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GEOLOGY OF THE NAMANGA-BISSEL AREA

EXPLANATION OF
DEGREE SHEET 58 N.E. AND S.E.
(with coloured geological map)

by

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FOREWORD

A few months ago Geological Survey reports on the Masai country south of Sultan Hamud and the southern Machakos area, immediately north of it, were published. The work carried out for those reports has now been extended to the west by Mr. Joubert who covered a large area between Kajiado and the Tanganyika border on the east flank of the southern part of the Kenya Rift Valley, and in the present report gives an account of his findings and conclusions. The area is particularly interesting as it adjoins the basin of the Turoka river, where in 1913 the late Dr. J. Parkinson mapped and defined a group of ancient metamorphosed sediments that he called the Turoka Series. The rocks of the series extend southwards into the Namanga-Bissel area, and form a considerable part of the exposed geological succession. Some years ago rocks of the Turoka Series and beds resembling them were grouped together in the Basement System, a term used to embrace all of what are considered to be the oldest rocks in East Africa. In the present report, however, as the Turoka Series is so readily distinguished on the ground, it has been found convenient to retain the name for the part of the Basement System that corresponds with Parkinson's type series. The name Turoka Series is familiar to all geologists in Africa south of the Sahara, and it is felt that its preservation together with a modern description will be welcomed.

The Namanga-Bissel area is also of great interest as it is adjacent to areas of unusual geological complexity in southern Machakos and near Sultan Hamud. In these areas notable concentric structures have developed in the Basement System rocks and have been ascribed to compression and rotation around centres of granitization. In the area mapped by Mr. Joubert there are no such centres, but his work has proved that the ancient rocks have been pushed from the east into a series of overturned folds. Mapping of the detail of the rocks has shown that lineation is usually almost at right-angles to the trends of the foliation traces. Little sign of overthrusting was seen during the mapping, except locally, but it seems likely that there must have been an unusual amount of stretching and dragging in the direction of the forces that caused the folding, and that when more time can be devoted to detailed mapping evidence of much shuffling and overthrusting will be found. Further north-east, where a large area has been mapped in the Kitui area, lineation is always approximately parallel to the foliation, and it is clear that it was not until the region of the Rift Valley was approached that effective resistance to forces from the east in Basement System times was encountered, so leading to the unusual structures described in this and earlier reports.

The area around Bissel has long been known for its bands of marble, and the map accompanying the report shows in detail how extensive and widespread they are. The suggestion is made that some of the bands may be composed of limestone suitable for the manufacture of cement. During the survey Mr. Joubert also discovered horizons in which kyanite is constantly found, though in a disseminated form and not as segregations. Graphite occurs in some of the kyanite-bearing beds, and is also found in non-kyanitiferous beds, where is is much more promising for working. A deposit north of Namanga has been worked for a few years on a small scale by a prospector experienced in methods used in Madagascar, and an account of his operations is given in the report.

Nairobi,
25th February, 1954.

WILLIAM PULFREY,
Chief Geologist.

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MAP

Geological Map of the Namanga-Bissel area, Kenya (Scale 1:125,000)	At end

ABSTRACT

The report describes an area in Southern Kenya enclosed by latitude 2° S., longitudes 36° 30′ and 37° 00′ E. and the Kenya-Tanganyika boundary. Five morphological features are recognized: (1) scattered relics of an old peneplain probably of late Jurassic age; (2) remnants of the end-Cretaceous peneplain; (3) the sub-Miocene peneplain; (4) the Rift Valley and (5) the end-Tertiary peneplain.

The rocks in the area comprise: (1) A thick succession of schists, gneisses, granulites and crystalline limestones of the Basement System, cut by minor acid and basic igneous intrusions; (2) Tertiary phonolites forming a small outlier in the north of the area; (3) olivine basalts of the Rift Valley occurring in the north-west part of the area; (4) lavas belonging to the Kilimanjaro flows in the south of the area, and (5) superficial deposits. The petrography of the rocks is given and the effects of granitization upon the rocks of the Basement System discussed. An account of the major and minor structural features of the Basement System is given and the economic prospects of the area are considered.

GEOLOGY OF THE NAMANGA-BISSEL AREA

I—INTRODUCTION

The area covered by this report comprises the north-eastern and south-eastern quarters of degree sheet 58 (Kenya Colony), bounded by latitude 2° 00′ S. and the Kenya-Tanganyika boundary, and by longitudes 36° 30′ and 37° 00′ E. The area, which is approximately 1,240 square miles in extent lies within the Kajiado district of the Southern Province of Kenya (formerly part of the Masai extra-provincial district), the administrative centre being Kajiado, twelve miles by road north of the area. Bissel, a trading centre near the northern boundary also contains a Police Post, a fairly large African school, a dispensary and a veterinary station. Namanga is situated on the Kenya side of the interterritorial boundary on the Great North Road, and consists, apart from a number of shops, of a Police Post, a dispensary, a restaurant and a well-known hotel with all modern conveniences. The only other small trading centre, Metu, is situated in the south-western corner of the area.

Environment

Except for two small Kikuyu settlements on Ol Doinyo Orok, Diasega and Gorogoro, where the land is intensively cultivated, the area is inhabited by the nomadic Masai. The distribution and density of the population depend largely on the distribution of bore-holes and surface water; during the dry seasons some areas are entirely devoid of human beings, all Masai *manyattas* being found in the vicinity of bore-holes or water-holes. Overgrazing at such places is evident and often accentuated by the grass fires at the end of every dry season.

Birds, game and big game are abundant in all parts of the area; the south-eastern half of the area forms part of the Amboseli National Reserve, while the rest of the area lies in the southern Game Control area where, however, occasional hunting is allowed.

The Namanga and Kidongai rivers, draining different parts of Ol Doinyo Orok, are the only perennial streams in the area and even they discharge into seasonal swamps when they reach low ground on the east, and disappear. While being raging torrents after heavy rains, the streams draining the other hills dwindle to mere trickles in the dry season, soaking into the ground and disappearing as soon as the plains are reached.

Permanent water occurs as seepages from the mountainous areas of Maparasha, Ol Doinyo Orok, Metu hills and Lemipoiti. Water is mostly obtained from small wells dug in the beds of sand-rivers, but these become dry towards the end of the dry season. Apart from the higher rainfall on and around Ol Doinyo Orok, the annual rainfall decreases towards the south-east with the relative decrease in elevation, the hilly areas having more rain than the adjoining plains. The greater part of the area lies between 4,000 and 5,500 ft. above sea-level, with a maximum precipitation from January to May.

Little data on the annual rainfall is available, owing to the paucity of observation stations (see table below taken from the published records of the E.A. Meteorological Department). Observations at Bissel only started in June, 1951. Measurements during 1951 are in concordance with the exceptional rainfall observed over most parts of Kenya during that year.

Station	Annual Total				Number of years recorded
	1950	1951	1952	Average	
Kajiado D.O.	12·81	46·51	17·22	20·02	22
Namanga Dispensary ..	20·67	46·41	20·55	28·72	8
Bissel	—	9·82*	18·39	—	1

*June to December, 1951, only.

Concrete reservoirs for the conservation of rain-water exist at Namanga and Lemipoiti.

Vegetation

The distribution of different types of vegetation is controlled by the moisture condition of the soil, the type of underlying rock and the elevation above sea-level. Areas of black cotton soil are covered by typical rank grass and the whistling thorn (*Acacia drepanolobium*). In the valleys between the hills, thickets of evergreen forest occur, with an abundance of nettles on rocks of granitic composition.

The presence of *Acacia pennata* Willd, a straggling thorny growth, always indicates quartzite or a quartzitic horizon and it was also found along the strike of silicified fault-zones. *Commiphora pilosissima* (Engl.) is common but especially abundant on calcareous horizons, where there is a relative decrease of grass cover. The species mentioned were very useful in following horizons in places where exposures were poor.

Patchy forest occurs on Ol Doinyo Orok above 6,000 feet elevation. According to a short report of the Forestry Department, the preponderance of *Croton* and Cape Chestnut trees, both relatively dry area specimens and the presence of large, mainly overmature *Piptadenia* and *Albizzia* trees, indicate that the forest is gradually changing from a wetter to drier type, and has an annual rainfall of about 35 inches.

Communications

The main Cape-to-Cairo route (A104) traverses the area from south to north and is usually in very good condition, but is sometimes closed to heavy traffic during periods of excessive rainfall. The other roads indicated on the map become waterlogged over long distances during the rainy seasons and the road from Namanga to Ol Tukai is closed, as no traffic is allowed in the Amboseli National Reserve during these periods. The road skirting the northern and north-eastern slopes of Maparasha is being extended to join the road leading to Selengai, east of the area. Immediately north of the area the railway line, linking Magadi Soda Lake with the Nairobi-Mombasa railway, runs east to west.

Maps

The topography of the geological map is based on G.S.G.S. No. 1764, Magadi district (1:250,000) published in 1916, and on E.A.F. No. 1284, Longido (1:125,000), 1943, for the south-eastern corner. It was found necessary to modify the topography given and to add much detail. Form-lines are not accurate on the present map, elevation measurements having been taken with an aneroid barometer. For the south-eastern corner, including most of Ol Doinyo Orok, air photographs were available, the rest of the mapping being done by plane-table.

Names were taken from existing maps, and alterations made where present pronunciation differed. Names for the same prominent topographical features were sometimes found to vary in different parts, but where one name was known over a wide area it has been adopted on the map. The Sokota river was found to have at least three names at different places along its course, but only the name appearing on the existing maps has been used.

Previous geological work

In 1883 Joseph Thomson passed through the area on his way to the north. He came past Lake Amboseli to Ol Doinyo Orok and from there through the Matumbato area towards Nairobi (Loftus, 1951)*.

J. Parkinson (1913) described a group of crystalline rocks situated immediately below the southern edge of the great lava-plateau of the Kapiti plains near Turoka station, north of the area under discussion. He proposed the name Turoka Series for the group, which includes a wide variety of metamorphosed sediments occurring at Turoka and in the present area, e.g. at Bissel (Il Besil of Parkinson). These rocks comprise the major part of the Basement System in the area under discussion.

J. W. Gregory (1921, pp. 181–183) described the lavas and phonolites of the Turoka-Magadi area and gave an east-west section across the Rift Valley in that area, illustrating the relationship between the Basement System, the Kapiti phonolite and later lavas.

In September, 1949, a graphite occurrence near the northern foot of Ol Doinyo Orok was examined by A. Huddleston of the Mines and Geological Department and assays were made on samples he collected. O. C. McMahon pegged claims on the occurrence during February, 1951, and started working in July of the same year. He was encouraged by the interest of an overseas firm to whom he had sent a specimen sample of good flake graphite. Assistance in various forms was given by the Department to aid the development of the prospect. Several visits were made by geologists, progress checked, and the graphite deposit mapped and reported on (unpublished reports, D. L. Searle, 1951; W. Pulfrey, 1951; D. K. Hamilton, 1951). Up to date Mr. McMahon has been unsuccessful in producing any large quantity of the quality of graphite required to meet commercial specifications.

*References are quoted on p. 49

II—PHYSIOGRAPHY

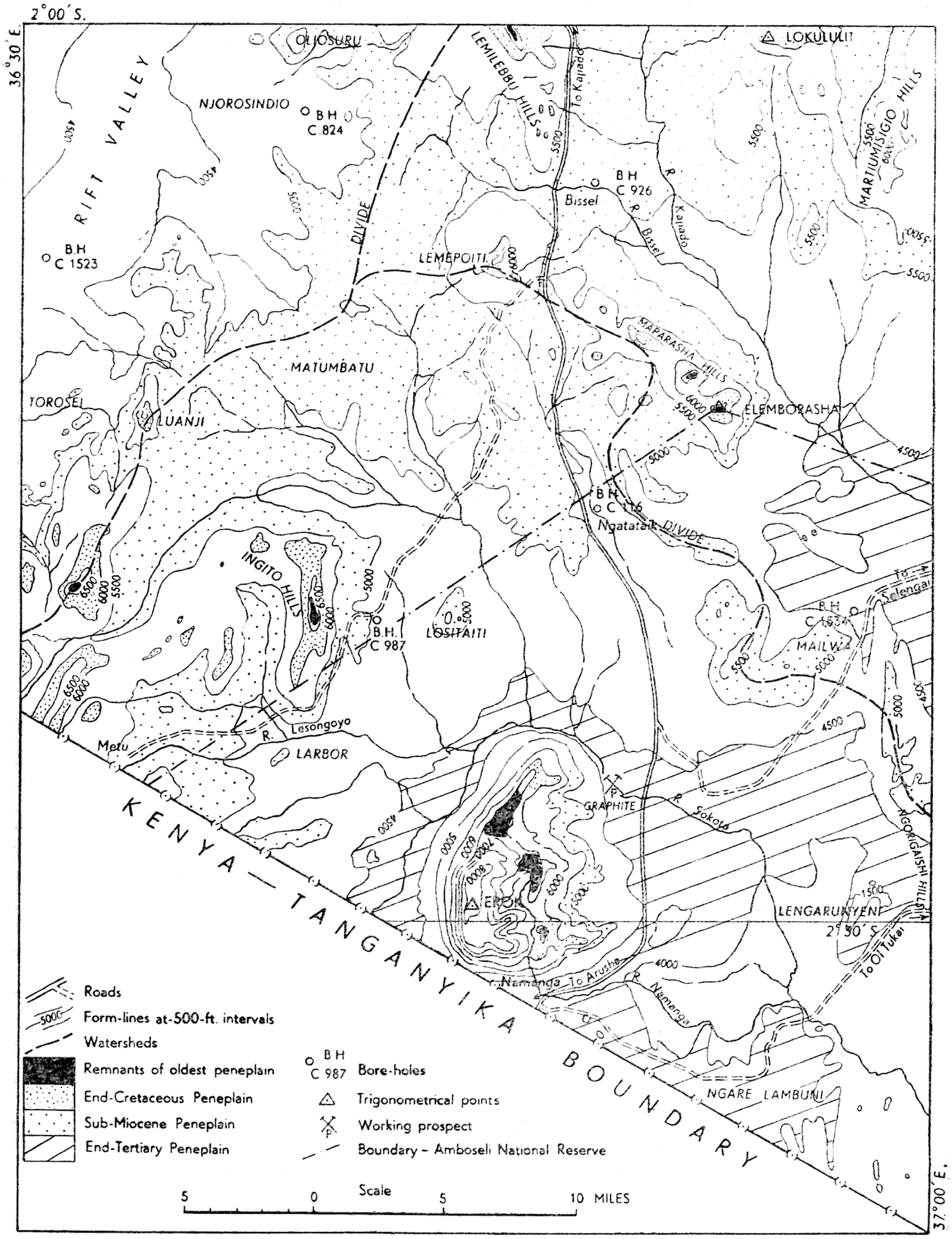


Fig. 1.—Physiographic sketch-map of the Namanga–Bissel area, showing also the location of water bore-holes and the situation of the graphite prospect in the Sokota valley.

Viewed as a whole the area is a fairly open grass-covered plain divided by ranges of hills and studded with inselbergs. The most prominent feature is Ol Doinyo Orok in the southern part, which rises nearly 4,000 ft. above the surrounding open country, attaining a height of 8,359 ft. above sea-level. Ol Doinyo Orok is crescentic in shape with the outer extremities pointing E.N.E. Similar shapes are displayed by the Ingito hills further north-west and by Lemipoiti in the north, and are ascribed to the effect of folding along axes striking S.W.–N.E.

The quartzites of the Maparasha hills form a continuous range of hills, stretching S.E.–N.W. up to Lemipoiti where they swing to the north and are continued in the Lemilebbu hills. In the north-eastern corner of the area psammitic rocks of the Lokululit and the Martiumisigio hills and, further south, the extension of the marble horizons of the Ngorigaishi hills, form prominent ridges.

The north-western corner of the area is occupied by the first major step of the Rift Valley. The step is an open, almost level plain, separated from the rest of the area by scarps west of the Luanji-Metu range of hills, and by a gentle slope west of the watershed further to the north.

Gneisses of granitic composition always form topographic prominent features, even when they occur as minor intercalations in semi-pelitic rocks. Ol Doinyo Orok, the Ingito hills and the hills of the Lokululit area are composed mainly of granitized gneisses. Flaggy biotite gneisses, on the other hand, are not normally topographically prominent. An exception occurs south of Bissel, where it is considered that the biotite gneisses had a protective covering of quartzite until recently, preserving them from erosion.

1. Erosion Surfaces

The physiographic history is well displayed on isolated hills and hill ranges in and around the area, and by wide expanses of dissected plains. There is evidence of base-levelling at several periods, when the country was reduced to peneplains. Remnants of the oldest recognizable peneplain occur between 6,800 and 7,300 ft. above sea-level, and are seen as flat grass- and soil-covered hilltops. Immediately north of the area the surface is represented by the high point of Lemilebbu which attains an elevation of 7,080 ft., while the highest parts of Lemipoiti and the Maparasha hills (Elemborasha, 6,874 ft.) are considered to be remnants of the same peneplain. Further south it is seen on central Ol Doinyo Orok and on its northern extension, as well as on the hill ranges west and south of Metu.

The next lowest peneplain, which is believed to be end-Cretaceous in age has a much wider distribution occurring as remnants on the Lokululit, Martiumisigio, Ingito and Luanji hills as well as in the hilly areas mentioned above. On Ol Doinyo Orok well-preserved benches on the northern and south-eastern extremities mark remnants of this surface. The peneplain lies at an elevation of 6,000 to 6,500 ft. above sea-level, usually just below 6,500 ft.

A gentle south-south-easterly tilt of the area away from the Rift Valley, as is characteristic of other areas bordering the eastern side of the Rift, is especially well-displayed by the sub-Miocene peneplain to which a large part of the present surface approximates (Fig. 1). On Oliosuru hill in the north-west the base of the Kapiti phonolite, which lies on the peneplain, occurs at an elevation of 5,650 ft. Here the sub-Miocene peneplain attains its maximum elevation and from there gently slopes down at a gradient of about 20 ft. per mile towards the south-east, usually grading into the end-Tertiary peneplain, which is the lowest erosion bevel recognized in the area. The sub-Miocene peneplain has a thick soil cover with surface limestone well developed on all calcareous rocks, and is being deeply dissected by rejuvenated rivers in the Matumbatu area and north-east of Bissel. The only ferricrete in the area was found at an elevation of 5,100 to 5,250 ft. on bevels forming part of the sub-Miocene surface. The parts of the area at elevations of 5,000 to 5,500 ft. are considered as being the remains of the sub-Miocene peneplain. They stretch from the south-western to the north-eastern corner, and there are isolated remnants on the Mailwa and Ngorigaishi hills, as well as on the bench east of the Diasega settlement on Ol Doinyo Orok.

The end-Tertiary peneplain occurs south-east of the sub-Miocene forming the low-lying open country around and east of Ol Doinyo Orok and east of the Maparasha hills. Here all calcareous rocks are entirely covered by surface limestone which occurs between 4,000 and 4,500 ft., and forms low ridges above the surrounding country. At this elevation (4,000 ft.) outliers of basalts of the Kilimanjaro group rest unconformably on rocks of the Basement System at Ngare Lambuni. The end-Tertiary peneplain slopes gently south-eastwards into an area of aggradation just below 4,000 ft., mainly composed of black cotton soil overlain by recent sandy deposits, into which the Sokota has incised its meandering channel. It is an area of bad drainage, in which the black cotton soil is subject to intense seasonal waterlogging.

2. Drainage

Three distinct drainage areas are recognized, divided by the two watersheds indicated on the physiographic sketch map (Fig. 1, p. 3). The rivers west of the N-S divide flow towards the west and discharge into the closed basin of the Rift Valley, flowing either into Lake Natron or into Kabongo Swamp. The waters of the Kajiado and Bissel rivers and their tributaries in the north-eastern part of the area add to the waters of the Selengai river on the way to the Indian Ocean. All the rivers of the southern and south-eastern parts are tributaries of the Sokota river, discharging into the Amboseli basin to the south-east. The Sokota probably flowed to the Indian Ocean before the eruption of Kilimanjaro diverted it, producing the dischargeless salt basin of Amboseli.

The Kajiado river after passing through a mature landscape, attains a relative old age below 4,750 ft. where, during times of flooding, large amounts of sediments are deposited on the end-Tertiary peneplain. On reaching an elevation of 4,000 ft., the Namanga and Sokota rivers flow on to wide areas of aggradation, where changes in course are apparent in the horseshoe and meandering channel cut-offs.

The direction of flow of the rivers is chiefly controlled by the strike of the underlying rocks. Highly resistant quartzites and quartz schists form a large part of the watersheds, while low ridges and hills are formed by resistant marble horizons. Where marble horizons alternate with rocks of pelitic origin, drainage is largely subsequent and a trellis pattern often develops with the addition of resequent, and more rarely, obsequent streams.

Faulting has affected the drainage comparatively recently. The Lesongoyo river north-west of Ol Doinyo Orok made a major change of channel during recent times by depositing a vast amount of sediment in its course and re-directing its flow along the strike of an old north-easterly fault in the Basement System. As would be expected, faulting along the Rift played a major role in altering pre-existant drainage, e.g. river capture is evident in a number of places in the Luanji-Metu range of hills. River capture of the tributaries of the Sokota in the north-western part of Matumbato took place as a result of the tilting of the eastern flank of the rift, and also caused rejuvenation of the rivers in the Matumbato area, resulting in the deep dissection of the sub-Miocene peneplain there. North-north-westerly faulting affected the profile of the river Sokota on the north-eastern flank of Ol Doinyo Orok, probably due to slight tilting. Upstream of the fault, immediately east of the mountain where it meanders and alters its channel, the Sokota has reached a cycle of old age, while along the fault-zone a sudden increase in the gradient of the profile is evident in a series of steps formed by surface limestone resting on Basement System rocks.

