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GEOLOGY OF THE BUNA AREA

DEGREE SHEET 22
(with coloured geological map)

by

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Geologists

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PREFACE

The geological field survey of the Buna area was undertaken between July and September 1961, and January and March 1962, by Dr L. Williams and Dr F. Matheson. The area covered by the survey falls administratively between the Eastern and North Eastern Provinces of Kenya, where communications and access (then as now) were difficult. The geological map of the Buna area was printed and published in 1970 and the subsequent long delay in the publication of this associated report is regretted. The delay has meant that some of the geological nomenclature may appear archaic, but such terminology has been retained in order to maintain consistency with the already-published map. Imperial measurements have been retained for elevations and rainfall, but all scientific measurements of grain or mineral sizes have been standardised to the metric system.

The report gives much detail of the mineralogical composition of the various lithologies that make up the Proterozoic metamorphic rocks of this area (previously called the 'Basement System'). It also contains useful stratigraphic sequences taken from boreholes penetrating the Wajir Beds, and summarises information on available water supplies at that time.

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ABSTRACT

The report describes the geology of an area of approximately 4,800 square miles in the Wajir, Marsabit and Isiolo districts of the North Eastern and Eastern Provinces of Kenya; the area is bounded by latitudes 2°00' and 3°00' N and longitudes 39°00' and 40°00' E.

Topographically the area consists largely of the end-Tertiary peneplain on which later sediments have been deposited in hollows. A possible remnant of the sub-Miocene bevel was also recognised.

The 'Basement System' rocks exposed consist of crystalline limestone; quartzites; calc-silicate granulites and gneisses; plagioclase amphibolites; hornblende gneisses; sillimanite-, kyanite- and garnet-bearing gneisses; micaceous granulites, gneisses and migmatites; and granitoid gneisses. Unfoliated granitic rocks are considered to be largely of metasomatic origin. Hypersthene-bearing pyroxenites and gabbros, with associated ortho-amphibolites are presumed to be Precambrian in age, with a similar age suggested for dykes of metadolerite and epidiorite. In contrast, basaltic dykes are thought to be Upper Tertiary or Pleistocene in age. Olivine basalt lavas were extruded during Pleistocene and, perhaps, Recent times. Superficial deposits cover the greater part of the area, obscuring the solid rocks. Quaternary deposits consist largely of a variety of residual soils.

Two periods of metamorphism and folding are postulated and the structures in the 'Basement System' rocks are described in detail. Few minerals of economic importance were encountered during the survey, but the water-supply position is reviewed and recommendations are made for improvements.

I. INTRODUCTION

The limits of the Buna area are defined by the meridians 39°00' and 40°00' E and 2°00' and 3°00' N. It comprises the complete degree sheet 22, and is some 4,800 square miles in area. For administrative purposes the area is divided into three separate districts: Wajir district of the North Eastern Province and Marsabit and Isiolo districts of the Eastern Province.

The area was mapped in reconnaissance style, the fieldwork being carried out between July and September 1961, and between January and March 1962.

Maps

The area is covered by four maps on a scale of 1:100,000 published by the British War Office and Air Ministry (GSGS Series Y633, sheets 46, 47, 58 and 59). The geological map was prepared from air photographs taken in 1957. During fieldwork, geological information was plotted on air photographs on a scale of about 1:80,000 and subsequently transferred to the 1:100,000 maps or reduced for direct transfer to final sheets at 1:83,333. Form lines were drawn from spot heights recorded with an aneroid barometer, corrections being made for diurnal variation. A height of 867 feet for Wajir was taken as a standard for the spot heights. Place names are taken largely from the published maps. Several additional motorable tracks and waterholes were added. The eastern part of the map area overlaps the Bur Mayo and Tarbaj sheets drawn by Thompson and Dodson (1960). As Thompson and Dodson themselves pointed out (*op. cit.*, p. 1), this is due to lack of sufficient ground control at the time of their survey in 1954.

Communications

The main road from Wajir to Moyale runs from south to north through Dela, Buna and Korondil, the earth surface being generally good in dry weather though deteriorating rapidly after rains, particularly the stretch across clay soils between Buna and Korondil. A secondary road leading to Takabba branches north-eastwards from Buna and, apart from occasional deep sandy patches, is in fair condition. The minor road to Arba Jahan and Habaswein through Aden Awale which leaves the main road about two and a half miles south of Buna is similarly in fair condition in dry weather, but would be impassable after heavy rain. Numerous tracks from the main road provide easy access to hilly areas and waterholes along Laga Bor and Laga Har. Giriftu on Laga Bor, just south of the area, is the starting point of tracks to Tarbaj and Aden Awale. The cut-line separating the former Wajir and Moyale administrative districts is motorable but is deeply rutted and gullied near some of the hills.

Buttelu is reached either by the track from Tarbaj, via the Ali Gollo hills, or from the Buna-Takabba road by a track which follows the former district boundary cut-line for several miles near the Reita hills. Dela is joined to the Tarbaj-Buttelu road by a track to the south of the Ali Gollo hills. In the Korondil area, tracks are generally poorly defined. Kuboli can be reached with little difficulty from Korondil or from the Moyale road via Nyata, but south

of Kuboli the track deteriorates rapidly and detours are necessary around some stretches of lava boulders. The old track across the lavas, south-west of Kuboli, has been abandoned for some years but, if required in the future, it could be reopened without a great deal of work, at least as far as the western boundary of the present area. Regular maintenance would, however, be necessary on many of the bouldery stretches. Better use could have been made of motorable stretches of volcanic soils at the eastern end of the track. The Korondil-Arba Jahan track is well defined in the north, but is practically unrecognisable south of Chipder. The western part of the south-eastern quarter and nearly the whole of the south-western quarter of the map area consists of open plains which are motorable, although the soil is dusty and, after rain, the grass thick.

Climate and vegetation

The area lies in a semi-arid zone that characterises a large part of north-eastern Kenya and, with its low rainfall, more closely resembles Wajir than Moyale, the latter standing at over 3,500 feet above sea level. Rainfall records have been kept at Buna Police Post only since 1957 and no others are available from within the Buna area. The following figures are taken from the records of the East African Meteorological Department:

Station	Annual rainfall (inches)				Yearly average	No. of years recorded
	1957	1958	1959	1960		
Buna	–	–	–	10.07	–	1
Wajir	20.15	9.93	3.62	13.53	9.04	34
Moyale	41.70	22.80	29.94	30.74	26.40	41

Rain generally falls between April-June and October-December, the heavier falls usually being in the earlier part of the year. At other times the climate is hot and dry but it is somewhat cooler between July and September.

East of the Laga Bor the vegetation mainly consists of a fairly thick growth of stunted thorn trees which is usually denser on the Wajir Beds than on the 'Basement System' rocks. On the Giriftu outcrop of the Wajir Beds, however, trees are scattered. West of the Laga Bor the open plains develop thick grass after the rains but the patches of soils derived from the 'Basement System' support some small trees. Along the *laga** the trees are thicker and more varied in character.

