastern side of Lundiro true calc-silicate gneisses are found. Specimen 51/469 from the former locality is well banded with layers of andesine separating diopside, which is partly replaced by hornblende. The melanocratic layers also contain some porphyroblasts of pink garnet, partly altering to chlorite. A little scapolite appears to be replacing the plagioclase, and biotite, quartz, epidote, apatite and magnetite are accessory.

Estimated volumetric modes of the calc-silicate gneisses are:—

	51/538	51/469	51/484
	%	%	%
Pyroxene	5	30	34
Hornblende	39	14	18
Epidote	5	6	—
Plagioclase	8	33	15
Scapolite	—	2	—
Garnet	—	3	5
Quartz	5	5	—
Sphene	5	1	3
Iron ore	—	2	—
Apatite	—	—	2
Calcite	33	—	23
Biotite	—	4	—

51/538 Semi-calcareous gneiss, south-east of Martiolkimbai.
51/469 Calc-silicate gneiss, west of Martiolkimbai.
51/484 Calc-silicate gneiss, east of Lundiro.

(2) Metamorphosed Pelitic and Semi-pelitic Sediments

The pelitic and semi-pelitic gneisses are described as one group for convenience, but outcrop in both the Turoka Series and the quartzo-felspathic gneisses which lie to the east of the former. As the name of the latter group implies, the pelitic and semi-pelitic gneisses form a very minor proportion of it but constitute a major part of the gneisses of the Turoka Series. To avoid repetition both kinds of gneisses are described together, for many of the rock-types are gradational according to the proportion of constituent minerals.

(*a*) *Graphitic Gneisses*

The largest outcrop of graphitic gneiss is found in the Lemilebbu hills, underlying the main quartzite horizon. Graphite also occurs in other rock types but never attains the status of a major constituent. In the Lemilebbu hills, graphite takes over the function of mica in producing a strong foliation, seen in specimens 51/495 and 51/522: these rocks have a dull graphitic lustre, making them quite distinctive. In thin section, the foliation is almost entirely composed of graphite which forms elongated flakes. A few blades of muscovite and biotite are associated with the graphite, and a yellowish amorphous alteration product formed from the graphite is usually fine-grained or fibrous, but sometimes occurs in larger crystals displaying pleochroism. Joubert (1957, p. 15) suggested that this alteration product is chloropal because a little opal is also found. Most of the rock consists of large and small anhedra of clear quartz, usually elongated in the direction of foliation. A few grains of sericitized albite appear to be of later origin. A little apatite and rutile are accessory, with the latter altering to leucoxene. 51/495 contains some flakes of fuchsite, the green chromian mica.

Joubert recorded a kyanite-graphite granulite beneath the limestone in the southern extension of the Lemilebbu hills but kyanite was not found in the Kajiado area. It could be that this horizon becomes completely graphitic to the north; in fact Joubert observed that where graphite becomes an important constituent, kyanite is absent. The graphite gneisses of the northern Lemilebbu hills certainly contain a much higher proportion of graphite than those from the south.

(b) *Mica Gneisses*

This group includes biotite gneisses and muscovite-biotite gneisses, for both types are found indiscriminately throughout the area. They probably represent local variations in composition rather than original stratigraphical differences or the effects of differential metamorphism. Gneisses in which muscovite is the only or dominant mica are not present, and muscovite seldom equals the biotite content. The micas give these rocks a well-marked foliation since leucocratic bands composed of quartz and felspar predominate.

In thin section the foliation is equally well pronounced, and in pelitic types such as 51/535 and 51/546 from the northern Lemilebbu hills and the northern tributary of the river Turoka respectively, mica forms continuous layers. The semi-pelitic types contain a lower proportion of mica so flakes are separate. Examples of this type are 51/468 from the western side of Martiolkimbai, 51/483 from Lundiro, and 51/537 from the south-east of Martiolkimbai. The directional orientation of the rock is also shown by the elongation of the larger quartz crystals normally set in a finer matrix of quartz and felspar. The felspar is a plagioclase ranging between albite and oligoclase; it is usually sericitized, and varies in quantity considerably. Microcline and microcline-microperthite are found in all mica gneisses; sometimes they are present only in minor quantities but elsewhere may predominate over the quartz and plagioclase. Accessory magnetite occurs in scattered grains, and limonite stains the edges of the leucocratic crystals. Epidote is sometimes an accessory.

The following volumetric compositions were estimated for these rocks:—

	51/535	51/546	51/468	51/483	51/537
	%	%	%	%	%
Quartz	14	14	25	17	37
Microcline ..	18	23	14	23	17
Plagioclase ..	41	38	47	51	34
Biotite	22	18	3	7	10
Muscovite ..	—	3	6	—	—
Magnetite ..	3	2	3	2	2
Epidote ..	2	2	2	—	—

51/535 Semi-pelitic biotite gneiss, northern Lemilebbu hills.
51/546 Pelitic biotite gneiss, northern tributary of river Turoka.
51/468 Semi-pelitic muscovite-biotite gneiss, west of Martiolkimbai.
51/483 Semi-pelitic biotite gneiss, Lundiro.
51/537 Semi-pelitic biotite gneiss, south-east of Martiolkimbai.

(c) *Hornblende Gneisses*

Hornblende gneisses without biotite are comparatively rare because their amphibole is usually replaced by a dark green biotite. They occur in the Turoka Series in similar positions to the biotite gneisses, but were probably slightly more calcareous originally. The rocks are well-banded in hand-specimen, with a good separation of leucocratic and melanocratic constituents. The presence of hornblende makes them darker in appearance than the biotite gneisses.

In thin section the rocks have much the same composition as the biotite gneisses, with hornblende substituting for biotite. The groundmass is formed of quartz and oligoclase with some orthoclase, but the hornblende layers are more irregular than those of biotite, because the crystals are larger and less flaky. Specimen 51/485 from north of Lundiro contains a little diopside associated with hornblende. The oligoclase is usually sericitized and the crystal edges are stained by limonite. In specimen 51/475, from the western side of Martiolkimbai, sphene in both angular and rounded forms constitutes a large proportion of the accessory minerals. A little biotite is associated with the hornblende in this specimen. Magnetite and apatite are normal accessories but not so abundant as sphene in this specimen.

Estimated volumetric modes of hornblende gneisses are:—

	51/475	51/485
	%	%
Hornblende	18	15
Plagioclase	22	26
Orthoclase	18	21
Quartz..	30	29
Biotite	5	—
Sphene	4	—
Magnetite	2	3
Apatite	1	1
Diopside	—	5

51/475 Western side of Martiolkimbai.
51/485 North of Lundiro.

(*d*) *Garnet Gneisses*

Garnetiferous bands occur frequently throughout the Turoka Series but are best developed along the eastern side of Martiolkimbai. Apart from the presence of garnet the rocks are very similar to the biotite gneisses, with biotite well developed in them, and reaching as a high a mineral percentage as in the pelitic biotite gneisses. The garnets stand out from the surface of the rock giving it a knobbly appearance, but in thin section are seen to be often altered to chlorite with the separation of iron ores. The garnets vary in size from half an inch across to almost a pin-head. Some of the larger garnets contain inclusions of quartz and hornblende, but are not arranged in a helicitic fashion. Specimen 51/478, from the eastern side of Martiolkimbai, which illustrates the internal structure of the garnet, is noteworthy in that it consists of extremely large crystals. Almost the entire band is formed of garnet with very little interstitial material.

The groundmass of typical specimens such as 51/454 and 51/471 from the eastern and western sides of Martiolkimbai respectively, are formed by quartz and oligoclase, usually present in approximately equal proportions. Microcline is generally subordinate to the other leucocratic minerals and replaces them at its borders. Apart from exceptional rocks, garnet is less abundant than biotite. Flakes of biotite impart a strong foliation which sweeps round the garnets indicating that they could have been formed during the folding which produced the foliation. From their lack of helicitic inclusions, on the other hand, they would appear to be post-foliation, so presumably the garnets must have forced the foliation apart during growth. Magnetite and apatite, the main accessories, are frequently found as inclusions in the quartz which is elongated parallel to the foliation.

(3) Metamorphosed Psammitic Sediments

This group comprises the quartzites, quartz-felspar gneisses, and quartz-felspar-biotite gneisses, all representing original psammitic sediments. The initial purity of these sediments is reflected by the type of rock developed during metamorphism. The quartzites represent the purest variety of sandstone, and with increasing argillaceous contamination the quartz-felspar-biotite gneisses developed. These gneisses are more susceptible to granitization than the pelitic and semi-pelitic rocks, but the quartzites proved highly resistant to this process. The quartzites which fall within the Turoka Series are well displayed on the Lemilebbu hills: other thin bands occur within the succession. Very little pure quartzite is found in the eastern gneisses, which are mostly composed of psammitic types. Outcrops of the latter are subordinate in the Turoka Series but the biotite gneisses shown on the map belong to the quartz-felspar-biotite gneisses.

(*a*) *Quartz-Felspar-Biotite Gneisses*

These rocks are similar to the semi-pelitic biotite gneisses in composition but the amount of biotite is less. They outcrop in thin bands in both the Turoka Series and the eastern quartz-felspar gneiss, and are weakly foliated, well-jointed, and pale brown or pink in colour. Their resistance to erosion enables them to stand out as ridges, often with steep cliff faces; exfoliated boulders are common. They form the gneiss within the Turoka marble and are well-developed on the western side of Martiolkimbai. Smaller bands are found in the western part of the Turoka Series, and are prominent in the western part of the eastern gneiss. The quantity of biotite though small is sufficient to impart a rude foliation, so they are termed gneisses rather than granulites. Iron ore is common, occurring as streaks or crystals, which give the rock a speckled appearance.

In thin section the gneisses show an irregular mosaic of quartz, microcline, microcline-microperthite and acid-plagioclase, ranging between albite and oligoclase, which is usually sericitized. Alternatively, the microcline and microcline-microperthite which form the largest constituent of the rocks are unaltered, and show replacive relations to the plagioclase and quartz. The biotite makes up a very small proportion of the rock, with minor quantities of iron ores.

Some estimated modes of these gneisses are:—

	51/467	51/549	51/572	51/587
	%	%	%	%
Quartz	23	24	40	30
Microcline.. ..	38	42	23	24
Plagioclase ..	27	28	26	37
Biotite	8	3	6	5
Iron-ore	4	3	5	4

51/467 Western side of Martiolkimbai.
51/549 Eastern side of Lemilebbu hills.
51/572 Kenya Marble Quarries.
51/587 Cairn hill.

(*b*) *Quartz-felspar Gneisses*

Rocks of this type form the greater part of the eastern gneisses and are sometimes found in the Turoka Series. They are white or buff, coarse- to medium-grained, and contain a little biotite which is insufficient to give a foliation, but a faint banding is sometimes exhibited by layers of varying composition.

The proportions of the leucocratic minerals are similar to those of the quartz-felspar-biotite gneisses. Under the microscope, in typical specimens like 51/520 and 51/618 from the eastern side of the Lemilebbu hills and the eastern side of the Kajiado–Laitokitok road respectively, the quartz consists of irregular recrystallized grains, but is subsidiary to seriticized oligoclase. The oligoclase displays myrmekitic structure towards the quartz and encloses small rounded quartz grains. Later microcline and microcline-microperthite, which show replacive contacts towards the quartz and plagioclase, vary in quantity in different rocks. Rare muscovite flakes are present in some specimens, notably 51/466 and 51/479 from the western and eastern sides of Martiolkimbai respectively, and 51/613 from the Ngoragaishi hills, but biotite predominates. Magnetite and apatite are accessory. Garnet appears in specimen 51/613 and sphene in 51/466.

Some estimated modes follow:—

	51/466	51/594	51/608	51/613
	%	%	%	%
Quartz	23	25	27	26
Microcline.. ..	27	28	36	34
Plagioclase ..	44	42	31	37
Mica	4	2	2	1
Accessories ..	2	3	4	2

51/466 Western side of Martiolkimbai.
51/594 Kitengela river.
51/608 River south-west of Sajaloni.
51/613 Ngoragaishi hills.

(c) *Quartzites*

The massive, well-jointed quartzites of the Lemilebbu hills are essentially similar to those described by Joubert (1957). They form the most resistant rocks in the area and their elevated position has led to the formation of much scree which often obscures their lower contacts against gneiss or limestone, giving a false impression of the true thickness of quartzite. On the flat summits of the hills, where the dips of the foliation are low, quartzites form low hillocks which are easily recognized by their sparse vegetation and mantle of quartzose gravels. The actual thickness of the quartzite bands is presumably less than the width of outcrop which was probably increased by folding in a similar manner to that observed in the crystalline limestone at the Kenya Marble Quarries. The impossibility of estimating accurately tectonic thickening and thinning, which is especially prominent in minor folds affecting quartzite, makes estimating the original thickness a matter of conjecture, but it could be between 50 and 400 feet (*see* p. 11 for actual thickness of limestone at Kenya Marble Quarries).

The pure quartzites are virtually homogeneous and coarsely crystalline; in colour they are white or grey on exposed surfaces but translucent in thin splinters. Most of the weathered surfaces are dotted with small cavities in which iron ores are found; iron staining also extends along the foliation and joints. Banding is commonly produced by alternating coarse- and fine-grained layers along which joints developed, giving the rocks a slabby appearance. Small mullions were often produced on the foliation during folding in addition to the fine striations usually found in the gneisses.

Under the microscope the pure quartzite such as specimens 51/501 and 51/550, from the northern and central Lemilebbu hills respectively, consist of a mosaic of elongated quartz grains, often sutured and strained. Dusty inclusions are common and thought to be graphite, because this mineral forms an important accessory in some quartzites, e.g. 51/534 from the central Lemilebbu hills. The graphitic quartzites do not form distinct layers extending over a wide area but are found in local lenses. Rounded diopside grains are found in 51/497 and 51/508 from the northern Lemilebbu hills, and 51/552, 51/557, and 51/559 from the central Lemilebbu hills. A few small flakes of mica are present in some specimens, notably 51/507 and 51/558 from the northern and central Lemilebbu hills respectively. Apatite is a common accessory in very small quantities in nearly all quartzites.

The smaller quartzite bands are generally less pure and contain some felspar.

(4) MIGMATITES

Most of the Basement System in the Kajiado area, although migmatized, is recognizably sedimentary in origin and so descriptions in the three preceding sections apply. Within these rocks, however, are larger leucocratic bands which are now described.

The Ngoragaishi hills in the south-east are composed of *augen* gneisses in which recognizable sedimentary features are largely obliterated, and secondary viscous flow is indicated by random contortions. These two types of migmatites are treated separately because their relationship to the host-rocks vary although both had a common origin. The bulk of evidence concerning migmatization within the Basement System and other Archaean terrains appears to favour the metasomatic rather than the magmatic hypothesis (Schoeman 1951, p. 11, Turner 1949, pp. 306–311).

(*a*) *Migmatitic Bands*

Two different types of migmatitic bands are represented by 51/451 from the stream south-east of the Turoka railway station, and 51/564 just north of the railway bridge crossing the river Kajiado. The bulk of the rock in each case is formed of felspar; sodic in the first example and potassic in the latter, indicating that both albitization and potash metasomatism occurred.

Under the microscope 51/451 shows banding caused by alternation of dominantly coarse-grained quartzose and felspathic bands. Commonly the quartz is elongated parallel to the banding with rare biotite; there is a little muscovite. The slightly sericitized felspar was determined as albite. Magnetite and iron staining are rare.

Specimen 51/564, from a much thinner band, is correspondingly finer-grained and the compositional banding is partly obscured by the later microcline and microcline-microperthite. These two minerals make up about 30 per cent of the rock with albite predominating over quartz in the remainder. The rare mica is mostly muscovite; epidote is found as an accessory in addition to magnetite.