III—SUMMARY OF THE GEOLOGICAL HISTORY OF THE AREA

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

Age	*Formation*	*Earth Movements and Erosional Phases*
Recent	Red brown sandy soil on Basement rocks, black cotton soil in areas of bad drainage in the Rift Valley, volcanic soils in the Malalda area, surface limestone, sands and laterites	Re-excavation of river sands and erosion of red earths

Age		*Formation*	*Earth Movements and Erosional Phases*
Pleistocene ..	U	Low terrace Sokota river sands and gravels	
			Gamblian Pluvial Period disturbance (?)
	M (?)	Low terrace Kajiado river sands and gravels	
			Kamasian Pluvial Period disturbance
		Amboseli bentonitic clay	
	L	Kilimanjaro basalts	Rift Faulting (?)
Pliocene			End-Tertiary peneplanation
			———— disturbance: Rift faulting
Miocene	U	Olivine basalts	
	L	Kapiti phonolites	
			Sub-Miocene peneplanation
			———— disturbance
			End-Cretaceous peneplanation
Cretaceous			
			———— disturbance
Late Jurassic (?) ..			peneplanation
Archaean		Basement System	

The greater part of the rocks occurring in the area are crystalline gneisses, schists and granulites of the Basement System, which is believed to be of Archaean age, while Tertiary and later volcanic rocks have a limited distribution, the main occurrences being in the Rift Valley in the north-western corner. A vast period during which no formations were deposited or if deposited not preserved, followed the deposition and metamorphism of the Basement System before the laying down of the comparatively recent volcanic rocks.

1. Deposition of the Basement System

During Archaean times a vast accumulation of material was laid down in a depression, probably in a sea, as is suggested by the enormous extent of the deposits and the large number of limestones in the succession. The lower series of the succession consists mainly of psammitic gneisses with minor intercalations of hornblende schists and gneisses, suggesting the fast deposition of an enormous thickness of arenaceous material with occasional volcanic outbursts and invasion by numerous sheets of basic magma. A subsequent comparatively short quiet period followed with fluviatile conditions, now represented by deposits of kyanitiferous pelitic rocks immediately underlying a quartzite in most parts of the area. Fluviatile conditions persisted, probably by the sinking of the depositional basin relative to sea-level, giving rise to sandy beds now represented by the quartzite. A hornblende schist is usually found above the quartzite and suggests subsequent widespread vulcanicity over the area. The rocks higher in the succession are mainly of pelitic type, and are often intercalated with marble horizons suggesting quiet deep-water deposition. Occasional thin psammitic and hornblende schist intercalations show divergence from such conditions over comparatively short periods.

2. Metamorphism of the Basement System

East-west compression subsequent to the deposition of the Basement System sediments resulted in their subjection to intense heat, pressure and deformation, transforming the succession into a metamorphic series of crystalline schists, gneisses and granulites. Some of the gneisses are banded and veined and it is believed that they were derived from the sediments mainly by metamorphic differentiation and segregation. Alumina-rich clayey deposits gave rise to the formation of rocks containing kyanite and sillimanite, carbonaceous material was transformed to graphite, while calcareous and siliceous oozes were transformed to associations of dolomitic marbles and quartzites. Quartzites, quartz schists and granulites were derived from sandstones, while clays and shales gave rise to the pelitic gneisses and schists that are so prevalent in the area.

Some of the rocks were later subjected to intense granitic *lit-par-lit* injection, giving rise to the banded nature of many of the rocks, and forming migmatites. The quartzites and limestones proved most resistant to granitic vein-intrusion as is indicated by the fact that banding due to introduction of felspathic material is not prevalent in the marbles and only rarely observed in the quartzites, though rocks both below and above such horizons are intensely banded.

Doleritic intrusives as sheets and irregular bodies probably followed on this phase of the metamorphism and were in turn followed by the introduction of more granitic and quartzose material in the form of discordant pegmatites and felspathic quartz veins, some of which were emplaced along fault-zones.

3. Successive stages in the erosion of the Basement System rocks

The compression and folding of the Basement System rocks led to the formation of mountains which, in the course of time, were intensely denuded, leading to the exposure of the more highly altered rocks in the core of the mountains. During this process a vast amount of material was removed, and must have been deposited as sediments elsewhere, though no remnants of such rocks exist in the present area. During subsequent periods there may have been other phases of mountain-building, followed by intense erosion, but there is no evidence in the area mapped to indicate whether or not such revolutions did take place. At some time in the Mesozoic era—pre-Cretaceous and probably during the Jurassic period—the area was reduced to a peneplain (p. 4), now preserved only as small relics on the high hills, and which was probably studded by inselbergs of resistant quartzites and banded gneisses of granitic composition, as were later, more extensively preserved, peneplains.

During Cretaceous times a disturbance caused uplift of the area leading to the partial destruction of the Jurassic peneplain and eventually to the formation of a second lower peneplain which attained its maximum development towards the close of the Cretaceous. A similar sequence of events gave rise in early Tertiary times to the sub-Miocene peneplain, the remnants of which still occupy a considerable proportion of the area.

4. Eruption of Plateau Lavas and Rift Faulting

After the maturation of the sub-Miocene peneplain the Kapiti phonolite lavas covered great stretches of south-central Kenya. At present only a remnant of the southernmost remaining exposures of the phonolites exists in the north of the area mapped, but a former far wider distribution of Kapiti phonolite in the area is indicated by water-worn pebbles of the lava in rivers not draining the region covered by phonolites in the north. Such pebbles were found to be numerous all over the area and especially abundant along the Sokota river, indicating the possible previous existence of a sheet of phonolite in Matumbatu.

The pouring out of the Kapitian phonolites was followed by the extrusion of olivine basalts, probably invading the country from the west. The periods of vulcanicity may have been separated by a period of denudation. The basalts now occupy the area of grid faulting within the Rift Valley. No representatives were seen of the later volcanic rocks that flooded out from the Rift Valley in other areas.

The grid faulting in the Rift Valley took place since Upper Miocene times, slicing the Kapiti phonolites to the north and the basalts in the north-western corner of the area. It is possible that movement took place along existing lines of structural weakness in the Basement System. With the faulting the south-easterly tilting of the area took place, so that river-courses altered and were mainly rejuvenated.

5. The End-Tertiary Peneplanation and Eruption of Kilimanjaro Lavas

The stable cycle following the Miocene period of upheaval resulted in the formation of the end-Tertiary peneplain. The flow of the Sokota river meandering on this plain on its way to the Indian Ocean was interrupted by the extrusion of the volcanics of Kilimanjaro during lower Pleistocene times. Basalts flooded a part of the area in the south-east, while the remainder of the south-eastern part of the area was strewn with volcanic ashes, resulting in the bentonitic clays of Lake Amboseli and giving rise to the formation of volcanic soils south of Lengarunyeni.

Renewed movement along the existing Rift faults may have taken place at this time and the presence of the Kilimanjaro basalts of the Lorlawi area may be attributable to movement during Upper Pleistocene times along the north-north-westerly fault in the Basement System there.

6. Superficial Deposits

The Kajiado and Sokota rivers laid down small deposits of ill-sorted pebbles, gravels and cross-bedded sands on their floodplains, probably during Pleistocene times. More recently, red brown soils were derived from Basement System rocks, while black cotton soils occur in areas of bad drainage. With the admixture of sand in areas of aggradation, black soils give rise to sandy loams. The grey sandy soils of the Rift Valley mask most of the basalts occurring there and grade into red-brown soil near the hills composed of Basement System rocks.

"Kunkar" or surface limestone is prevalent in the area because of the abundance of calcareous rocks in the Basement System. The extensive deposits of volcanic soils occurring south of Lengarunyeni in the Malalda area thin out towards the west, forming patchy deposits at Ngara Lambuni.

IV—DETAILS OF THE GEOLOGY

1. The Basement System

The gneisses, schists and granulites belonging to the Basement System are of sedimentary origin for the greater part. The stratiform sequence of successive layers of differing lithology, persistant over long distances along the strike regardless of present disposition and structure, and the occurrence of numerous conformable limestone horizons can only be attributed to a sedimentary succession. Bedding of the original sediments persists in the metamorphosed rocks as foliation planes and relic banded structures. Subsequent regional metamorphism of a high degree and the introduction of material of a granitic composition has, however, masked the original appearance of the rocks to such an extent that it is sometimes difficult, and in cases impossible, to decide the origin.

For purposes of classification the Basement System rocks and ancient rocks intrusive into them can be grouped as follows:—

Sedimentary rocks
- (*a*) Calcareous rocks
  - (i) Crystalline limestones (marbles)
  - (ii) Semi-calcareous gneisses
  - (iii) Calc-silicate granulites
- (*b*) Pelitic and semi-pelitic rocks
  - (i) Sillimanite schists
  - (ii) Graphitic schists and gneisses
  - (iii) Kyanitiferous schists, gneisses and granulites
  - (iv) Mica schists and gneisses
  - (v) Hornblende gneisses
  - (vi) Garnetiferous para-gneisses and para-granulites
- (*c*) Psammitic rocks
  - (i) Quartzites
  - (ii) Graphitic quartz schists
  - (iii) Sillimanite-kyanite-quartz schists
  - (iv) Pyroxene-quartz schists and granulites
  - (v) Garnetiferous biotite-quartz gneisses
  - (vi) Magnetite-quartz granulites and schists

Volcanic rocks

Intrusive rocks
- (*a*) Granites
- (*b*) Pegmatites and aplites
- (*c*) Basic igneous types
  - (i) Meta-dolerites
  - (ii) Garnetiferous pyroxene granulites
  - (iii) Amphibolites
  - (iv) Pyroxenites

Granitized rocks
- (*a*) Calcareous types
- (*b*) Pelitic and semi-pelitic types
- (*c*) Psammitic types

Rocks of unknown origin
- (*a*) Pyroxene and epidote granulites
- (*b*) Garnetiferous hornblende-pyroxene gneisses

The stratigraphical succession of the sediments is described on a later page (p. 30).

Parkinson (1913) proposed to designate a group of altered sediments occurring in the Turoka and Bissel areas by the name of the Turoka Series. No comprehensive description of the stratigraphic succession nor a definition of its limits was, however, attempted. By correlating Parkinson's rock types with the succession established in the present area it appears that the lowest horizon included by Parkinson in the Turoka Series is the kyanite schists (*op. cit.* p. 538), which are the stratigraphic equivalents of the kyanite schists underlying the lower quartzite in most parts of the present area. Where the kyanite schists are absent their place is taken by a coarse-grained biotite schist, with or without small amounts of kyanite.

The kyanite schists overlie banded biotite and hornblende gneisses and are in turn overlain by hornblendic gneisses and schists. Pelitic schists and gneisses intercalated with prominent calcareous and subordinate semi-calcareous, semi-pelitic and psammitic types form the upper part of the Turoka Series. The thickness of the Turoka Series in the area under discussion is estimated at approximately 10,000 ft. Its upper limit could not be determined accurately because the sequence is terminated by N.W.–S.E. faults in the north-eastern part of the area. The Turoka Series, therefore, forms less than one third of the metamorphosed sedimentary succession of the Basement System as exposed in the area, the thickness of which is estimated at approximately 35,000 ft.

(1) Sedimentary Rocks of the Basement System

(*a*) *Calcareous Rocks*

In the Turoka Series, which occurs over the greater part of the area, calcareous rocks are widespread. They are usually covered by surface limestones and often no exposures available.

(i) *Crystalline Limestones* (*Marbles*)

The limestones are abundant all over the area except for the part south-west of Matumbatu. They occur in zones which are persistent along the strike and can be followed for many miles and, because the marbles are more resistant than the enclosing country-rocks, they form ridges, which are usually covered by surface limestone. The ridges can be followed but, because of poor exposures away from the ridges, mapping the bands for long distances along the strike is not easy. The prolific growth of certain small trees on the limestone horizons proved, however, to be most useful in tracing their extent. Exposures of the horizons were usually found just on the top of the ridges and occasionally where streams cut across the strike, but with strike and dip measurements usually unobtainable because of the small outcrops and the crystallinity of the rocks. Contortions and major changes of dip within short distances in these rocks, which is a feature of most of the formations in this area, made the following of the limestone beds no easy task. The horizons as mapped often do not consist of single marble beds but are interlaminated with, and sheathed by hornblendic rocks, considered to have been formed by the metasomatism of calcareous rocks. The exact thickness of the limestones themselves can rarely be measured and the width of surface limestone cover was usually taken to represent the widths of the occurrences, so that the limestone horizons on the whole are represented with exaggerated thicknesses.

Major thicknesses of the crystalline limestones occur in the Ngorigaishi hills, on the hills and ridges south and west of Elemborasha, and along the western slope of the Lemilebbu hills. Traverses across the strike provided evidence of repetitions of the succession, indicating that the set of rocks has been crowded into recumbent isoclinal folds. There are several limestone horizons but a group of three marble beds with pelitic intercalations is the most important. These feature prominently south of the Maparasha hills and after successive folding thin out towards the south-west, until they disappear east of Luanji. Thinner marble horizons occur higher in the sequence, but are not so prominent nor so persistent along the strike. Between Elemborasha and Lositaiti, a distance of nearly 12 miles, at least 15 major marble outcrops are traversed, representing five horizons.

Graphitic rocks are often associated with the main set of crystalline limestones, usually occurring just below the lowest member, but they also occur between the members of the sequence. The marbles are also sometimes graphitic and often show green copper-staining and emit a fetid odour on fracturing. Kyanite is associated with a graphitic marble found in the valley one and a quarter miles west of the Metu road in the Matumbatu area. Thin quartzites are often associated with the marble horizons as has already been mentioned. Quartzite occurs at the base of the major group of marbles, but is sometimes separated from the lowest limestone by thin pelitic beds. Limestones and quartzites are closely associated and interlaminated in the hills east of Ngatataik, and in the Mailwa area.

Banding of the marbles parallel to the strike is often observed and is produced by a number of properties inherent in them. Most prevalent and distinct is banding due to alternations of white and coloured crystalline limestones, the bands varying in thickness from less than a quarter of an inch to thicknesses that can be measured in feet, with grey and brownish-grey bands most abundant while bluish colours are uncommon. Pink, brown, yellowish-brown and green bands are distinctive of certain parts of the area and, because of its concordant nature, the banding is thought to be of sedimentary origin in the majority of cases.

Impurities occurring in layers in the original limestones allowed the formation during metamorphism of distinctive minerals in zones and bands along the marble horizons. The presence of these minerals often also indicates the originally dolomitic composition of the rocks. The forsterite marble of the northern extension of the Ngorigaishi hills is of this type (58/146)*. This white fine-grained marble is studded with small yellow forsterite crystals and occasional white mica flakes. A thin section shows, in addition to these minerals, tremolite, an appreciable percentage of pyroxene and a small amount of epidote, with the forsterite altering to antigorite, and the bulk of the rock consisting of a sutured aggregate of carbonate. The intimate association between thin bands of quartz and marble has given rise to an interesting suite of minerals. Specimen 58/126, from the valley east of Lemilebbu near the northern boundary of the area, displays thin contorted quartz ridges on the weathered marble surface, intercalated with schistose bands, composed of a shiny white tabular mineral with linear arrangement. The microscope reveals the presence of diopside replacing calcite, with a small amount of tremolite. Calcite occurs as small relics enclosed by or associated with diopside, interstitially, and infilling cracks. At Longai ‚resistant, highly contorted bands of quartz-wollastonite schist (58/179) stand out against the white marble because of their brown pitted appearance on weathered surfaces. The well-orientated crystals of wollastonite (parawollastonite ?) form about 58 per cent of the rock, while quartz is the other major constituent. A small amount of diopside is present as small scattered crystals.

In specimen 58/183 from the same locality the presence of more iron in relation to silica is apparent in the mineral assemblage. Large crystals of orientated wollastonite with chadacrysts of diopside form the major constituent of the rock, but streaks of iron-bearing minerals occur parallel to the lineation, consisting of garnet usually bordered by a halo of epidote. All the quartz of the original rock has been used in the formation of silicate minerals. North of Longai less lime was available in such bands so that a smaller amount of wollastonite was formed and consequently a higher percentage of silica remains, the resulting rocks being granulose in appearance (58/184) and having only a vestige of lineation.

Often variation of crystallinity of the marble has produced a marked banding. A prominent coarsely crystalline marble bordered by more fine-grained marbles was followed for long distances along the strike in the Lormotoo, Mailwa and Ngorigaishi areas. South of the Maparasha hills a fine-grained thin marble horizon of ornamental quality appears in the calcareous series, displaying the highly contorted disposition of the rocks there. In the same area flowage of the marble by gliding on crystal cleavage planes and recrystallization of the calcite, as well as the differential separation of impurities, has produced a peculiar banded structure. Specimen 58/57 displays fine-grained bands composed of calcite, wollastonite and apatite alternating with layers of crystalline calcite with minor impurities. The fine-grained impure layers display an indistinct linear fabric, while recrystallization of the calcite has caused randon orientation in the calcite-rich layers.

It is not always easy to distinguish between original impurities in the marbles and minerals introduced by subsequent hydrothermal and metasomatic processes. Yellowish and brown colours have obviously been produced by the introduction of iron in the form of limonite and goethite, interstitially or along the cleavages of the calcite, and often giving rise to marked turbidity of the calcite and dolomite though seemingly without the production of siderite. In a chocolate-brown crystalline limestone (58/52), on the hill five miles west of Elemborasha, the presence of brecciation and of short irregular veins of oxidized ferrous material showing delicate colloform banding, together with the occurrence of silica as chalcedony and as aureoles around meta-crysts of diopside and flakes of biotite, as well as pseudomorphs of quartz after calcite, suggest hydrothermal alteration. The replacement by iron usually prefers crystal directions and where goethite is prevalent in the slide, iron ore occurs as small scattered grains or as interstitial masses associated with fine-grained aggregates of quartz and calcite. The diopside is usually considerably replaced in mesh-fashion by secondary calcite. White coarsely crystalline calcite bands traverse this chocolate-brown marble, as is seen in specimen 58/60. Microscopically these bands consist of vermicular

*Numbers 58/146, etc., refer to specimens in the regional collection of the Geological Survey, Nairobi.

"eutectoid" intergrowths of calcite in crystalline dolomite with occasional resorbed tremolite metacrysts, and it is thought that the bands developed by recrystallization under stress. Clinozoisite-epidote crystals often form up to 5 per cent of these brown crystalline limestones, while sphene occurs, usually associated with quartz, as small metacrysts. A solitary colourless garnet crystal was found in a brown marble from Lengarunyeni.

The presence of minerals like hornblende, plagioclase, epidote-clinozoisite, pyroxene and scapolite, often with linear orientation, usually gives rise to banding in the crystalline limestones. These minerals sometimes increase in amount to such an extent as to form schists and amphibolites, either interlaminated with or sheathing the marble horizons. There is little doubt that some of these minerals originated by metasomatic processes forming intercalations of schistose rocks in the marble horizons, the unaltered marble having a flaggy appearance. The composition of the rocks varies considerably, ranging from that of impure marble on the one hand to that of plagioclase amphibolites on the other, and all intermediate gradations can be recognized in the field.

Blue marble was encountered in two localities in the area. The marble of the Maparasha area is pale blue and has a fine-grained granoblastic texture (58/54) with diopside as the only impurity. Closely associated with this marble are aggregates of diopside and garnet, occurring as fine-grained nodules or irregular bands. West of Longai a blue crystalline marble with numerous small equant yellow-green crystals of forsterite occurs. Occasional ovoid translucent olive-green vesuvianite grains, varying greatly in size, are scattered throughout the whole thickness of the horizon. The slide of one rock (58/178) from this locality exhibits, however, only scattered rounded grains of diopside with a little tremolite (?) and rare zoisite as impurities. The most remarkable properties of the calcite in the blue marble are its bent cleavage traces and twinning planes and its biaxial character. In other marble specimens it was usually observed that flowage has been accommodated by displacement along the cleavage planes of the calcite, while in the blue marble this phenomenon was not observed so that the blue colour may possibly be attributed to straining of the calcite. The same conclusion was reached by J. L. Rosenholtz and D. T. Smith (1950). Spectrographic examination of the Crestmore Blue Marble showed a small amount of iron and no other colouring elements in white and blue specimens, while structural strain in the Blue Marble was revealed by X-ray examination. A colour change from blue to white marble can be induced by heat treatment under 300° C. The colour change is not due to chemical action, but apparently to the relief of residual strain by heat.

The introduction of pegmatitic material so prevalent in most of the other rocks of the area was found to be comparatively rare in the crystalline limestones. Where exposed, the upper and lower parts of a horizon, however, normally show banding due to conformable veins of material of granitic composition.

In the northern Matumbatu area the existance of a fault was substantiated by the occurrence of a thick brown micro-crystalline surface crust on a marble displaced by the fault-zone. Because of its hardness the rock forms a capping on top of a hill. It is composed of dolomitic limestone with chalcedonic spherules and masses, and traversed by thin irregular veinlets of magnesite. Iron is present as limonitic staining of the dolomite, as haloes around the calcareous component, and as small scattered magnetite grains. Occasional flakes of a greenish altered mica occur, possibly of detrital origin.

Magnesite formed through hydrothermal or groundwater alteration was seen locally associated with the marble. Fine-grained magnesite occurring as veins in the graphitic schists of the Sokota river occurs along the strike of a marble horizon, and is thought to have been formed in one of these ways.