* Local names used below include *laga* (a watercourse, usually dry); *dololo* (a depression dug in a watercourse to hold water after a flood has passed); and *aduli* (an earth bund placed at the foot of a steep, rocky outcrop to catch runoff).

Population

The area is sparsely populated. Somalis of the Degodia clan are found in the extreme east of the north-eastern quarter and to the east of Laga Bor in the south-eastern quarter. Adjuran are found in the rest of the area except where Boran encroach in the north-west near Korondil. All are nomadic, their movements being controlled entirely by seasonal water and grazing for goats, sheep and camels. Goats and sheep are found in all parts of the area but the Degodia keep large herds of camels and few cattle, whereas the Adjuran do the opposite.

Oryx are found in all parts of the area, and among the gazelles gerenuk predominate in the thicker bush in the east but Grant's gazelle appear to prefer the open plains in the west. Predators are rare but jackals are fairly common.

II. PREVIOUS GEOLOGICAL WORK

Little recorded geological work has been carried out in the Buna area. In 1914-15, Parkinson (1920) travelled through parts of the Northern Frontier District, passing on his way from Wajir to Moyale across the present area. On a map accompanying his report he showed the Buna area to be underlain by gneisses and schists with volcanic rocks in the west, and mentioned the Eil Lass-Geriftu lake (Laga Bor) as being one of the feeders of the sub-surface water at Wajir (p. 15). During a journey from Moyale to El Wak, Parkinson visited Ajow (Ajao) and Buttellu (Buttelu). He referred the rocks at these localities to the Turoka Series, in view of the similarity between the quartzites at Ajao and those exposed near the headwaters of the Turoka river in southern Kenya (p. 25). The quartzites at Ajao were said to be composed largely of pure quartz, though locally containing magnetite, small flakes of green and white mica and tourmaline. Near the Ajao wells, Parkinson found a fine-grained grey micaceous gneiss with associated pegmatite interbedded with the quartzites (p. 26). At Buttelu, rocks of the Turoka Series were said to be principally marbles, with interbedded quartz schists, the rocks showing signs of crush. The marbles were described as being free from lime-magnesian silicates with variations being largely textural. A few bands of biotite gneiss were found associated with the limestones, and dips of about 40° to 45° to the SW were recorded. A number of other interesting rocks from Buttelu were described (pp. 26-28). One is composed of quartz, pinkish garnet and reddish-brown mica together with subordinate microcline. Closely associated with it, Parkinson found a strongly-foliated, coarse-grained rock containing brownish-red garnet, mica, sillimanite, a little felspar, and locally rare quartz. Other sillimanite-bearing rocks encountered at Buttelu included a coarse quartz schist or quartzite containing felspar, garnet and micas, and a micaceous gneiss in which felted masses of sillimanite form almond-shaped lenticles up to 20 mm long. Parkinson regarded the rocks as metasediments, the sillimanite lenticles representing pellets or streaks of clay. Cataclastic textures were reported in some of the rocks. Fragments of a rock containing quartz, magnetite and augite were found about three miles north-east of Buttelu. It was also referred to the Turoka Series.

In 1943, Dixey travelled over a large part of northern Kenya in the course of hydrographic surveys and later (1948) prepared a report on the geology of this part of the country. A geological map attached to the report showed the present area as underlain by 'Basement System' rocks, with Tertiary-Recent volcanics in the west. Examples of minor fissure eruptions of olivine basalts were described (p. 8) from a locality about 35 miles west of Buna, just beyond the western boundary of the Korondil sheet, and the remarkably fresh appearance of the lavas from these fissures was noted, though they were described as breaking through older basalts. In a map illustrating the distribution of erosion surfaces in the Northern Frontier District, Dixey (*op. cit.*, Fig. 1) showed the end-Tertiary peneplain sloping to the south-east across the present area and, standing above it at Korondil and at a mass representing the Ajao hill, remnants of a mid-Tertiary peneplain (termed the Abyssinian plateau).

In 1950 and 1951, F.M. Ayers, an ECA geologist seconded to the Government, carried out a reconnaissance survey of the Mesozoic and Tertiary sediments farther east, with a view to the prospect of discovering oil. He did, however, mention that the Ali Gollo hills are largely composed of crystalline limestone (Ayers, 1954, p. 4). Several hills between Buna and Takabba were examined and found to be composed of quartzites.

Bestow (1953) prepared an unpublished report on the geology and hydrology of the Wajir District, based on fieldwork carried out in 1952. His map accompanying the report shows the whole region east of the Laga Bor as Tertiary sediments except for the undoubted outcrops of 'Basement System' rocks. He also noted the granite at Haragal and dug several pilot wells in the Wajir Beds.

Between 1950 and 1958 Messrs. Howard Humphries and Sons acted as consulting engineers for a water development scheme in northern Kenya. In a report submitted to the Government in 1958, specific mention of the present area is largely confined to a discussion of work carried out to improve water supplies and recommendations for future work. Buna borehole was sunk in 1955, providing excellent water, and elsewhere wells, dams and tanks were dug or constructed. The report noted (p. 38) that wells proved disappointing, so *dololo* were constructed at Yakho and Maddo to supplement the earlier pans at Dela and Halati and access tracks provided. Giriftu, however, proved suitable for the construction of wells so six new ones were constructed and several older ones improved.

Thompson and Dodson (*op. cit.*) carried out a geological survey of the Bur Mayo-Tarba area, immediately east of the present area, in 1954. As a result of insufficient ground control and difficulties in plane-table resection, the meridian 40°00' was displaced about two miles to the west on their maps, so that the Ali Gollo hills were included and mapped in the Bur Mayo area. A re-examination of part of the hills during the present survey provided additional structural information without any significant changes in the geological boundaries and rock types given in the earlier report.

P. Joubert (1963) mapped the Wajir-Wajir Bor area in 1956 giving details of the Wajir Beds at the type locality and establishing a succession for the soils.

In 1960-61, Walsh (1972) geologically surveyed the Moyale area, lying immediately north of the Buna area.

III. PHYSIOGRAPHY

1. Topography

The area is dominated by an extensive plain from which rises a number of isolated hills and ranges. The plain is best developed in the north-west, south-west and south-east quarters, where it slopes gently southwards from nearly 1,800 feet in the north to about 1,000 feet near the southern boundary. A slight rise in the surface towards the western edge of the area is due to a thin cover of lavas resting on the plain, and a slight depression occurs approximately along the meridian 39°30', corresponding to the major drainage system. The plain rises steadily towards the central and northern parts of the north-eastern quarter. It lies at about 2,000 feet in the north, falling to some 1,400 feet in the south-west and south-east, and to about 1,450 feet in the south-central part of the quarter.

The heights of some of the more important hill summits in the area are: Ajao (west) 3,690 feet; Korondil 3,630 feet; Kijibil and Ajao (east) a little over 3,300 feet; Mojo 3,080 feet; Gogai 2,935 feet; highest point in the Buttelu range 2,900 feet; Reita 2,770 feet; Ghote hills 2,515 feet.