(*b*) *Augen Gneisses*

The *augen* gneisses outcrop in the Ngoragaishi hills and extend southward to Lokululit in the Namanga–Bissel area. They lie along the boundary of the Turoka Series and the eastern quartz-felspar gneisses, but embay into the latter more than the former. In the quartz-felspar gneisses there is a strong development of microcline and microcline-microperthite, but these do not become sufficiently large to form *augen*. The boundary of the *augen* gneisses was delimited where *augen* are easily visible macroscopically, but even within these rocks there are zones of greater *augen* density. In these cases sedimentary structures are almost completely obliterated, whereas the less intensely migmatized types retain a certain amount of sedimentary setting. The western boundary of the *augen* gneisses is more abrupt against the Turoka Series, which are themselves less granitized than the quartz-felspar gneisses; in addition, this boundary is complicated by faults in some places. The *augen* gneisses are resistant to erosion, and so tend to occur as hills; this is especially true of the more migmatitic parts, and near Lokululit steep cliffs of bare rock extend for hundreds of feet.

Specimen 51/601, from the Ngoragaishi hills, represents the less migmatitic type of *augen* gneiss. The main part of the rock is similar to a quartz-felspar-biotite gneiss with bands of elongated quartz separated from sericitized oligoclase by some mica, mostly biotite. Small replacive crystals of microcline are scattered throughout this matrix, which is the host rock to several large crystals of microcline-microperthite forming the *augen*. Epidote and apatite are accessory.

The continuation of the migmatization process is shown by 51/600 from the same locality. Here the host rock, similar to 51/601 except that it contains accessory sphene, is very much reduced and nearly the entire specimen is composed of *augen*. These *augen*, which are larger than in 51/601, are made up of several crystals of microcline and microcline-microperthite, containing a few relic crystals of partly resorbed quartz.

Specimen 51/598, also from the Ngoragaishi hills, representing almost the final stage of the process, approaches a granitoid gneiss in composition, but occurs only in a thin band. It is almost entirely formed of microcline and microcline-microperthite, with isolated grains of rounded quartz and sericitized plagioclase as remnants of the host rock. These and some randomly orientated flakes of mica are too few to give a microscopic foliation, but in the field the *augen* impart a rough foliation to the rock since they follow the layering of the host rock. The relic elements were displaced by the growth of the *augen* and now lack orientation. Magnetite and epidote are accessory.

A small *augen* gneiss band, separated from the main outcrop, was found in the Turoka Series two and a half miles south of Sajaloni (51/609). Under the microscope this rock appears to be essentially similar to 51/601, except that some hornblende is associated with biotite in the groundmass of the host rock.

(5) Anatectic or Palingenetic Rocks—Pegmatites

Pegmatites which are ubiquitous throughout the Basement System are the only representatives of this group within the Kajiado area. They are found in all the rock types with the exception of the main quartzites and limestones. Both concordant and discordant pegmatites are found; the former are smaller and follow the foliation while the latter cut across it. These two types can also be distinguished by their mineral contents: the concordant pegmatites are largely composed of plagioclase and the discordant of microcline. Accessory minerals are rare apart from mica flakes and garnet, seen in specimen 51/545 from the northern tributary of the river Turoka which runs parallel to the Magadi railway.

The concordant pegmatites occur as small irregular bodies with gradational contacts. In a typical example, such as specimen 51/476 from the eastern side of Martiolkimbai, the dominant felspar is usually sericitized albite or oligoclase. Small rounded quartz grains are enclosed in the felspar while the little amount of microcline-microperthite shows replacement of other minerals. Fairly rare muscovite is usually the sole accessory except for magnetite.

Two generations of discordant pegmatites can be recognized in the Kajiado area, both having distinct margins. The earlier ones are partly concordant along foliation planes but transgress them in numerous places, while the later are dyke-like in form. In the large stream running west from the Lemilebbu hills, some of the later type which trend east–west are cut by others striking north–south. An example of the latter, specimen 51/491, contains a larger proportion of plagioclase, determined as oligoclase, than usual in the discordant pegmatites. Generally, however, the discordant pegmatites are almost entirely composed of microcline-microperthite; indeed no other mineral is present in specimen 51/612, from the Ngoragaishi hills, except isolated flakes of mica forming crystal boundaries. Specimens 51/487 and 51/489 from the eastern flank of the Lemilebbu hills and Lundiro, are representative. In these quartz and plagioclase, either albite or oligoclase, appear in small grains often resorbed by the microcline-microperthite. Accessory minerals are present in small quantities; muscovite is more abundant than biotite within the pegmatite, although biotite often forms selvedges against the country-rock. Magnetite is the common iron ore, while fragmental crystals of sphene appear in specimen 51/619 from the Kajiado–Laitokitok road.

A weathered pegmatite from the northern tributary of the river Turoka (51/542) consists of approximately equal parts of chloritized microcline-microperthite and a completely sericitized plagioclase with much secondary calcite. A few flakes of muscovite are unaffected.

(6) Metamorphosed Intrusive Rocks—Amphibolites

The only rocks of igneous origin found in the Basement System of the Kajiado area are amphibolites, which were originally minor intrusions, following the foliation. The fact that they are aligned parallel to the foliation does not necessarily mean they were emplaced after it had formed, because the axial plane foliation in the limbs of isoclinal folds would follow an earlier surface such as bedding. The amphibolites are too small to be shown on the geological map.

Some of the amphibolites may have been extrusive in origin, but as no evidence for this was found all of them are treated as intrusive. They are dark green in colour and display the usual banding parallel to which minerals are elongated. Garnet is present in some specimens, usually as small porphyroblasts but sometimes forms larger crystals.

In thin section, most of the rocks are seen to be plagioclase amphibolites, but specimen 51/543, from the eastern side of the Lemilebbu hills, contains a lower proportion of plagioclase, determined as andesine. Much pale green augite is associated with the hornblende. Hypersthene, showing schiller structure and replacing augite, occurs in specimen 51/624 from Olkeloriti. In the more typical plagioclase amphibolites such as 51/486 from east of Lundiro, augite is less plentiful and is partly replaced by hornblende. In specimen 51/606 from the Mataraguesh river no pyroxene remains. The large garnet crystals with inclusions of plagioclase, present in 51/461 from the western side of Martiolkimbai, are partly replaced by hornblende. Sphene is the commonest accessory while magnetite and epidote are present. Rutile needles are often enclosed in the felspar.

Some estimated volumetric modes of the amphibolites follow:—

	51/461	51/486	51/543	51/606	51/624
	%	%	%	%	%
Hornblende ..	34	27	53	43	36
Pyroxene ..	14	11	22	—	31
Plagioclase ..	27	56	17	47	28
Garnet	20	—	—	—	—
Accessories ..	5	6	8	10	5

51/461 Western side of Martiolkimbai.
51/486 East of Lundiro.
51/543 Eastern side of Lemilebbu hills.
51/606 Mataraguesh river.
51/624 Olkeloriti bore-hole.

2. The Tertiary Volcanic Rocks

Volcanic rocks, which cover about two-thirds of the Kajiado area, are thought to be mostly of Tertiary age, but the youngest are probably Pleistocene. The oldest lava, the Kapiti Phonolite, rests on the sub-Miocene surface, and may date from the Miocene by analogy with other parts of East Africa, where similar flows overlie sediments containing Miocene fossils (Kent, 1944, p. 19). The other datable horizon is in the Olorgesailie Lake Beds, the fossil content of which indicates an upper Middle Pleistocene age that is younger than the volcanic rocks of this part of the Rift Valley. Between these two horizons there is no break in the volcanic sequence apart from periods of quiescence, and the two upper members, the alkali trachytes and the orthophyre-trachyte of the Plateau Trachyte Series, found only in the floor of the Rift Valley, are placed in the Pleistocene because age dating puts them near the Pliocene-Pleistocene boundary and they are relatively unweathered. The next oldest member of the sequence, the Ol Keju Nero Basalts, outcrops at a similar locality, but is placed in the Tertiary because the possibly equivalent Kirikiti Basalts on the western side of the Rift were faulted before the eruption of the Plateau Trachytes. Several members of the sequence have recently been dated by the potassium-argon method in the University of California by Prof. Evernden and his colleagues. The Kapiti Phonolite collected at the bridge over the Stony Athi river on the Nairobi–Mombasa road was dated at 13 million years, which would place it in the Upper Miocene according to the University of California's figure of 12 million years for the base of the Pliocene. The figure of 5·8 million years for the Olorgesailie phonolitic nephelinite from Loitigoshi would place it in the Middle Pliocene, indicating a long period of quiescence after the Kapiti phonolite. Alkali trachytes from the Magadi area have an age of 1·7 million years, agreeing with the figure for the Limuru Trachyte north of the Ngong hills. This age places them near the Pliocene-Pleistocene boundary. Pumice from the Olorgesailie prehistoric site lake beds agrees with the fossil evidence of 0·4 million years.

(1) The Kapiti Phonolite

The largest outcrop of the Kapiti Phonolite is found in the east and north-east, forming the western part of the Kapiti plains. To the west it disappears under younger volcanic rocks, but emerges west of Kajiado, extending to the Rift Valley and the Turoka valley. On the southern side of the Turoka Valley it caps the hill of Martiolkimbai, which continues to the southern edge of the area. Some small down-faulted outliers outcrop on the floor of the Rift Valley near its eastern edge.

The surface of the Kapiti Phonolite is flat with little dissection, so exposures are generally poor except in river valleys; on the plains it outcrops as rounded exfoliated boulders. Where the phonolite forms scarps above the Basement System exposures are good, especially along the Rift Valley, the Turoka valley, round Martiolkimbai, and on the northern side of the Mataraguesh river. Its thickness is variable since it was extruded around hills rising above the sub-Miocene peneplain, but attains a maximum of between 200 and 300 feet at the edge of the Rift Valley. Here the effect of the hills on the sub-Miocene surface diminishes and the top of the phonolite is preserved by younger volcanic rocks, so the amount of erosion is negligible.

The rock consists of a dark greenish grey microcrystalline groundmass with numerous large, white, elongated felspar phenocrysts and less frequent waxy, nepheline hexagons. Crosses are sometimes formed by two felspars growing at right-angles, and white patches of zeolites occur on the surface of the rock. Under the microscope specimen 51/442, from an outlier forming a small hill to the north of the Kenya Marble Quarries road, agrees with the character of the specimen from twelve miles north-east of Kajiado station described by Campbell Smith (1950, pp. 9–11). The felspar phenocrysts showing Carlsbad twinning were determined as anorthoclase and are usually idiomorphic and unaltered, while the nepheline is subhedral and contains marginal inclusions. The matrix is intersertal and anorthoclase laths lie at random, tending to divide the field into triangular areas occupied by felspathoids and melanocratic minerals. The felspathoids are both nepheline and subordinate analcite enclosing smaller nephelines. The predominant ferromagnesian mineral is pale brown kataphorite; with some darker brown cossyrite and pale green aegirine-augite. Dark brown crystals of iddingsite associated with iron ore prisms are probably altered olivine micro-phenocrysts.

The Kapiti Phonolite is thought to have been extruded from fissures or small vents because no associated central volcanoes were found in this or other areas, but these could be buried under younger rocks.

Gregory (1921, p. 100), by analogy with other lava fields, held that small vents are more likely than fissures, because feeder dykes would extend into areas now denuded of phonolite. It appears that these small vents are all hidden below the younger lava for none of them have been found in the denuded areas. The present outcrop of phonolite may be identical with the locality where it was originally thickest, while the eroded parts probably represent the thinner parts of the flows farthest from the vents. Gregory suggested that the vents are probably arranged in a network at the intersection of fractures, and their flows united to form the widespread lava sheets.

Gregory (1921, p. 186) and Schoeman (1948, p. 6) believed that the Kapiti Phonolite of the Yatta plateau flowed along an ancient river valley, but Dodson (1953, p. 4) held that the texture of the rock would invalidate this theory. He pointed out that the parent magma must have undergone slow cooling in a reservoir to produce the phenocrysts, followed by rapid cooling after extrusion to give the fine groundmass. He thought, therefore, that the lava must have been fairly viscous and so could not have flowed the distance necessary if a parent volcano was postulated. Accordingly, he believed that the lava of the Yatta plateau was emplaced by fissure eruption along an old fault.

Walsh (1963, pp. 6–9) on the other hand, pointed out that felspathoidal lavas are the least viscous of any type, so the phonolite of the Yatta plateau could have flowed along a valley. A central volcano may well have been the source of the Kapiti Phonolite, and its absence may be explained by the fact that such mobile lavas would not build a high mountain. The flow forming the Yatta plateau could indeed have originated from a series of vents in the type area of the Kapiti Phonolite, as maintained by Gregory, and followed a pre-existing valley.

(2) The Upper Athi Tuffs

These rocks are a group of tuffs and ashes laid down by explosive volcanic activity on top of the western part of the Kapiti Phonolite. It is believed that they were laid down in water because they are stratified. Their outcrop is much less widespread than that of the phonolite but extends into the North Machakos–Thika area to the north-east (Fairburn 1963, p. 22). They are best developed between the largest outcrop of Kapiti Phonolite and the hills formed of younger volcanic rocks along the edge of the Rift Valley. To the east they thin, and only outcrop as isolated patches on the eastern bank of the Stony Athi river, dying out to the south about ten miles north of Kajiado. As the tuffs are friable they do not build any pronounced features but form a capping on the Kapiti Phonolite, which is now exposed for long distances along rivers that have rapidly eroded through the Upper Athi Tuffs.

The Upper Athi Tuffs are best exposed in pits dug for road metal along the Kajiado–Athi River road, where they are usually light grey when fresh or yellowish when weathered. Bands which are darker and lighter in colour are subordinate, but crystals of felspars and melanocratic minerals are often scattered in the matrix. Specimen 51/588, from the river some eight miles to the north of Senya Masai School, was silicified probably after deposition.

Under the microscope specimen 51/595, from the Kitengela river, shows the tuffs are formed by a fine matrix of glassy, poorly cemented volcanic fragments. In this groundmass are fragments of felspar with some pyroxene and biotite.

(3) Mbagathi Trachyte

The Mbagathi Trachyte overlies the Upper Athi Tuffs in the north of the Kajiado area, where it outcrops beneath the Olorgesailie phonolitic nephelinite, the youngest lava associated with that volcano. Earlier members of the Olorgesailie sequence which outcrop farther south also rest on the Upper Athi Tuffs but do not contact the Mbagathi Trachyte.

The surface of the Upper Athi Tuffs upon which the Mbagathi Trachyte was extruded slopes gently upwards to the south. The source of the lava is probably farther north where it is thickest, while it thins and peters out southwards. The most extensive outcrop is at the Kitengela river where it forms scarps standing above the Upper Athi Tuffs. The Olorgesailie phonolitic nephelinite caps the southern scarps.

When fresh the Mbagathi Trachyte is a grey rock with numerous small laths of clear felspar, usually orientated in the direction of flow, and set in a coarse trachytic matrix. Near contacts it is vesicular, and weathered surfaces are soft and rusty-brown in colour. When a weathered rock is broken the trachytic texture is enhanced by bands which have weathered to a colour lighter than the usual grey.

In thin section the trachytic texture in specimen 51/596, from the river Kitengela, is fairly typical, but in 51/647, from Kajiado–Kiserian road, it shows many convolutions which are often visible in the field. In both specimens the felspars were determined as sanidine. The felspars of the groundmass are sometimes arranged radially, with a moss-like intergrowth of sodic amphiboles—the dominant ferromagnesian constituent of the rock. Kataphorite predominates over the darker cossyrite; both occur as small grains between laths together with a little aegirine. A few small square and hexagonal nepheline crystals are also present while magnetite is the only accessory of note.