(ii) *Semi-calcareous gneisses and granulites*

With decrease in lime content of the marbles due to the development of silicates, the crystalline limestones grade into semi-calcareous gneisses. In some cases these rocks are thought to have developed as a result of original impurities in the sediments, with subsequent addition of constituents by metasomatic processes. In most cases, however, metasomatic additions to the original composition have played a major role in the formation of these rocks. Still further types represent gradations to the calc-silicate granulites (p. 13).

The semi-calcareous gneisses occur over a wide area in the upper parts of the Turoka Series, grading into and associated with crystalline limestones. Some of them are intercalated with marble horizons or occur along their margins, while others gradually replace marble horizons along the strike. Although representatives of this group are numerous they are never found as major horizons in the succession.

Specimen 58/93 found in the northern extension of the Lemilebbu hills is a yellowish-brown granular rock, indistinctly banded by lenticles of quartz and with a small amount of graphite imparting a feeble foliation to the rock. In thin section the quartz is found to occur as a coarse mosaic, as evenly dispersed grains or intergrown with hornblende and epidote. The other major constituents of the rock are calcite and plagioclase. Calcite occurs as large grains while a few slightly turbid equidimensional oligoclase crystals together with small ragged anhedra of scapolite constitute the rest of the leucocratic component. Sphene, apatite, rutile and graphite are present in small amounts as accessories. Locally the amount of quartz increases to such an extent as to give rise to a quartz granulite. Specimen 58/84 from Bissel hill has a mineral composition similar to that of the rock described above, except for a very high quartz content and the addition of a small amount of garnet. Here the plagioclase is a basic oligoclase about An_{29}.

Because of the origin and gradational character of these rocks their mineral assemblages vary to a large extent; the following table, giving estimated composition by volume, illustrates this feature. Specimens 58/90 and 58/102 are included here to illustrate gradational types between the semi-calcareous gneisses and the calc-silicate granulites.

	58/90	58/84	58/93	58/102	58/87	58/51	58/83
	%	%	%	%	%	%	%
Pyroxene	15	—	—	60	—	40	—
Amphibole	15	3	8	1	75	35	75
Epidote	10	1	5	4	5	3	—
Plagioclase	8	5	25	—	8	15	25
Scapolite	6	—	2	20	—	7	—
Calcite..	15	10	30	2	—	—	—
Quartz..	1	75	30	10	11	—	—
Garnet	20	2	—	—	—	—	—
Sphene	5	2	+	2	1	—	—
Apatite	5	2	+	1	—	—	—
Graphite	—	—	+	—	—	—	—

58/90. Calc-silicate granulite, southern extension of Lemilebbu hills, three miles north of Bissel.

58/84. Calcite-quartz granulite, southern extension of Lemilebbu hills, one mile north of Bissel.

58/93. Graphite-calcite gneiss, eastern slope of Lemilebbu hills, central.

58/102. Calc-silicate granulite, four miles east of Elemborasha.

58/87. Plagioclase amphibolite, Bissel river, west of bridge, main road.

58/51. Plagioclase amphibolite, four miles east of Elemborasha.

58/83. Plagioclase amphibolite, southern extension of Lemilebbu hills, one mile north-west of Bissel.

The increase of mafic minerals produces melanocratic banded gneisses or schists, referred to here as plagioclase amphibolites, usually sheathing or interbedded with marble horizons. In the Maparasha hills black fine-grained eucrystalline lens-shaped bodies occur, varying in thickness from a few inches up to two feet. The lenses are perfectly concordant with the crystalline limestone horizons and their lengths vary from a few feet to hundreds of feet.

The pyroxene in such rocks is usually found to be pale green to colourless diopside, and is always in an advanced state of amphibolization. Where larger crystals are present they are of poikiloblastic nature, containing chadacrysts of plagioclase, scapolite, epidote, quartz and calcite. In a thin section of specimen 58/51 the pyroxene is revealed as slightly pleochroic titaniferous augite in the form of stout poikiloblasts.

Long subhedral prisms of hornblende are the common amphibole of these rocks and two varieties, one pleochroic in yellow and green and the other in brown and green, are found. Chadacrysts of epidote are common. In specimen 58/83 the amphibole is pale green paragasite, which occurs as euhedral to anhedral prisms with occasional chadacrysts of plagioclase. Where hornblende is present it is usually seen to have formed due to replacement of pyroxene, most if not all being derived from that source.

The plagioclase is usually present as equidimensional crystals and in the thin section of specimen 58/87 shows faint zoning. A wide range in composition of the plagioclase was encountered, varying from oligoclase in the thin section of specimen 58/93 to bytownite in specimen 58/83, which is in accordance with the variable mineral assemblage characterizing this group of rocks. The plagioclase is usually fresh but is sometimes slightly turbid or saussuritized.

Epidote occurs as euhedral prisms, columnar aggregates, or as micrographic intergrowths with quartz and hornblende. Scapolite is usually in the form of equant crystals evenly dispersed throught the rocks or, where only small amounts are present, exists as small ragged anhedra. Calcite, where it is an important constituent, occurs as large anhedral and irregular grains but with diminishing amount becomes interstitial or is present as chadacrysts in pyroxene. Quartz forms lenticular sutured anhedra, markedly strained and slightly biaxial in specimens where it is abundant, but also occurs interstitially or as rounded grains between large crystals of the more abundant minerals.

Garnet is not a distinctive mineral of this group and only becomes prominent where the rocks grade into the calc-silicate granulites. In the thin section of specimen 58/90, large spongy garnet masses occur replacing hornblende and enclosing chadacrysts of calcite and sphene.

Sphene and apatite are sometimes abundant as accessories. Sphene occurs in irregular anhedra or in distinctive lozenge-shaped crystals when abundant. Apatite forms small to minute prisms. Iron ore in the form of limonitic stain is rare, while rutile was only noticed in one thin section representative of this group.

(iii) *Calc-silicate granulites*

The calc-silicate rocks occur as highly resistant lens-like bodies scattered over most of the area under discussion. Although abundant in the north-eastern part of the area, they never occur as large bodies and therefore are never topographically important, despite their weather-resistant qualities. Commonly they are dark grey to reddish, medium to fine-grained, display rarely a maculose texture, and are sometimes faintly banded due to garnet-rich or siliceous layers. The origin of the calc-silicate granulites is ascribed to the regional metamorphism of partly calcareous sediments, although occasional occurrences are far removed from notably calcareous horizons. As can be seen in the field and by their mineral assemblages, they grade into calcareous gneisses.

Specimen 58/71 was found as a small irregular xenolith with sharp contacts in a pegmatite, two miles due south of Bissel. The rock has the lithology, mineral assemblage and soft pale yellow surface encrustation typical of this group. From the occurrence it is clear that it is a relic of some calcareous horizon that has survived dissolution.

Specimen 58/140 was taken from a calc-silicate border surrounding and associated with basic intrusive rocks at Lositaiti, where the rocks sometimes show copper mineralization in the form of thin bornite veins. Under the microscope the granulite is seen to have metacrysts of pyroxene and nodular segregations (?) of quartz embedded in a fine-grained resinous groundmass.

A high percentage of garnet was found consistently in all representatives of the calc-silicates in this area forming anhedral to subhedral crystals, and usually occurring in aggregates, the individual grains sometimes coalescing to form spongy masses in imperfect porphyroblastic growths. Helicitic structures are displayed by chadacrysts of quartz and sphene. In a thin section of specimen 58/68, from two miles north-east of Bissel, garnet aggregates are arranged in a rough linear pattern crudely separated from quartz bands by scapolite and epidote. Intergrowths of scapolite and epidote with garnet are not uncommon.

Pale-green or colourless xenoblastic diopside is the most abundant pyroxene, and is usually marginally altered to amphibole. Because of the colour and larger extinction angles of the diopside in thin sections of specimens 58/86 and 58/140, from the Bissel river bed two miles west of Bissel, it is there considered to be enriched in the hedenbergite molecule.

Hornblende occurs as green or brown marginal encroachments on pyroxene, or as pseudomorphs after it. Most of the hornblende, if not all, has formed from pyroxene. Usually it occurs as patchy replacements of the pyroxene, but when replacement is far advanced it forms long prisms enclosing relic diopside grains. Chadacrysts of garnet can also be seen.

Epidote is common as granules and prisms or columnar aggregates, and occasionally occurs as reaction borders between plagioclase and pyroxene, in which case it is sometimes accompanied by zoisite. Scapolite occurs as distinctive subhedral crystals replacing plagioclase, its high birefringence suggesting meionite.

Plagioclase, which occurs as clear anhedra in the calc-silicate granulites, was determined as having a composition approximating that of bytownite. The plagioclase in the thin section of specimen 58/140 varies in composition continuously from centre to margin.

Quartz is usually subordinate or absent but forms 30 per cent of a thin section of specimen 58/68, where it occurs as strained lenticles with numerous fine inclusions in linear arrangement. In the thin section of specimen 58/140 the "nodules" of quartz occasionally enclose aggregates of epidote and plagioclase with a few small grains of diopside. Sphene is sometimes abundant as typical lozenge-shaped crystals but is usually present in minor amounts. Another common accessory as apatite.

The following estimated volumetric compositions of the calc-silicate granulites are considered to be representative of their range:—

	58/68 %	58/140 %
Pyroxene	4	20
Hornblende	—	—
Epidote	10	20
Plagioclase	1	10
Scapolite	6	—
Garnet	45	30
Quartz	32	20
Sphene	2	—

58/68. Calc-silicate granulite, bore-hole, Bissel.
58/140. Calc-silicate granulite, eastern slope, Lositaiti.

(*b*) *Pelitic and Semi-pelitic Rocks*

(i) *Sillimanite Schist*

The only true sillimanite schist (specimen 58/50) was found in the northern foothills of the Maparasha hills. It is a reddish-brown finely laminated micro-crystalline rock showing striae on lamination planes and thin schistose layers of sillimanite in a dark reddish-brown groundmass. In the thin section of the rock sillimanite as needles, prisms or as fibrolitic masses, all orientated parallel to the banding of the rock, is seen to occur along irregular layers associated with quartz. These layers are separated by a mosaic of potash felspar, plagioclase and quartz. The fibrolitic masses usually contain kyanite laths with sillimanite needles radiating outwards along planes of schistosity. Also associated with the kyanite and sillimanite are yellow amorphous and anisotropic alteration products such as are usually prevalent in kyanitiferous schists.

The potash felspar is seen as large grains of microcline and microcline-perthite, with numerous dust-like hematite grains along the cleavage planes. Plagioclase occurs as small fresh oligoclase anhedra. Quartz occurs as strained lenticles, which are usually cracked roughly perpendicular to the banding. The alteration of kyanite has given rise to small flakes of muscovite, while occasional grains of magnetite, sphene and epidote comprise the accessory content. The reddish-brown colour of the rock is due to dust-like hematite, prevalent through the rock.

The volumetric composition of this rock (58/50) was estimated as:—

	%
Quartz	30
Potash felspar	35
Plagioclase	5
Sillimanite	20
Kyanite	5
Alteration products and accessories	5

(ii) *Graphitic schists and gneisses*

Graphitic schists and gneisses were found to be numerous in the area, occurring stratigraphically both above and below the major quartzitic horizons in the succession of the Turoka Series. Usually the graphite is associated with kyanite; where graphite attains any importance as a constituent, however, kyanite is absent, but not all the non-kyanitiferous graphitic rocks are of economic importance.

A graphitic gneiss of the northern extension of the Lemilebbu hills, specimen 58/94, consists of a large percentage of clear large and small quartz anhedra, small scattered flakes of graphite, and a yellow alteration product, associated with a little opal and accessory apatite. The alteration product is usually fine-grained but occasionally occurs in larger crystals and is sometimes fibrous, displaying pleochroism from colourless to canary yellow to greenish-yellow. Other optical properties as well as the association with opal indicate that the mineral is chloropal.

The graphitic schists of the Sokota river occur above the lowest member of the crystalline limestones. Kyanite is absent here, but along the strike to the north-west kyanite is evident in equivalent horizons. At the Sokota river deposit the schists contain a small amount of biotite in addition to the minerals mentioned in the description of the thin section of specimen 58/94.

(iii) *Kyanite schists, gneisses and granulites*

Kyanite in the Namanga-Bissel area originated in rocks of variable composition, the original sediments ranging from pelitic to psammitic in character. For convenience, and because of the stratigraphical position of the occurrences in the Turoka Series, most of these rocks are here grouped together.

Kyanite-graphite schists are common in the area, occurring below the lowest member of the marble group. Lateral variation in the amount of kyanite as well as graphite is marked. These horizons are never topographically prominent, usually cropping out in river beds or along the western slopes of limestone ridges. Locally kyanite and graphite occur within the marble itself.

The kyanite occurs as xenoblastic crystals often enclosing rounded chadacrysts of quartz. A great variation in size of the individual xenoblasts, which are often partly altered to muscovite, is noticeable. Masses of fine-grained unorientated muscovite indicate total replacement of kyanite grains. The kyanite is always aligned parallel to the schistosity but needle-like crystals are sometimes wrapped around the kyanite metacrysts, in which case bent cleavage traces are seen.

The graphite flakes are variable in size, and always arranged parallel to the foliation planes. Usually kyanite and graphite occur together but in specimen 58/72, from the main road due west of Elemborasha, the graphitic and kyanitiferous components are separated, giving rise to a marked banding, which is enhanced by the introduction of thin bands of concordant pegmatitic material.

Small amounts of plagioclase are present in all the representatives of this group. It was determined as oligoclase, having a composition of An_{25}. The plagioclase often occurs as small remnants, in nearly all cases being partly replaced by opal, the replacement being irregular or following crystallographic directions. In the thin section of specimen 58/72 half of a plagioclase twin is replaced. Larger crystals of plagioclase are often cracked and display bent twinning lamellae, and in a thin section of specimen 58/124 (from the river bed between Lokululit and Lemilebbu, three miles east of the main road) some plagioclase occurs in ophitic relationship with biotite.

Lenticular quartz anhedra aligned parallel to the schistosity are often abundant. They are strained and are often of a slightly biaxial character. Quartz also occurs as abundant smaller disseminated grains.

Foliation is imparted to the rocks not only by graphite but also by biotite, usually occurring associated with other dark minerals in bands. It is fresh and pleochroic in straw-yellow and brown, and is sometimes orientated around metacrysts of garnet. Garnet is usually present as a subordinate constituent, sometimes containing chadacrysts of quartz, and is often cracked with secondary muscovite and a little chlorite occupying the fractures.

Opal, probably a hydrothermally introduced constituent, is on occasion abundant. It encloses granules of quartz and is often associated with graphite and a yellow anisotropic mineral. A similar yellow amorphous alteration product occurs interstitially along bands of dark minerals. Sericite is abundant in the thin section of specimen 58/187, from the northern extension of Luanji, where it occurs marginally around and replacing kyanite, and in "veinlets" that split up some of the garnet crystals. A distinctive accessory of these rocks is rutile, which occurs as slightly elongated oval grains.

A graphitic kyanite-garnet granulite (58/88) occurs stratigraphically immediately below the crystalline limestone in the southern extension of the Lemilebbu hills. Large garnet metacrysts are imbedded in a greyish white fine-grained matrix, which is yellowish-brown on exposed surfaces. Minute graphite flakes are scattered throughout the matrix with no obvious orientation. Similar rocks were described by J. Parkinson (1947, p. 19) from north-west of the Teita hills.

In the thin section of specimen 58/88 garnet occurs as idiomorphic porphyroblasts enclosing rounded and irregular chadacrysts of quartz. The margins and the cracks in some of the garnet porphyroblasts are stained brown by iron ore, possibly limonite. The large kyanite xenoblasts contain rod-like chadacrysts of quartz which in places are in a linear helicitic arrangement, obliquely across cleavage traces of the kyanite. White mica, here as well defined muscovite crystals, again occurs replacing the kyanite. Plagioclase present is altered to opal with ironstaining around peripheries and along cracks. The plagioclase was determined as oligoclase.

Quartz is abundant and contains minute inclusions arranged in zones. Around the kyanite crystals, the quartz in places contains numerous needles of sillimanite usually arranged parallel to the lenticular quartz chadacrysts in the kyanite. Graphite occurs as small thin flakes, often bent around the garnet porphyroblasts.

The occurrence of a small amount of staurolite in this rock is interesting. It is seen as chadacrysts in garnet and as one grain associated with kyanite, displaying distinctive colourless to golden-yellow pleochroism. Rutile is abundant as scattered individual grains and aggregates. The following volumetric composition was estimated:—

	%
Garnet	35
Quartz	25
Kyanite	20
Plagioclase ..	2
Rutile	5
Graphite	2
Muscovite	1
Staurolite	+
Secondary minerals ..	10

Kyanite-biotite schists are found in the Luanji-Metu hills, stratigraphically immediately below the quartzite horizon in that area. The schists are not very thick (10 to 15 ft.), though by repeated folding the width of exposure is often increased, and are remarkably constant over distances of many miles. Although of wide distribution the thickness of the schists is usually so small that they are not shown on the map but are included with the banded gneisses of that area. Outcrops are frequent on account of the protection afforded by the weather-resistant overlying quartzite; where no outcrops are seen, the abundance of kyanite crystals strewn on the surface demarcates the position of the horizon. The size of the kyanite crystals and their abundance is highly variable along the strike and across the bed, and in specimen 58/190 which occurs immediately below the quartzite, kyanite crystals attain a length of three inches. Away from the quartzite, stratigraphically lower, the size of the kyanite crystals decreases rapidly until they are hardly recognizable with the unaided eye, the siliceous content of the rock visually decreasing at the same time. Along the strike the kyanite sometimes disappears altogether as is seen in specimen 58/203 from Luanji. Locally intensive *lit-par-lit* injection of granitic material took place in these rocks, with a marked increase in size of kyanite crystals adjoining the granitic bands.

The kyanite occurs as anhedral, prismatic oikocrysts with numerous scattered elongated quartz chadacrysts and occasional biotite inclusions, and is commonly partly replaced by muscovite marginally or on cleavages and cracks. In a thin section of specimen 58/190 a highly altered potash felspar associated with muscovite occurs in a crack in a kyanite crystal. The kyanite displays a rough lineation both in the hand-specimen and in thin sections.

Large thick crystals of biotite in the rocks are usually fresh, displaying pleochroism from reddish-brown to brownish-yellow, but some are partly chloritized, with the release of iron ore. Muscovite occurs as large and small flakes usually concordant with the foliation displayed by the biotite, but is often also seen cutting sharply across biotite flakes, perpendicular to the foliation.

The plagioclase present is variable in amount and is usually saussuritized. Where it is well twinned and fresh the composition was determined as oligoclase, An_{25}. Quartz occurs as lenticular anhedra or as interstitial grains. Garnet forms very small grains or occurs as medium-sized well-crystallized trapezohedrons. Subhedral grains of magnetite and small prisms of apatite are present as accessories in the more quartz-rich varieties.

The following volumetric composition of a kyanitiferous muscovite schist (58/209) from Luanji was estimated:—

	%
Plagioclase	30
Quartz	25
Kyanite	10
Muscovite	15
Biotite	15
Garnet	5

Kyanite-biotite gneisses and granulites occur on Lositaiti hill in the same stratigraphical position as the kyanitiferous schists of the Luanji area. The kyanite-biotite gneiss (58/143) is distinctly banded, with well-foliated dark bands alternating with reddish-brown leucocratic layers. The rock is fine-grained with small red garnets and slightly larger orientated prisms of kyanite occurring along dark bands.

The kyanite forms columnar oikocrysts in parallel orientation, the biotite is of a fresh greenish-brown variety, while the pale pink garnet metacrysts are small though sometimes several small grains form larger aggregates. Plagioclase present is slightly altered and was again determined as oligoclase, while a small amount of potash felspar occur as larger untwinned anhedra. Quartz is clear, while magnetite is more abundant than in any of the other representatives of this group. Apatite is the only other accessory.

A very fine-grained leucocratic kyanitiferous granulite (58/142) occurs with the above described gneiss at Lositaiti. The hand-specimen is of a distinctive rose-pink colour due to the abundance of evenly dispersed small granules of garnet. In the thin section of this specimen sillimanite is seen to have formed at the expense of much of the kyanite. One almost unreplaced crystal of kyanite surrounded by quartz contains elongated quartz inclusions with helicitic structure, arranged partly in a distinct whorl. Small needles of sillimanite occur in the quartz surrounding the kyanite and occasionally in the pools within it. The whorl-like structure of the crystal is ascribed to rotation during crystallization.

Garnet occurs as small euhedral crystals or rounded grains evenly scattered throughout the thin section. Orientated masses of kyanite crystals sometimes entirely surround garnet metacrysts or rutile grains while sillimanite is scattered more or less throughout, though usually of patchy distribution and always showing parallel orientation. Small flakes of reddish-brown biotite are also scattered in the groundmass which is composed of a sutured mosaic of quartz with very small altered anhedra of plagioclase, microcline and large untwinned grains of potash felspar.

The estimated volumetric compositions of these two specimens follow:—

	58/142 %	58/143 %
Kyanite	15	15
Sillimanite	10	—
Felspar	25	40
Quartz	10	15
Garnet	35	5
Biotite	5	20
Magnetite	—	5
Rutile	+	—

(iv) *Mica schists and gneisses*

The kyanite-bearing schists of the Luanji area often grade into mica schists devoid of kyanite. These schists are highly fissile along their foliation planes, and have a mineral assemblage, excluding kyanite, essentially the same as that of the kyanite schists already described. Muscovite is more abundant, forming large shining flakes, while biotite occurs in aggregates of small greenish, partly altered flakes. In the thin section of specimen 58/203 from Luanji small biotite flakes are inter-laminated with larger muscovites and sometimes contain garnet chadacrysts.