2. Drainage

The main drainage of the area is along the Laga Bor and the Laga Har (Laga Chamu upstream), the former receiving all the drainage from the 'Basement System' except that of the eastern side of the Ali Gollo hills. Buna is situated on the Laga Bor, a little south of its confluence with the Laga Jara, the latter differing from the other main streams in flowing south-westwards down the local slope of the plain. The Laga Chamu (Laga Har downstream) is separated from the Laga Bor by a number of prominent hills defining the Buna anticline.

A low ridge extends westwards from the hills so that small steams flow northwards before swinging west to join the Laga Bor. A minor radial drainage pattern has developed around many of the hill masses in the area, though northward-flowing watercourses of any importance are rare.

West of the main *laga* the drainage of the plains is carried by several small, isolated *laga,* but much of the rainfall appears to be absorbed in the red-brown clayey soil.

The smaller *laga* on the 'Basement System' soils are marked by low depressions with thicker vegetation but even these die out when the Wajir Beds are reached, indicating that most of the flow is underground.

3. Erosion surfaces

The plain described above is part of the extensive end-Tertiary peneplain, a surface that is

widely developed in the eastern half of Kenya. It is the best-preserved erosion surface in the area, though it is broken by numerous hills, representing remnants of earlier bevels, and by a zone of dissection now occupied by the Laga Jarti Guda – Laga Jara – Laga Bor – Laga Chamu drainage system. In the north-west, the overall southward slope of the end-Tertiary peneplain is about 10 feet per mile, though the gradient decreases from 12 feet per mile in the north to only about 5 feet per mile near the southern boundary (see Fig. 1). Near Buna, the end-Tertiary surface has a south-westward slope of some 18 feet per mile towards the Laga Bor; in the extreme north-eastern corner the slope is 37 feet per mile in the direction a little south of east; and in the east-central part of the area, the surface slopes due southwards at 26 feet per mile. Along the meridian 38°30', the end-Tertiary peneplain shows up to 50 feet of dissection and the surface is now represented by occasional low inselbergs.

Remnants of earlier erosion bevels are preserved in hill masses rising above the end-Tertiary peneplain, though difficulty is encountered in dating the surfaces with any degree of accuracy. No fossiliferous sediments occur on any of the peneplains within the present area. The first bevel above the end-Tertiary peneplain slopes approximately south-westwards at about 18 feet per mile, falling from some 2,500 feet in the north to about 1,800 feet near El Las. This surface is clearly the one described as the sub-Miocene peneplain by Walsh (*op. cit.*) in the area north of the Buna sheet (there is a discrepancy of approximately 100 feet in form lines between the two areas, explaining the figure of 2,600 feet quoted by Walsh at the southern boundary of the Gurar area). The surface also corresponds approximately with the height of the sub-Miocene bevel shown by Pulfrey (1960), though the direction of slope deduced from the present work differs from that indicated by Pulfrey (he shows the surface sloping to the south at about 17 feet per mile across the present area).

Another bevel, about 250 feet above the presumed sub-Miocene surface, is best preserved in the Ghote hills and in some of the high ground at Buttelu and Kuro. Isolated remnants of the same bevel occur at El Las, Garse Buna, Sala, Butei, Datacha Mudi, west Gogai and doubtfully at Karari Guda. In the Korondil area the small hill at Tuli Roba may represent an extension of the bevel. This surface has not been recognised in the Gurbar-Kubi Halo area, north of the Buna sheet, and further discussion is better postponed until the survey of the Moyale area has been completed. Contour lines for the bevel are shown in Fig. 1, together with those for the sub-Miocene surface. In the Buna area, the slope is south-westwards; in the Korondil area it is impossible to estimate accurately the gradient and direction of slope of the sub-Miocene and intermediate bevels, but it is likely that the slopes become more southerly to parallel the end-Tertiary peneplain. Similarly, a swing to a south-eastward slope is likely in the Bur Mayo area, east of the Buna sheet.

In the Gurar-Kubi Halo area (Walsh, *op. cit.*), accordant summit levels of the larger hills are taken to represent the end-Cretaceous surface. The summits at Ajao and Korondil lie on this postulated bevel, with Kijibil, Mojo and Gogai evidently being reduced remnants of the end-Cretaceous peneplain.