(4) Olorgesailie Trachytes, Augite Basalts and Agglomerates

These rocks are found on the ancient volcano of Olorgesailie which lies entirely within the Magadi area, and they have been fully described by Baker (1958, pp. 11–15) as the lower part of the Olorgesailie Volcanic Series.

(5) Olorgesailie Biotite Phonolite

This term was applied by Gevaerts (1957, p. 10) to a small lava flow which he believed to overlie the Olorgesailie phonolitic nephelinite south of the river Kibeto. The two lavas are separated by part of the Ol Doinyo Narok Agglomerate in which the upper lava is enclosed, so the term Olorgesailie biotite phonolite is here used by the writer to designate a lava flow extending along the edge of the Rift Valley, from the north-west of Kajiado to near the Nairobi–Magadi road. This rock underlies the Olorgesailie phonolitic nephelinite, the youngest rock found on the volcano, and may be equivalent to the augite trachytes on the lower part of Olorgesailie.

The writer's Olorgesailie biotite phonolite is best developed in the Kajiado area on the plains to the south of Ilyagaleni, where it lies on the Kapiti Phonolite overlapping on to the hills formed by the Basement System. It extends to the north along the eastern side of the Ol Doinyo Narok plateau resting on the Upper Athi Tuffs until it disappears under the Olorgesailie phonolitic nephelinite. On the western side of the plateau it extends almost as far as the Nairobi–Magadi road but the outcrop is disrupted by rift faulting. The peak of Telethungetung, standing above the Kapiti plains to the west of Kajiado, is formed by an outlier of this biotite phonolite. Its thickness varies between 100 and 150 feet but it thins northwards.

In hand-specimen there are two different types probably representing separate flows. One of these is dark and fine-grained with a few small phenocrysts of pyroxene, while the other is coarser, grey green, and contains more abundant phenocrysts of pyroxenes and iron ores. The first type is represented by specimen 51/580 from the river Seure, and the second by 51/633 from the rift scarp to the east of the Nairobi–Magadi road. Under the microscope the iron ores are seen to form strong reaction rims around biotite and occasional hornblende crystals, and some patches of similar iron ores may represent completely resorbed biotite crystals: the iron ore is magnetite. The pyroxene is usually augite or more rarely titanaugite, and often shows a thin reaction rim of magnetite against the small laths of alkali felspar which compose most of the groundmass. Specimen 51/579, from the headwaters of the river Kajiado, contains, besides resorbed biotite and hornblende, some phenocrysts of sanidine and albite, which are normally confined to the trachytic groundmass; some small nephelines are also present in the groundmass. Aegirine-augite is the dominant ferromagnesian mineral but a little acmite is present in 51/646 from the eastern side of the Rift Valley. Magnetite occurs as small grains in the groundmass while calcite is sometimes secondary.

(6) Olorgesailie Phonolitic Nephelinite

In the Kajiado area, the Olorgesailie phonolitic nephelinite forms the east-west trending ridge of Loitigoshi, with steep cliffs above the Upper Athi Tuffs on its southern and eastern sides; to the north, it slopes gently down to the underlying Mbagathi trachyte. At its south-western corner it overlaps the Olorgesailie biotite phonolite, before disappearing under the Ol Doinyo Narok Agglomerate and the equivalent Kerichwa Valley Tuff to the west. It reappears on the eastern side of the Rift Valley in narrow strips controlled by faults.

Baker (1958, p. 12) refers to this rock as the Olorgesailie nephelinite, but in the Kajiado area it is thought preferable to call it a phonolitic nephelinite, because it contains an appreciable quantity of felspar in the groundmass. Although there is no outcrop of the phonolitic nephelinite between the side of the Rift Valley and Olorgesailie, it is assumed that it has been covered by younger rocks since the rock-types at both of these localities are identical. In addition the alignment of the phonolitic nephelinite on the plateau would, if produced, run directly towards the capping of phonolitic nephelinite on Olorgesailie. It attains a maximum thickness of about 200 feet.

The Olorgesailie phonolitic nephelinite is a hard greenish-grey lava with numerous large, waxy, green nepheline phenocrysts. In some specimens, such as 51/645 from the eastern side of the Rift Valley, sanidine laths outnumber the nepheline phenocrysts but this is exceptional. Specimen 51/592 from the Kajiado–Kiserian road is typical, with sanidine very subordinate to nepheline. In thin section the nepheline phenocrysts are idiomorphic and often show lines of bubbles. Aegirine-augite and sphene form microphenocrysts in 51/645, where sanidine is idiomorphic. Nepheline microphenocrysts are generally more rounded than macrophenocrysts. The groundmass generally possesses a trachytic texture of sanidine crystals which are the chief constituent, but these are sometimes arranged radially. Amongst the felspars are grains of aegirine and cossyrite, and some small nepheline crystals; magnetite and sphene are accessory. Specimen 51/630 from the eastern side of the Rift Valley appears to be a marginal variety of the Olorgesailie phonolitic nephelinite for its mineralogy is identical, but it lacks phenocrysts.

(7) Ol Doinyo Narok Agglomerate and Kerichwa Valley Tuff

These two formations are described together because they occupy the same horizon. The Ol Doinyo Narok Agglomerate outcrops on the plateau of that name and thins to the north, forming lower ground, before passing laterally into the Kerichwa Valley Tuff which extends as far as Nairobi. The Kerichwa Valley Tuff consists of tuffs which are subordinate in the Ol Doinyo Narok Agglomerate. Both lava and lahar flows are enclosed within this agglomerate.

The base of the agglomerate at 5,900 feet occurs slightly below the base of the cliffs forming the walls of the Ol Doinyo Narok plateau; in addition, the rock caps low hills of Olorgesailie biotite phonolite. The top of the plateau is generally about 6,400 feet, but rising above it are several small rocky hills such as Ol Doinyo Arau, 6,632 feet; and Ol Doinyo Narok, 6,644 feet, giving a total agglomerate thickness of 700 feet. These hills may represent small vents from which the agglomerate was ejected, or alternatively the ring of low hills are the remnants of the lip of a much larger crater, whose western rim was removed by rift faults. The possibility that this vent or vents extruded only agglomerate is suggested by the fact that the earlier lavas can be traced to other sources, and do not slope up towards Ol Doinyo Narok, as shown by the lavas associated with the undoubted central volcano of Ol Esakut/Ol Esayeiti.

Along the edge of the Rift Valley, to the north of Ol Doinyo Narok, the base of the agglomerate lies at 5,700 feet, whereas on the eastern side of the outcrop the level of the base is maintained at 5,900 feet as far north as the Olorgesailie phonolitic nephelinite. This may indicate that the lower volcanic sequence thinned; for instance the Kapiti Phonolite may not be present, or the surface on which northerly volcanic rocks were laid down was actually lower than that farther south. A third alternative is that the agglomerate was stepped down by a fault east of the rift scarp, which cannot be recognized on the ground because of the homogeneous nature and poor exposure of the agglomerate. The only suggestion of a fault is that several of the streams which flow over the scarp run north or south about half a mile back from the scarp. The decisive factor appears to be that farther north, where the fault emerges from the scarp, the level of the base of the Kerichwa Valley Tuff is 5,900 feet, so some displacement must have occurred.

The Ol Doinyo Narok Agglomerate is a coarse rock, always containing lava blocks which vary considerably in size and composition both laterally and vertically. As a result no type succession can be applied to the whole formation. The lava blocks include coarse- and fine-grained phonolites and trachytes. The matrix is tuffaceous as in specimen 51/582, from the hills north-west of the upper part of the river Seure, where a fine matrix of anorthoclase laths with some nepheline and analcite encloses phenocrysts of felspar and biotite. Some of the phenocrysts are composed of small felspar laths which appear to have come from the matrix of an older lava. Specimen 51/584 from the hill north-east of Ilyagaleni has a glassy matrix containing phenocrysts of altered felspar. Caves have been formed within a lahar in the hills north of Ilyagaleni; this rock resembles the finer-grained parts of the agglomerate, but the groundmass in specimen 51/585 from this locality is composed of cemented volcanic fragments.

As the agglomerate is traced northward from the Ol Doinyo Narok plateau it becomes more tuffaceous, passing laterally into the Kerichwa Valley Tuff. The change commences farther south at the bottom of the group and the proportion of agglomerate increases towards the top. The thickness of the Kerichwa Valley Tuff is about 300 feet.

As the tuffs are softer than the agglomerate, the Kerichwa Valley Tuff does not form scarps like the Ol Doinyo Narok plateau above the older volcanic rocks, except where cut by rift faults. It is generally a grey tuff which does not contain as much yellow, ashy material as the Upper Athi Tuff. In a thin section of specimen 51/642, from the Ngong–Ol Doinyo Narok plateau track, a cryptocrystalline matrix of sanidine laths, with nepheline squares and some acmite and magnetite, encloses phenocrysts of sanidine and smaller aegirine and acmite crystals.

The lava within the Ol Doinyo Narok Agglomerate, which is shown on the map to the south of the river Kibeto, is a fine-grained dark grey rock containing a few felspar phenocrysts and weathering to a lighter grey. Under the microscope specimen 51/669, from just west of the Ngong–Ol Doinyo Narok track, is seen to be a phonolite. It contains a few microphenocrysts of sanidine set in a fine-grained groundmass composed essentially of sanidine laths with a little nepheline and some aegirine and kataphorite; limonite staining is common. The relationship of the Ol Doinyo Narok Agglomerate and the Kerichwa Valley Tuff to the older lavas is shown in Fig. 3. In this region the Ol Esayeiti phonolite, the only flow from the volcano found on the plateau east of the Rift Valley, outcrops to the west of the section shown in Fig. 3.

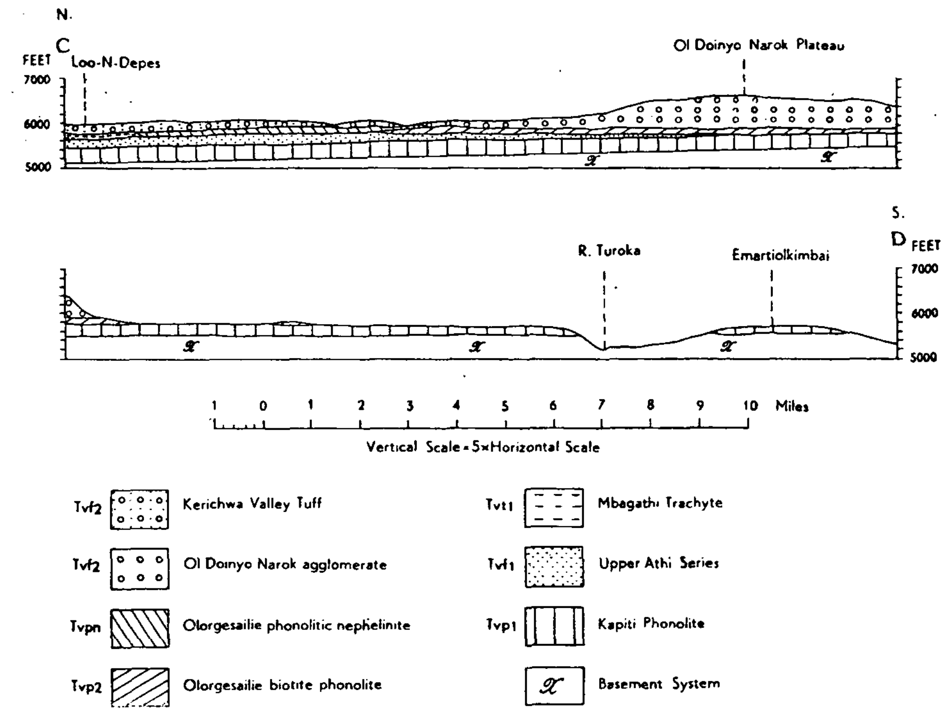

Fig. 3—Section showing the relationship of the volcanic rocks of the plateau

(8) Ol Esayeiti Lower Trachyte

This rock is the oldest lava of the Ol Esayeiti Volcanic Series (originally named by Gevaerts (1957)) and occurs on the lower southern and western slopes of Ol Esakut. To the east it is cut out by faulting apart from some small outcrops. The flow which is about fifty feet thick does not form pronounced features but frequently outcrops in river sections.

The lower trachyte is a dark, fine-grained rock with a few scattered phenocrysts of felspar. Under the microscope a typical specimen, such as 51/666 from the southern side of Ol Doinyo Gerr, consists of elongated sanidine phenocrysts with some smaller crystals of titanaugite which are rimmed by flakes of aegirine-augite set in a cryptocrystalline groundmass. The latter is composed mainly of sanidine laths with some small nepheline crystals. A little acmite is associated with aegirine-augite, the principal ferromagnesian mineral. Magnetite is the chief accessory, but apatite hexagons and zircon needles are also present.

In specimen 51/662 from the south-eastern side of Ol Esakut, in addition to the small crystals in the groundmass, nepheline forms microphenocrysts, some of which are partly altered to cancrinite.

(9) Ol Esayeiti Oligoclase Tephrite

This flow is termed an oligoclase tephrite because its plagioclase is oligoclase, but in other respects it is typical of the tephrites. Gevaerts (1957, p. 9) refers to it as a tephrite but does not mention which plagioclase is present. Oligoclase tephrites have also been described by Wright (1966) in the Narok area on the western side of the Rift Valley. Similar rocks, intermediate between tephrites and phonolites, were called nepheline andesites by Johanssen (1938, p. 215) and andesitic phonolites by Marshall (1906, pp. 601–2).

The Ol Esayeiti oligoclase tephrite is associated with the lower trachyte which it caps, but the former being harder, outcrops over a larger area. These two flows together form the lower slopes of Ol Esakut and extend beyond the base of the mountain. The oligoclase tephrite also outcrops on the plateau to the south of the Ngong hills, but does not extend into the Kajiado area. On the other hand, the lower trachyte only occurs as far east as the fault blocks between the floor of the Rift Valley and the top of the plateau. The present outcrop of the lower trachyte appears equivalent to its original extent, since the Ol Esayeiti phonolite rests on the Kerichwa Valley Tuff immediately to the east, therefore overlapping both the lower trachyte and the oligoclase tephrite. The oligoclase tephrite, however, extended farther east than the trachyte, and rests on the Kerichwa Valley Tuff, but was prevented from flowing southwards into the Kajiado area by the gentle upward slope of the Kerichwa Valley Tuff. The later Ol Esayeiti phonolite then overlapped the oligoclase tephrite and surmounted the slope of the ground to the south, to overlie the Kerichwa Valley Tuff. The oligoclase tephrite is between fifty and a hundred feet thick.

In hand-specimen the Ol Esayeiti oligoclase tephrite has a dark, fine-grained groundmass similar to that of the lower trachyte, but is distinguished from the older flow by the predominance of ferromagnesian minerals in the phenocrysts.

Under the microscope the flow is seen to be somewhat variable in character and has trachytic texture in parts, especially in specimen 51/644 from the Ngong–Ol Doinyo Narok track. The ferromagnesian crystals are grey augite in specimen 51/636, from the western bank of the Lodo Ariak river, but in 51/644 the pyroxenes are accompanied by some basaltic hornblende, separated from the matrix by a strong reaction rim formed mostly of magnetite. There are some phenocrysts of oligoclase which as lath-shaped crystals form the bulk of the groundmass; other constituents are nepheline, augite, hornblende and accessory magnetite. A little analcite is present in 51/644. Olivine is sometimes enclosed in the augite crystals of 51/636, but in specimen 51/650, from the eastern side of Ol Esakut, olivine is so abundant the rock is termed a basanite. The olivine forms large phenocrysts rimmed by iddingsite which has almost completely replaced some of the smaller olivine crystals; otherwise the rock is similar to the oligoclase tephrite, except that the plagioclase is labradorite.