Biotite gneisses are common throughout the succession, but are most abundant amongst the rocks occurring stratigraphically below the lower quartzite horizon. They are never topographically prominent but it was possible during the mapping to separate in certain places the pelitic from the semi-pelitic rocks. With an increase in granitic material the biotite gneisses grade into banded gneisses.

The biotite gneisses are always fine-grained and leucocratic, ranging in colour from yellowish-brown to reddish-brown. Lineation is often displayed by the directional orientation of aggregates of fine flakes of biotite, while banding is usually indistinct because of the small amount of dark minerals present, but can be detected by the alternation of fine- and coarse-grained layers, as well as by the orientation of quartz lenticles.

In thin section directional orientation is well displayed by large quartz lenticles in a fine-grained granulose mosaic of quartz and felspar (58/38, 58/45). Plagioclase was determined as acid oligoclase and is present in variable amounts from rock to rock. The amount of microcline and microcline-perthite sometimes increases to such an extent that plagioclase is present only as a subordinate constituent. The felspars are usually sericitized and the turbidity of the felspars, as well as limonitic staining, impart the yellowish and reddish-brown colours to the rocks. Muscovite usually occurs as interstitial flakes or replacing biotite. Iron ore is sparsely distributed as grains, and as a result of weathering occurs as stains along crystal boundaries and cleavages. Garnet is present only in small quantities as small rounded grains.

(v) *Hornblende gneisses*

Biotite-free hornblende gneisses are comparatively rare in the area as their amphibole is usually replaced by a dark green biotite. Representatives of the group are found associated with the banded gneisses of the north-eastern and south-western parts of the area, and have their widest distribution between the pelitic sediments and the banded gneisses. Although banding is prominent in most of the representatives, linear fabrics are indistinct or absent.

Specimen 58/220 from the hill north of Kaku hill is a fine-grained leucocratic hornblende gneiss displaying very delicate irregular banding. Under the microscope it is seen to consist of small hornblende crystals in an equigranular mosaic of calcic oligoclase, orthoclase and quartz. The hornblende is pleochroic from yellow-green to dark olive-green. Accessories are magnetite, sphene and apatite. The potash felspar is sometimes turbid due to alteration along cleavages, while the sphene is often surrounded or veined by a typical white amorphous alteration product (leucoxene). In the field this rock grades along the strike into a coarse-grained hornblende gneiss (58/222) forming prominent boulders and tors and which, under the microscope, displays an increase in the potash felspar with concomitant decrease in quartz content. A small percentage of greenish-brown biotite is present. The estimated volumetric compositions of the two rocks follow, and illustrate the effect of granitization:—

	58/220	58/222
	%	%
Hornblende	5	8
Plagioclase ..	30	25
Orthoclase	30	40
Biotite	+	2
Quartz	35	25
Magnetite, apatite and sphene	+	+

With an increase in the hornblende content the hornblende gneisses become melanocratic and grade into plagioclase amphibolites. In such types potash felspar is subordinate or absent. In addition to the hornblende, a small amount of garnet sometimes increases the mafic content, while the amount of quartz is highly variable, decreasing as the plagioclase amphibolite stage is neared.

An increase of lime content in the original sediments allowed the formation of minerals like diopside and epidote, and with the increase of these minerals, the hornblende gneisses grade into the semi-calcareous gneisses. They then become less banded and the colour changes from darker green to light green. Under the microscope small amounts of epidote and diopside appear. In a thin section of specimen 58/19 from the eastern slope of Lokululit relics of diopside are surrounded by alteration rims of bastite, while fibrous or crystalline aggregates of tremolite are present where pyroxene has been altogether digested. In specimen 58/13 from Lokululit the pyroxene has been partly replaced by amphibole with the release of iron ore.

Very rarely fresh folia of biotite are noticed. The occurrence of garnet seems to be linked with the degree of migmatization. Specimen 58/44 from Bissel is a highly migmatized representative of this group with medium-sized porphyroblasts of garnet surrounded by bleached zones, or with the garnets arranged along bands more leucocratic than adjoining relatively garnet-free parts.

Epidote occurs as well-formed columns and aggregates often graphically intergrown with quartz. Plagioclase is always present, the composition varying from An_{25} to An_{50}, though crystals are often encountered in which there is a gradual transition from more calcic cores to more sodic margins. With the increase of calcareous minerals, microcline sometimes becomes an important constituent as a result of granitization.

The stratigraphical position of one of these more calcareous hornblende gneisses is remarkably constant and it forms a good marker horizon.

To illustrate the range of mineral assemblages encountered in rocks of this group, and of rocks transitional to the semi-calcareous gneisses, the estimated volumetric compositions of some specimens are given below:—

	58/217 %	58/44 %	58/19 %	58/13 %	58/98 %	58/85 %
Hornblende	50	30	70	50	15	15
Pyroxene	—	—	3	6	5	15
Epidote	—	5	—	+	5	30
Plagioclase	40	55	25	30	19	10
Microcline	—	—	—	—	30	10
Biotite	—	—	—	4	—	—
Quartz	—	—	—	7	25	15
Garnet	10	10	—	—	—	—
Accessories	+	—	+	3	1	+
Tremolite (secondary) ..	—	—	2	—	+	—
Calcite (secondary)	—	—	—	—	—	5

58/217. Plagioclase amphibolite, river-bed south-west of Ingito hills.

58/44. Garnetiferous plagioclase amphibolite, Bissel river-bed, half a mile west of bridge on main road.

58/19. Hornblende gneiss, hillside immediately east of Lokululit trigonometrical point.

58/13. Hornblende gneiss, confluence of valleys north-east of Lokululit trigonometrical point.

58/98. Semi-calcareous hornblende gneiss, ridge south of Lemipoiti.

58/85. Hornblende-diopside-epidote gneiss, Bissel river-bed, half a mile west of bridge on main road.

(vi) *Garnetiferous paragranulites and paragneisses*

Rocks of this type have been described by Shackleton (1946, p. 10) but one granulite found in the present area needs mentioning. It is represented by specimen 58/173 from Longai and has large metacrysts of garnet embedded in a brownish-grey granulose matrix. Under the microscope the garnet metacrysts are seen to contain numerous rounded quartz chadacrysts yielding sieve structures, and sometimes the quartz forms parallel stringers across the garnets. The garnet crystals are associated with partly chloritized brownish-green biotite flakes and usually have abundant small iron ore inclusions. The matrix is fine-grained and equigranular, consisting mostly of quartz and a little sericitized plagioclase (oligoclase). Numerous small inclusions of magnetite and prisms of apatite can be seen in the quartz.

(*c*) *Psammitic rocks*

(i) *Quartzites*

In addition to the minor and patchy occurrences of quartzites over the whole of the area, quartzites build the prominent hills of Maparasha, Lemipoiti, Lemilebbu and Luanji. Notwithstanding the conspicuousness of the quartzites they were found to occur as thin beds which are highly variable in thickness along the strike. Lenses of quartzite in the Lemilebbu hills sometimes thin and there are no outcrops, but the continuation of the horizon can be traced by numerous quartzite pebbles and typical straggly vegetation. The quartzites and associated rocks proved to be the major marker horizons of the Turoka Series. The succession in the Elemborasha and Luanji areas suggests the presence of two different quartzite horizons separated mainly by intrusive rocks with high hornblende content. At Luanji the two quartzites have approximately the same thickness, while in Elemborasha the upper quartzite forms the Maparasha hills and the lower quartzite occurs as small ridges along the southern slopes of the hills.

The basic intrusions were mostly found emplaced immediately below the upper quartzite, while the gneisses were found to be coarser-grained and more leucocratic below the quartzite horizons than above.

The prominence of the quartzites in the Maparasha hills is due to repeated isoclinal folding with the close repetition of the same bed, giving rise to quartzite ridges along the north-eastern slope of the hills. Further west the folds are not so tight, and repeated limbs of the quartzites are separated by gneisses. Folding can also be seen along the tops of the Maparasha-Lemipoiti hills where the amount of dip to the east decreases and eventually the quartzites lie horizontal, or even have local dips to the south-west.

The relative thinness of the quartzites is evident in all exposures in the area, apart from those in the Maparasha hills where this feature is not easily discerned. The foothills along the eastern extremities of the Maparasha hills, composed of migmatitic rocks, have a thin veneer of quartzite on their tops, the slopes of which coincide with the dip of the quartzite. This feature established the thinness of the quartzite in that area.

The quartzites are massive, translucent in thin splinters and usually white on exposed surfaces. On freshly fractured surfaces fine-grained compact vitreous texture is displayed, with individual grains usually elongated parallel to the dip, imparting an indistinct linear fabric to the rocks. Near the junctions the texture is often markedly granular, in which case the rocks are usually brown due to iron staining and give rise on weathering to coarse siliceous gravels.

The quartzites are often banded due to inherent properties of the rock. The most common banding is due to alternating coarse- and fine-grained layers along which closely spaced bedding joints often develop, giving a slabby aspect to the outcrops. Striations are visible on such joint planes and their directions coincide with the plunge of the lineation.

Under the microscope the quartzites are seen to consist of a fine-grained mosaic of elongated sutured and strained quartz grains, which are sometimes dusty with numerous minute inclusions that usually occur on crystallographic planes of the crystals. Apatite is found as numerous subhedral to euhedral prisms and apatite-rich layers are often encountered giving rise to concordant pitted bands on exposed surfaces. Graphitic layers often impart a distinct banding to the quartzites. In a thin section of specimen 58/31 from Lemipoiti graphite is seen to occupy interstitial spaces or sometimes to occur in cracks in the quartz grains.

Pegmatites were not often encountered in the quartzites, but where pegmatitic material occurs it is always concordant with their bedding. Pegmatitic material in the quartzite on the hill north of Bissel has a marked green copper-staining and emits a fetid odour on fracturing. The quartzite from the western ridge of Maparasha (specimen 58/40) has a finely laminated appearance due to the introduction of leucocratic material along the bedding, in which quartz occurs as sutured, strained lenticles with their longer axes parallel to the banding. Spherulitic chalcedony with colloform structure associated with iron staining and small amounts of opal occurs as irregular and rounded pools in distinct bands across the thin section and in veinlets. Associated with these minerals, anhedral and rarely euhedral prisms of a colourless mineral occur with their longer axes parallel to the banding. They are tentatively identified as an amphibole (edenite ?) because of biaxial positive character and the presence of two prominent prismatic cleavage directions. The refractive index (β) is 1·6067. Calcite is also associated with these minerals, as small rounded granules.

Colour variations are rare in the quartzite. Iron staining on grain peripheries is often encountered in the granular quartzites, while rosy tints along certain horizons are distinctive and due to the dust-like inclusions in the quartz grains. About two miles north of Luanji a prominent emerald green massive aventurine quartzite crops out at the top of the Rift Valley scarp. In specimen 58/201 the green colour is due to six-sided crystals of green mica ($2V=40° \pm$), tentatively identified as fuchsite, occurring along the planes parallel to the bedding of the quartzite. The width of the mica flakes varies but is usually between 1 and 0·5 millimeters.

The quartzite above the meta-dolerite south of Luanji has undergone a major change in composition as a result of the metasomatic effect of the intrusion. The rock produced is pale olive-green in colour and has a fine-grained granulose texture (58/212). Under the microscope the rock is seen to consist of epidote and pyroxene aggregates usually associated with a little andesine, in a base of large sutured and strained quartz anhedra.

(ii) *Graphitic quartz schists*

Immediately below the quartzite in the Lemilebbu and Maparasha hills graphitic quartz schists occur, and are occasionally interbedded with the quartzite itself. The schists are grey and fine-grained, with a feeble schistosity revealed by numerous graphite flakes. An indistinct banding is imparted to the rocks by lenticular aggregates of quartz and felspar. The rocks are highly fissile, breaking along thin bands which are often rich in small bright green micaceous flakes. Under the microscope quartz is seen to form the major constituent as large strained lenticular aggregates forming a sutured mosaic, while graphite forms flakes of variable size and is associated with opal and the yellow amorphous alteration product typical of all the graphitic rocks in the area. In specimen 58/64 from the northern foothills of Maparasha goethite is also associated with the graphite. Plagioclase is sometimes absent but small twinned anhedra, determined as oligoclase in specimen 58/96 from central Lemilebbu, are not infrequent, with opal forming at their expense. A typical though not abundant mineral of this horizon is a green, faintly pleochroic mica, tentatively identified as fuchsite. A small amount of muscovite and a few flakes of a pale brown mica are seen in specimen 58/96 in which there is none of the green mica. Zoisite and epidote are scarce as small crystals.

The following volumetric compositions were estimated for these rocks:—

	58/41 %	58/96 %
Quartz	75	80
Felspar	5	10
Graphite	5	5
Opal and alteration products	10	5
Zoisite	2	—
Mica	3	+

58/41. Graphitic quartz schist, western extension of Maparasha hills, one mile east of main road.

58/96. Graphitic quartz schist, Lemilebbu hills central, two miles west of main road.

(iii) *Sillimanite-kyanite-quartz schists*

Rocks of this class are represented by specimen 58/189 which was collected in the northern Luanji area. It is a white quartz schist with occasional large well-orientated crystals of blue kyanite, and with a high degree of schistosity imparted by fine white bands composed of sillimanite. Small scattered shiny micaceous flakes can also be noticed along the white bands. In the thin section large clear, sutured, strained quartz forms the matrix for small, patchily dispersed, acicular crystals of sillimanite and occasional xenoblastic crystals of kyanite containing numerous, usually rounded, quartz chadacrysts and a few rutile grains. Rutile crystals also occur around the kyanite porphyroblasts. The quartz anhedra are elongated and markedly cracked perpendicular to the elongation.

(iv) *Pyroxene-quartz schists and granulites*

These rocks crop out in the western Longai area and are associated with quartzites, quartzo-felspathic gneisses and crystalline limestones. Specimen 58/176 from Longai has a slabby appearance due to well-developed bedding cleavage on which there are indistinct

striations as well as numerous shiny micaceous flakes, some of which are of a bright green colour. Specimen 58/177 contains numerous dark minerals emplaced along bedding (?) planes in the otherwise quartzose rock, producing distinctive pitted exposed surfaces where the minerals have been removed by weathering. Under the microscope the major dark mineral of these rocks is seen as medium-sized roughly oval xenoblasts of diopside, to a large extent replaced by hornblende. Large grains of calcite, some of which are partly rounded, together with apatite are present as accessories, and small amount of magnetite is the only other impurity in the large sutured quartz anhedra forming the matrix.

(v) *Garnetiferous biotite-quartz gneisses*

Below the quartzites in the Elemborasha area a garnet porphyroblast gneiss occurs intermittently along the strike. It is a mesotype rock, banded and fine-grained, with indistinct foliation picked out by biotite crystals. In thin section biotite flakes and metacrysts of garnets with occasional prismatic apatites can be seen along zones in a sutured mosaic of quartz with undulose extinction. Magnetite is usually associated with the biotite, or as chadacrysts within the garnet. Small plagioclase (oligoclase) crystals occur sporadically through the rock usually showing slight alteration along the (010) cleavages. The estimated volumetric composition of specimen 58/128 from just below and east of Elemborasha trigonometrical point is as follows:—

	%
Quartz	80
Biotite	12
Garnet	7
Plagioclase	1

(vi) *Magnetite-quartz granulites and schists*

A remarkably constant magnetite granulitic horizon occurs underlying the normal quartzite in the Maparasha and Lemipoiti areas. In this brownish-black rock well-formed crystals of magnetite of variable size occur embedded in a quartzitic base with the larger magnetite crystals displaying well-developed crystal faces. In a thin section of specimen 58/43 from the northern extension of Lemipoiti irregular to euhedral magnetite crystals occur in a strained quartz mosaic, the volumetric ratio of quartz to magnetite being approximately 7:3. The quartz grains are clear with occasional planes containing minute inclusions. Specimen 58/27 contains a small amount of apatite as an accessory.

In the same stratigraphical position an indistinctly banded magnetite granulite, represented by specimen 58/32 from Lemipoiti South, occurs. Under the microscope it exhibits a medium-grained mosaic of quartz in which elongation of some of the quartz grains gives an indistinct foliation, together with abundant aggregates of iron ore crystals that are often also elongated along the foliation. Pink garnet is an accessory, and is usually rimmed by limonite which also occurs in the irregular cracks of the garnet. Irregular veinlets containing small radiating needles of goethite and small rounded globules of limonite traverse the quartz.

Immediately above the quartzite of the western Maparasha area an iron-rich manganiferous quartzitic schist occurs, containing small scattered graphite flakes. It is thin, highly altered and weathers to an iron-rich powder on exposed surfaces. In the same stratigraphical position a black shiny, highly fissile quartz schist occurs in the north-north-western extension of the Ngorigaishi hills, where the metallic content is mainly manganese with a little iron. Under the microscope, specimen 58/147 is seen to consist of a quartz mosaic with interstitial veinlets and patches of manganiferous ore, enclosing in places crystals of a pale greyish-violet, almost colourless, pyroxene-like mineral, tentatively identified as a manganese-bearing silicate (? rhodonite). The mineral occurs in stout anhedral crystals partly altered to the ore and in some cases is completely replaced by a fibrous, nearly isotropic mass surrounded and traversed by manganiferous ore. Manganese ore also forms tuft-like growths in cracks in the quartz. A little apatite occurs as scattered globular anhedra in the quartz.

(2) Volcanic Rocks

In a large sedimentary sequence such as the Turoka Series, it is more than probable that some representatives of volcanic rocks should be present. The most likely position for volcanic rocks to appear in the succession is obviously at some place where there has been a disturbance in the normal sequence of deposition.

In this area, where the quartzites may be taken as indicative of a disturbance in the otherwise normal sedimentary sequence, some of the hornblendic rocks occurring below the upper quartzite may perhaps be taken as representing rocks of volcanic origin. The mineral composition of these rocks in the Maparasha hills is in accord with that of the meta-amygdaloid described by Shackleton from the Maralal area (1946, p. 13), comprising hornblende, andesine, diopside, sphene, iron ore and apatite. Specimen 58/37 from the western extension of the Maparasha hills also contains a small amount of scapolite. The amount of plagioclase is variable in the different types and it was found to be nearly absent from specimen 58/28 from the top of Maparasha, though the rock in addition to the minerals listed above contains epidote, garnet and a little interstitial calcite. A garnetiferous amphibolite, in a lens-like body, dovetails with the apparent meta-amygdaloids on the southern foothills south of Elemborasha (58/105).

The following estimated volumetric compositions are given to illustrate the typical mineral assemblage of the supposed volcanic rocks:—

	58/125 %	58/37 %
Hornblende	80	35
Diopside	15	30
Plagioclase	5	30
Accessories	+	5

58/125. Plagioclase amphibolite of presumed volcanic origin, between Lokululit and Lemilebbu, two miles east of main road.

58/37. Plagioclase amphibolite of presumed volcanic origin, Maparasha hills, western extension, quarter mile east of main road.

(3) Intrusives

(*a*) *Granite*

Leucrocratic to meso-type pink granitic gneiss crops out west of Metu as large bald crags and small tors. In hand specimens (e.g. 58/214) no banding is visible, but an indistinct large-scale banding was noticed in the field, where also aggregates of dark minerals in certain planes impart a lineated fabric to the otherwise medium to fine-grained granulose rocks. The direction of lineation corresponds with the strike of foliation of the country-rock, while the outcrops cut obliquely across the strike. No actual contacts were seen but marked textural difference between the country-rock and the granitic rocks, the finer-grained chilled margins of the latter and the discordant relationship were taken as indicative of intrusion.

Under the microscope medium-sized orthoclase and perthite, slightly smaller plagioclase and sutured strained, slightly elongated quartz occurring in a mosaic, are seen. The orthoclase usually displays alteration as lines of turbidity along cleavages and cracks while the plagioclase is clear. Small subhedral, sometimes twinned crystals of potash felspar are often found enclosed by the larger orthoclase, perthite and plagioclase anhedra. The composition of the plagioclase was determined as An_{20} (oligoclase). The quartz grains are often elongated parallel to the linear pattern of the rock, the larger grains occurring along zones in the granite.

The dark constituents, hornblende and biotite, show imperfect parallelism. Long prisms of hornblende show olive-green to bottle-green pleochroism. Fresh biotite flakes, pleochroic in yellowish-brown to dark brown, are associated with grains of rutile which they sometimes enclose. Anhedral grains of magnetite and sphene, the latter altering to typical light yellow amorphous masses, occur as accessories. The volumetric composition of this rock was estimated as:—

	%
Potash felspar ..	45
Plagioclase	25
Quartz	25
Hornblende	3
Biotite	2
Accessory minerals ..	+

(*b*) *Pegmatites and aplites*

Pegmatites in the area occur as concordant auto-segregations in migmatitic rocks and as discordant intrusive pegmatites. The former type has arisen through metamorphic differentiation and occurs as small veins forming irregular knobs and lenses, usually only a few feet across, along the strike. Mafic borders along the leucocratic bands indicate the transferance of felsic material. These pegmatitic segregations are often sufficiently abundant to give rise to the formation of veined gneisses. Preponderance of plagioclase over microcline in them distinguishes them microscopically from the intrusive pegmatites.

Intrusive pegmatites greatly predominate in the area, having a major distribution around Lokululit, Ol Doinyo Orok and along the Rift scarp below the Luanji quartzites. Where they attain a notable width, they cut obliquely across the strike of the country-rock and are sometimes perpendicular to the grain for short distances. The sharp contacts of these pegmatites give clear evidence of their intrusive origin. Thin intrusive pegmatites are commonly found as *lit-par-lit* injections or as systems of anastomosing veins dissecting the country-rocks.