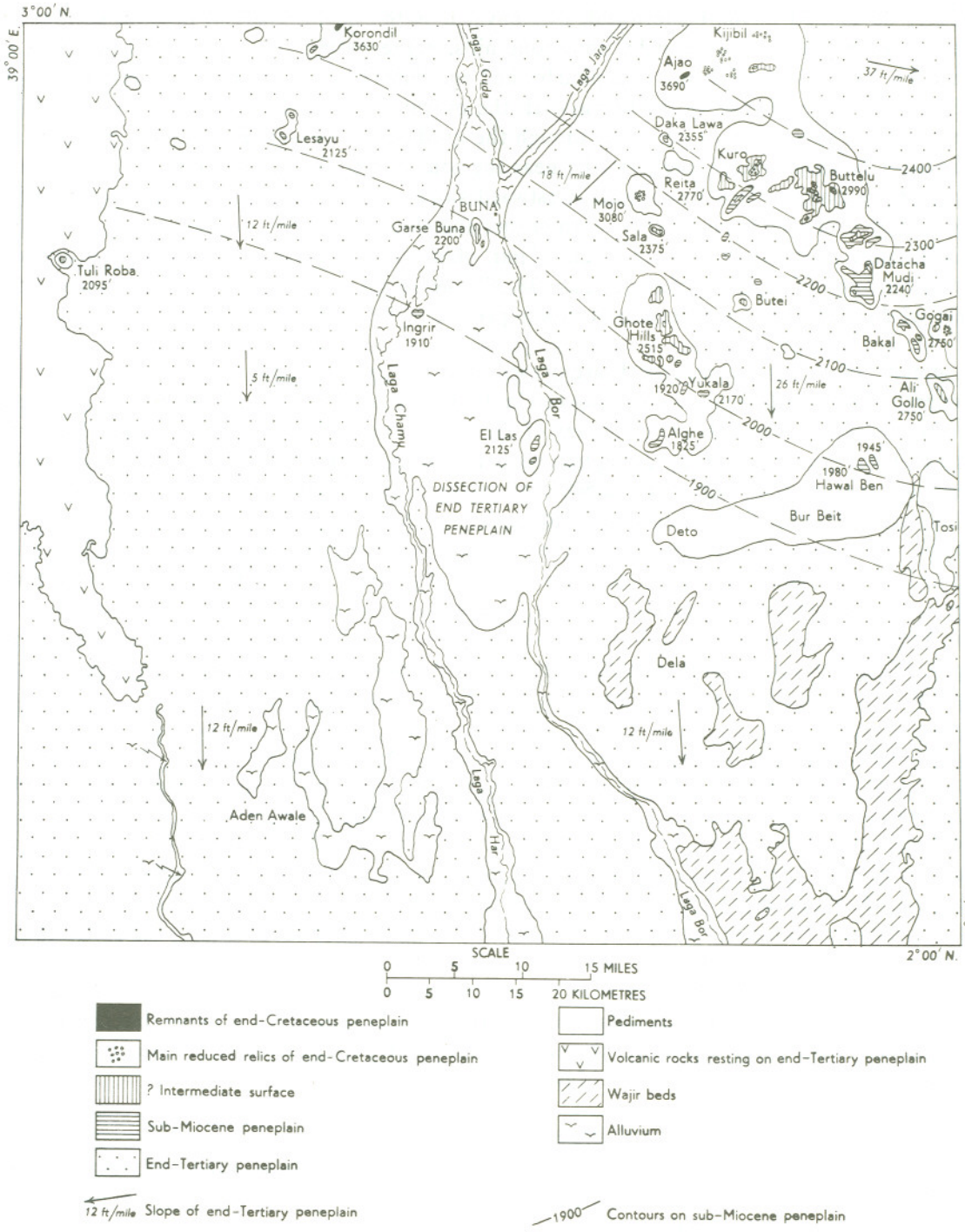


Figure 1 Physiographical map of the Buna area

IV. SUMMARY OF GEOLOGY

The rocks mapped in the Buna area fall into the following broad divisions:

a) 'Basement System' rocks
b) Unfoliated granitic rocks
c) Intrusive rocks
d) (?)Pleistocene sediments (the Wajir Beds) and
e) Pleistocene to (?)Recent volcanics.

Most of the area is believed to be underlain by rocks of the 'Basement System', which is Precambrian in age. Only in the north and east, however, are the rocks exposed and in other parts the 'Basement System' is represented by residual red sandy soils. Rocks of the 'Basement System' represent a metamorphosed, thick sedimentary succession. The widespread development of crystalline limestones, calc-silicates and amphibolitic gneisses indicate the abundance of calcareous and semi-calcareous sediments in the original sequence. Similarly, numerous bands of quartzites show that sandstones were well represented. Occurrences of sillimanite-, garnet- and kyanite-bearing gneisses provide further evidence of the sedimentary origin of the local 'Basement System' rocks and represent metamorphosed clays and mud-stones. Micaceous gneisses, granulites and migmatites are the metamorphosed and granitized equivalents of semi-pelitic sediments; a more advanced stage of granitization is preserved in occurrences of granitoid gneisses. Pegmatites were rarely encountered and, of those examined, many are concordant bodies of metasomatic origin.

Medium- to coarse-grained, unfoliated granitic rocks occur in isolated hill masses, inselbergs and accumulations of boulders. In mineralogical composition, they range from biotite granites, through biotite adamellites to rare biotite granodiorites. Contacts with the surrounding rocks are not exposed but, from a consideration of bands and inclusions in the granites, it is concluded that the unfoliated rocks originated largely by metasomatic processes and represent an end stage in the *in situ* granitization of 'Basement System' gneisses. Locally, however, there is evidence to indicate that the granitic rocks attained some degree of mobility.

Rocks of undoubted intrusive character comprise a single boss of pyroxenites and gabbros, and basic dykes of two different ages. The plutonic rocks are hypersthene-bearing varieties and display marginal metamorphism to plagioclase amphibolites. By comparison with similar intrusives in other parts of the country, the pyroxenites, gabbros and associated ortho-amphibolites are considered to be Precambrian in age though younger than the 'Basement System'. An older suite of dykes, that cut 'Basement System' rocks and locally contain hypers-thene, comprises metadolerites and epidiorites and is probably the hypabyssal equiva- lent of the basic and ultrabasic plutonic rocks. In contrast, more common minor intrusives are composed of basalt and olivine basalt. They cut both 'Basement System' rocks and Precambrian hypersthenic gabbros and show affinities with Quaternary lavas so that they are provisionally dated as Upper Tertiary-Lower Pleistocene.

A sedimentary sequence, the Wajir Beds, was laid down in lakes formed in hollows eroded in the end-Tertiary peneplain. The deposits are arenaceous in the lower part and calcareous in the upper with no gypsum as found at Wajir itself. The reason is probably that the present area lay nearer the margin of the original basin so only the lower part of the Wajir succession is present. The Wajir Beds were dated as Lower and Middle Pleistocene by Joubert (1963, *op. cit.*) on their correlation with similar beds in the Daua valley to the north.

Olivine basalt lavas that rest on the end-Tertiary peneplain in the western parts of the Korondil area are assigned to the Pleistocene; though, judging by the fresh appearance of the latest flow, both in the field and in thin section, some extrusion may have occurred during Recent times.

The Quaternary deposits in the area are largely soils, those in the Buna area being predominantly red and red-brown sandy varieties whilst clayey and dusty soils covering a large part of the Korondil area range in colour from grey and brown to reddish-brown.

The 'Basement System' is characterised by red sandy soil, whereas the red soil on the Wajir Beds is finer and somewhat lighter in colour. Dark to reddish-brown, clayey, alluvial soils are associated with the present drainage systems, and dusty volcanic soils occur in the extreme west. Poorly-consolidated grits fringe some of the granite hills and superficial limestones near the Ali Gollo hills overlie fluviatile deposits, probably of Lower to Middle Pleistocene age.

V. DETAILS OF GEOLOGY

1. The 'Basement System'

Although outcrops are few, more than half the area is believed to be underlain by rocks of the 'Basement System' which is of Precambrian age. In and near the Ali Gollo hills practically all the outcrops are composed of resistant quartzites and limestones. The intervening ground is covered by red sandy soil which presumably represents more easily eroded gneisses. By analogy other stretches of similar red sandy soil are thought to cover rocks of the 'Basement System' even where there are no exposures. It is of interest to note that the red sandy soil of the Aden Awale area contains more quartz pebbles than are found in the Dela area. This may indicate that erosion has proceeded further in the west so that even quartzites are represented only by soil and pebbles.

With such poor exposures no estimate can be made of the total thickness of the 'Basement System', but the granitoid gneisses south of El Las appear to reach a maximum of 3,000 feet. At Bafuf and Bur Beit the succession is as follows:

Gneisses	2,000 + feet
Limestone	800 feet
Quartzite	150 feet
Limestone	700 feet
Muscovite-biotite gneiss	200 feet
Felspathic quartzite	100 feet
Limestone	800 feet
Gneisses	3,000 feet
Limestone	700 feet
Gneisses	3,000 + feet
Total	11,450 + feet

For descriptive purposes, the rocks of the 'Basement System' are classified as follows:

(1) Metamorphosed calcareous sediments
- (a) Crystalline limestones
- (b) Calc-silicate granulites and gneisses
- (c) Anthophyllite-talc-dolomite-quartz schists

(2) Metamorphosed semi-calcareous sediments

- (a) Plagioclase amphibolites and hornblende-biotite gneisses
- (b) Hornblende-diopside-biotite gneisses
- (c) Hornblende-garnet gneisses

(3) Metamorphosed pelitic sediments

- (a) Biotite-sillimanite gneisses
- (b) Garnet-biotite-sillimanite gneisses
- (c) Biotite-muscovite-sillimanite-kyanite gneisses
- (d) Biotite-garnet gneisses
- (e) Garnet-quartz-felspar granulites

(4) Metamorphosed semi-pelitic sediments

- (a) Biotite migmatites, gneisses and granulites
- (b) Muscovite gneisses and granulites

(5) Metamorphosed psammitic sediments

- (a) Quartzites, muscovite quartzites and magnetite quartzites
- (b) Grunerite-(kyanite)-sillimanite-garnet quartzites

(6) Granitoid gneisses

- (a) Biotite-(actinolite) granitoid gneisses
- (b) Quartzofelspathic granitoid gneisses
- (c) Hornblende-biotite granitoid gneisses

(7) Pegmatites

In addition to the above, a number of unfoliated granitic rocks are believed to have formed largely by the metasomatic replacement of 'Basement System' gneisses, representing the end stage in a process of progressive granitization. Logically, therefore, the granitic rocks should be described with the 'Basement System' rocks but, until the origin of the unfoliated types has been conclusively established, it is considered wiser to describe them separately in a later section.