(10) Ol Esayeiti Phonolite

This rock outcrops over most of the slopes of Ol Esakut and its foothills. Its wide extent is explained by the fact that this phonolite and the other lavas slope towards the summit slightly less steeply than the present-day surface. The gradient is about five degrees on the southern and eastern slopes, steepening to fifteen degrees on the west. It is a more resistant rock than the lower trachyte and the oligoclase tephrite, so often outcrops in steep cliffs standing above river valleys. On Ol Esakut it is over 300 feet thick, but where it extends to the plateau on the eastern side of the Rift Valley it is only 150 feet thick. Sikes (1939, p. 20) stated that this phonolite forms the northern slope of Ol Esakut but thought it originated on Ol Doinyo Narok because of the outcrops east of the Rift Valley.

The Ol Esayeiti phonolite has a fine, bluish-grey matrix with phenocrysts of elongated felspar, and rectangular, waxy, olive-green nepheline. The phenocrysts are usually abundant with felspar predominating over nepheline. Specimens 51/643 and 51/660, from the Ngong–Ol Doinyo Narok track and the eastern side of Ol Doinyo Gerr, are typical examples, while 51/658 also from the eastern side of Ol Doinyo Gerr, represents the less porphyritic type. Thin section examination of both types show similar mineralogy except for the proportion of phenocrysts to groundmass. The felspar phenocrysts are anorthoclase but nepheline phenocrysts are rare. Numerous microphenocrysts of aegirine-augite have replaced titan-augite which shows a strong reaction rim in contact with the groundmass. The groundmass is composed of anorthoclase laths, small nepheline crystals, aegirine-augite with a little acmite, together with the usual sodic amphiboles, and accessory magnetite, while sphene is present in some specimens.

(11) Ol Esayeiti Upper Trachyte

This flow covers a much smaller area than the other Ol Esakut lavas and is only found capping the phonolite. It is best developed to the south of the agglomerate forming the peak of Laisagut South and also outcrops near other patches of vent agglomerates and in small outliers. The trigonometrical beacon of Laisagut South lies just off the sheet to the north of the point where the name of Ol Esakut is shown. The lava attains a maximum thickness of 100 feet, but this may have been reduced by erosion for no younger rocks protect it. In most outcrops it is only a few feet thick.

In the field it can be easily distinguished from the Ol Esayeiti lower trachyte by its slabby jointing parallel to the trachytic texture of its crystals. The trachytic banding is also apparent in hand-specimens and is sometimes formed by light and dark layers. The felspar phenocrysts are distinctively elongated parallel to the banding.

Under the microscope the felspar phenocrysts were determined as sanidine but albite is present in 51/637 from the western side of the Lodo Ariak river. In specimens 51/637 and 51/661, from the north-eastern side of Ol Doinyo Gerr, microphenocrysts of aegirine are found, and some augite is present in 51/661. In more typical specimens such as 51/662, from a small hill near the eastern side of the Rift Valley, and 51/655, from the south-eastern side of Ol Esakut, pyroxenes are confined to the groundmass, in which sanidine laths are the most important constituent. The felspar laths are usually elongated in the flow direction but sometimes are arranged radially forming knots. Other minerals in the groundmass are aegirine-augite sometimes replaced by acmite, and more rarely kataphorite and cossyrite. Magnetite is usually accessory, but in specimen 51/637 it forms a few microphenocrysts, probably as a result of replacement of a mineral not in equilibrium with the groundmass. Specimen 51/653, from the summit of Ol Doinyo Gerr, has a glassy groundmass in which only a few laths of sanidine have crystallized.

Another trachyte, somewhat similar to the Ol Esayeiti upper trachyte, occurs within the Ol Esayeiti agglomerate between the trigonometrical beacons of Laisagut North and Laisagut South, the former being about two miles north of the latter. Specimen 51/664 is typical, and appears to be more basic than the usual Ol Esayeiti upper trachyte, because as well as a few phenocrysts of anorthoclase seen in the hand-specimen biotite phenocrysts with a thick reaction rim are nearly completely resorbed; much titaniferous augite is also present.

(12) Ol Esayeiti Agglomerate

The main outcrop of this rock, thought to be a vent agglomerate, is on the summit ridge of Ol Esakut, while other smaller outcrops on its flanks are probably subsidiary vents. The higher part of Ol Doinyo Gerr to the east of Ol Esakut, is also formed by the Ol Esayeiti agglomerate.

It is a somewhat variable, brownish-grey rock weathering light brown or buff, and containing many fragments of older lavas. Specimen 51/663 is a typical example of this agglomerate; the glassy groundmass contains some phenocrysts and a few laths of sanidine. A more tuffaceous example, 51/656, comes from a small oval outcrop on the south-eastern slopes of Ol Esakut. It is lighter in colour than the usual agglomerate and contains only microphenocrysts of sanidine and ferromagnesian minerals. A basic variety is represented by specimen 51/654 from the flat-topped hill north of Ol Doinyo Gerr, where augite and olivine phenocrysts are set in a glassy matrix.

(13) Ol Keju Nero Basalts

These basalts were named the Ol Keju Nyiro Basalts by Shackleton (1945, table opp. p. 6), but Baker, who established a sequence in the Ol Keju Nero river, referred to them as the Ol Keju Nero Basalts (1958, p. 15). Their outcrop at that locality is small, but they cover a much wider area farther east forming a continuous outcrop extending into the Namanga–Bissel area. Nevertheless a succession is difficult to work out because they are extensively grid faulted, whereas the outcrop at Ol Keju Nero was protected from the faulting by the mass of Olorgesailie to the south. Where large rivers dissected the fault scarps, several flows which are each between thirty and fifty feet thick are visible in their banks. These lavas are usually massive but sometimes are vesicular throughout when they are only a few feet thick. Several inches of red bole is common above the individual flows.

Hand-specimens of these basalts are always fine-grained, non-porphyritic, and dark grey in colour. This constant character is maintained in thin section when the only variation is the proportion of fresh olivine or iddingsite. Specimens showing fresh rounded olivine microphenocrysts are represented by 51/446, from the track between Mile 46 and Singiraini, and 51/530, almost seven miles south of Mile 46. Olivine partly replaced by iddingsite is seen in specimens 51/527 and 51/678 from north of Singiraini and south of Ol Esakut respectively. Olivine completely replaced by iddingsite is visible in 51/524 from the river

Turoka, south of Singiraini. This specimen contains a few microphenocrysts of labradorite but is the exception rather than the rule. The microphenocrysts are set in a matrix of labradorite and tabular augite crystals, usually purplish-brown in colour. Probable ilmenite is accessory, usually occurring as scattered, interstitial, angular grains but sometimes forming aggregates. Limonite stains olivine microphenocrysts especially near the margins.

Baker (1958, p. 12) believes that the Ol Keju Nero Basalts represent the last stages of the Olorgesailie vulcanicity, but he could not trace them to vents on that mountain. The basalts in the Ol Keju Nero section overlie the Olorgesailie volcanics and are covered by the alkali trachytes. In the Kajiado area however, the Ol Doinyo Narok Agglomerate and the Ol Esayeiti lavas separate the basalts from the Olorgesailie volcanics. The Ol Keju Nero Basalts outcrop on the lower slopes of Ol Esakut where they overlap various members of the Ol Esayeiti sequence. It seems probable therefore that they originated as the last stages of the Ol Esayeiti eruptions; a short interval elapsed between the basalts and the earlier flows. If the basalts were erupted from Olorgesailie as well, it would mean a return to activity after a considerable period of quiescence. The basalts flowed southwards indicating that the floor of the Rift Valley was down-tilted in that direction as at present. If the basalts flowed northwards they remain hidden under younger rocks.

3. The Pleistocene Volcanic Rocks

(1) Alkali Trachytes

These alkali trachytes are extensively developed in the Magadi area where they form the lower part of the Plateau Trachyte Series; the orthophyre-trachytes represent the upper section. For a comprehensive account *see* Baker (1958, pp. 18–21). They outcrop in a narrow strip along the western boundary of the Kajiado area where they are well-exposed in scarps formed by grid faulting on the Rift Valley floor. The bases of the troughs between fault scarps are usually covered by superficial deposits, masking the underlying rock, but on the tops of the fault-blocks bare rock is mantled by boulders and thin, dusty soil. The surface exposures are often vesicular, but underneath the rock becomes massive, broken only by closely-spaced horizontal joints and more widely-spaced vertical joints. The alkali trachytes overlie the Ol Keju Nero Basalts and the Ol Esayeiti volcanics, but do not come in contact with any older rocks, except for some hills lying on Basement System soil, on the first step of the Rift Valley floor north of the river Seure. These are grouped with the alkali trachytes on their mineralogical similarity although separated from the main outcrop.

The trachytes weather to a reddish brown colour with prominent, yellowish phenocrysts of felspar. When fresh the trachytes are seen to be fine-grained with scattered, clear phenocrysts of felspar. Their colour is usually greenish grey, but some specimens are lighter grey with a reddish tinge.

Under the microscope the rocks are very uniform in character and conveniently described as one group. Representative examples are specimens 51/529 from north of Singiraini, 51/566 from the hills north of the river Seure, and 51/680 from south of Ol Esakut. Sanidine forms the felspar phenocrysts and also stubby laths constituting the bulk of the groundmass. The phenocrysts, which are one to two millimetres in size, correspond to the microphenocrysts described by Baker. Their outline is often irregular with a dusty zone, including prisms of aegirine near their margins. Microphenocrysts of aegirine present in specimen 51/680 are somewhat elongated, but aegirine is usually confined to the groundmass. Cossyrite and kataphorite are also found in this specimen, but in 51/529, aegirine definitely predominates. The two sodic amphiboles are usually present, but are subordinate to pyroxene. In 51/566 however, cossyrite is the most abundant ferromagnesian mineral. A little interstitial quartz is present in specimens 51/681 from south of Ol Esakut and 51/566, but Baker suggests quartz may be widespread throughout the trachytes on the evidence of norms calculated from analyses of specimens collected near Magadi. Iron ore, probably magnetite, is rather rare in these alkali trachytes. The texture is generally trachytic but not as pronounced as in other trachytes which contain more abundant aligned laths of felspar. A non-trachytic variety is represented by 51/597 from the hills to the north of the river Seure; it is fine-grained and probably marginal in character.

Baker (*op. cit.*), suggested the Plateau Trachytes may be correlated with the Limuru Trachyte on petrological similarity; mapping of the intervening ground is required to confirm this. The Limuru Trachyte laps round the northern side of Ol Esayeiti so could connect with the plateau trachytes outcropping on the western side of Ol Esakut.

(2) ORTHOPHYRE-TRACHYTE

This trachyte is included in the Plateau Trachyte Series by Baker (1958, p. 21) because it rests horizontally on the alkali trachytes with complete conformity; it is similar mineralogically, and containing neither quartz nor felspathoids exhibits complete saturation. Nevertheless it is a most distinctive rock in the field and because of different weathering and porphyritic characteristics is separated from the alkali trachytes in this report. It outcrops in several places separated by grid faults on both banks of the Ol Keju Nero and a small occurrence on the Nairobi–Magadi road overlies the alkali trachytes in a fault block. The distinctive surface features of this lava enable outcrops to be easily distinguished both in the field and on aerial photographs. The surface is much rougher than that of other lavas and the trachyte outcrops as large rounded boulders protruding through a thick soil cover. In the Magadi area Baker (1958, p. 7) describes "hot cross-bun" and "tor" structures, originally discovered by Temperley (1955) when examining aerial photographs. These features, however, were not found in the more easterly outcrops. Baker concludes that the lava is still undergoing rapid erosion and disintegration because of these structures, the exfoliated and jointed nature of the outcrops, and the character of the surrounding soil.

The orthophyre-trachyte weathers to a dark brown or black surface from which abundant, large, felspar phenocrysts protrude. The rock is grey in colour with felspar phenocrysts less conspicuous than on weathered surfaces, because when fresh they resemble the colour of the groundmass. The surface is pitted with numerous small angular cavities where crystals have weathered out, imparting a porous appearance. Under the microscope specimen 51/679, from the outcrop on the Magadi road south of Ol Esakut, is seen to be composed of anorthoclase microphenocrysts in a groundmass similar to the alkali trachytes. Macrophenocrysts up to a centimetre in size are present in the hand-specimen. The microphenocrysts, which are approximately rectangular in shape, show cross-hatch twinning and limonite staining along cracks. Some microphenocrysts of green augite are also present, but are smaller than the anorthoclase. The bulk of the groundmass consists of anorthoclase laths which are not so well orientated as in the alkali trachytes. Although green augite forms microphenocrysts it is subordinate to cossyrite in the groundmass. A few rutile needles, magnetite and apatite are the accessory minerals.

4. Superficial Deposits

(1) OLORGESAILIE LAKE BEDS

Although some of these sediments are shown on the geological map, their main outcrop falls within the Magadi area and they have been fully described by Baker (1958, pp. 33–37). A detailed map of the Olorgesailie Prehistoric Site, geologically surveyed by R. M. Shackleton in 1944, is included in Baker's report.

(2) RECENT DEPOSITS

Reddish brown sandy soils, which overlie most of the gneisses of the Basement System, are best developed on the sub-Miocene surface and around hills. Along the river Turoka a deposit of sandy alluvium, not unlike the Basement System soils although often coarser and containing pebble beds, forms cliffs reaching a height of forty feet in places. The alluvium grades into a grey sandy soil overlying the first step of the Rift Valley. This grey soil also passes into redder soil found near the Basement System hills. It may have originated from the usual reddish brown Basement System soils, either by more arid conditions in the Rift Valley or by admixture with soil of the Ol Keju Nero Basalts. To the west the basalt is separated from the grey sandy soil by a strip of black-cotton soil believed to cover the eastern part of the basalts, which may extend farther east under the grey sandy soil.

Limestones of the Basement System yield a poor thin soil with abundant limestone fragments, while kunkar deposits cover much of the parent limestone and neighbouring rocks. When kunkar is formed from hornblendic rocks they often have a reddish tinge instead of the off-white colour indicating derivation from crystalline limestone. Kunkar deposits sometimes form sedimentary dykes, usually following the foliation planes of the gneisses but ramifications extend along fractures. Quartz debris with a little soil is produced from the quartzites and often masks rocks below the quartzite.

Black-cotton soil forms in areas of poor drainage on the Basement System rocks, and is also well-developed to the east and north-east of Kajiado where the overlying lavas have recently been removed. This is the most common volcanic soil type in the area, covering all the lava flows except the Ol Esayeiti and Pleistocene volcanics, which yield a red volcanic soil. The red soil is found on both the Ol Doinyo Narok Agglomerate and the first step of the Rift Valley in the northern part of the area. The Upper Athi Tuffs produce grey soil, and the Kerichwa Valley Tuff a black-cotton soil, which also occurs along rivers flowing through the Upper Athi Tuffs.

In the Basement System river sands consist mostly of quartz, felspar and mica flakes, while garnet, hornblende and iron minerals scattered throughout the sand are rarely well sorted. Felspar, pyroxenes and amphiboles are the commonest sand minerals in rivers flowing through volcanic rocks.

VI—METAMORPHISM

Rocks of the Basement System in the Kajiado area have been subjected to high-grade regional metamorphism. The rock types showing critical mineral assemblages which determine the grades of metamorphism attained, are the pelitic gneisses, limestones and amphibolites.

Garnet is both widespread and abundant in the gneisses, while kyanite and sillimanite are absent, so the area falls into the garnet zone of the Scottish Highlands as described by Barrow (1893). The application of a further classification proposed by Fyfe, Turner and Verhoogen (1958), gives the relationship of gneisses in this zone to mineral assemblages in other rock types.

The lower part of the Turoka Series and the quartzo-felspathic gneisses would appear to fall within the kyanite-muscovite-quartz sub-facies of the almandine-amphibolite facies, while the upper part of the Turoka Series lies in the quartz-albite-almandine sub-facies of the greenschist facies.