Xenoliths of country-rock surrounded by scattered garnets are often seen in the pegmatites with the strike of their banding usually not conforming to the strike of the near-by country-rock. Aggregates of garnets signify the total absorption of smaller xenoliths. Schorl often occurs as large columnar aggregates in the pegmatites while small, highly fractured beryl crystals are rare. In an occurrence at Bissel the fine-grained margins of a pegmatite are separated from a coarsely crystalline central part by a zone containing numerous aggregates of magnetite crystals. The fine-grained marginal rock displays a feeble foliation parallel to the strike of the country-rock. Magnetite was found to be a very common mineral in all the intrusive pegmatites.

Fine-grained cross-cutting *aplites* are numerous but rarely attain any great thickness. Two specimens collected in the Bissel area are medium- to fine-grained granulose pink rocks, the colour being due to the altered and turbid state of the felspar content. One of them (58/67) is much more highly altered than the other (58/79), all its felspars being turbid and the original biotite completely replaced to chlorite. Both occur in the field as small clear-cut dykes, cutting obliquely across the country-rock.

In these rocks plagioclase forms small well-twinned crystals in mosaics composed of quartz, microcline and orthoclase, the plagioclase having the composition of oligoclase, and often shows bent twinning lamellæ. Sericitization is prominent, myrmekite being subordinate. The microcline and orthoclase are sericitized; muscovite is abundant in the more altered rock (58/67) as large replacive flakes, although it is absent from specimen 58/79. Biotite is present as numerous greenish-brown crystals in the fresh rock, but is now represented by chlorite in the altered specimen. Quartz anhedra are large and clear, having only occasional stringers of minute inclusions. Calcite, as secondary aggregates is present in both specimens, while apatite, magnetite and pyrite are present as accessory minerals. The following is the approximate volumetric composition of specimen 58/79:—

	%
Potash felspar ..	40
Plagioclase	30
Quartz	15
Biotite	15
Calcite	+
Accessory minerals	+

(*c*) *Basic igneous types*

(i) *Meta-dolerites*

Meta-dolerites were encountered as small lenticular or dyke-like intrusive bodies, the outcrops being characterized by the typical spheroidal weathering of these rocks. Usually the rocks are in an advanced state of weathering making the collection of specimens impossible. The exposure of a dolerite body south of Luanji where large bounders are strewn on the scarp is due to Rift faulting.

Under the microscope specimen 58/210 is seen to consist of large phenocrysts of schillerized hypersthene, containing ex-solution lamellæ of "augite", small stout rounded anhedra of a pale green schillerized monoclinic pyroxene (augite ?), surrounded by alteration rims

of light brownish-green hornblende. These minerals are emplaced in large andesine xenoblasts. Small biotite flakes occur scattered along the edges of plagioclase pools and among the pyroxenes occasionally forming larger ragged flakes some of which display bent cleavage traces. Where hornblende is absent between pyroxene and plagioclase its place is sometimes taken by aggregates of small garnet grains, though often the garnet occurs normally outside the hornblende and in places forms small diablastic aggregates within plagioclase pools, sometimes enclosing pyroxene. The original ophitic texture of the dolerite is hardly recognizable due to the advanced stage of replacement. Secondary quartz forms small interstitial grains or aggregates, sometimes enclosing garnet or biotite. Specimen 58/211, taken from the same occurrence, displays much more hornblende and quartz with plagioclase occurring only as small relics and with an entire absence of biotite and garnet.

(ii) *Garnetiferous pyroxene granulite*

This rock may well have been a dolerite but subsequent metamorphic replacement has obliterated all original textures. Specimen 58/193 occurs as a small lenticular intrusive wedged between the quartzite and hornblendic gneiss of the northern Luanji area. This fine-grained hypermelanic rock is studded with evenly distributed small red garnets. Microscopically it consists of large pale green augite diablasts often containing oval, vermicular growths and variably replaced by dark green hornblende, which in places forms large irregular growths. Sphene is abundant as numerous large lozenge-shaped crystals or aggregates of subhedral crystals while garnet is scattered throughout the thin section, in which can be seen the corrosion of some garnets by vermicular intergrowths of hornblende and quartz. The alteration of the sphene has given rise sporadically to globular and worm-like masses of ore. Plagioclase determined as basic oligoclase occurs interstitially and in part forms a base for the other minerals. Small amounts of quartz are also present interstitially. The following volumetric composition was estimated for this rock:—

	%
Augite	50
Hornblende	17
Plagioclase	7
Sphene	15
Garnet	8
Quartz	3

(iii) *Amphibolites and actinolite schists*

Thin amphibole schists and amphibolites were found to be numerous in the area, their field relations obviously indicating igneous origin. Mostly they are hornblendites with small amounts of pyroxene, usually augite, and quartz. Plagioclase is not rare while sphene is always present. Other accessories are epidote, calcite, scapolite and rutile. Most of these rocks are considered to have been derived from pyroxenites through the replacement of augites by hornblende and therefore some of the amphibolites will be considered under the heading of pyroxenites.

Associated with the meta-dolerite intrusion south of Luanji is a green rock consisting of acicular minerals occurring in fibrous radiating masses. No thin section is available but the constituent minerals were determined as actinolite and chlorite.

Along the fault-zone between the hills of Martiumisigio and Lomunye a soft and friable greyish-green actinolite-chlorite schist (58/121) crops out, the rock being highly fissile and having marked rounded yellowish spots on the foliation planes. In the thin section, actinolite and chlorite are seen to occur in an inequigranular mosaic displaying an indistinct parallelism, with numerous small angular grains of magnetite dispersed throughout the rock and occasional larger anhedra or rounded granules.

(iv) *Pyroxenites*

Although some of the representatives of this group are described with the pyroxenites, they actually contain more amphibole than pyroxene, but as amphibolization of original pyroxene in them can be proved, they can be most conveniently described with the pyroxenites.

A series of rock types was collected from the northern Bartinaro area, where a pyroxenite is emplaced between crystalline limestones. The core of the intrusion (specimen 58/11) consists mainly of large augite crystals containing numerous small chadacrysts of epidote, scapolite and calcite, the pale-green augite being slightly replaced by hornblende along its margins and internally in patches, though hornblende also occurs as angular interstitial

grains. In another specimen (58/12) basic plagioclase appears as interstitial anhedra and as chadacrysts in some of the pyroxenes, some being orientated parallel to the (110) cleavage. The margins of the intrusion are markedly different in macroscopic appearance, specimen 58/10 for example showing marked banding parallel to the strike of the country-rock. The banding is also obvious under the microscope, the rock having bands consisting mainly of plagioclase and bands containing mostly hornblende and pyroxene. In addition to the increase in plagioclase content, bluish-green hornblende becomes much more abundant, while scapolite features more prominently as interstitial crystals. To illustrate the variation of this pyroxenite, the following estimated volumetric compositions are given:—

	58/11	58/12	58/10
	%	%	%
Pyroxene	90	78	30
Hornblende ..	5	7	40
Plagioclase	—	10	20
Scapolite	3	4	10
Epidote	1	1	—
Calcite	1	—	—

A basic intrusive at Lositaiti is distinctive as the outcrop is totally surrounded by calc-silicate granulites. The calc-silicate rocks often show green copper-staining and locally have very thin veins of bornite traversing their more granular portions. The central dyke-like body (58/139) consists of a dark fine-grained rock, sheathed by a coarse-grained green mantle adjacent to the calc-silicates. Occasional lens-like pockets (?) of a greyish-green fine-grained rock appear within the intrusive.

Under the microscope in a thin section of the intrusion large stout hypersthene xeno-blasts are seen, being slighly pleochroic and partly replaced by brownish-green hornblende, while diopside occurs as small subhedra and, in conjunction with the replacive diablastic hornblende, forms the matrix. Zoisite is an accessory, while a little secondary quartz fills interstitial spaces. The reason for the coarse-grained sheath (58/137) is seen under the microscope in the copious formation of large diablastic hornblende prisms. The replacive relationship is obvious through the occurrence of numerous diopside chadacrysts in ragged hornblende xenoblasts.

The greyish-green finer-grained lenticular pockets of this occurrence are seen under the microscope as a diopsidic mosaic, the diopside being equidimensional or occasionaly stout prismatic. Scapolite appears interstitially or as numerous small chadacrysts in the diopside.

A black pyroxene granulite, the origin of which is obscure, was found outcropping immediately south of Ngatataik and is described here because of the numberless small ultra-basic intrusives occuring at the same stratigraphical position. In thin section the granulite (58/135) is found to consist of large pale green augite xenoblasts altered marginally to hornblende, medium-sized subhedral prisms of clear apatite, and interstitial scapolite, the latter mineral occasionally showing one or two crystal faces. The augite encloses numerous chadacrysts of prismatic apatite and scapo lite. The scapolite is usually stained brown along the margins and occasionally replaces the augite, while calcite occurs as small interstitial angular grains or forms sub-rounded aggregates enclosed by augite.

(4) Granitized Rocks

Nearly all the rocks comprising the Turoka Series have undergone a major change in composition due to the influx of material of "acid" composition. Notable exceptions are the quartzites and main marble horizons.

Although replacement by metasomatism has affected nearly all the rocks in this area, the final product, namely granitoid gneiss, was not found in the area. The cores of Ol Doinyo Orok and the Ingito hills may well be composed of granitoid gneiss, as the structures along the sides of these hills are very similar to structures found encircling granitoid cores north-east of the present area (Baker, 1954, p. 20 and Searle 1954, p. 23). The degree of granitization of the members of the Series often corresponds with the stratigraphical position, rocks underlying the major quartzite horizons always having a higher content of introduced granitic material than the rocks above. The processes responsible for the great physical and chemical changes throughout the metamorphic succession have been summarized by Schoeman (1951, pp. 11–12). The effects of granitization, which has produced a wide variety of rocks, are discussed in succeeding paragraphs.

(*a*) *Calcareous rocks.* Macgregor and Wilson (1939, p. 204) in summarizing the work of Adams and Barlow in the Haliburton–Bancroft area of Ontario, where the granitization of marbles has been demonstrated, state: "The composition of the material introduced into the limestones in the earlier stages consisted mainly of SiO_2, Al_2O_3, FeO, Fe_2O_3, MgO and some alkalies. In the later stages Al_2O_3, iron oxides and alkalies increased in relation to the other constituents. A certain amount of lime was fixed during the reconstitution process; the excess, above the amount required for combination with the introduced materials, was expelled". They further state: "Comparison of the material that was introduced for the acidification of the limestone with that which entered the schists and quartzites, *from the same parental source*, again brings out the selective manner in which various rocks seem to be able to fix the correct emanation constituents to suit their own individuality".

Although it seems likely that the lime silicate minerals in the marbles resulted from impurities in the original sediments, the introduction of iron and silica could have provided the source of some of the iron-bearing silicates diopside, hornblende, tremolite and garnet, while the presence of plagioclase and mica may indicate enrichment in alumina and alkalies. Forsterite was formed by the dedolomitization of the marbles and wollastonite occurs only where there is evidence of the presence of bands of quartzite in the marbles.

(*b*) *Pelitic and semi-pelitic rocks. Migmatites* are abundant in the area and comprise a considerable part of the succession of the Turoka Series. Leucocratic bands, which are often ptygmatically folded, produced by the introduction of leucocratic material in layers concordant with the foliation, may have been actively injected into the host-rock. The fissility and the selectiveness of replacement so distinctive of these rocks are considered by some writers, however, as being indicative of magmatic soaking and in other cases of differential fusion. It was with some reluctance that a distinction was made on the map between the migmatites of pelitic and migmatites of semi-pelitic origin. The coarser grain as well as the higher leucocratic mineral content of the apparently semi-pelitic migmatites may well have resulted from more intense granitization of the same rocks at a lower level. It was found necessary, however, to distinguish between these two kinds of rocks in the field to establish the sequence in the Turoka Series. The resistance to erosion of the semi-pelitic migmatites facilitated the distinction.

Microscopically the rocks are fine-grained and finely laminated, well foliated, and often contain metacrysts of garnet with bleached haloes. Under the microscope anhedral prisms of hornblende show alteration to biotite which occurs as irregular replacive flakes. These dark minerals are nearly absent in the leucocratic haloes around large cracked metacrysts of garnet which are embedded in a mosaic of plagioclase and quartz. Plagioclase, determined as oligoclase in specimen 58/25 from the peak north of Elemborasha and andesine in specimen 58/77 from Bissel, occurs as small equidimensional anhedra, while the quartz crystals have sutured edges and show great variation in size. Epidote-clinozoisite is sometimes abundant, occurring within bleached aureoles around garnet metacrysts or as euhedral prisms or columnar aggregates scattered throughout the rocks. Sphene and apatite are the most abundant accessories, while specimen 58/24 from Elemborasha contains small amounts of scapolite and secondary calcite. Granulation is often suggested by the equigranular mosaic of small plagioclase anhedra, while the linear arrangement of quartz lenticles indicates recrystallization.

Banded gneisses have been produced by the *lit-par-lit* injection of material of mainly granitic character as dykelets between thin leaves of schists and by the replacement of original metamorphic rocks by permeating fluids, producing rocks with a bulk composition approaching that of a granite. The banded gneisses of the Lokululit-Martiumisigio area have a clear sedimentary setting in the field. They are fine-grained leucocratic to mesotype rocks, with alternating coarser and more fine-grained layers, the latter containing the bulk of the dark constituents. Under the microscope specimen 58/112 from the hilltop three miles south of Lokululit is seen to contain biotite, dichroic from dark to light brown, and associated magnetite distributed along fine-grained zones composed of felspar and quartz. Oligoclase occurs as small lucid anhedra and often displays bent twinning lamellæ. Microcline or microcline microperthite forms the major felspathic component, however, while quartz occurs as small scattered anhedra among the felspars or as large lenticles orientated parallel to the banding.

These banded gneisses are topographically prominent, forming the Martiumisigio and Ingito hills and Ol Doinyo Orok. At Ol Doinyo Orok the same mineral assemblages as before were found but characteristically with a much higher percentage of quartz, potash felspar and hornblende, macroscopically visible in wider leucocratic bands. Biotite is not

always present in such rocks, but when hornblende is absent from parts of a thin section its place is always taken by biotite enclosing chadacrysts of quartz. The potash felspar present consists of both microcline and orthoclase, showing turbidity due to an even distribution of small dark granules. Garnet occurs as aggregates, elongated roughly parallel to the banding.

In specimen 58/38 from three miles east of Lemipoiti, there has been a development of rudimentary "augen" or nodules, consisting of lenticular aggregates of felspathic material, along the leucocratic bands. The mineral constituents of such rocks remain generally the same as in the more usual banded gneisses but somewhat larger amounts of dark minerals are present including small scattered garnet crystals, which sometimes coalesce to form "spongy" masses like imperfect porphyroblastic growths. The biotite flakes often deviate from the direction of foliation, being packed around the peripheries of garnet metacrysts. Most of the plagioclase has the composition An_{20} (oligoclase), but a plagioclase chadacryst encountered in a garnet has a more calcic composition. Biotite replaces hornblende, and sometimes enclosed remnants of it.

As Lokululit is neared from the west, the development of "nodules" in the leucocratic bands become increasingly prominent, until bald crags composed of augen gneiss are reached. These rocks occur in lenticular bodies, aligned parallel to the strike of the banded gneisses in which they occur. The rocks are well foliated with large felspar augen imparting a well-developed lineation. Microscopically the augen are found to be composed of orthoclase and perthite, and lie in a fine-grained granulose matrix composed of quartz, felspar and biotite and/or hornblende.

In specimen 58/17 an aggregate that can be seen by eye to consist of quartz, felspar and biotite with random orientation, forms a nodule emplaced like the potash felspar augen. In a thin section of the nodule it was found to be banded and with lineation displayed by prismatic hornblende anhedra, which are slightly replaced by ragged flakes of biotite. Hornblende, biotite and magnetite occur along the dark bands, but occasional dark bands are devoid of hornblende where this mineral has been substituted by biotite. The dark minerals are emplaced in a granulose matrix composed of quartz and felspar, the plagioclase felspar being rarely indistinctly twinned and occurring as aggregates of equidimensional anhedra, with individual relics enclosed by potash felspar or as vermicular intergrowths. The potash felspar in addition to that of the phenocrysts, occurs as aggregates linked by veinlets. Sphene and apatite occur as accessories.

In the central part of the augen-gneiss body of Lokululit specimen 58/109 was collected. It is coarse-grained due to the development of large felspar metacrysts, and banding is indistinct and irregular with quartz forming pronounced lenticles. Under the microscope the lucid microcline-perthite metacrysts are seen to enclose turbid relics of plagioclase, the plagioclase having the composition An_{20} (oligoclase) and often showing alteration to sericite. Associated with the biotite in the matrix is magnetite, a little epidote, and chlorite. Occasional apatite prisms are encountered while, secondary calcite is prominent along cleavages and in cracks. Large sutured and strained anhedra of quartz occur in the matrix which is composed predominantly of plagioclase, microcline and quartz. This specimen is considered to be the nearest to granitoid gneiss that was encountered in the area.

While the above-mentioned banded gneisses are considered to be mostly due to the forcible injection of leucocratic material into a host of sedimentary origin, certain usually indistinctly banded gneisses as well as granulites below the upper quartzite horizon, are considered to have been given their present appearance mainly by the permeation of magmatic fluids. Banding in these rocks is much less distinct as they are characterized by a lack of dark minerals. The development of leucocratic nodules resembling augen can be seen in certain areas, but no single felspar metacryst was found forming such growths. The junctions with adjoining rocks are always gradational, the dark constituents decreasing in amount with distance into the granitized rock, and eventually forming only irregular streaks in an otherwise homogeneous, leucocratic, coarsely crystalline rock.

A distinctive feature of rocks of this type is the prevalence of replacement of the plagioclase content by potash felspar and muscovite. In a thin section of specimen 58/92 from the Lemilebbu hills, three miles north of Bissel, potash felspar is seen to replace albite along twinning lamellæ, while plagioclase relics are often enclosed by microcline. The plagioclase is clouded, sericite featuring prominently. Megascopically, muscovite often forms large

shiny flakes on foliation planes, and under the microscope they are seen as large irregular and thick crystals, sometimes containing chadacrysts of oligoclase. Specimen 58/99 from the ridge south of Lemipoiti often shows a coarse intergrowth between quartz and muscovite, where muscovite has replaced the plagioclase component of earlier intergrowths. Quartz is nearly always prominent as large, usually lenticular, sutured anhedra, the lenticles being irregularly cracked perpendicular to the banding. Biotite is not prevalent but occurs as small scattered flakes, while garnet is sometimes present surrounded by alteration rims of iron ore. Apatite is sometimes present as an accessory.

(*c*) *Psammitic rocks. Migmatites* of this type are not rare, occurring as thin horizons interbedded with the sediments of pelitic origin. They are leucocratic rocks usually devoid of dark minerals and sometimes display a prominent gneissose structure due to abundant orientated quartz lenticles. They do not weather so easily as the migmatites of pelitic origin in which they occur as intercalations, and are usually exposed as ridges across river-beds. A thin section of specimen 58/61 from two miles south of Bissel shows large lenticular strained quartz anhedra in a mosaic of microcline, perthite, plagioclase and a little quartz, with the felspar turbid due to alteration while the quartz is quite clear. The plagioclase is oligoclase, and is partly replaced by microcline. Ragged replacive crystals of muscovite are sparse.

In the quartzites the first step of granitization seems to be the introduction of muscovite along bedding (?) planes. Felspathization of a quartzite is seen north of Luanji where pure quartzites grade into quartzo-felspathic gneisses. Specimen 58/181, representing an intermediate stage, is indistinctly banded with alternations of quartzitic and pink felspathic layers, the latter containing mica. Under the microscope it is seen that in the felspathic bands quartz forms large sutured, strained lenticular anhedra separated by aggregates of equigranular microcline-microperthite with occasional small highly altered plagioclase remnants. Large crystals and aggregates of muscovite are present and are usually surrounded by a border of altered felspar. Some of the mica flakes are faintly pleochroic in pale green and it was found that such greenish mica distinguishes the quartzites in the northern Luanji and Longai areas.

Leucocratic quartzo-felspathic granulite outcrops are numerous in the area but never attain great thickness, but all the rocks of this type encountered show the effects of potash metasomatism by the replacement of plagioclase by microcline. Dark spots often develop in the rocks because of turbidity in the plagioclase. Muscovite is usually present as replacive crystals, while the quartz occurs as large sutured strained anhedra with minute inclusions arranged along planes.

(5) Rocks of Unknown Origin

(*a*) *Pyroxene and epidote granulites*

A roughly circular, coarsely crystalline nodule, a few feet across, was found in the quartzite in the northern Luanji hills. Under the microscope it is seen that the rock (58/188) consists of large amphibolitized pyroxene prisms associated with acidic plagioclase, embedded in quartzite. In the same area a pyroxene-scapolite-quartz granulite (58/199) occurs underlying the quartzite of north-western Luanji, the granulite being coarsely crystalline with large pyroxene crystals in a white granulose matrix, dotted with occasional large lozenge-shaped sphene crystals. Microscopically it was found that irregular and sometimes coarsely sieved replacive diopside crystals, slightly replaced by a light-coloured hornblende, small crystals of epidote that often have orthite cores, and sphene constitute the mafic content, while a considerable amount of large irregular grains of scapolite occur with the large sutured quartz anhedra that form the base of the rock.