(1) Metamorphosed calcareous sediments

The abundance of calcareous sediments, many of them highly dolomitic, in the original succession, is shown by the widespread development of crystalline limestones and calc-silicate granulites and gneisses. Substantial variations in the carbonate content of the sediments, together with differences in composition of the non-calcareous impurities present in many of the original limestones, has given rise to a range of metamorphic rock types. Other mineralogical variations are apparently related to the grade of metamorphism attained in

various parts of the area. Most of the occurrences of crystalline limestone are characterised by numerous knots and lenses of silicates. Carbonate-poor or -free granulites and gneisses also occur abundantly and are described separately as calc-silicates. Unusual anthophyllite-talc-dolomite-quartz schists are also described.

(a) Crystalline limestones

Crystalline limestones are extensively developed in the east-central, eastern and north-eastern parts of the area, the main outcrops forming a parabolic curve, open to the south. The eastern limb trends NNW-SSE and is defined by the ranges of hills extending from Ali Gollo to Buttelu; the western limb of the curve has a more N-S orientation and is marked by less impressive, isolated features between Kuro, Yukala, Alghe and Deto. Other outcrops of marble occur within the main curve, forming small hills at Bur Beit, Hawal Ben, Garapaadi, Bafuf, Tosi, Burchilin and Kubi Dula. Minor exposures of limestones were encountered in the western parts of the Ghote hills and in the northern foothills of the Ajao range. No crystalline limestones crop out in the Korondil area, though calc-silicate rocks exposed there were clearly derived from impure calcareous sediments. Broad bands of marble have, however, been mapped in the Gurar area (Walsh, *op. cit.*), immediately north of the Buna area, and a continuation of the rocks described here is clearly to be sought in that direction.

Where best developed, the limestones usually form ranges of rounded hills and ridges, intervening valleys being generally devoid of rock exposure. Intercalated quartzites often exert a strong influence on the topography of these hill masses, with the siliceous rocks frequently forming strong ribs. Many of the smaller limestone outcrops are topographically insignificant and are commonly covered by kunkar so that good exposures of the marbles are rare. Owing to structural complexity, it is seldom possible to forecast with certainty the positions of marble bands between the scattered outcrops, though locally-distinctive textures visible on air photographs offer some assistance.

Variations in colour in the crystalline limestones are related to the amount, nature and degree of alteration of minerals that commonly accompany the carbonates. In purer portions of the marble, fresh surfaces are white or pale grey and individual calcite or dolomite crystals frequently attain a diameter of 5.0 mm.

The crystalline limestones vary in composition and to a lesser extent in texture. The purest found was the upper band at Bur Beit from which specimen 22/155* was collected. This is a white coarse-grained rock with brown weathered crust but no impurities. In thin section it was seen to consist of a mosaic of pure calcite crystals. Most of the limestones, however, contain some iron ore which is disseminated through the crystals and gives a grey colour to the rock, but in 22/149 from a low hill south of Tosi magnetite forms accessory grains set in the calcite mosaic.

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* Specimens referred to are in the regional collection of the Mines and Geological Department in Nairobi.

A variation from pure calcite in the limestones is an increase in the proportion of dolomite. Specimen 22/142 from the low hill south of Bafuf shows the first stage in this process. It is a medium-grained, blue-white rock which under the microscope reveals that dolomite is subsidiary to calcite. Specimen 22/150 collected at a low hill half-way between Bafuf and Bur Beit is a medium-grained, brownish-grey rock in which dolomite is nearly as abundant as calcite and some quartz grains are accessory. The rocks occasionally bear a sprinkling of small brown phlogopite flakes. The commonest impurity in the limestones is diopside, which is often accompanied by pale amphibolites though the latter are indistinguishable from the pyroxene in hand specimens. These silicate aggregates occur as irregular grey or bluish-grey patches that weather to a pale brown colour and often stand out as knots on weathered surfaces. Forsterite marbles are abundant in parts of the area and the rocks are characterised by pale yellow, yellow-green or pale brownish portions in an otherwise whitish limestone. Sometimes the forsterite occurs in evenly-distributed distinct grains, rather than ill-defined aggregates, giving the marble a finely-mottled appearance. Locally, the forsterite marbles bear bands and lenses of ophicalcite, which is typically a brown and white, coarsely-mottled rock that is often traversed by fine white parallel veinlets of calcite that stand out as fins on weathered surfaces. Differential weathering of ophicalcites produces a rough surface with yellow-brown granular masses of serpentinous material standing out from carbonate portions of the rock. Although impurities in the crystalline limestones often produce pale brown tints on weathering, exposed surfaces of the bulk of the marble generally become dark brown or dark grey-brown.

For descriptive purposes, the crystalline limestones are conveniently subdivided into forsterite- and serpentine-bearing varieties, and forsterite-free marbles.

(i) Forsterite marbles and ophicalcites

Crystalline limestones containing abundant forsterite are best developed at Kuro, in the north-central part of the Buna area, but other occurrences were encountered in the northern and southern parts of the Buttelu hills; at a locality in the northern part of the Datacha Mudi range; in the northern foothills of the Ajao range; and within limestone outcrops around Butei, in the centre of the Buna area. Forsterite is apparently absent in limestones exposed in the south-eastern quarter of the Buna area, but the mineral is reported (Walsh, *op. cit.*) as a common constituent of marbles in the Gurar area, north of the Buna sheet.

Rocks in which forsterite is completely replaced by serpentine (ophicalcites) are less common. However, they were encountered at many localities in the Kuro hills, where they are patchily developed within forsterite marbles, and a little ophicalcite was encountered in coarse white crystalline limestones at the eastern hill of the Yukala range. It should be stressed that, at all the above localities, forsterite- and serpentine-bearing marbles occur as bands and patches in a sequence that may be composed dominantly of purer limestones. More detailed sampling than was possible during the present work would be required to determine with certainty the distribution of forsterite.

Table 1 shows the mineral composition of several specimens of forsterite marble and ophi-

calcite, together with a number of forsterite-free limestones. Since the proportions of constituent minerals often vary considerably throughout even a single hand specimen, with the silicates frequently concentrated in patches, no attempt has been made to indicate the estimated modes of these rocks.