The quartzo-felspathic gneisses are characterized by the following assemblages:—

plagioclase-muscovite-biotite-epidote-microcline-quartz
plagioclase-hornblende-biotite-epidote-microcline-quartz.

The presence of microcline indicates that these rocks belong to the potash-rich division of the kyanite-muscovite-quartz sub-facies. There is a possibility however that some of the microcline was introduced during later metasomatism. In gneisses of the lower part of the Turoka Series the same assemblages are common, but with different proportions of the constituent minerals on account of original variations in composition. When garnet is present the following assemblage appears:—

plagioclase-muscovite-biotite-garnet-quartz.

The crystalline limestones are often dolomitic and when impure display critical mineral assemblages such as:—

diopside-epidote-calcite
diopside-tremolite-calcite.

The presence of forsterite at Lundiro indicates that this limestone falls within the silica-poor division of the kyanite-muscovite-quartz sub-facies.

Characteristic assemblages of the amphibolites are:—

plagioclase-hornblende-epidote(-biotite-quartz)
plagioclase-hornblende-almandine(-biotite-quartz).

Biotite and quartz are insignificant in amount because of the original composition of the rocks, while epidote often appears as an accessory mineral. Both assemblages are typical of the kyanite-muscovite-quartz sub-facies.

The upper part of the Turoka Series (above the main limestone horizon) belongs to a lower grade of metamorphism, that of the quartz-albite-almandine sub-facies of the greenschist facies. Typical assemblages are:—

Quartz-microcline-albite-epidote-biotite-muscovite
Hornblende-albite-epidote-biotite.

The former assemblage is characteristic of the psammitic and semi-pelitic rocks, the latter of the amphibolites.

Granitization in the Kajiado area is concentrated in the eastern quartzo-felspathic gneisses, and culminated in the production of *augen* gneisses of the Ngoragaishi hills. As these hills are approached both the number and size of the microcline *augen* gradually increase in the host rocks. In the Turoka Series *augen* are not visible, but under the microscope some microcline replaces earlier minerals. Other felspars are thought to be the result of metamorphic differentiation rather than of granitization, since they do not show replacive contacts.

VII—STRUCTURE

1. The Basement System

The principal structural features are shown in Fig. 4. As in many other areas of Basement System rocks in Kenya the foliation strike is generally NNW.-SSE. but the lineations and minor folds trend ENE.-WSW. whereas it is usual for them to roughly parallel the strike of the foliation. This feature appears to indicate that the structure is abnormal.

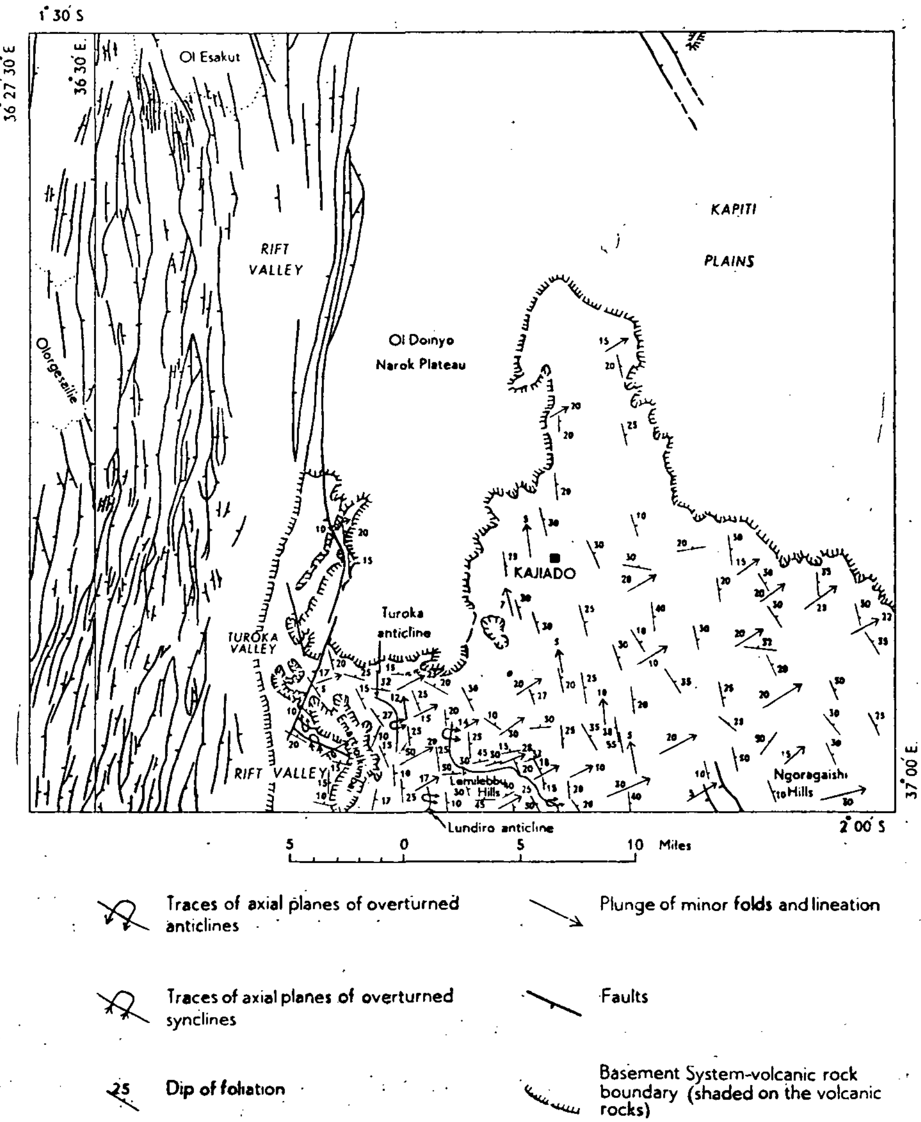

Fig. 4—Structural map of the Kajiado area

(1) Minor Structures

The minor structures will be described first since the interpretation of the major structures largely depends on their evidence.

In the Kajiado area the regional foliation shows variations from the usual generally north-south trend of the Basement System. These variations, which are most prominent along the Turoka Valley and in the Lemilebbu hills and trend approximately east-west, are shown on the structural map, Fig. 4, and plotted stereographically in Fig. 5.

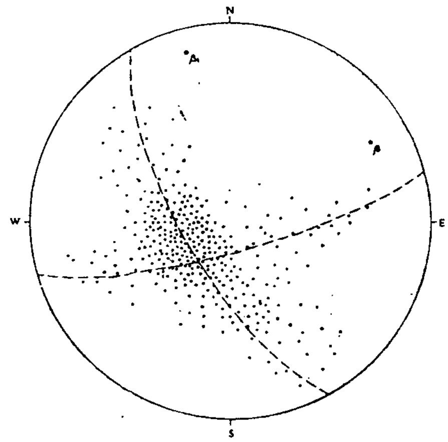

Fig. 5—Stereogram of poles to foliation in the Kajiado area

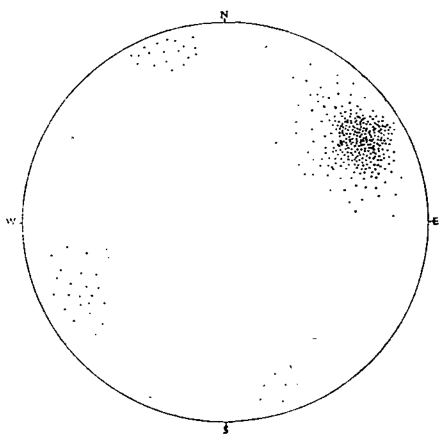

Fig. 6—Stereogram of plunges of minor folds and lineations in the Kajiado area

The most abundant minor structures are folds and lineations which plunge uniformly to the ENE. at angles between 20 and 30 degrees, affecting the regional foliation and the concordant pegmatites emplaced along it. Their orientation is shown statistically in Fig. 6, and is in agreement with fold axis β of Fig. 5 so the lineations are *b*-lineations. The NNW.-SSE. folds plotted on Fig. 6 show the wide discrepancy between their plunges and those of the ENE.-WSW. folds. Except in a belt along the river Kajiado however, the NNW.-SSE. folds are rare. Only one occurrence was observed by the author in the area mapped by Weiss (1958), where mullions plunging NNW. affect a quartzose band on the floor of the northern part of the Kenya Marble Quarries.

The style of the minor folds is well displayed on *ac*-joint surfaces, which, being normal to the fold axes, provide transverse profiles of the folds (Fig. 7). The NNW.-SSE. folds are isoclinal with short limbs and sharp noses, and with overturning towards the west, but the ENE.-WSW. folds range between monoclinal and isoclinal. Their noses also are sharp, but their limbs tend to be long. In some of the tighter ENE.-WSW. folds an axial plane foliation is formed by the re-orientation of mica flakes, which usually parallel the regional foliation of the limbs of the folds.

The commonest type of lineation associated with the ENE.-WSW. folds is striations on foliations. Mineral elongation and intersections of the two foliations were also noted, while rodding is well developed in the quartzites.

Three different types of joints were recognized in rocks of the Basement System. A flaggy jointing parallel to the foliation in the quartzites imparts a slabby aspect to the rocks. Two sets of joints oblique to the ENE.-WSW. lineations are normal to the foliation, and cut each other at angles usually less than 90 degrees. The third type of joint is normal both to the foliation and to the ENE.-WSW. folds and lineations. They occur most frequently near the folds and are *ac*-joints associated with the folds. Although not contemporaneous with the folds, they were formed by the final release of stresses set up during folding.

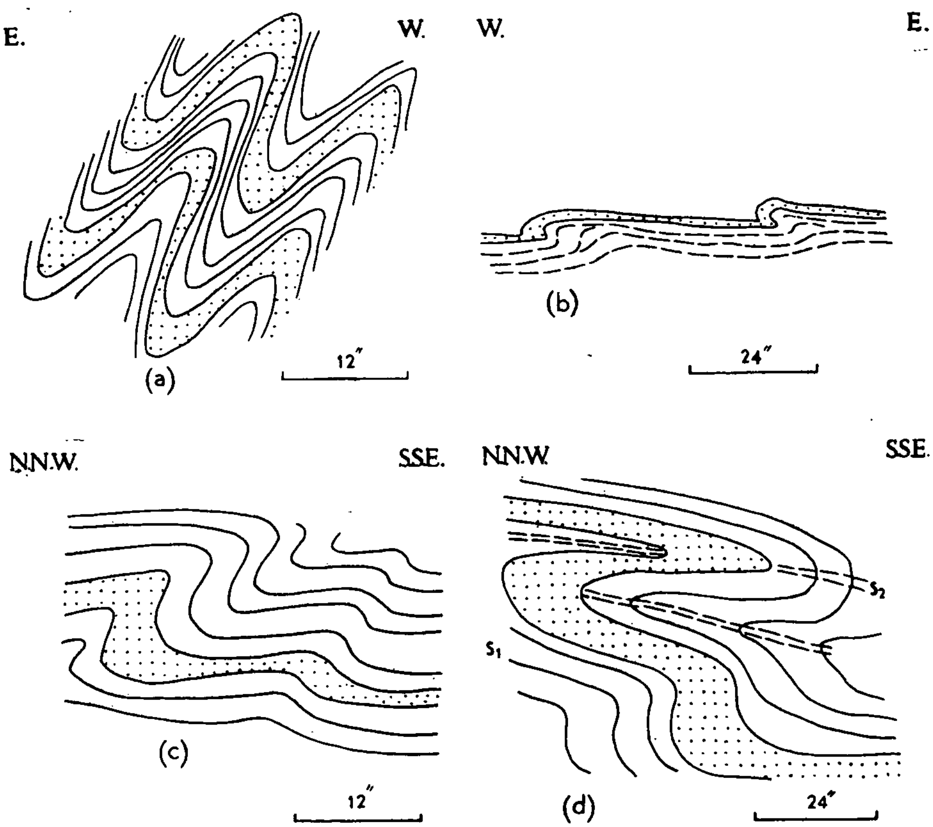

Fig. 7—Minor fold styles

(2) MAJOR STRUCTURES

Major folds can be distinguished only to the west of the river Kajiado, where limestones and quartzites are abundant. As practically all the minor structures in this region trend ENE.-WSW. the major folds probably also trend in the same direction. To facilitate description of the folds, a transverse profile of the region was constructed on the statistical evidence of plunge of the ENE.-WSW. minor folds and lineations at 20° in a direction N. 62° E. (Fig. 8).

Farther east major folds cannot be recognized on account of the similarity of rock types, but on comparison with the orientation of minor structures NNW.-SSE. folds are thought to control the structure along the river Kajiado and ENE.-WSW. folds that to the east of it. The *augen* gneisses of the Ngoragaishi hills are believed to have been formed along a zone of intense movement between the undifferentiated gneisses and the eastern quartzo-felspathic gneisses.

(*a*) *The Turoka Fold*

This fold is formed by a lensoid outcrop of limestone, which encloses biotite gneiss. The Kenya Marble Quarries are located on the northern part of the limestone. The foliation usually dips eastwards at low angles, but in the north the dip is northerly. At the southern closure of the limestone there is a steep belt striking ENE.-WSW., with foliation which is less than vertical dipping towards the SSE. The great majority of the minor folds and lineations plunge to the ENE., but in the northern part of the Kenya Marble Quarries workings there are strong lineations trending NNW.-SSE.

Stratigraphically the biotite gneiss appears to be older than the limestone, so the fold is anticlinal.

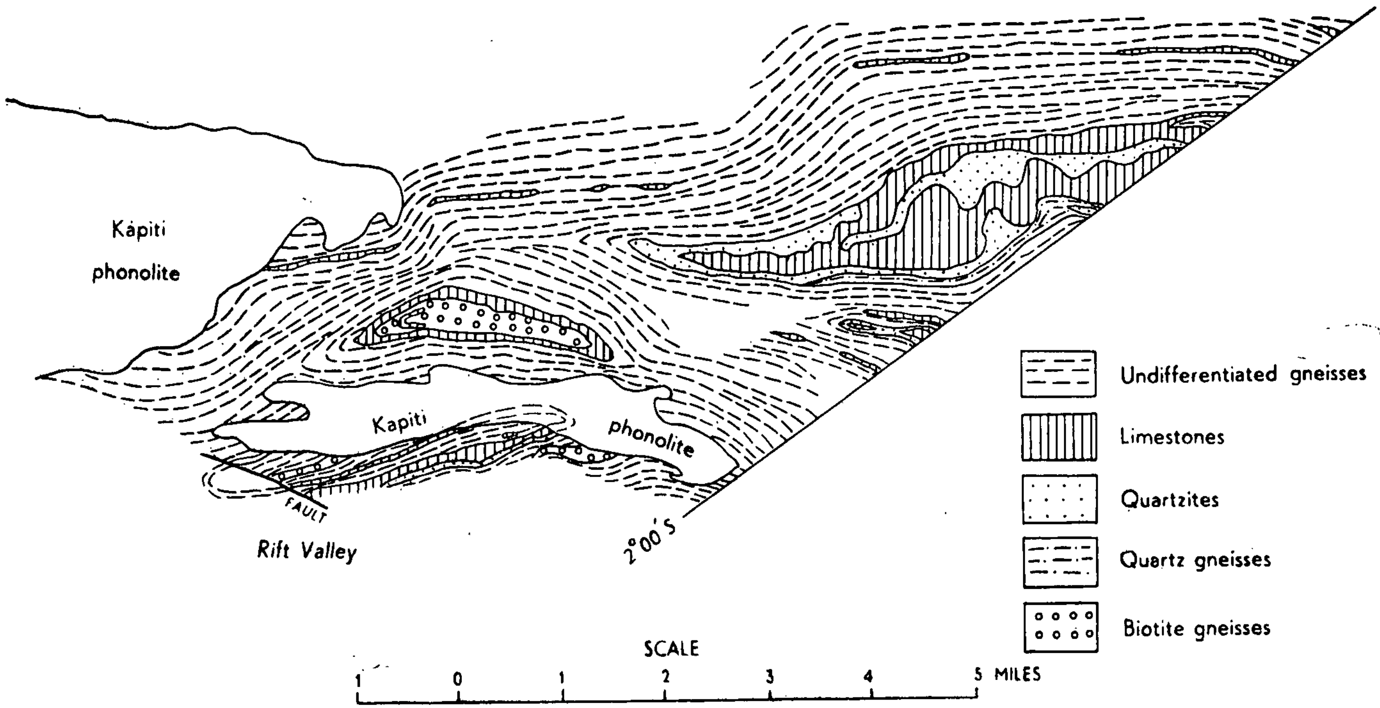

Fig. 8—Transverse profile of the region west of the river Kajiado

(b) The Lundiro Fold

South-south-east of the Turoka fold a crescent-shaped outcrop of limestone forms the low hill of Lundiro at the boundary between the Namanga–Bissel and Kajiado areas. In the southern part the strike of the foliation is ENE.-WSW., with steep dips to the SSE., but in the northern part, lying within the Kajiado area, the dip is 20° to the east. Well-developed minor folds and lineations everywhere plunge towards the ENE.