Another unusual type is represented by specimen 58/200 from the north-western extension of Luanji. It is an olive-green maculose granulite, having large porphyroblasts of hornblende, the general colour being imparted to the rock by abundant epidote, which is sometimes seen as large grains. In thin section it is seen that the hornblende forms large irregular crystals, usually associated with columnar epidote. Sphene is also associated with epidote, sometimes forming diablastic growths, so that it has an ophitic relationship with the epidote. Sodic oligoclase is associated with the groups of dark minerals, the whole lying in a matrix of strained sutured quartz.

(*b*) *Garnetiferous hornblende-pyroxene gneisses*

Within the syncline east of the Ingito hills, south of the Ingito bore-hole, lies a distinctive leucocratic to mesotype garnetiferous hornblende-pyroxene gneiss (58/218). It is a coarsely crystalline porphyroblastic gneiss with aggregates of dark minerals that impart a linear fabric to the rock. The occurrence, size and field relationships of this rock point to a sedimentary origin, but subsequent metamorphism has altered it to such an extent as to give rise to a mineral assemblage that more resembles that of an igneous rock. An equigranular coarse mosaic of basic plagioclase (An_{70}, labradorite-bytownite), interspersed with replacive scapolite grains, forms the matrix for roughly lenticular mafic aggregates. Rims or trains of garnets enclose or accompany the dark minerals, consisting of light green hornblende crystals which in places have partly replaced stout enstatite prisms, occasional angular deep brown rutile grains, with a little pyrite or its oxidation products and quartz. This gneiss grades into a dark brown granular (58/219) rock situated under the quartzite forming the eastern dip slope of the hill. Large schillerized enstatite xenoblasts are traversed by vein-like aggregates of hypersthene and hornblende and surrounded by replacement rims of hornblende. Schiller inclusions are notably absent near the enclosed minerals and the hypersthene is quite clear and sometimes forms graphic intergrowths with iron ore. Accompanying the increase of mafic constituents in this specimen, garnet now forms coronal rims around remnants of plagioclase (i.e. reverse coronas). The twinning of the plagioclase is rendered hazy by incipient alteration, and the crystals contain numerous acicular and platy inclusions. The former appear to be diopside, but the platy crystals are probably alteration products in the form of aluminium silicates. Small sub-rounded diopside anhedra were also noticed among the hornblende groups.

The following volumetric compositions for the two rocks were estimated:—

	58/218 %	58/219 %
Enstatite	5	45
Hypersthene ..	—	10
Diopside	—	4
Hornblende	15	15
Plagioclase	40	5
Scapolite	10	—
Garnet	30	20
Iron ore	+	1

(6) Geological Succession of the Basement System

Parkinson (1913) gave the name Turoka Series to rocks of the Basement System occurring in the Turoka area but, although a wide variety of rock types was mentioned, no major stratigraphic sequence was described. As a result of the mapping carried out in the present area it is possible to make an attempt to define the sequence of the Series with the assistance of marker horizons and successions mapped along well-exposed hillsides. The lens-like character of most of the beds, which are often highly contorted, in addition to major folding and faulting, complicates the deciphering of the sequence. Although exposure of the Basement System in the area is as ideal as can be expected, numerous parts where it seems likely that critical structures must occur are masked by soil cover. Although the possibility of strong unconformities cannot be excluded, such erosional gaps in the succession will be difficult to prove.

The quartzitic horizons are the most valuable markers in the area, particularly because they give rise to prominent ridges and hills owing to their weather-resistant qualities, the underlying rocks being also usually well-exposed and illustrating the succession and construction of the Turoka Series in those parts. The quartzite horizons often disappear along the strike, but minerals like kyanite, graphite and sillimanite were usually found at such places in rocks that are normally adjacent to the quartzites and were sufficient to establish the sequence.

The occurrence of crystalline limestones and numerous semi-calcareous horizons in the upper parts of the Turoka Series above the upper quartzites (*see* Table, p. 32) renders discrimination from the succession below the quartzite obvious. A marked increase in granularity of the rocks below the upper quartzite compared with the texture of the succession stratigraphically above also facilitates a distinction between upper and lower parts of the

succession. In the Bartunaru area where exposures are few, occasional outcrops of banded gneiss, and the occurrence of kyanitiferous and graphitic rocks prove the repetition of the lower members in that area even though the quartzite is very thin or non-existent.

The prominent series of crystalline limestones above the upper quartzite, consisting of three major and several minor marble horizons intercalated with mainly pelitic and semi-calcareous sediments, often gives great assistance in elucidating the sequence and structure of the Turoka Series. The crystalline limestones, eroding more slowly than intercalated pelitic sediments, have given rise to a series of ridges in a gently undulating landscape and hence form prominent marker horizons. In the "depression" south-west of the Maparasha hills the highest members in the stratigraphic sequence are preserved in the central part of an isoclinal syncline. They constitute the top of the Turoka Series as seen in this area, and no lithological or textural difference exists between them and the underlying upper part of the Turoka Series. They consist of an alternation of crystalline limestones and mainly pelitic sediments, but often display associations of quartzite and marble.

The banded gneisses occupying the north-eastern corner of the area are separated from the Turoka Series by a fault-zone, but the sequence of rock types from south-west to north-east across that area suggests that they are the lowest part of the general succession, occupying the same stratigraphical position as the banded gneisses west of Luanji in the south-western part of the area. It is possible, however, that the gneisses of the north-east corner of the area may represent a series stratigraphically higher than the Turoka Series *sensu stricto*. The banded gneisses of the Luanji-Metu and Ingito areas underlie all the other rocks encountered in the rest of the area. Two prominent hornblendic gneiss horizons occur near the upper part of this group, the upper often displaying numerous thin quartzite intercalations. The banded gneisses become richer in biotite upwards and eventually pass into biotite schists, which usually are kyanitiferous. Kyanite also occurs in the lower quartzite horizon which follows the biotite schist in the succession. Characterizing this stratigraphical level are numerous basic intrusives occurring below the quartzite, and which sometimes contaminate it. The lower quartzite often has a thin hornblende schist horizon overlying it in the south-western parts of the area, while a thin sporadic crystalline limestone occurs immediately above it in the Maparasha area. The upper quartzite horizon is separated from the lower by melanocratic rocks rich in hornblende, the major representative being a hornblende-pyroxene gneiss that is migmatitized in the Maparasha area where biotite often forms a constituent of the hornblende rocks.

The upper quartzite forms the prominent hills of Maparasha, Lemipoiti and Lemilebbu, where it is of a much greater thickness than the lower quartzite. Kyanite and graphite occur just below the lower quartzite, but sillimanite was found only associated with the upper quartzite, which serves to distinguish the two. Unfortunately the sillimanite is only rarely observed in the field, and the discovery of the association was made during petrographic studies after the field-work was completed. The quartzitic horizons are usually thin and sometimes impersistent, but the occurrence of minerals like kyanite and graphite always indicates the middle group of the Basement System in this area, separating the upper part of the Turoka Series from the lower part of the System.

Underlying the upper prominent quartzite in the Maparasha and Lemipoiti hills a thin ferriferous quartzitic granulite, usually a magnetite-quartz granulite, serves to distinguish inverted successions. A manganiferous horizon, which is also often graphitic occurs at the top of the quartzite but as it seldom forms outcrops its use as a marker horizon is meagre.

Usually the upper quartzite is separated from the lowest marble of the crystalline limestone group by semi-calcareous gneisses, a member of which forms a distinctive marker in the north-eastern parts of the area. Where the semi-calcareous gneiss is absent the lower marble rests directly on the quartzite, giving rise to the remarkable marble-quartzite associations of Longai, Lemilebbu and the hills east of Ngatataik. A marble triplet is favourably exposed south of the Maparasha hills, with very thin migmatitic biotite rocks separating the members. These intercalations are much thicker in many places but not as thick as the migmatites separating the limestones from the next higher marble horizon. Two major marble horizons lie higher in the succession within migmatites and with pelitic and semi-calcareous neighbours. They are distinguished from the crystalline limestone triplet only by being narrower, sometimes lens-like and therefore less constant, the lower band being often associated with thin quartzites.

STRATIGRAPHICAL SUCCESSION OF THE BASEMENT SYSTEM IN THE NAMANGA-BISSEL AREA

General Stratigraphical Succession			Intrusives	Localized Sequences		
				Maparasha area	Lositaiti area	Luanji area
Upper (Limestone Group)	TUROKA SERIES	Banded pelitic mica-amphibole-quartz-felspar schists and gneisses with prominent calcareous and subordinate semi-calcareous, semi-pelitic and psammitic types. Intensely migmatized.		Alternation of calcareous and pelitic gneisses with subordinate semi-pelites.	Migmatites (pelitic host) Marble Migmatites (pelitic host)	Migmatites (pelitic host) Marble Migmatites (pelitic host)
Middle (Quartzite Group)		Quartzite Hornblendic gneisses and schists, often with pyroxene and garnet. Quartzite Biotite schists	←BASIC INTRUSIVES→	Sillimanite-quartz schists Quartzite (Major) Kyanite-graphite-schists Magnetite-quartz granulites Hornblende-rich rocks Marble (thin, sporadic) Quartzite Kyanite-graphite schists	Kyanite-sillimanite granulites Quartzite Hornblendic rocks Hornblende schists Marble Quartzite Kyanite-biotite gneisses	Sillimanite-kyanite-quartz schists Quartzite Hornblende-pyroxene gneisses Hornblende schists Quartzite Kyanite-biotite schists
Lower (Banded Gneiss Group)		Banded biotite gneisses Hornblende gneisses (melanocratic) with numerous thin conformable quartzites Banded hornblende and/or biotite gneisses Hornblende gneisses (melanocratic) often with pyroxene Banded hornblende and/or biotite gneisses.	←Granitic sheet and vein intrusion→	Banded biotite gneisses	Migmatites with semi-pelitic host-rocks	Banded hornblende-biotite gneisses intercalated with melanocratic hornblende gneisses

2. Post-Archaean

(1) Kapiti Phonolite

A solitary outlier of Kapiti phonolite occurs on Oliosuru hill, where it lies with marked unconformity on the Basement System. The phonolites lie on a relatively uneven surface which is strewn with numerous quartzitic pebbles, some of which are waterworn. Originally the Kapitian phonolite was thought to be of Upper Cretaceous age, (Gregory, 1921, p. 105) but is now dated as probably late Lower Miocene (Kent, 1944, p. 19).

As the occurrence is small no great variation was noticed in the texture of the phonolite, the only diversity visible being the increase of the number of amygdales as the base of the outlier is neared. Elongated amygdales display an indistinct parallelism consistent with a roughly north-south orientation of the anorthoclase phenocrysts.

The description of a phonolite by Campbell Smith (1950, pp. 9–11, with chemical analysis, norm and Niggli values p. 5), collected 12 miles north-east of Kajiado station, fits the megascopic and microscopic characters of the phonolite of Oliosuru exactly. There is a greenish-black compact groundmass containing numerous large white platy crystals of anorthoclase and infrequent greyish nepheline hexagons together with numerous white patches and amygdales of zeolite, determined as natrolite. The matrix has intersertal texture and consists of simple twins of felspar, numerous pale brown amphibole crystals (kataphorite), darker cossyrite, turbid nepheline, small amounts of aegerine-augite, analcite enclosing minute nephelines together with iron ore and apatite, and finally reddish-brown masses of iddingsite considered to represent original olivine phenocrysts.

(2) Olivine Basalts

(*a*) *Rift Valley Olivine Basalts*

Outcrops of the olivine basalts within the precincts of the Rift Valley occur as small scattered knolls and occasional ledges representing small scarps produced by the intense grid-faulting in the north-western part of the area. Where there are no exposures outcrops are often betrayed by the presence of profusely scattered rounded pitted brown pebbles and boulders on the surface. The boundary of the basalts is nowhere exposed and the outcrops are separated by large tracts of soil, and the limits of the basalt as shown on the map were inferred from the most easterly outcrop north of the area, extended south to include float south-west of Njorosindio and at the bore-hole C.1523. A sample of the sludge from this bore-hole contained numerous small olivine grains and it is presumed that the basalts were pierced.

Megascopically the basalts are all much alike, having a dense grey-black groundmass, usually containing small infrequent plagioclase phenocrysts. Vesicles are numerous and of patchy distribution within the rocks. Specimen 58/206 from south-west of Njorosindio shows an increase in the amount of plagioclase phenocrysts over what usually appears in these rocks.

Under the microscope slight variations in the crystallinity of the specimens is noticeable, though all have distinctive intersertal texture. Occasional insets of plagioclase have the composition of labradorite and occur in a holocrystalline groundmass consisting of plagioclase laths and tiny prisms of pale purplish augite. Slightly larger olivine insets, usually stained yellow around the margins and partly replaced by iddingsite, occur in specimen 58/206. The composition of the plagioclase phenocrysts was determined as labradorite but in specimen 58/205 from west of Njorosindio it is bytownite. Ore tentatively identified as ilmenite, occurs as scattered interstitial angular grains or aggregates.

The relationship of these basalts to the Basement System and Kapiti phonolite could not be determined in this area as subsequent Rift faulting lowered the basalts into the Rift, a throw of at least 2,500 ft., and separating these rocks from the older formations and old land-surfaces. The petrographical characters of the basalts conform closely with those of the basalts of the Samburu Series (Shackleton, 1946, p. 30) and the Simbara Series (Shackleton, 1945, pp. 16–17) which have been considered of Miocene age, and the Kijabe type described by Shand (1937, pp. 265–267). Similar basalts were described by Campbell Smith (1931, pp. 251–252 and 1938, p. 527) and Prior (1903, p. 248).

(*b*) *Kilimanjaro Lavas*

Basalts derived from the Kilimanjaro group of volcanoes and resting on the perfectly level end-Tertiary peneplain occur as a series of small hillocks at Lorlawi in the Ngare Lambuni district. The basalts display an indistinct lamination which dips to the west, while weather resistant bands indicate a strike coinciding with the line of the chain of hillocks. The rocks have numerous small idiomorphic phenocrysts of olivine set in a dark brownish or greyish aphanitic groundmass. Numerous small vesicles filled with soft white material sometimes impart a spotted appearance to them, while irregular veins of secondary material, usually occurring along lamination planes, contribute to the irregular fissility. The alteration of olivine is sometimes megascopically visible.

Under the microscope specimen 58/165 shows large, usually altered, rounded olivine and idiomorphic prismatic augite phenocrysts, embedded in a fine-grained matrix of augite and magnetite with scattered small crystals of brown biotite, in a colourless isotropic base (analcite ?). Alteration of the olivine along fracture lines has produced fine lines of limonite. Iddingsite is a prominent alteration product of the olivine, of which it often encloses remnants, while pools of calcite and opal sometimes occur near the olivines. The euhedral phenocrysts of augite are violet, revealing a titaniferous composition, and often show marked zonal growth with simple (100) twinning. Magnetite is abundant in the rock, occurring as anhedral grains usually surrounding augite phenocrysts or as small specks among the dense fine-grained second generation augite in the glassy base. Secondary minerals, occurring in the vesicles and along irregular planes, consist of analcite usually bordered by natrolite, or fibrous natrolite and analcite occur in cavities lined by calcite. This rock is an example of a very rare type, as Johannsen (1938, p. 345) states: "No extrusive of the composition of a basalt but with all of its felspar proxied by analcime has been found described". The mineral assemblage indicates that the rocks are analcime basalts or analcime basanites.

A Lower Pleistocene age is indicated for the main Kilimanjaro eruption by Gregory (1921, p. 105), which is substantiated by the fact that the Lorlawi lavas lie on the end-Tertiary peneplain which is planed on the Basement System. The preservation of the lavas here can possibly be ascribed to a fault immediately east of the outcrops and parallel to the line of the Lorlawi hills. The arbitrary strike and dip of the lamination of the basalts is taken to be evidence for the existence of such a fault.

3. Superficial deposits

(1) Pleistocene

(*a*) *Amboseli Lake Beds*

The Amboseli Lake Beds occur in the extreme south-eastern corner of the area where the seasonal lake Amboseli extends into low-lying parts from the east in finger-like inlets separated by resistant crystalline limestone ridges. No stratification of the beds was noticed and their thickness is highly variable in this area. The lake beds consist of a yellowish-brown gritty bentonitic clay, which is sufficiently calcareous to effervesce strongly with dilute hydrochloric acid. Under the microscope it is seen to consist mainly of small aggregates of turbid calcite and lamellar aggregates of montmorillonite (?), the gritty texture being imparted by angular fragments of basic plagioclase, green slightly pleochroic amphibole and volcanic glass. The clay is considered to be the residue from the weathering of volcanic ash laid down in the lake and in age therefore correlated with one of the volcanic outbursts of Kilimanjaro.

(*b*) *Gravels and Boulder Beds*

Patchy occurrences of ill-sorted pebble-beds and gravels occur on the end-Tertiary peneplain east of Elemborasha. The pebbles are sub-rounded and form the major constituent of the beds, though the occurrence of large boulders is by no means rare. The matrix is a soft friable consolidated sandy loam. The quartzite pebbles and boulders were derived from the Maparasha quartzite and deposited in the flood valley of the Kajiado river, which since has incised its course into the sediments. No artifacts or fossils provide a clue to the age of the beds but because of the advanced stage of cementation and their occurrence on the end-Tertiary peneplain they have been classified as possibly mid-Pleistocene.

The Sokota river has cut a deep gorge into older unconsolidated sediments, composed of cross-bedded sandy loams with occasional lenticular grit and gravel bands. These ill-sorted beds may have been deposited during the torrential conditions prevalent during the

Gamblian Pluvial period of the later Pleistocene by the Sokota when it reached the more or less level flood plains. The deposits occur over a wide expanse of country below 4,250 ft. elevation east of Ol Doinyo Orok.

(2) Recent Deposits

Red-brown sandy soils in the area are indicative of underlying Basement System rocks. Such soils are widespread over the area and have their widest distribution on the sub-Miocene peneplain. Around the hills great thicknesses of them occur, usually deeply gullied by seasonal streams running from the steep hillsides.

Areas covered by black cotton soils are indicated on the map as seasonal swamps. Such soils occur where there is bad drainage, and mostly overlie Basement System rocks in this area.

The first step of the Rift Valley is covered by a thickness of grey sandy soil, masking most of the basalts in the area. It was found grading into red-brown soil near the hills where rocks of the Basement System occur. In certain parts of the area it is overlain by a thin veneer of quartzitic sands produced by rainwash. In the area of aggradation of the Sokota river recent sands have been washed over the black cotton soil, giving rise to a sandy loam.

The volcanic soils south of Lengarunyeni are similar to and could easily be mistaken for black cotton soil, but they can be distinguished by the occasional small pebbles and larger stones of obsidian encountered on them and by the fine dust produced on the surface. The occasional conspicuity of light coloured patches also facilitates recognition. The volcanic soils were also found as patchy occurrences in the Ngara Lambuni area, grading into grey sandy soils or red-brown soils derived from the Basement System rocks.

Surface limestone (kunkar) often covers large areas underlain by calcareous deposits. The colour often indicates the nature of the concealed underlying rock, off-white indicating marble while a reddish colour is imparted to the kunkar by hornblendic rocks. Kunkar often replaces schists along foliation planes, the result being a rock consisting totally of calcrete with laminations retaining the original strike and dip of the foliation.

Numerous pebbles of all sizes, originating usually from pegmatites or quartzites in the Basement System and occasionally from the Kapiti phonolite, occur in the sandy river-beds. The sands consist mostly of quartz, felspar and micaceous flakes, while garnet, magnetite, ilmenite and hornblende occur in all river-beds as dark heavy layers in the ill-sorted sandy beds. Topaz was found in the sands of the Bissel river, while the sands of the south-westerly part of the area usually contain abundant kyanite derived from the kyanitiferous biotite schists occurring there. The sand of the river draining the area north of Kaku hill contains a few grains of beryl, and epidote is abundant in the same area. Occasional rutile, apatite and pyroxenes are common over the whole of the area. Staurolite was found in a heavy concentrate brought from the Maparasha area by a prospector.

V. METAMORPHISM

1. Metamorphic zoning of the area

The rocks of the Basement System in the Namanga-Bissel area have been subjected to a high grade of regional metamorphism. The minerals and mineral assemblages indicative of higher degrees of metamorphism are indicated on Fig. 2, the metamorphic zoning displaying a marked concurrence with the structure of the Basement System. The minerals and mineral assemblages critical of a higher range of pressure and temperature occur between the lower leucocratic gneisses, where the degree of metamorphism is masked by the effects of granitization, and the sequence of pelitic and calcareous sediments forming the upper part of the succession.

Garnet is prevalent in the area, occurring in nearly all rock types except in the originally arenaceous sediments and most of the crystalline limestones. On the other hand, distinctive mineral assemblages in the limestones, in rocks of pelitic origin and in amphibolitic types usually serve to determine the metamorphic facies as advocated by Turner (1948, pp. 61–107).