Table 1 Mineral composition of crystalline limestones and associated rocks

	6	7	52	56	53	54	57	72	161*	186*	196*	200*	332*	336*
Calcite/ dolomite	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Forsterite	X	X	X	X	X	–	–	–	–	–	–	–	–	–
Serpentine	X	X	X	X	X	X	–	–	–	–	–	–	–	–
Diopside	X	X	X	?	–	–	X	X	–	X	X	–	–	X
Tremolite	X	X	X	X	–	–	X	–	–	X	–	–	–	X
Amphibole (opt. +ve)	X	X	X	X	–	–	–	X	–	–	X	–	–	–
Phlogopite	X	–	–	X	X	X	X	–	–	X	–	X	–	–
Quartz	–	–	X	–	–	–	X	–	X	–	–	–	–	–
Spinel	–	X	–	X	X	–	–	–	–	–	–	–	–	–
Magnetite	–	–	–	X	X	X	–	–	X	–	–	–	–	–
Pyrite	–	–	–	–	X	–	–	–	–	–	–	–	–	–
Brucite	–	X	–	–	–	–	–	–	–	–	–	–	–	–

* Sample nos. prefixed by 23/ (from degree sheet 23, listed for comparison)

X = present; – = absent

22/6 Forsterite marble, north Ajao
22/7 Forsterite marble, north Ajao
22/52 Forsterite marble, north-east of Halima
22/56 Forsterite marble with phlogopite-amphibole band, south Buttelu
22/53 Forsterite marble/ophicalcite, Kuro
22/54 Ophicalcite, Kuro
22/57 Diopside-quartz lens, Buttelu
22/72 Diopside lens, Hawal Ben
23/161 Crystalline limestone, Garabid hill
23/186 Crystalline limestone, Ali Gollo
23/196 Diopside lens, Ali Gollo
23/200 Crystalline limestone with phlogopite, Ali Gollo
23/332 Crystalline limestone, near Gosieh hill
23/336 Crystalline limestone, north-west of North Ali Gollo

Forsterite marbles that are poorly exposed near Kara Garsum in the northern part of the Ajao hills, are pale grey or off-white, medium- to very coarse-grained rocks. The coarser

portions of the limestone are invariably composed of pure carbonate in crystals up to 12 mm across. The forsterite occurs in olive green or brownish, rounded grains varying from 1.0-5.0 mm in diameter, the colour depending largely on the degree of alteration. Locally, small brown flakes of phlogopite are conspicuous. The thin section of specimen 22/6 shows abundant carbonate, occurring in anhedral plates commonly 0.5-1.0 mm across and displaying rhombohedral cleavage and polysynthetic twinning. Small ragged flakes of phlogopite are dichroic from pale brown to nearly colourless and have a negative optic angle which is so small that the mineral often appears to be uniaxial. Occasional anhedral to subhedral grains of colourless forsterite ($+2V = 85°$-$90°$) show alteration to cross-fibre veinlets of pale brown chrysotile and to colourless tremolite, the latter frequently being patchily replaced by calcite. Colourless amphiboles and subordinate colourless diopside occur in clusters of small subhedral crystals. Both tremolite and an optically-positive amphibole were identified in these clusters, the latter having a moderate optic angle and extinction $c \wedge Z = 20°$. The positive amphibole has a higher relief than tremolite and is distinguished from diopside by characteristic cleavages and smaller extinction angles. The pyroxene displays alteration to tremolite and calcite. In the portion of the limestone sectioned, silicate minerals constitute less than 5% of the rock. In another specimen (22/7) of forsterite marble from the same locality, phlogopite is absent but the rock contains rounded grains of green spinel up to 0.5 mm in diameter. The forsterite is generally fresh, though occasionally shows alteration to pale brown antigorite. It is often rimmed by colourless tremolite, which also occurs in small subhedral crystals together with diopside and an optically-positive amphibole ($2V = c.60°$). A mineral identified as brucite or colourless chlorite occurs as a rare alteration product of amphibole.

The forsterite marbles exposed north of Buttelu, and some two and a half miles north-east of Halima hills, are medium-grained, white or pale yellow rocks bearing numerous 50-75 mm long lenses and patches composed of aggregates of small grey bladed crystals exhibiting strong cleavage parallel to the length, and prominent cross fractures. Weathered surfaces of the limestones are commonly marked by pale brown nodular projections about 12 mm across and protruding about 25 mm above the rough surface of the marble; many are almost square in cross-section. The thin section of specimen 22/52, from this locality, shows that in the whitish or pale yellowish portions of the marble, carbonates are often accompanied only by abundant rounded grains of colourless forsterite ($+2V = c.85°$) altering to antigorite. The grey patches in these rocks consist essentially of aggregates of colourless pyroxene and colourless amphiboles. Individual crystals are seldom more than 2.0 mm long. Diopside has $+2V = c.60°$ and maximum extinction $c \wedge Z = 41°$, and displays strong (100) partings in addition to typical pyroxene cleavages. Tremolite, having $-2V = c.85°$ and $c \wedge Z = 17°$, is accompanied by an optically-positive amphibole ($+2V = c.80°$ and $c \wedge Z = 20°$). Carbonate occurs abundantly, mainly in anhedral plates but also replacing the pyroxene and amphiboles. Small rounded quartz grains are rare. The pale-brown-weathering nodules described above are composed dominantly of diopside, showing widespread alteration to carbonate. These nodules are not formed by single large crystals of pyroxene, but of collections of subhedral grains.

Forsterite is not a conspicuous constituent of the crystalline limestones forming the Buttelu

hills, but an interesting occurrence was encountered about two and a quarter miles south-east of Buttelu wells, on the west side of a valley near the end of the range. The yellow-green or brownish forsterite marble at this locality contains a dark, micaceous, vein-like band about 25 mm wide, having rather sharp margins. A thin section of specimen 22/56 shows rounded grains of forsterite in the host limestone, altering to yellow-brown serpentine that is partly composed of cross-fibre veinlets of chrysotile. The grains are often surrounded by a thin rim of colourless tremolite. Towards the margin of the dark band, there is a progressive increase in the degree of serpentinization of forsterite and the development of numerous grains of green spinel. The dark band is composed of an impersistent marginal zone of near-uniaxial, very pale brown to colourless phlogopite, bearing irregular grains of opaque ore and green spinel, and a little interstitial carbonate. The bulk of the band is formed of pale amphiboles and a few grains of unconfirmed diopside. The commonest amphibole is an optically-positive variety, very weak pleochroic in shades of pale brown, and having extinction $c \wedge Z = 25°$. Optically-negative tremolite shows maximum extinction $c \wedge Z = 19°$. Occasional grains of spinel, small flakes of phlogopite and rare interstitial plates of carbonate are visible in the amphibolitic portion of the rock.