The limestone outcrop is enclosed by a thin band of quartzite, but as this can be traced only in the northern part in the Namanga–Bissel area it is thought to be of local significance and not representative of the main quartzite horizon, which appears to be older than the limestone. It therefore seems likely that the fold is anticlinal.

(c) The Martiolkimbai Anticline and Syncline

On the western side of Martiolkimbai the foliation dips to the NNE. at low angles, but towards both the southern and northern ends of the outcrops dips become more easterly. The easterly dip continues northwards across the Turoka valley, with a corresponding change from the usual WNW.-ESE. strikes found in the valley. Minor folds and lineations mapped west of Martiolkimbai plunge to the ENE.

Stratigraphically, there is evidence of an anticline near the trigonometrical beacon of Turoka, consisting of an envelope of limestone separated from the core of quartz-felspar-biotite gneiss by more pelitic gneiss. The limestone of the southern limb of this anticline forms the northern limb of a syncline with a core of pelitic and semi-pelitic gneisses. A thin band of quartzite outcrops below the limestone in the southern limb of the syncline, but is not represented elsewhere in the two folds. To the west the folds are cut off by a rift fault and to the east they disappear under the Kapiti Phonolite capping Martiolkimbai. As only ENE.-WSW. minor structures were observed the axial planes of the folds must plunge towards the ENE. To agree with the style of the minor folds it seems probable that the anticline closes westwards and the syncline eastwards.

(d) The Lemilebbu Anticline

The Lemilebbu hills are elongated NNW.-SSE., being composed of sections trending north–south alternating with shorter stretches of east–west alignment. The north–south hills are paralleled by the strike of the foliation, which dips eastwards at low angles, but where the strike is east–west the dip tends to be steeper in a northerly direction. At the changes of strike open folds plunging mostly ENE. can be recognized and are parallel to the ubiquitous minor folds and lineations.

Stratigraphically the quartzite enclosed by limestone in the central part of the hills appears to be the main quartzite horizon which can be traced southwards to the Lemepoiti and Maraparasha outcrops in the Namanga–Bissel area. The quartzite enveloping the limestone at the northern end, on the other hand, dies out on the eastern side, and to the west it passes laterally into quartzose gneisses, and so appears to be only local in extent. As the main quartzite horizon is believed to be older than the limestone, the main fold is anticlinal. It plunges to the ENE., because all the minor folds and lineations plunge in that direction; its roots probably lie in the Namanga–Bissel area. The open ENE.–WSW. folds mentioned above are ascribed to a continuation of the pressures which formed the main fold.

(3) Structural Synthesis

In describing the Namanga–Bissel area Joubert (1957, pp. 38–40) postulated that major folds trend NNW.–SSE. parallel to the regional strike of the foliation. He held that the folds must be isoclinal because he recognized repetition of sequences, with foliation and bedding usually dipping to the east at low angles. He noted that most of the lineations plunge in a direction about 60° east of north (*op. cit.*, p. 42), relating them and open folds on the same trend, which deflect the traces of the NNW.-SSE. folds, to a parallel set of faults. Around Luanji and Metu however, he recorded several lineations plunging at low angles to the NNE. and also related them to faulting on this trend.

The difference between the trends of the supposed major folds and lineations led to a detailed investigation by Weiss (1958) of a small area near the Kenya Marble Quarries, which overlaps both the Kajiado and Namanga–Bissel area. Weiss concluded that the lineations and related minor folds are in fact complementary to the major folds, the latter being recumbent in style, and trending ENE.-WSW. He explained the plunge of the folds to the ENE. by rotation of the whole area about a NNW.-SSE. axis, which must have taken place in a non-tectonic environment, for instance by tilting, since it left no trace on the micro-fabric of the rocks. He thought this tilting took place at a late stage in the deformation because the axis of tilt is normal to the trend of the ENE.-WSW. folds.

It has been shown in the previous sections that there are in the Kajiado area two sets of folds, and the relationship between the two sets is of great importance in the interpretation of the structural history. Unfortunately neither set of minor folds was seen to refold the other or its associated lineations, and both sets fold what appears to be the same foliation, so there is no direct evidence of their relative ages.

If Joubert's hypothesis for the area further south, that isoclinal NNW.-SSE. folds control the structure, were adopted, variations in the trend of the fold-axes from NNW.-SSE. could be attributed to refolding by open ENE.-WSW. folds, which however are too gentle (Fig. 8) to explain the numerous strong minor structures in this direction. The rarity of NNW.-SSE. minor structures west of the river Kajiado, where the variety of rock types enables major folds to be recognized, indicates however that this hypothesis is untenable.

The possibility that the NNW.-SSE. folds are later appears at first sight unlikely because the regional foliation dip is almost always easterly at an average of 25° and there are hardly any reversals of dip which would enable open folds to be recognized. Tighter NNW.-SSE. folds later than the ENE.-WSW. folds could be expected to have produced much more numerous and widespread minor structures and deflections in the trend of the ENE.-WSW. structures than are present, but it is noteworthy that in the only part of the area where lithology can be of assistance in deciphering folds, i.e. in the region of Turoka and the Lemilebbu hills, deflection of the traces of the axial planes of the recumbent folds is mappable. As only ENE.-WSW. minor structures are present the deflections are best explained by continued movement on the same axis.

Although there is a lack of clear evidence indicating the relative age of the two sets of folds the author considers that they are contemporaneous or at least have a genetic connexion, because the two fold-trends are almost mutually perpendicular (Rast, 1958, p. 41; Weiss, 1958, pp. 28–34). Weiss pointed out that the axes of unrelated superposed folds are generally mutually oblique, though they can be perpendicular if the strains producing them are perpendicular.

Regardless of the history of the folding it is believed that in any part of the area the dominant set of minor structure on either trend indicates the style of the major structure present in that region. As it is accepted that the more abundant ENE.-WSW. minor structures reflect the main structure, the Turoka fold must be a rootless elipsoidal cylinder plunging ENE. Weiss (*op. cit.*, p. 50) concluded that the features of the gneissic foliation at the southern closure suggest that the fold once rooted towards the south.

It is suggested that the discrepancy between the style of the major recumbent ENE.-WSW. folds and the monoclinal or isoclinal minor folds can be explained by the presence in all the major folds of limestones which would deform plastically under stress. The minor folds, on the other hand, were nearly all observed in the more competent gneisses.

It is interesting to speculate on the possible cause of the dominance of ENE.-WSW. folds in that part of Kenya between the Rift Valley and the Nairobi–Mombasa railway and the Chyulu volcanics. Although ENE.-WSW. folds are present in other parts of Kenya NNW.-SSE. folds also are found in association with them, whereas Fig. 9 shows the preponderance of ENE-.WSW. folds over the whole region. No NNW.-SSE. folds comparable with those along the river Kajiado have been recorded. The β-axis is somewhat more northerly than in the Kajiado area but this appears to be due to swinging of the axis, for the swing becomes more pronounced farther away from Kajiado, reaching NE.-SW. in the Amboseli area (Williams, report in preparation).

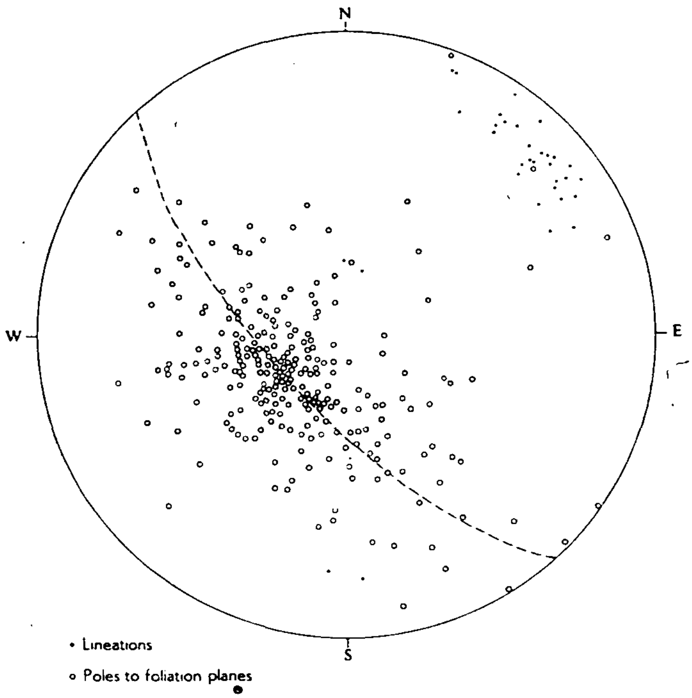

Fig. 9—Stereogram of poles to foliation and minor structures south and east of the Kajiado area

A possible explanation for the presence of ENE.-WSW. folds may be found in the belts of banded, granitoid and *augen* gneisses which trend NNW.-SSE. across the region. The most easterly of these, along a line of granitic domes with concentric structures in the southern Machakos and Sultan Hamud areas (Baker, 1954, pp. 20–22 and Searle 1954, p. 25), forms the north-eastern limit of the region under discussion. Others occur in the south-eastern part of the Kajiado area and in the south-western part of the Namanga–Bissel area. If the *augen* gneisses indicate movement along these zones the place of NNW.-SSE. folds could be taken by thrusting, leaving only rare occurrences of folds as along the Kajiado river. It must be emphasized that this idea is highly speculative and further detailed work would be needed to prove if it is indeed the true explanation of the predominance of ENE.-WSW. folds.

(4) Faults

Two faults were found in the Basement System which are not attributed to rift faulting, since they trend NNW.-SSE. They occur in the south-east and downthrow the *augen* gneisses to the WSW. against the underlying Turoka Series. The fault-planes must be nearly vertical because they do not deviate in direction where they cross areas of different elevation.

2. The Rift Valley

The eastern side of the Rift Valley near Kajiado is a steep scarp formed by several faults. It attains a height of 1,600 feet at the Ol Doinyo Narok plateau but drops to 600 feet in the south. North of the Ol Doinyo Narok plateau the height falls to 1,000 feet, and further north still the scarp consists of several wide fault-blocks instead of one steep slope. The first step on the floor of the Rift Valley is a flat area covered by soils; to the west this gives place to a series of north–south grid-fault scarps cutting volcanic rocks.

The main rift faulting occurred after the formation of Ol Esakut because lavas from this volcano are found on the plateau east of the Rift Valley, as well as on the floor. Major faulting did not affect the Ol Keju Nero Basalts, which are confined to the floor and do not reach the scarp.

The faulting appears to be earlier than the Ol Keju Nero Basalts, but in the west of the Magadi area the Kirikiti Basalts, which Baker (1958, p. 16) suggests may be the equivalent of the Ol Keju Nero Basalts, are cut by the western rift faults. If the eastern rift faults are the same age as the western ones they would therefore be younger than the Ol Keju Nero Basalts. The Eastern faults could then be correlated with either the fault found by Saggerson (report at the press) cutting the Kirikiti Basalts but not the overlying Lengitoto Trachyte, or Baker's second Nguruman fault, which occurs between the Lengitoto Trachyte and the Plateau Trachytes.

Although the main rift scarp is covered by debris, the faults can be recognized both by morphological features and by the displacement of formations. Small outcrops of different rock types on the Rift Valley floor show that the total displacement approximates to the height of the scarp in the north, but to the south where the Basement System and its capping of Kapiti Phonolite were affected, displacement is less. Here there is one fault only with a downthrow of 400 feet, indicated by the displacement of the base of the Kapiti Phonolite. Although the majority of the faults downthrow to the west, there are two notable ones downthrowing eastwards. One of these is found south-west of the river Kibeto, where the Olorgesailie phonolitic nephelinite outcrops at the top of the scarp normally formed by the Ol Doinyo Narok Agglomerate and the Kerichwa Valley Tuff. The effect of this fault is more the uplifting of a small horst rather than a downthrow to the east. The second fault downthrowing to the east separates the hills west of the Ol Doinyo Narok plateau from the plateau itself. The low area between is a small graben bounded on the east by a fault which downthrows to the west.

The Plateau Trachytes which overlie the Ol Keju Nero Basalts in the Kajiado area lap against the Nguruman escarpment at the western wall of the Rift Valley, and outcrop in small hills near the eastern wall, south-west of the Ol Doinyo Narok plateau. They appear to have been erupted therefore after the formation of the main rift faults. These trachytes and the underlying Ol Keju Nero Basalts are cut by grid-faults, with displacements varying from a few feet to several hundred feet, and which often die out rapidly to be replaced by a similar sub-parallel fault. The fault-planes are scree-covered at the base of the scarps. The direction of downthrow is variable so the Rift Valley floor consists of alternating troughs and flat-topped ridges, and as the cumulative downthrow is towards the west the valley floor descends in that direction. The date of grid-faulting is thought to be lower Middle Pleistocene since the Olorgesailie Lake Beds of upper Middle Pleistocene age lap against their scarps. The effect of the two older central volcanoes, Olorgesailie and Ol Esakut, on the grid-faulting varies considerably. The faults north and south of Olorgesailie are less intense than usual, since the bulk of this mountain shielded the adjacent rocks from faulting. South of Ol Esakut on the other hand the faults maintain their intensity, dying out gradually on the lower slopes of the mountain itself. This effect may be due to the faulting having occurred soon after the formation of Ol Esakut, whereas Olorgesailie had been quiescent for a considerable period. It is thought more likely, however, to have been caused by the closer proximity of Ol Esakut to the rift scarp where the grid-faults were probably more intense. Both volcanoes appear to be approximately equal in bulk and are composed of similar rock types, so variation in material would not explain their different behaviour.

Minor faulting which affected the Olorgesailie Lake Beds in the Upper Pleistocene appears to consist of rejuvenation of the grid-faults. The throws in the lake beds are only a few feet, but these can often be traced into grid-faults of much larger throw which affect the underlying volcanic rocks.

Two faults trending NNW.-SSE. cut the Upper Athi Tuffs, the Mbagathi Trachyte and the Olorgesailie phonolitic nephelinite at the river Kitengela, but they cannot be traced far to the SSE. because of the poor exposure of the Upper Athi Tuffs. Both downthrow eastwards, with the eastern fault having a displacement of 40 feet, and the western somewhat less. These faults are believed to be connected with the rift faulting because they affect Pliocene volcanic rocks, but as their trend parallels faults in the Basement System, it seems likely that they represent renewed movements along old lines of weakness.