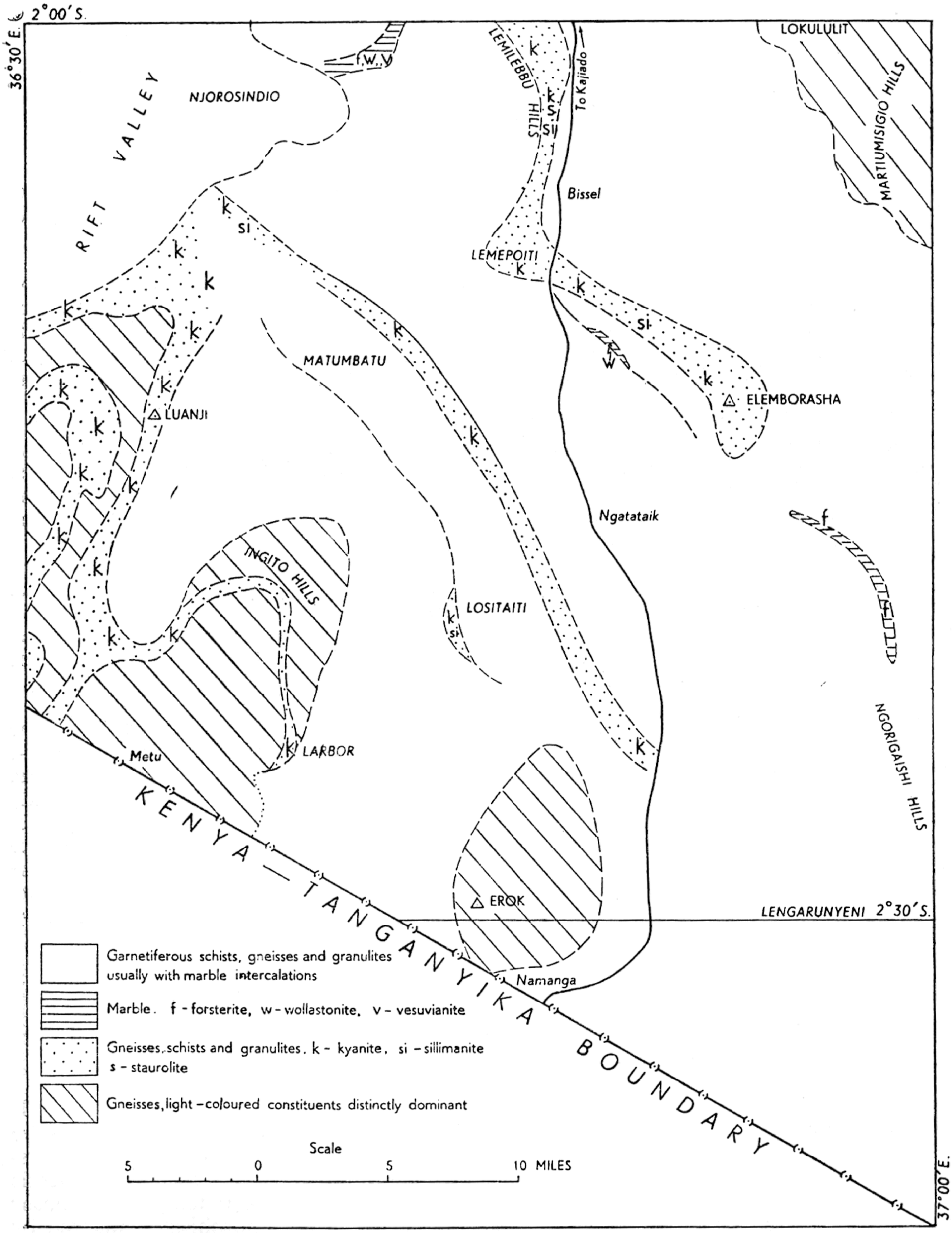


Fig. 2.—Metamorphic zones in the Basement System rocks of the Namanga-Bissel area.

The crystalline limestones are usually dolomitic and often contain an excess of silica, and therefore display distinctive critical mineral associations. Progressive steps in metamorphism observed in these rocks commence with the appearance of tremolite which is superseded by forsterite, followed by diopside, the place of which in turn is taken by wollastonite in the highest grade of metamorphism in the area. The formation of these minerals involves the emission of carbon dioxide, a process which is greatly retarded by increasing pressure.

The following assemblages fall within the cordierite-anthophyllite sub-facies of the amphibolite facies:

Deficient silica: tremolite-diopside-forsterite-calcite
vesuvianite-diopside-forsterite-calcite.

Excess silica: diopside-quartz-wollastonite.

The occurrence of vesuvianite in the second assemblage has no influence on its classification as the mineral is stable over a wide range of metamorphic temperatures.

The presence of the cordierite-anthophyllite sub-facies implies moderate temperatures and pressures during metamorphism, while the staurolite-kyanite sub-facies involves strong deformation under higher pressures. Staurolite was found only as chadacrysts in garnet in a granulite of which the mineral assemblage was obviously not in equilibrium. Here, as well as in all other rocks where sillimanite was found, kyanite is being replaced by sillimanite, while garnet takes the place that would be occupied by staurolite in type assemblages. Numerous examples of the staurolite-kyanite sub-facies occur in the area, having the following assemblages:—

plagioclase-muscovite-biotite-kyanite-garnet-quartz.
plagioclase-muscovite-biotite-garnet-quartz.

The amphibolitic rocks associated with the lower quartzite commonly have mineral assemblages conforming to the staurolite-kyanite sub-facies. A common association is:—

plagioclase-hornblende-garnet-biotite-quartz.

When an excess of potash is present it is revealed by the appearance of microcline, as is indicated by the following association:—

plagioclase-hornblende-diopside-epidote-microcline-quartz.

No representatives of the highest grades of normal regional metamorphism as typified by the sillimanite-almandine sub-facies was found in the area, all the sillimanite associated with kyanite pointing to disequilibrium.

The almandine-diopside-hornblende sub-facies is represented in the area by amphibolites and granulites. The following mineral assemblages are taken to be representative:—

hornblende-epidote-plagioclase-quartz
hornblende-garnet-epidote-plagioclase-quartz
hornblende-diopside-epidote-oligoclase-quartz
garnet-diopside-hornblende-plagioclase.

In the marbles the following assemblage indicates this sub-facies:—

calcite-phlogopite-diopside.

The association epidote-diopside-hornblende-scapolite-plagioclase occurs in the calc-silicate granulites.

All these mineral assemblages occur within the zones demarcated on Fig. 2, which include all the rocks that have suffered a higher degree of metamorphism. The assemblages are all embraced by the amphibolite facies, while the overlying part of the succession is demonstrably of a lower grade of metamorphism. A common assemblage encountered in the upper part of the succession is hornblende-epidote-plagioclase with or without any of the following minerals—biotite, garnet, quartz. This assemblage is classified as the chloritoid-almandine sub-facies of the albite-epidote amphibolite facies. The grade of metamorphism of these rocks correspond approximately to the almandine zone of regional metamorphism as defined for pelitic schists.

East of the Ingito hills the hornblende gneisses and granulites approach an association comparable to the granulite facies having plagioclase-hypersthene-diopside-hornblende assemblages, but the rims of garnet separating the plagioclase from the dark constituents prove a state of chemical disequilibrium.

The metasomatic effect of an intrusion was seen in the quartzite above a meta-dolerite south of Luanji, where is has given rise to the formation of a pale olive-green fine-grained granulose rock (58/212, *see* p. 21).

2. Retrogressive metamorphism

Diaphthoresis can be recognized in many rocks of the area, the adjustment to changed physical conditions having caused degradation from the stage attained during regional metamorphism.

Along the fault-zone west of the Martiumisigio hills the occurrence of an actinolite-chlorite schist associated with the hornblendic gneisses of that area can only be explained by retrogressive metamorphism, the assemblage indicating the lowest degree of metamorphism encountered in the area.

The mineralogical changes accompanying retrogression are numerous, the most common being the amphibolitization of the pyroxenes and the alteration of biotite to chlorite. The alteration of garnet also often yields chlorite, while the diaphthoresis of lime-garnets in the high-grade calcareous rocks has yielded zoisite or clinozoisite. In the kyanite schists fine aggregates of white mica with interstitial quartz form distinct pseudomorphs after kyanite, and the alteration of sillimanite to muscovite can be observed in nearly all the rocks that contain it. Sericitization of potash felspar and saussuritization of plagioclase though encountered, are not pronounced. Forsterite, wherever it occurs in the marbles, has usually altered to antigorite along cracks and around the margins.

VI—STRUCTURE

1. General

The major structural features of the Basement System in the area are indicated on the structural sketch map, Fig. 3. The deciphering of the complicated structure of the Basement System was greatly facilitated by the establishment of the stratigraphy of the Turoka Series. The trend of the metamorphosed sediments broadly follows the general north-north-westerly strike of the Basement System of Kenya, dips being on an average about 30° to the east. The repetition of sequences including well-defined marker horizons proved the existence of large recumbent isoclinal folds. Within large synclinal troughs the upper part of the succession has been preserved, while the lower members are exposed in the culminations of the anticlines.

Owing to north-easterly faulting, the general strike of the metamorphosed sediments has been deviated from place to place, giving rise to arcuate structures between the fault-zones. A more prominent set of faults striking north-north-westerly also traverses the area, rejuvenation of movement during comparatively recent times facilitating their recognition. Rift faulting has caused prominent scarps west of the Luanji-Metu hills, while small grid-faults exist within the Rift Valley displacing the olivine basalts of that area and presumably the Basement System, which it may be assumed underlies them. Displacement and "drag" along the faults east of the Rift are not always recognizable, but the fault-zones are always silicified. The vegetation found only on quartzose soils often follows the strike of faults even when they traverse marble horizons. Another indication was that along fault-zones of the Metu and Lokululit areas solitary quartz prisms terminated by rhombohedrons are found lying on the surface, whereas crystallized quartz is never seen in the rocks that have been faulted.

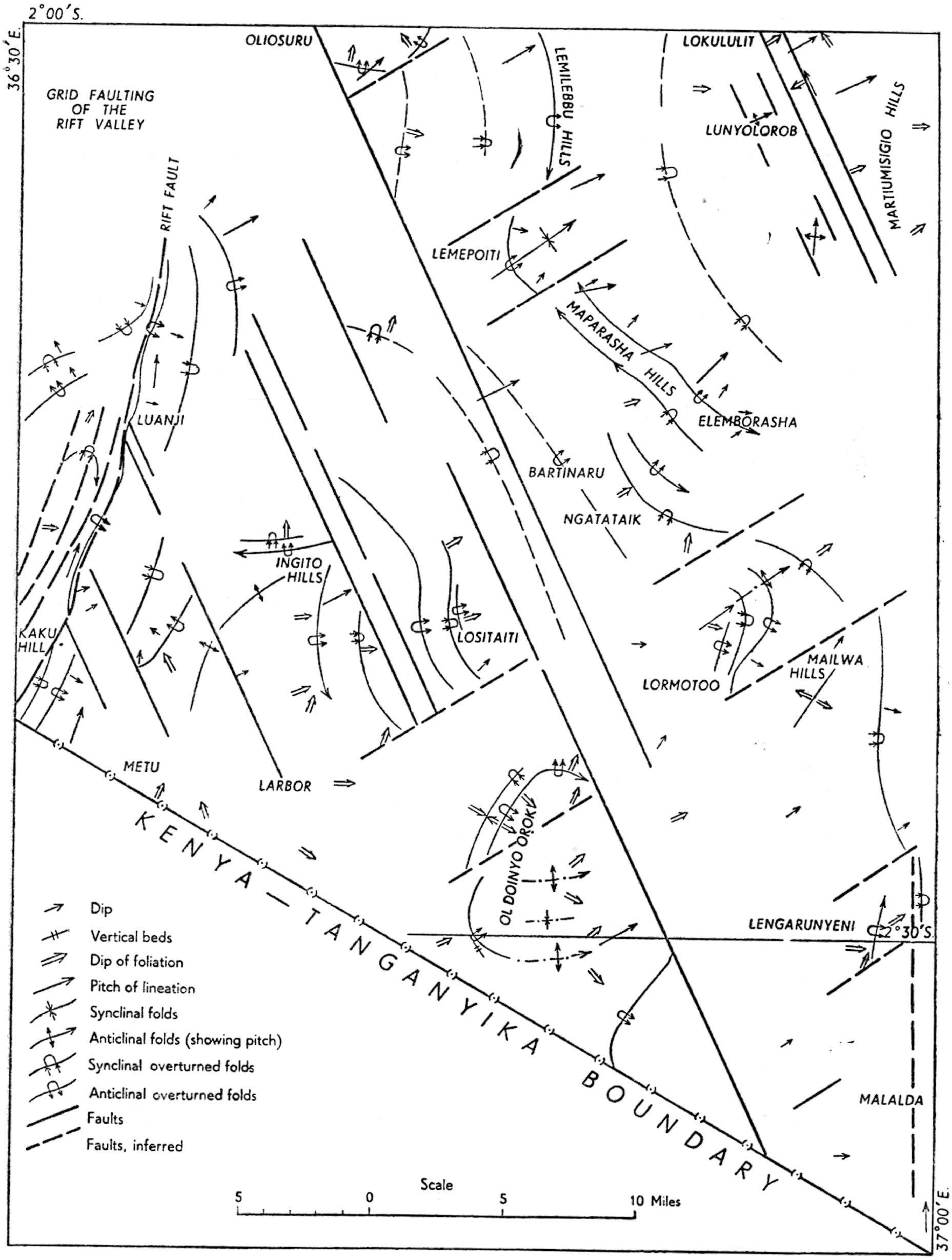


Fig. 3.—Structures in the Basement System in the Namanga-Bissel area. It should be noted that several inferred faults are shown that are not included on the geological map.

2. Folds

(1) Major Folds

The recumbent folds are easily recognized in the hilly areas, where marker horizons often crop out. Within them numerous smaller drag-folds occur, with the traces of their axial planes usually parallel to the traces of the axial planes of the larger folds.

(*a*) *The Maparasha-Lemipoiti-Lemilebbu anticline*

A simple isoclinal fold with the axial plane dipping eastwards, forms the parallel ridges of the southern extension of the Lemilebbu hills. A repetition of a resistant quartzite gives rise to the hills, crystalline limestone underlying the quartzite to the west forming the dip slope on the east. Between the two lines of hillocks that form the tops of the hills marker horizons, which are often graphitic, prove the anticline by repetition. Lemipoiti is formed by the creast of a major anticline, while the repetition of the quartzite eastwards from the summit where in places it is interbedded with the adjacent migmatites, displays repeated close folding in that direction. Similar close folding is remarkably well displayed on the eastern flanks of the Maparasha hills. The major structure is again an anticline, culminating at Elemborasha and pitching to both north-west and south-east from that locality. The strike of the quartzite on the south-eastern extremity of the Maparasha hills at the nose of the fold is nearly perpendicular to the strike of the anticlinal axis.

(*b*) *Ingito Hills*

The major structure is again an overturned anticline that can be proved by the repetition of hornblendic marker horizons, and which is itself folded by a normal N.E.–S.W. cross-fold so that the trace of its axial plane maps as a chevron. The anticline is responsible for the exposure of the lowest part of the Basement System. Close-folding along the southern limb of the overturned anticline is evident in the syncline in the hillocks on the south-east side of the main hills. Another syncline is evident on the northern limb of the anticline.

(*c*) *Ol Doinyo Orok*

Ol Doinyo Orok is composed of the same rocks as the Ingito hills with similar types of structures again evident. Close folding on the east is again recognized by the repetition of a distinctive biotite-rich gneiss which was used as a marker horizon. The mountain is encircled by an arcuate anticlinal fold which is overturned to the west for the greater part of its length, though it becomes vertical for a short distance along the northern flank and eventually overfolds inwards. A complementary overturned syncline occurs on the north-western slopes. On the southern flank of the mountain the main fold passes into a normal anticline. The axis of the anticline plunges at the north-eastern and south-eastern extremities. A well-defined north-easterly trending fault traverses the mountain and is evident in the displacement of beds and in conflicting dips close to the fault-line on the top ridge of the mountain. The downthrow of this steep normal fault is to the north, resulting in the preservation of the highest part of the anticline, where the beds in the northern limb of the anticline dip locally to the west.

(*d*) *The Bartinaro ridge*

This anticline can be recognized by the disposition of various types of rocks, including kyanite- and graphite-bearing horizons and occasional thin quartzitic bands, as well as by the topographic prominency of the ridge compared with the area to the south-west.

(*e*) *Major synclines*

After the major anticlines had been recognized the position of the synclinal axes could be inferred, the repetition of occasional marker horizons, though rare in the parts of the succession represented in the synclines, facilitating deductions. The remarkable uniformity of the upper part of the succession, however, and the lack of outcrops between the marble horizons often made the recognition of synclines no easy task. The syncline south-west of the Maparasha anticline is a tight fold, while the syncline to the north-east is an open fold in the sense of Bailey Willis. Minor puckering of the beds in the latter syncline can very often be seen, the limbs dipping either to the east or the west according to their position in the main fold, whether on the overturned limb or on the lower limb. At places along the Kajiado river the beds lie horizontally, and it is believed that such slackenings of dip indicate the position of the keel of the syncline.

(2) Arcuate Structures, Minor Domes and Anticlines

Superimposed on the major folds are cross-folds the axes of which are perpendicular to the strike of the axes of the major folds, and which have resulted in bending of the earlier axes along arcuate and crescent-shaped lines, now followed by the summits of the hills. Smaller anticlines and elongated domes occur within these arcuations, e.g. east of Ngatataik. As these structures are probably connected with the north-easterly trending faults, they will be referred to again under that heading.

3. Faults

(*a*) *North-easterly fault system*

These faults divide the area into a series of well-defined blocks. The location of the faults is not only indicated by displacement, but also by the arcuation of the beds and fold axes in adjoining blocks. Faults of this kind were first recognized in the hills south-east and east of Ngatataik where they cross the crystalline limestone and are represented at surface by silicified zones. Between the faults of the fault-zone traversing the Mailwa hills, the beds are folded into small anticlines, each anticline being situated between two faults, a structure certainly indicating intense compression.

In the area north of Lormotoo the outcrops of limestones and quartzites are curved, and the overturned folds in which they are disposed are themselves folded on a S.W.–N.E. axis. Structures similar to this and sometimes forming elongated domes, were repeatedly seen where the north-easterly faults traverse competent beds.

The fault traversing Ol Doinyo Orok, already described, continues the line of the fault traversing the Mailwa hills though it is clear that the two faults do not join. Towards the south-west the Mailwa faults seem to pass into a monocline as is evident in the flexures produced in the marble beds there. The extension of the line of the fault north of the Lormotoo hills to the south-west separates the Ingito area from the southern low-lying parts, though again no fault can be traced east of Lositaiti. The possibility of a fault-zone in the area south of Lositaiti and the Ingito hills is substantiated by the sharp "drag" structure displayed by the hornblende-pyroxene gneisses where they meet the Lesongoyo river.

The sudden termination of the northern end of the Ingito range is probably due to another north-easterly trending fault north of the hills, although there is little evidence to substantiate this suggestion.

At Lemipoiti a definite displacement of the quartzite has taken place as compared with its strike on Lemilebbu and in the Maparasha hills. The arcuation of the quartzite of Lemipoiti, as well as the occurrence of a gentle anticlinal structure at Lunyolorob further north-east, substantiate the possibility of two north-easterly faults, one on each side of Lemipoiti.

(*b*) *North-north-westerly faults.*

A prominent set of strike faults traverses the area nearly at right-angles to the previously described fault trend. The direction of the strike of these faults coincides with the trend of the Pare Mountain scarp, further south-east in Tanganyika.

Separating the Likululit-Martiumisigio gneisses from the pelites to the south-west is a distinct fault-zone, which can be recognized by shearing and contortion of the rocks with resultant change of dip and lineation direction, and by the distinctive vegetation. A pegmatite at Lunyolorob also follows a similar strike, and was probably emplaced along a fault-plane. The fault traversing the Bartinaro ridge and extending to Oliosuru is easily recognized by the displacement of the limestone horizons. Similar features were again noticed in connexion with all the other faults of comparable strike.

The dip of these faults is near to vertical as no pronounced deviation in strike direction is noticed as their outcrops change in elevation. The fault west of the Ingito hills shows as a silicified line with a steep deep dip towards the north-east.

Rejuvenation of movement during the periods of Rift faulting took place along these faults, making them now easily discernible. This effect can be seen in the fault east of Ol Doinyo Orok, for example, where the Sokota valley is mature west of the fault, but is rejuvenated at the fault scarp. The north-eastern face of Ol Doinyo Orok is a sharp drop, which is probably a result of the same fault, while, as previously mentioned, the fault may have been the cause of the preservation of the Kilimanjaro lavas of Lorlawi.

(*c*) *North-south faults*

A fault, trending north-south and with a downthrow to the west, separates the crystalline limestone and underlying rocks of Lengarunyeni from the limestone of the Ngorigaishi hills. Further south, the fault is seen in the displacement of crystalline limestone at Malalda and at a line of outcrops in the form of large boulders composed of a distinctive granulite on a hillock further south.

(*d*) *Thrust faulting*

The repetition of the quartzite on the Maparasha hills is ascribed to close folding, but it is likely that the lower limbs of the isoclinal folds may pass into small thrust-faults along the north-eastern slopes of the hills, beds above the faults moving upwards relative to those below. No field evidence of any large scale thrust-planes has been encountered in the area but the prominent lineation evident in all parts is believed to indicate that thrust faulting almost certainly contributed largely to the present disposition of the beds. The base of the quartzite is a plane along which thrusts might have taken place, the lineation indicating the direction of movement.

(*e*) *Rift faulting*

(i) *Rift scarps.*

A series of four normal, nearly vertical major faults has given rise to the escarpment west of the Luanji-Metu range of hills, though the actual faults themselves cannot always be readily recognized. The hills north of Luanji hill show distinctive triangular facets with steep slopes to the west, and define the most easterly fault producing the scarp. The second fault a little further west forms a narrow zone, having the downthrow to the east, a "graben" being formed between the two easternmost faults. The third fault has a downthrow to the west in the north and hinges to a downthrow to the east further south, but there is also strong evidence of horizontal movement along the fault-plane, as is shown by the displacement of quartzite bands in the middle section of the fault. The most westerly Rift fault starts at Torosei and increases in amount of throw as it passes to the south, where there is a large scarp.