At the western end of the Kuro hills, the limestones are marked by advanced stages of serpentinization of forsterite leading ultimately to the production of numerous lenses of ophicalcite. A typical specimen (22/53), collected from the north-western part of the hills, is a medium-grained marble containing abundant greenish grains of altered forsterite and a yellow-green serpentinous lens that bears prominent 2.0-3.0 mm long grains of ore and small, dull green spinel. A thin section shows cloudy carbonate and colourless forsterite, the latter largely altered to antigorite, fibrous chrysotile, small grains of magnetite and reddish-brown iron oxides. Irregular, cracked grains of very pale green spinel attain a length of 2.5 mm, and are rarely flanked by fine flakes of phlogopite, dichroic from pale brown to colourless. The ore is apparently dominantly magnetite though some pyrite was identified. In a specimen (22/54) of coarsely-mottled, brown and white ophicalcite, collected from the southern part of the Kuro hills, numerous pseudomorphs after forsterite, occasional flakes of colourless phlogopite and rare grains of ore are set in an inequigranular carbonate base. The yellow-brown pseudomorphs are composed of fine granular, fibrous and amorphous minerals of the serpentine group, together with a little magnetite and limonitic oxides, rare flakes of colourless phlogopite and grains of carbonate. No unaltered forsterite is visible. The section is traversed by veinlets of serpentine (?antigorite) and fine granular or fibrous carbonate.

(ii) Forsterite-free marbles

Crystalline limestones in which no forsterite has been recognised crop out extensively in the south-eastern quarter of the Buna area, between Datacha Mudi, Ali Gollo and Hawal Ben. Most of the limestones at Buttelu, Alghe, Yukala and around Butei are apparently forsterite-free, although this conclusion is based on the paucity of coloured varieties of marble and evidence from a limited number of specimens available for microscopic examination. The essential variations in mineralogical composition are shown in Table 1.

Many of the limestones lack any visible impurities and the white or off-white rocks are composed simply of an inequigranular mosaic of anhedral calcite or dolomite. Some marbles contain brownish or colourless phlogopite, and occasional grains of magnetite and quartz are visible in thin sections. The commonest minerals accompanying carbonates are diopside and colourless amphiboles. These occur in greyish lenticular patches, composed of aggregates of bladed crystals, that are easily recognisable on fresh surfaces of the marble. The silicates often stand out on weathered portions of the limestone, forming nodules or thin bands. With the possible exception of limestones at Alghe, Kubi Dula and around the Butei hills, pale pyroxene-amphibole patches were seen at all marble localities in the Buna area. The minerals are particularly prominent at Bakal, Hawal Ben and parts of the Buttelu hills.

In specimen 22/72, from the north-eastern part of the Hawal Ben hills, a silicate-rich portion of the marble consists of broad blades of colourless diopside ($c \wedge Z = 38°$) showing patchy alteration to carbonate and colourless amphibole. The latter has $+2V = c.70°$, extinction $c \wedge Z = 19°$ and $\beta = 1.662$. Colourless diopside ($+2V = c.60°$ and $c \wedge Z = 40°$) is also prominent in specimen 22/57 from a locality north-east of Buttelu wells, and shows streaky alterations to colourless, fibrous tremolite (–2V large) and carbonate. Large crystals of the pyroxene enclose small subhedral grains of the same mineral, and small grains also occur interstitially to the crystals. The rock, taken from a tough lens or band in purer crystalline limestones, also contains abundant quartz. Part of the thin section shows a mosaic of quartz grains with small interstitial crystals of pyroxene and amphibole and a little fine interstitial carbonate, some of which might have originated by the alteration of pyroxene.

Crystalline limestones of the Ali Gollo hills were mapped and described by Thompson and Dodson (*op. cit.*, p. 10) in a report on the geology of the Bur Mayo-Tarbaj area, immediately east of the Buna sheet. Recently published maps of this part of the country place the greater part of the Ali Gollo hills within the present area. Thompson and Dodson (*op. cit.*, pp. 10 and 44) record common occurrences of wollastonite in the Ali Gollo limestones but, since the mineral was not identified in specimens collected during the present work, a selection of the earlier material was re-examined. Many of the thin sections of crystalline limestones and associated silicate-rich rocks show abundant colourless or neutral diopside that occurs both in broad blades and in smaller subhedral or anhedral grains. In its bladed form, the pyroxene displays a patchy or streaky alteration to colourless amphiboles that are readily distinguished from the host diopside by lower relief and smaller extinction angles ($c \wedge Z$). Fine, patchy replacement by carbonate is common throughout the body of the crystal and a similar alteration is frequently seen along prominent cleavages and partings. Typical (110) pyroxene cleavages are very commonly accompanied by a prominent parting parallel to (100) and a strong parting parallel to (001). It is believed that the appearance of (100) partings in near-basal sections may have been partly responsible for the misidentification of some of the pyroxene as wollastonite. In other sections, the (100) parting is accompanied by only a single set of (110) or ($1\bar{1}0$) cleavages, producing a pattern not unlike that associated with amphibole basal sections. The pyroxene has the following optical properties: $+2V = 50°\text{-}60°$; extinction $c \wedge Z = 38°$.

Two colourless amphiboles partly replace the pyroxene described above and also occur as separate subhedral or anhedral crystals in many of the crystalline limestones. In specimen 23/336, reported to have been collected from a locality north-west of North Ali Gollo, the diopsidic pyroxene is locally replaced by tremolite having $-2V = 80°\text{-}85°$ and $c \wedge Z = 18°$, and by carbonate. Thompson and Dodson (*op. cit.*, p. 10) record rare wollastonite in this specimen, together with large crystals of diopside and both minerals are said to be partly replaced by calcite. Tremolite was not reported and it seems likely that the amphibole was incorrectly identified as wollastonite. The present identification is based on the large optic angle, common oblique extinction in longitudinal sections, invariable length-slow character and evidence showing that the trace of the optic plane lies parallel to the length of the crystal. Specimen 22/138 from Tosi is an off-white, medium-grained rock with thin darker bands of ferromagnesian minerals. In thin section a little dolomite is present in the calcite layers while the mafic bands are composed of tremolite which has formed from diopside since relict grains of the latter were seen. A similar patchy replacement of pyroxene by tremolite ($-2V = c.85°$ and $c \wedge Z = 19°$) and carbonate is visible in specimen 23/134 from Warawatot but in 23/196, from the Ali Gollo Hills, the pyroxene is replaced by a colourless amphibole having $+2V = c.80°$ and maximum extinction $c \wedge Z = 20°$.

Thompson and Dodson (*op. cit.*, p. 44) describe a large lens of silicates in the crystalline limestones at Warawatot hill, south-east of Gosieh and beyond the eastern boundary of the present area. Specimen 23/158 from this locality is composed of interlocking sheaves of large columnar and occasionally elongate tabular crystals showing prominent cleavages and partings that produce rather ragged terminations. The crystals are grey with a vitreous lustre on fresh surfaces and weather to a pale brown colour. They are not decomposed by hot 25% hydrochloric acid. Thin sections show colourless diopside partly replaced by carbonate and somewhat fibrous colourless tremolite. The amphibole develops principally in streaks parallel to the axis of the pyroxene although occasionally it replaces the host crystal along (001) partings. Abundant granular carbonate, bearing small flakes of tremolite, occupies the interstices between diopside crystals. It is estimated that, generally, less than 10% of each pyroxene crystal is replaced by carbonate and amphibole. Thompson and Dodson (*op. cit.*, p. 10) quote a partial analysis of material, probably of similar composition.