VIII—ECONOMIC GEOLOGY

The most important economic rock or mineral in the Kajiado area is limestone worked by the Kenya Marble Quarries Co. Ltd. Deposits of quartzite and diatomite were sampled during regional mapping. Metallic minerals were rarely observed but graphite, kyanite and mica found within the Archaean rocks are not sufficiently concentrated to be considered economically interesting.

1. Limestones

The limestone now worked by the Kenya Marble Quarries Co. Ltd. was first prospected in 1919 by Messrs. R. W. Anderson and A. L. Lawley who pegged claims. Before the 1914–1918 war Mr. Pelham Burn had taken out a prospecting licence covering the area but did not pursue the matter.

The Kenya Marble Quarries Company was formed in 1922 with Messrs. Lawley and D. Newmark as partners, who took over the previous leases.

Quarrying commenced in 1922 with an output of fifty tons valued at £140, but for the first few years a loss was made due to production difficulties. In 1924 the company was taken over by Messrs. E. B. Gill and T. A. Wood, and output increased to 2,020 tons worth £2,200 by 1926.

In 1927 the Company granted a sub-lease to Mr. C. Udall, who took over the original leases and the company in 1943. At the present it remains under control of the Udall family who extended the lease to the present area in 1950, and converted it from a mining to a quarrying lease.

The production remained at approximately the same level until 1941, when the value of all products had risen to £5,573. Since then production has risen, apart from a drop just after the war, to a level of 5,000 tons in 1957 worth £29,000. The most important material now produced is slaked lime for agricultural purposes which is burned in several small pit kilns; the large rotary kiln is not used at present. The production of statuary marble has declined because of the lack of suitable marble. The average number of labourers employed in 1957 was forty men quarrying, eighteen processing and sixteen burning. A breakdown of production figures since 1953 is given in Table I.

In 1945 L. O. Svedlund applied for a licence to work the same limestone horizon, farther down the Turoka Valley, for possible cement manufacture. The limestones however proved unsuitable and the project fell through. During this period the East African Portland Cement Co. Ltd. investigated the Turoka limestones before deciding to establish their present quarry at Sultan Hamud. Kenboard Ltd. also prospected the limestones during 1953.

The Turoka limestone forms a triangular outcrop, the eastern side of which runs north-south, the northern boundary east–west, and the western NNW.–SSE. (Fig. 10). The Company's quarry and factory are situated at the north-eastern corner, adjacent to the Magadi railway. R. M. Shackleton (1943) wrote a report for the Mines and Geological Department commenting on the suitability of the limestone for cement manufacture which is referred to here. The core of the outcrop is formed by a pink quartz-felspar-biotite gneiss, while the rocks outside the limestone are biotitic and hornblendic gneisses with thin quartzite bands cut by small pegmatites. The northern side of the limestone band dips north between 30° and 35°, while the eastern and western sides dip east at 20° to 30°.

The cross-section of limestone in the quarry shows a measured thickness of 70 feet, but folding at 60° has caused the width of outcrop to reach a minimum of 1,000 feet. The major band is formed of beds of limestone of various composition, intercalated with bands of siliceous and calc-silicate rocks. The dark silicates are chiefly hornblende, epidote, and diopside, with garnet, phlogopite and wollastonite. They were produced during metamorphism which recrystallized the calcite and dolomite of the limestones. The texture of the latter is coarsely granular, with component grains varying from perhaps 1 mm. to 10 mm. but commonly about 3 mm.

TABLE I.—LIMESTONE PRODUCTION—KENYA MARBLE QUARRIES CO. LTD.

	1956		1957		1958		1959	
	Tonnage	Price per ton (F.O.R.)	Tonnage	Price per ton (F.O.R.)	Tonnage	Price per ton (F.O.R.)	Tonnage	Price per ton (F.O.R.)
		Sh.		*Sh.*		*Sh.*		*Sh.*
Quicklime for caustic soda manufacture	—	—	—	—	—	—	—	—
Quicklime for other purposes..	14	190	4·42	140	11	190	5·75	160
Slaked lime for sugar manufacture	50	155	—	—	—	—	—	—
Slaked lime for other purposes	1,600	155	1,438	175	1,433	170	1,225	170
Lime grit	400	160	855	160	403	160	293	140
Agricultural lime	1,080	58	1,493	58	650	58	373	58
Marble chips	113	140	—	115	—	—	707	160
Marble sand	320	115	217	85	188	140	539	115
Lime for stock feeding ..	510	85	992	—	1,211	85	1,442	85
Total tonnage	4,087	—	4,999·42	—	3,985	—	4,584·75	—

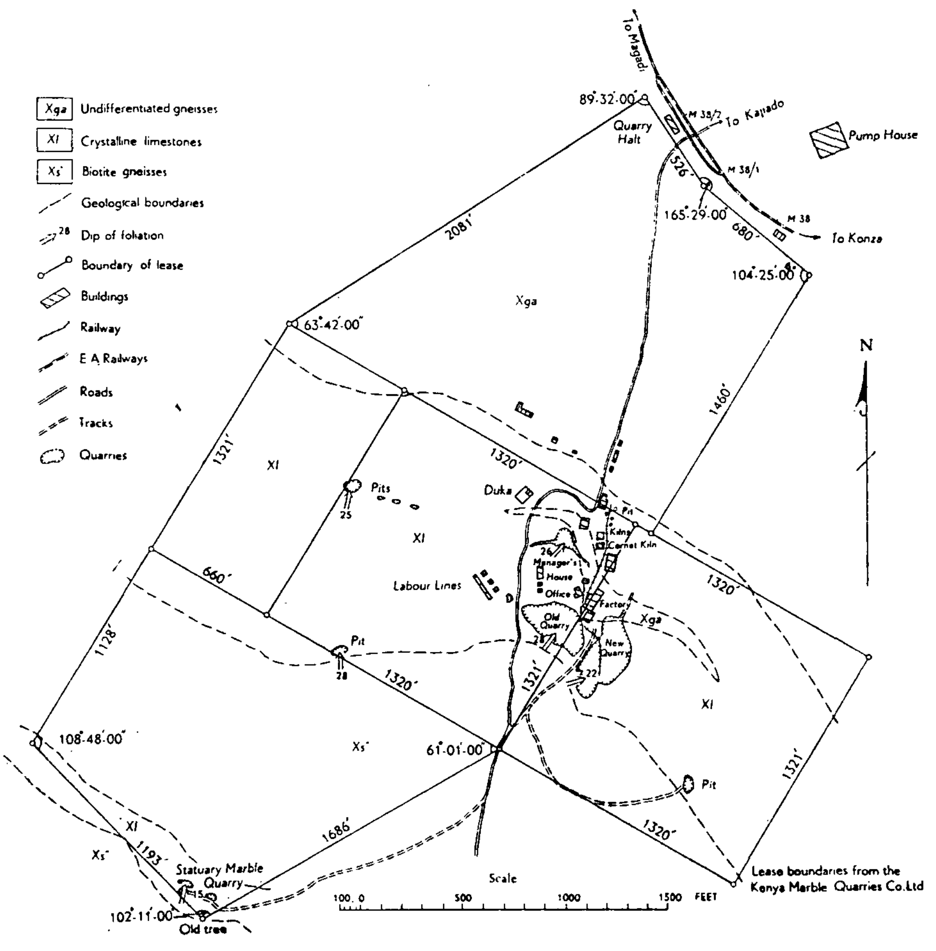

Fig. 10—Plan of the Kenya Marble Quarries

The chemical composition of various samples of the limestone in the quarry are shown below:—

No.	17·547	1812 (1)	1812 (2)	1808	1–13	1–16	1–17
	%	%	%	%	%	%	%
Moisture	—	0·39	0·14	0·12	—	—	—
Loss on ignition	39·79	39·57	36·15	42·04	39·9	40·4	41·1
SiO_2	7·66	5·26	11·38	2·17	3·4	3·6	2·5
Fe_2O_3	1·04	0·86	0·84	0·31	1·0	1·1	0·7
Al_2O_3	1·68	1·24	1·81	1·11	1·0	1·1	0·8
CaO	45·06	43·40	41·79	47·57	48·6	50·1	52·2
MgO	5·13	10·21	7·29	2·55	5·7	3·2	2·2
Alkalis	0·22	—	—	0·37	0·3	0·4	0·3
SO_3	0·66	—	—	—	—	—	—
	100·64	100·93	99·40	96·24	99·9	99·9	99·8

Sample No. 17.547 is a bulk analysis of 30 ft. 9 in. on the face of the new quarry (*see* detailed map Fig. 10), analyst Miss A. F. R. Hitchens, 14.10.44. 1808 is from the white marble quarry, analyst W. Pulfrey, 10.2.45, who also analysed 1812 (1) and 1812 (2) from the north face of the new quarry. Analyses on other samples from this series were not completed since they had a silica content too high for cement manufacture. The remaining three samples were collected by R. M. Shackleton along a measured section through the limestone band in the old quarry on the line of the tramway cutting. They are composite samples giving averages of the beds which he numbered 1–16 from the top. All analyses show too high an MgO content for cement manufacture, although specimen 51/518 from the statuary marble quarry contained only 1·48% MgO. Experimental mixes with red clay from Kikuyu, Athi clay, and black-cotton soil gave a good hydraulic modulus and usually a low silica modulus, but with magnesia running high and lime content and cementation index low, they did not conform to the British Standard Specification.

Other large bands of limestone outcropping in the Lemilebbu hills, at Lundiro and on the west side of Martiolkimbai have not been fully analysed, but hand-specimen 51/462, from the western side of Martiolkimbai, was found to contain 2·20% of MgO. They appear to belong to the same horizon as the Turoka limestone but are less accessible.

2. Diatomite

A deposit of diatomite at Mile 61 on the Magadi railway was first recorded by Prof. Simpson in 1916. The British Government became interested in it for use in the production of dynamite, and it was investigated in 1917 by V. H. Kirkham, then Kenya Government Analyst, whose map is reproduced as Fig. 11. He had 1,500 pits dug, some of which reached a depth of sixteen feet, and information from his detailed account is used in this report.

The deposit is situated at the boundary of the Kajiado and Magadi areas, where the Rift Valley floor is formed by a number of north–south faults. The diatomite occurs in two fault troughs formerly occupied by lakes where the diatoms, whose skeletons form the deposit, lived. Many other diatomite outcrops are found in similar fault troughs in various parts of the Rift Valley.

The diatoms of these deposits differ markedly, and Creighton (1911) has described some of them from localities farther north. The differences may have been due to variation in alkalinity of the waters of the different lakes. Kirkham (*op. cit.* p. 269) states that the frustrules of this deposit are the cylindrical type, similar to those in lake deposits of the Kedong Valley further north. A few acicular forms are also present.

The deposit extends three miles from north to south, with a breadth of some 1,800 feet, and is bounded on both sides by volcanic scarps. The outer fringe of the deposit is generally greatly contaminated with clay and volcanic dust. The diatomite varies from a coarse, green type, through a dark, blue-grey rock, to greenish and yellowish mixtures of diatomite and clay. This becomes whiter before finally grading to the best, light and porous, white diatomite. These changes are sometimes found in clearly defined zones, but at other times are transitional. Accordingly, the boundary on the map was drawn where an arbitrary standard of whiteness, lightness and softness was reached.

The larger eastern deposit attains a depth of eleven feet at the railway embankment, where it was traced for 7,500 feet. It is estimated that the diatomite covers an area of 67 acres and contains some 425,000 tons of diatomite. The northerly extension is very shallow, covering some 10¼ acres, which contain 16,000 tons. The isolated patches south of the main outcrop have a combined area of 4¾ acres, with about 16,000 tons. In the western deposits, covering 33½ acres, there may be 161,700 tons of diatomite, which reach a depth of sixteen feet at the northern extremity. The total area of diatomite surveyed was 115 acres with a computed content of about 620,000 tons.

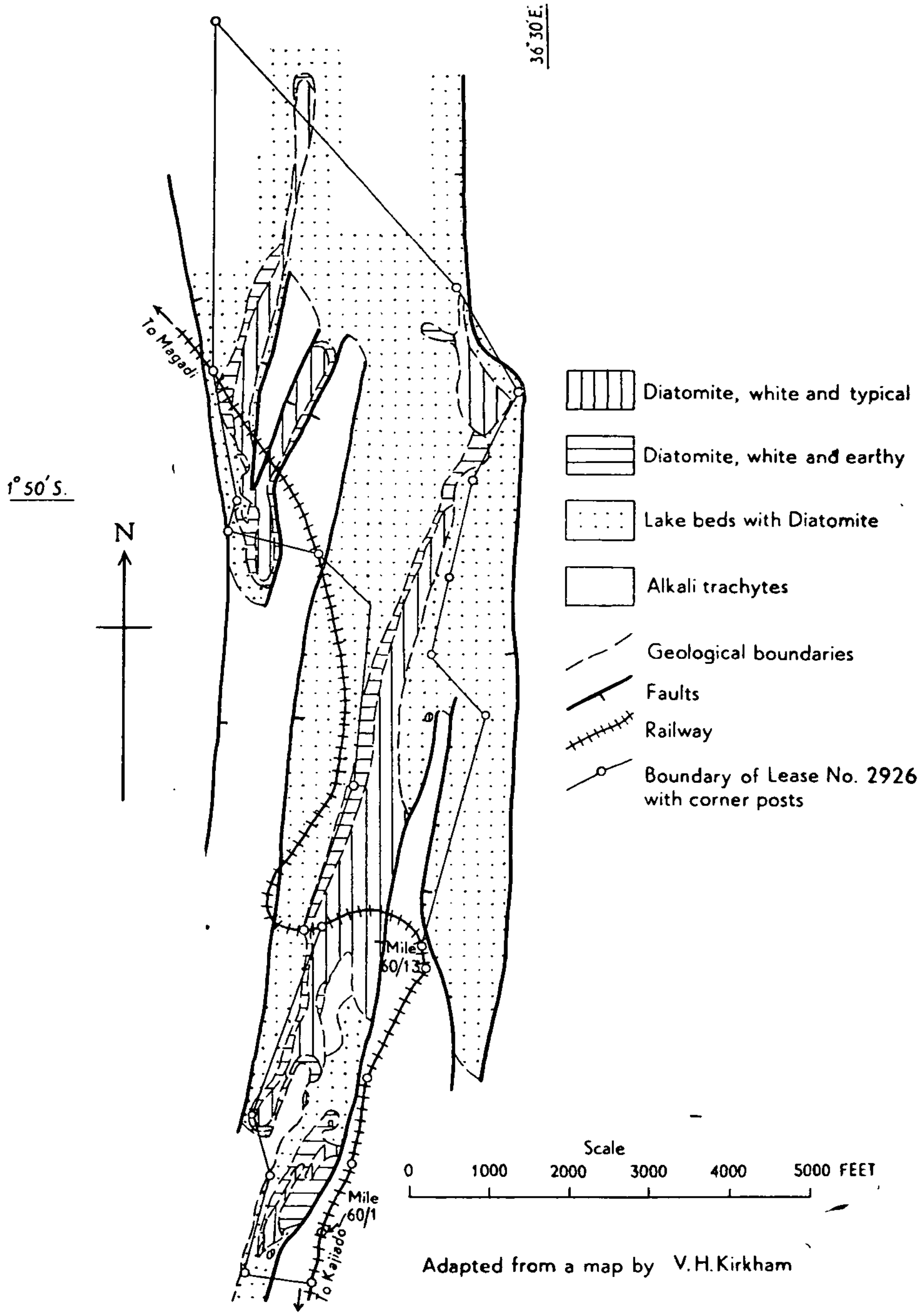

Fig. 11—Plan of the diatomite deposit between miles 60 and 62½ on the Magadi railway

Kirkham subsequently had four composite samples analysed by the Imperial Institute as follows:—

	a	*b*	*c*	*d*
	%	%	%	%
Fe_2O_3	4·04	5·67	5·13	4·97
Al_2O_3	8·86	8·33	7·92	6·78
CaO	2·60	1·63	3·10	1·76
MgO	1·55	1·09	1·23	1·27
SO_3	0·12	0·10	0·11	0·14
P_2O_5	trace	trace	trace	trace
Na_2O	0·50	0·97	0·98	1·42
K_2O	0·70	1·47	0·12	1·00
Sand as SiO_2, etc.	5·40	1·85	3·01	1·30
Loss on Ignition (H_2O)	16·66	14·84	15·20	15·05
Sol. Silica (by difference)	59·57	64·05	62·20	66·29
	100·20	100·00	99·00	99·98

On account of the low nitroglycerine absorption, the deposit would be unsatisfactory for the manufacture of explosives but could be used in the preparation of a catalyst for fat hardening, insulation and abrasives.