The intricate pattern of folding parallel to the Rift faulting of the Basement quartzites of Luanji is not found beyond the second fault from the east. Further west the quartzites are only mildly folded.

(ii) *Grid faulting.*

Grid faults occur in the olivine basalts in the northern part of the Rift Valley included in the area, small ridges or small outcrops of the lavas occurring along the strike of the faults.

4. Lineation and Jointing

Lineation was often observed, being revealed by the parallel arrangement of elongate minerals such as felspar "augen", kyanite or hornblende, by parallel streaks of platy mineral such as biotite, as striations on bedding cleavage of the quartzites and rarely as very small crenulations in the sediments of pelitic origin. The lineation plunges throughout the area in a direction about 60° east of north, which coincides with the direction of the north-easterly faults and axial planes of the arcuate structures, but is tentatively attributed to movement in a south-westerly direction.

Less pronounced lineation is locally developed along the fault-zone west of the Martiumisigio hills, and a very indistinct horizontal lineation in the kyanitiferous schists of the Luanji-Meto area was found to be parallel to the fault-zones there. Away from the faults the lineation direction coincides with the prevalent strike of lineation for the area.

In the quartzites a prominent parting parallel to the bedding imparts a slabby aspect to the outcrops. This jointing is accompanied by prominent strike joints approximately at right-angles to the bedding joints and foliation. These types of joints are prevalent in the area, being developed in all types of rocks, but a third set which developed vertically, perpendicular to the bedding joints and parallel to the lineation direction (i.e. N. 60° E.) was only seen in the quartzite.

5. Conclusions

The structures of the Basement System in this area suggest the operation of "east-west" compressional forces while the sediments were in a semi-plastic state under high temperature and pressure. Large recumbent isoclinal folds resulted, the axes of which have a north-north-westerly trend. The formation of the folds was probably controlled to a certain extent by relatively stable blocks situated at Ol Doinyo Orok and Ingito. These stable centres probably acted in a manner similar to granitoid gneiss bodies in the southern Machakos and Sultan Hamud areas further north-east, which controlled structures during compression (Baker, 1954, p. 20: Searle, 1954, p. 23). The sediments were compressed against the eastern parts of the centres in a series of close folds. This feature as well as the prevalent dip to the east suggest that the upper part of the succession moved to the west relative to the stable blocks. During the compression major shears in two directions nearly at right-angles to one another were formed and it is thought led to the arcuation of the axes of the isoclinal folds.

VII—ECONOMIC GEOLOGY

A wide variety of minerals occurs in the area under discussion but most of the deposits, although of scientific interest, are of no economic significance.

1. Bentonitic clays

The Lake Amboseli clays, occupying the south-eastern corner of the area, were found to possess the thixotropic properties ascribed to bentonitic clays. The clays within the area are of a yellowish-brown colour, salty and of a gritty nature, but east of the area they are of greenish colour and without the gritty component. The high alkali content is due to the salinity of the dischargeless basin of Amboseli and the volcanic origin of the clays. The deposits are extensive, occupying the whole of the Amboseli basin, the thickness being unknown. The clays are overlain by a calcareous crust or concretions of kunkar limestones.

The following partial analyses were made of clays and the surface limestones obtained in the Amboseli basin:—

	1	2	3	4	5	6
	%	%	%	%	%	%
SiO_2	45·70	42·02	41·32	n.d.	n.d.	n.d.
CaO	9·70	5·62	6·25	14·64	12·60	14·06
MgO	5·52	10·12	10·57	n.d.	n.d.	n.d.
Alkalies (as Na_2O) ..	3·96	6·84	6·42	n.d.	n.d.	n.d.

n.d.=not determined.

1. Bentonitic clay, south-west Amboseli, east of Lorlawi.
2. Bentonitic clay, north-western Amboseli.
3. Bentonitic clay, central Amboseli.
4. Calcareous clay with concretions, north-eastern shore, Amboseli.
5. Calcareous clay, one mile west of Ol Tukai rest camp, Amboseli.
6. Calcareous clay, two miles west of Ol Tukai rest camp, Amboseli.

Analyst: W. P. Horne.

The analyses of the lake beds indicate the homogeneous composition of the clays within the precincts of the lake, though there is a decrease in alkali and magnesia content with concomitant increase in lime and silica as one passes from the centre towards the outer reaches of the basin.

2. Graphite

Numerous graphitic schists and gneisses occur in the middle group of the Basement System. Usually the graphite is associated with kyanite, in which case neither mineral is present in large enough quantities to warrant exploration. Two deposits of graphitic schists exposed along the Sokota river-bed, however, merit careful consideration.

The first deposit is situated where the old Namanga-Kajiado road crosses the Sokota valley, east of the northern extension of Ol Doinyo Orok. Mr. O. C. McMahon who has had experience of graphite extraction in Madagascar, had been investigating this deposit at the time of writing (January, 1953) for about a year but had not, owing to the normal difficulties of starting work on new deposits, produced any large quantity of the quality of graphite required to meet commercial specifications. For various periods he has been unable to make any progress owing to difficulties over supplies and labour and for political reasons.

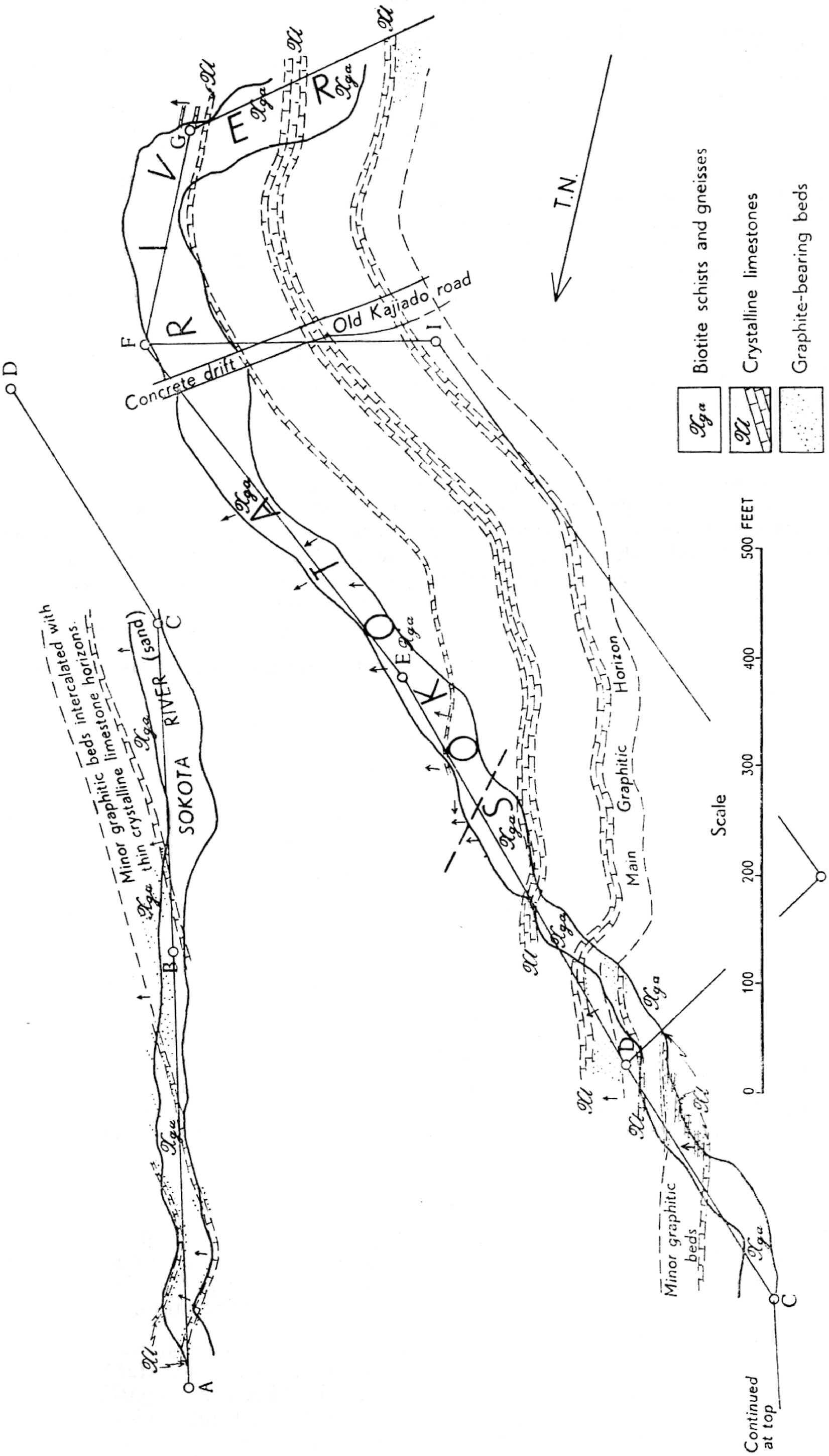


Fig. 4.—Graphite Deposits, Sokota valley.

He had produced four tons of graphite up to the end of 1952 according to Departmental records. The graphitic schists are patchily exposed along the Sokota over a distance of approximately 2,000 ft. and the graphitic bands occur over a width varying from 80 to 100 ft. across the strike (*see* Fig. 4, which comprises the ground covered by Mr. McMahon's claims (516/1, 4, 7 and 8) at the date of the survey). The formation is gently folded along the strike, which is N.N.W., and dips at an average angle of 30° to the east. The graphite occurs in thin graphitic schists interbedded with soft, friable schists or relatively hard marbles and gneisses. A concentration of graphite is usually noticeable immediately below the marble beds. In the southernmost outcrop the graphite is associated with a thin magnesite band. The graphite occurs as fairly large flakes but sometimes forms small fine-grained nodules known to the trade as "amorphous" graphite. The amount of graphite in the graphitic bands, the widths of which vary from a few inches to eleven ft., is variable. Mostly the schists are highly weathered and fissile.

No attempt to calculate the available tonnage can be made before the deposit is more extensively exposed. Concentrates produced by crushing, screening, flotation and winnowing of samples indicate that various bands of the schists contain the amounts of graphite indicated in the following table:—

Year	Sample Number	Total graphite (+60 mesh B.S.S.) in ore	Width of exposure (feet)	Remarks
		%		
1949 ..	1	3·22	10	Taken across graphite horizons and including non-graphitic rocks.
	2	3·57	20	
1951 ..	1	8·50	unknown	Graphitic rocks as mined.
1952 ..	1	3·0	8	Taken across graphite horizons and including non-graphitic rocks.
	2	5·5	4	
	3	4·4	11	
	4	2·3	5	
	5	5·3	8	

Some of the schists contain biotite, which has to be removed during the processing of the graphite, and the variable quantity of graphite along the strike calls for selective mining.

The Sokota river is dry for the greater part of the year, but the Kidongai river, two miles to the south, flows even during dry seasons. The area is wooded in most places, and timber for nearly all purposes could be had. The deposit is near to the main Namanga-Kajiado road about forty miles from the nearest point on rail, Kajiado. The seasonal flooding of the Sokota river makes open-cast work in the river-bed impracticable unless the floods can be deviated.

In the vicinity of the McMahon prospect a number of poor graphitic outcrops were noticed, usually associated with resistant marble horizons. Approximately a mile downstream from the bridge on the main road a graphitic gneiss is exposed in the bed of the Sokota, underlying a prominent marble horizon. The width of this outcrop is approximately 30 ft., the thin foliated graphitic bands alternating with fine-grained leucocratic gneisses. A representative sample taken over 15 ft. across the strike, yielded a concentrate indicating a content of 9 per cent (+60 mesh) graphite.

3. Kyanite and sillimanite

Kyanitiferous gneisses and schists occur in the middle group of the Basement System, the kyanite being usually a minor constituent and often associated with sillimanite. Deposits of sillimanite of economic importance were not encountered and it is doubtful if such deposits will be found in the area. Kyanite, on the other hand, forms a major constituent of the biotite-kyanite schists which occur immediately below the main quartzite horizon for a distance of over twenty miles in the Luanji-Metu hills. Repeated folding of the rocks often increases the widths of the kyanitiferous outcrops, the exposures being preserved by the resistance of the overlying quartzite. Numerous small kyanitiferous outcrops occur in the Rift Valley fault-zone as well as in the area below the scarps. South-west of the Ingito hills the same sequence of rock types were noticed, but in this part of the area kyanite is a minor constituent of the rocks.

The kyanite crystals were found to be rather small, up to an inch in length away from the quartzite horizon, though an increase in the size is evident as soon as the quartzite is neared, and patches of kyanitiferous quartz-biotite schist sometimes contain crystals up to three inches in length. The kyanite forms 15 per cent to 20 per cent of the rocks, but no kyanite segregations were observed. The high biotite content as large flakes imparts a fissility to the rocks that would facilitate mining and easy separation of the kyanite. The replacement of kyanite by muscovite which is prevalent in larger crystals might prove to be detrimental.

4. Crystalline limestone

Marble occurs in unlimited quantity in the Namanga-Bissel area. The upper part of the Turoka Series consists of an alternation of crystalline limestones and migmatites formed mainly from pelitic rocks. The crystalline limestone horizons, due to their weather resistant qualities, form the ridges of the gently undulating country as well as the range of hills known as Ngorigaishi. In addition to the latter major occurrence, large outcrops of marble form the southern foothills of the Maparasha hills, the ridge east of Bartinaro and the hills west of Longai.

It is generally assumed that the magnesia content of the crystalline limestones of the Basement System is too high to permit the production of *cement* conforming to the British Standard Specification. It is now known, however, that in the Sultan Hamud area, for example (Searle, 1954, p. 31), some of the beds are low in magnesia and could be used for the manufacture of standard cement. No chemical analyses of the limestones of the present area are available, but during investigations of the marbles at Turoka a few miles further north by the Geological Survey some years ago, it was shown that parts of the beds are suitable for cement manufacture. At the same time it was shown that, by suitable proportioning, soils and clays found in the same area could be used as the argillaceous constituents in making cement, and that probably standard cements could be produced. It is likely that the same conclusions would be reached in connexion with the materials available in the area mapped.

The principal use of marble is as *monumental stone*. Although taken as a whole the marble of the area is rather coarse, fine-grained impurity-free facies occur which often will take a good polish. The numerous small bridges of the main road are nearly all built of marble quarried from the area. In this connexion can be mentioned the possibility of the use of marble chippings as ballast in concrete and in the various forms of highway construction.

Ornamental marble in various pale shades of red, brown, yellow, grey and blue, often banded, were encountered along the junctions of the marble beds. Of special interest is the fine-grained pale blue marbles found on the crest of the marble hill five miles west of the trigonometrical point of Elemborasha and the blue marble on the western slope of the top ridge west of Longai. The decorative effects of these marbles are almost unlimited while the pure white marbles can be used for memorial stones, statuary and novelties. The calcining of marble from the northern extensions of the beds mapped in the Bissel area is undertaken by the Kenya Marble Quarries at Turoka for the manufacture of lime for agricultural, building and other purposes.

5. Quartzite

The quartzites of Maparasha and Lemipoiti often contain pure translucent crystalline facies, sometimes containing specks of graphite. Crushed quartzite has many uses as an abrasive, but the pure facies could be used as sources of silica in the manufacture of glass and refractories.

Clear crystal quartz was encountered north of Metu where it occurs as numerous prisms strewn on the surface. The crystals were usually about three inches long and one inch across, but because of numerous veils they are of no use for piezo-electric purposes.

6. Other minerals

The minerals described here were encountered in the area, but most of them are considered to be of little economic importance because of various factors, such as insufficient quantity, distance from rail and ruling market prices.

Beryl occurs in the pegmatites of the area as hexagons too small and too sporadic to warrant exploitation.

Copper-staining occurs frequently on nearly every rock type of the Basement System. Small bornite veins were found traversing a calc-silicate granulite associated with a basic intrusive at Lositaiti. A sample taken over a width of ten feet assayed 0·45 per cent copper.

Garnet is abundant in the area usually as a minor constituent of the Basement System rocks, but large idiomorphic crystals occur at Lengarunyeni in a hornblendic gneiss, while a massive garnet horizon, perhaps four inches thick in places, occurs below the crystalline crystalline limestone east of Longai. The garnet is unfortunately intergrown with epidote. No garnet of gem value was encountered.

Felspar. A large pegmatite occurring on the crest of Lunyolorob hill, south-west of Lokululit, is composed of very large perthite crystals. The prominent cleavages impart a slabby aspect to the outcrops while large cleaved crystals lie strewn along the hillside. The potash-soda ratio, which would determine the value of this felspar in the manufacture of china and glass, is not known.

Kaolin occurs in a small pocket on top of the southern flank of Ol Doinyo Orok, east of the Kikuyu settlement of Gorogoro.

Magnesite was found in minor quantities, usually associated with marble.

The pegmatites of the area carry abundant aggregates of *magnetite* and *tourmaline* (schorl), none of which were found in economic quantities. At Lemipoiti vermiculitized mica flakes occur scattered on a ridge formed by a pegmatite, and the same mineral was encountered three miles east of Namanga.

7. Water

The head-waters of the only permanent streams in the area, the Namanga and Kidongai rivers draining Ol Doinyo Orok, start in the elevated regions of the mountain and gradually increase in amount before the steep drop, which takes the water down to the surrounding plains, is reached. The drop is nearly 2,000 ft. in one and a half miles at Namanga while the Kidongai drops more than 1,000 ft. over a short horizontal distance. The flow of these rivers is not substantial but constant enough for the generation of small amounts of electricity. The amount of electricity that could be used at Namanga is not great, while the possibility of the generation of electricity at Kidongai would be an added attraction for the graphite deposit in the Sokota valley.

Most of the bore-holes in the area are situated in low-lying parts where drainage lines from catchment areas converge. These parts are usually wide open valleys with thick soil cover, where black clays indicate bad drainage. Water occurs in sandy layers in the clay or at the base of the clay where it lies on the Basement System, the weathered bedrock forming an aquifer. In numerous cases water was found in the bore-holes in biotite gneisses, often laminated with pegmatitic material.

Details of the bore-holes drilled in the area, abstracted from the records of the Hydraulic Branch of the Public Works Department, are given in the table below:—

BORE-HOLE DATA—BISSEL-NAMANGA AREA

Bore-hole No.	Location	Depth in feet	Depth at which water was struck (feet)	Height to which water rises (feet)	Yield (gal./24 hrs.)
C.116 ..	Ngatataik ..	122	80	63	45,600
C.139 ..	Eluanata ..	175	106 onwards	95	12,480
C.142 ..	Malalda ..	250	—	—	Nil
C.824 ..	Njoro Sindio ..	600	452	450	120
C.875 ..	Njoro Sindio ..	500	337	240	144
C.926 ..	Bissel	400	292	70	15,600
C.942 ..	Metu	420	411	139	1,080
C.987 ..	Ingito	520	126;370	136	11,400
C.999 ..	Malalda ..	330	77	57	67,200 (saline)
C.1009 ..	Malalda ..	182	107	—	24,000 (saline)
C.1523 ..	Torosei (N.) ..	433	—	—	Nil
C.1534 ..	Mailwa	208	129	68	76,800

Bore-hole C.1523, sunk in the basalts in the Rift Valley, went down to a depth of 433 ft. without striking water, being in lava all the way. That area is very dry, having no surface

water, and it is suggested that a more favourable site for drilling would be further east in the Basement System, at the confluence of the valleys draining the northern Matumbatu area.

The following bore-hole logs compiled by geologists of the Hydraulic Branch of the Public Works Department are available:—

(*a*) Njoro Sindio—No. C.824

Depth From	Depth To	
feet	*feet*	
0	46	Brown "sandy and subsoil"
46	102	Biotite (granitic) gneiss
102	105	Quartz-mica schist
105	110	Pegmatitic gneiss
110	300	Quartz-muscovite gneiss and schist
300	350	Hornblendic mica schist
350	382	Biotite gneiss
382	435	Epidote-quartz schist
435	444	Biotite gneiss
444	452	Quartz schist or gneiss
452	486	Pegmatite
486	600	Quartz-schist, partly epidotic. Bottom of bore-hole.

(*b*) Njoro Sindio—No. C.875

Depth From	Depth To	
feet	*feet*	
0	52	Brown sandy soil and gneissic detritus
52	67	Brown sandy soil with fragments of lava
67	148	Weathered granitic gneiss with some micaceous schist
148	160	Biotite gneiss or schist
160	182	Quartzitic biotite gneiss
182	280	Quartz-muscovite-biotite schist, partly garnetiferous
280	310	Garnetiferous muscovite-biotite gneiss
310	363	Biotite gneiss with pegmatite veins
363	434	Quartz schist with muscovite and epidote
434	500	Muscovite-biotite gneiss and schist. Bottom of bore-hole.

(*c*) Bissel—No. C.926

Depth From	Depth To	
feet	*feet*	
0	5	Black clay
5	60	Pink and grey clays
60	80	Grey micaceous clayey silt
80	153	Grey weathered biotite gneiss
153	283	Grey, highly weathered, clayey biotite gneiss
283	400	Fresher grey biotite gneiss. Bottom of bore-hole.

Other possible aquifers in the area are (i) the quartzites, which are highly fractured and (ii) "crystalline limestones (dolomitic) interbedded with hornblende-, epidote- and calc-schists and passing into soft siliceous biotite schists and gneisses, which are good water carriers" (Sikes, 1934, Plate XIV, Fig. 2).

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