Applications to work this deposit have been received from time to time, but none were followed up, with the exception of periodical quarrying by the Magadi Soda Co. Ltd.

3. Quartzite

The quartzites of the Lemilebbu hills were investigated by the author at the request of Kenya Glassworks Ltd. Samples were collected at the northern end of the Lemilebbu hills, and also from a hill adjoining the Kajiado–Namanga road east of the summit of Lemilebbu; these are the most convenient sites for railway and road transport respectively. At both localities the quartzite is massive and translucent with some exceptionally pure horizons. Apart from a few graphitic bands, small amounts of muscovite and magnetite are the only impurities visible in thin section. Numerous iron-stained cavities are present on the surface of the quartzite but do not appear to extend to depth. Chemical analyses in the Mines and Geological Department laboratories, however, indicated 2·7% Fe_2O_3 on selected chips from the purer grab samples collected near the surface. Pitting would be necessary to ascertain the depth of iron-staining.

Once a quarry had been established at a suitable site the tonnage available by working along the strike would be practically unlimited, but no further work has been undertaken by the Company.

4. Graphite

Graphite occurs sporadically throughout the gneisses of the area. The most important horizon is a graphitic gneiss which underlies the lowest marble horizon in the Lemilebbu hills, but the crystals are too small to be worked economically and the location is inaccessible.

5. Radioactive Minerals

A geiger counter was carried during much of the mapping of the Basement System but only near some pegmatites were slight increases recorded over the normal background. These are caused by the usual accessory minerals, such as tourmaline and zircon, which are not sufficiently radioactive or abundant to work profitably, or the potash felspars.

The thick non-radioactive soil cover over much of the Basement System tends to blanket the location of radioactive minerals beneath it.

6. Other Minerals

Copper staining was seen in gneisses of the Basement System but consists of small films of chalcopyrite along the foliation and is infinitesimal in amount.

Garnet is abundant but usually forms small impure crystals. Even when purer the crystals are too small and scattered to be workable.

Pegmatites are frequent throughout the Basement System; the discordant types are usually composed of large crystals of *perthite*. This potassic felspar is suitable for use in the manufacture of china and glass. *Magnetite* and *tourmaline* are often present in pegmatites, but always as small, scattered crystals.

7. Building Sand

A. N. Sharma Ltd. of Nairobi and Athi River maintains a camp near the river Senya from which sand for building is dug. Although the river here flows through the Kapiti Phonolite the sand used is derived from the Basement System drained by the head waters. Other rivers such as the Kajiado, Turoka and Mataraguesh should be equally suitable, but have only been used locally because of their distance from industrial centres.

The upgrading of quartz-rich sand especially in rivers draining the quartzites, should not be difficult, and may be worth consideration. The resultant product should command a better price, being more suitable for certain building requirements.

8. Road-metal and Railway Ballast

Where the Athi River–Kajiado road runs across the Kapiti plains, the Upper Athi Tuffs are used as metal, giving a stony surface which is rough but passable in wet weather. The material is obtained from pits alongside the road. Farther south where the road lies on the Basement System, murram is preferred, as is the case on most of the Kenya Marble Quarries road, although over parts of the latter marble chips are common. Other roads remain unmetalled.

The Kapiti Phonolite is important for railway ballast, and was railed to parts of the track lying on the Basement System. In the Rift Valley the olivine basalts and alkali trachytes are also used for this purpose.

9. Water

No perennial rivers flow in the area so water supplies are scarce, and the local population depends largely on bore-holes and the old pipeline to Magadi. Water can be obtained by digging in the bed of the Kajiado river, and several small dams retain some of the flow. More dams are being constructed in various parts of the Kajiado District in connexion with a Masai grazing scheme. There are also some perennial springs on the Ol Doinyo Narok plateau: localities are shown on the geological map.

The pipeline is administered by the Ministry of Works because the Magadi Soda Company now obtains water from the Loita hills. The headworks on the south-eastern slopes of the Ngong hills consist of springs, reservoirs, wells, and a borehole, with a total yield of between 75,000 and 95,000 gallons per day. The pipeline runs to Kajiado and then follows the railway towards Magadi. The consumption at Kajiado is about 20,000 gallons per day, shared between the railway and some private consumers.

The pipe-line also supplies Quarry Halt, Turoka, Mile 46 and Singiraini railway stations, together with plate-layers' huts along the line. The piped supply may be supplemented by three bore-holes near Turoka station which can provide up to 30,000 gallons per day.

Most of the bore-holes in the area are situated in natural drainage basins, obtaining water from permeable bands such as biotite gneisses, within the Basement System. In volcanic areas the best supply comes from the junction of volcanic rocks and the Basement System, the weathered surface of which acts as aquifer.

Details of bore-holes drilled in the area, from records of the Hydraulic Branch of the Ministry of Works, are tabulated below; localities of bore-holes are shown on the geological map.

BORE-HOLE DATA—KAJIADO AREA

Bore-hole No.	Location	Depth in feet	Depth at which water was struck	Height to which water rises	Yield
			(*feet*)	(*feet*)	(*gal./hr.*)
C.138	Kajiado Dam..	240	120	17	330
C.155	Kajiado No. 1	183	105, 165	78	850
C.381	Kenya Marble Quarries ..	421	102	74	900
C.451	Turoka mile 42/4	450	360, 395, 442	348	1,500
C.587	Ol Kiloriti	301	135, 185	78	2,000
C.605	Turoka mile 42/12	490	370, 428, 445	400	2,000
C.811	Oloiyangalani	425	78	59	980
C.998	Ngorika	450	393	97	200
C.1368	Mile 34, Kajiado road ..	600	110, 360	80	340
C.1387	Mile 37, Kajiado road ..	180	150	23	360
C.1390	Turoka, mile 45	560	—	—	—
C.1391	Turoka, mile 43/2	500	450	363	2,300
C.1427	Kajiado No. 2	451	95, 330	79	580
C.1539	Sajaloni	375	77	52	2,310
C.1569	G. C. Jarens	202	156	12	10,600
C.1713	Kibeto..	582	319	180	120
C.2587	Kajiado No. 3	600	160, 360, 536, 582	75	650
C.2646	Daudi Mokinyo Ranch ..	300	200, 265	125	320

The following bore-hole logs were compiled by geologists of the Hydraulic Branch of the Ministry of Works:—

C.138. KAJIADO DAM

Depth (*feet*)	*Section* (*feet*)	*Strata*
12	12	Topsoil.
18	6	Gneiss.
42	24	Gneiss and quartz.
144	98	Very hard gneiss.
188	44	Very hard gneiss.
240	52	Granitoid-gneiss.

C.155. KAJIADO NO. 1

Depth (*feet*)	*Section* (*feet*)	*Strata*
5	5	Red soil.
50	45	Weathered gneiss.
183	133	Gneiss and granulite.

C.381. Kenya Marble Quarries

Depth (feet)	*Section (feet)*	*Strata*
20	20	Brown sandy soil.
90	70	Weathered epidote-muscovite gneiss.
230	140	Quartz-biotite-muscovite gneiss.
270	40	Quartz-biotite gneiss.
422	152	Pyritized graphite gneiss.

C.451. Turoka Mile 42/4

Depth (feet)	*Section (feet)*	*Strata*
21	21	Cemented, gneissic, detritus subsoil.
120	99	Gneissic and fragmented gneiss.
125	5	Granitic biotite gneiss.
160	35	Quartzo-felspathic schist.
176	16	Granitic-gneiss.
208	32	Biotite gneiss.
274	66	Quartz-epidote-muscovite schist.
282	8	Biotite gneiss.
288	6	Pegmatite.
354	66	Biotite schist.
392	38	Quartzitic gneiss.

C.587. Ol Kiloriti

Depth (feet)	*Section (feet)*	*Strata*
4	4	Soil.
301	297	Gneiss.

C.605. Turoka Mile 42/12

Depth (feet)	*Section (feet)*	*Strata*
8	8	Brown soil.
208	200	Cemented, gneissic detritus.
210	2	Pegmatite.
250	40	Muscovite-biotite schist.
310	60	Felspathic schist (weathered).
368	58	Biotite schist.
370	2	Quartz-biotite gneiss.
490	120	Coarse biotite gneiss.

C.811. Oloiyangalani

Depth (feet)	*Section (feet)*	*Strata*
48	48	Grey Tuff.
86	38	Phonolitic-trachyte.
110	24	Phonolitic-trachyte.
123	13	Grey Tuff.
187	64	Grey lava (? K.P.).
425	238	Grey Tuff at top followed by sub-aqueous tuffs and lake beds, over residual Basement deposits.

C.998. NGORIKA

Depth (feet)	Section (feet)	Strata
82	82	Grey clay.
159	77	Granitic gneiss pink.
254	95	Granitic gneiss grey.
299	45	Granitic gneiss; grey and pink pegmatite.
338	39	Pink pegmatite.
393	55	Grey, granitic gneiss.
422	29	Quartz-biotite gneiss.

C.1368. MILE 34 KAJIADO ROAD

Depth (feet)	Section (feet)	Strata
3	3	Grey sand.
28	25	Greenish clay.
105	77	Greenish tuff.
186	81	Lava or lava fragments in clay.
310	124	Felspathic lava.
405	95	Lava and deposits.
500	95	Lava and deposits.
600	100	Lava with red mineral.

C.1387. MILE 37 KAJIADO ROAD. SENYA DETENTION CAMP

Depth (feet)	Section (feet)	Strata
4	4	Soil.
35	31	Lava K.P.
92	57	Lava K.P.
101	9	Glassy lava.
148	47	Quartz sand.
180	32	Quartz-biotite gneiss.

C.1390. TUROKA MILE 45

Depth (feet)	Section (feet)	Strata
165	165	Soil.
545	380	Trachyte.
551	6	Old sand surface.
560	9	Volcanic ash.

C.1391. TUROKA MILE 43/2

Depth (feet)	Section (feet)	Strata
40	40	Soil.
210	170	Weathered gneiss.
500	290	Gneiss.

C.1427. Kajiado No. 2

Depth (feet)	Section (feet)	Strata
2	2	Clay.
35	33	Gneiss.
45	10	Mica.
345	300	Gneiss.
451	106	Schist.

C.1539. Sajaloni

Depth (feet)	Section (feet)	Strata
377	377	Metamorphic rocks.

C.1569. G. C. Jarens

Depth (feet)	Section (feet)	Strata
25	25	Kapiti phonolite.
135	110	Alkali phonolite.
202	67	Sand and gravel.

C.1713. Kibeto

Depth (feet)	Section (feet)	Strata
40	40	Clay.
205	165	Hard black lava.
520	315	Lava.
582	62	Clay.

C.2587. Kajiado No. 3

Depth (feet)	Section (feet)	Strata
18	18	Brownish, silty soil.
22	4	Grey, ashy silt.
26	4	Yellowish, ashy silt.
29	3	Yellowish, silt with fine biotite.
120	91	Weathered, biotite granulite.
165	45	Weathered, biotite granulite with pink felspar.
402	237	Grey, biotite granulite with felspar.
441	39	Black, hornblende granulite.
500	59	Grey biotite granulite.
519	19	Greyish brown biotite granulite.
600	81	Grey, biotite granulite.

C.2646. Daudi Mokinyo Ranch

Depth (feet)	Section (feet)	Strata
53	53	Decomposed gneiss.
300	247	Gneiss.

Water from several of the bore-holes has been chemically analysed, and the results are given in Table II. Although most of the water is somewhat hard it is suitable for domestic consumption, but the fluorine content is usually on the high side. Most of the water analysed is from bore-holes in the Basement System, and the fluorine content is appreciably lower than water found in volcanic parts of the country.

TABLE II.—WATER ANALYSES FROM THE KAJIADO AREA

Borehole No.	C.138	C.155	C.587	C.811	C.1387	C.1390	C.1391	C.1427	C.1713	C.2587
Lab. No.	558/1946	4080/1954	1168/1947	161/1949	1191/1951	318/1951	319/1951	1270/1951	458/1952	4163/1956
Date	3–6–46	26–11–54	25–9–47	7–2–49	3–7–51	12–2–51	12–2–51	14–7–51	17–3–52	4–12–56
Turbidity	—	None	—	—	Slight	Nil	Nil	Nil	Opalescent	None
Colour	—	Clear	—	—	Clear on standing	Nil	Nil	Clear	Faint whitish	None
Odour	—	None	—	—	Slight earthy	Nil	Nil	Nil	Sulphurous	None
Suspended Matter	—	None	—	—	Some clay	Nil	Nil	Some inorganic	Some inorganic	Slight
pH	6·9	7·1	7·1	7·9	7·5	7·1	7·1	7·05	8·7	7·3
Alkalinity (as $CaCO_3$)										
carbonate	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	5·6	Nil
bicarbonate	35·0	38·6	38·9	38·7	36·4	36·3	42·2	42·2	100·5	39·4
Ammonia										
saline	0·005	0·008	Nil	Trace	0·022	—	—	0·01	—	0·020
albuminoid	0·004	0·004	Nil	0·003	0·006	—	—	0·004	—	0·008
Oxygen absorbed										
4 hrs. at 80° F.	—	—	—	Trace	0·109	—	—	0·05	—	—
Chlorides (as Cl)	9·6	20·2	2·0	11·3	8·5	13·9	28·1	32·4	22·8	25·1
Sulphates (as SO_4)	2·8	Trace	Trace	3·2	3·8	2·0	2·0	2·0	19·2	2·5
Nitrites (as NO_2)	Nil	Nil	Trace	Trace	Present	—	—	Nil	Nil	Nil
Nitrates (as NO_3)	Nil	Trace	Present	Present	Present	—	—	Trace	Trace	Nil
Calcium (as Ca)	7·3	10·2	9·74	3·4	5·0	10·2	18·4	13·9	—	13·3
Magnesium (as Mg)	3·8	3·9	6·16	1·4	0·55	3·7	5·6	4·6	—	3·8
Iron (as Fe)	—	0·15	—	0·07	0·015	0·12	0·18	0·03	0·055	0·06
Silica (as SiO_2)	—	7·2	—	2·4	4·2	6·0	2·6	7·0	1·3	6·0
Total Hardness (Soap)	34·0	41·6	49·6	14·2	18·9	40·8	69·0	53·6	2·0	48·9
Permanent Hardness	6·0	3·6	12·5	—	Nil	4·5	26·8	11·4	—	9·5
Temporary Hardness	28·0	38·0	37·1	—	18·9	36·3	42·2	42·2	—	39·4
Free Carbon Dioxide	Present	—	Present	—	—	—	—	—	—	—
Total Solids	60·0	84·5	47·0	68·4	67·8	81·0	124·0	114·1	180·0	189·0
Fluorides (as F, p.p.m.)	2·7	2·2	—	—	3·4	—	—	2·15	3·1	0·9

All analyses are in parts per 100,000 except for the fluorine which is in p.p.m.

Analyst: Government Chemist.

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