(b) Calc-silicate granulites and gneisses

Pale diopside-amphibole rocks have already been described with the crystalline limestones, in which they occur as lenses and irregular patches. Other calc-silicates of more diverse composition were encountered in both the Buna and Korondil areas, some having a lenticular form within marble and developed on too small a scale to permit differentiation on the geological maps. Others occur in mass, notably at several localities in the Ajao hills; at Chabicha, south-west of Buna; beside the Laga Chamu, a few miles north of the Buna-Moyale road; and at Kubi Urgi near the road west of Korondil.

All these rocks contain epidote and felspars, commonly accompanied by quartz, diopside, amphiboles, carbonates, calcite and sphene. Estimated modes of a selection of calc-silicates are shown in Table 2 to illustrate variations in the proportions of constituent minerals. In most of the calc-silicates described here, the diopside is a pale green pleochroic variety, in contrast to the colourless pyroxene commonly found in the crystalline limestones. Similarly, the amphiboles in the calc-silicates are typically green and are usually strongly pleochroic.

The massive calc-silicate granulites exposed in the Ajao hills are dark green and white, mottled, medium- to coarse-grained rocks. The thin section of a typical specimen (22/9) from the northern part of the range shows abundant anhedral grains of diopside, commonly 0.5-1.0 mm long. The mineral is weakly pleochroic in shades of very pale green and has $+2V = c.40°\text{-}50°$ and extinction $c \wedge Z = 38°$. It is partly altered to strongly-pleochroic hornblende with X = pale brown; Y = olive green; Z = dark grass-green; $-2V = c.70°$ and maximum extinction $c \wedge Z = 17°$. Colourless epidote is accompanied by some optically-positive clinozoisite, the minerals occurring in irregular cracked grains up to 2.0 mm long. Andesine, showing albite twinning, is largely replaced by scapolite, and quartz occurs in strings of anhedral grains. Anhedral sphene, distinctly pleochroic in shades of pinkish-brown, is the commonest accessory mineral. Calcite is present in an occasional interstitial plate and rare, very irregular grains of tourmaline are strongly pleochroic from pale blue to dark greyish-blue in the centres and from pale to dark brownish-green around the edges.

At Chabicha hill, in the Korondil area, well-banded and foliated calc-silicate gneisses bear concordant pegmatites up to 30 cm wide and thin quartzitic bands. The gneisses are composed of fine, alternating pyroxene-amphibole-epidote and quartzofelspathic bands. In thin section, specimen 22/98 displays an inequigranular texture with felspars forming about half the rock and with coloured constituents concentrated in thin bands. Green pleochroic diopside is partly replaced by hornblende showing strong pleochroism from bluish-green to grass-green. Pale yellow-green to nearly colourless epidote occurs in abundant anhedral grains or clusters of grains, and sphene is not uncommon in lozenge-shaped grains. Quartzofelspathic portions of the rock contain abundant microcline with subordinate oligoclase-andesine. Apatite is present in small rounded or subhedral grains and interstitial calcite has an uneven distribution in the rock. Table 2 shows the modal variation in the Chabicha rocks. Specimen 22/99 and 22/100 demonstrate a progressive increase in the proportion of quartz, largely at the expense of microcline, close to thin quartzitic and pegmatitic bands. In specimen 22/101, from a

whitish, quartzofelspathic portion of the outcrop, microcline is accompanied by partly sericitized antiperthitic intergrowths of optically-positive plagioclase and potash felspar. A little brown biotite locally replaces rare crystals of green hornblende. Banding in the Chabicha outcrops, though perhaps partly a reflection of compositional variations in the original sediments, has undoubtedly been enhanced by metamorphism and granitization.

Diopside-epidote granulites and gneisses, exposed near the Laga Chamu north of the Buna-Moyale road, have a similar mineralogical composition to the calc-silicates described above. They lack, however, the distinctive banding of the Chabicha rocks. The thin section of a medium-grained greenish granulite (22/95), collected near Laga Chamu, shows abundant subhedral pleochroic diopside (X = pale green; Y = pale green; Z = olive green), locally altering to hornblende, pleochroic from brown to dark green. Yellowish to neutral epidote is a prominent constituent of the rock, in which microcline is accompanied by subordinate oligoclase.

Coarse-grained calc-silicate rocks that form Kubi Urgi hill near Korondil, display conspicuous dark green and white mottling on fresh surfaces. A typical specimen (22/115) contains no pyroxene and the rock is composed essentially of two weakly-coloured amphiboles and saussuritized oligoclase. The amphiboles form complex aggregates of large ragged blades with smaller subhedral crystals of the same minerals, either arranged interstitially or as inclusions. Tremolite (X = very pale green; Y = very pale green; Z = pale green; $-2V$ = c.80°-85° and $c \wedge Z = 15°$) often encloses, and sometimes clearly replaces, an optically-positive amphibole (X = colourless; Y = very pale brownish-green; Z = pale green; $+2V$ = c.70°-80° and $c \wedge Z = 20°$). Epidote occurs in small prismatic crystals, with clinozoisite generally forming more irregular grains. Both minerals clearly originated by the alteration of plagioclase, in which they are abundantly developed. Sphene is present as rare inclusions in the amphiboles.

Rounded boulders of dark green, coarse-grained granulite lying along the roadside west of Korondil are related to the Kubi Urgi rocks. Both optically-negative and -positive pale amphiboles together constitute about two-thirds of specimen 22/114 taken from one of these boulders, the remainder of the rock being mainly plagioclase, quartz and clinozoisite. Tremolite (X = pale grass-green; Y = grass-green; Z = pale bluish-green) and the positive amphibole (X = very pale brown; Y = pale green; Z = pale bluish-green) occur in ragged, interlocking plates, typically showing stronger colours and pleochroism around the fringes of individual crystals. They contain inclusions of quartz, felspar, clinozoisite and rare carbonate. Interstitial to the amphiboles are anhedral aggregates of labradorite, quartz and clinozoisite.

Table 2 Estimated modes of a selection of calc-silicate granulites and gneisses

Specimen No.	22/9	22/49	22/65	22/95	22/98	22/99	22/100	22/101	22/102	22/114	22/115
Diopside	30		35	25	10	5	10	–	15	–	–
Tremolite/ actinolite	–	}10	–	–	–	–	–	–	–	}65	}50
Amphibole (opt. +ve)	–	–	–	–	–	–	–	–	–		
Green hornblende	5	–	5	+	5	5	+	+	5	–	–
Epidote/ clinozoisite	15	20	20	15	20	20	10	+	20	5	25
Plagioclase	5	5	15	5	10	10	20	}50	20	25	25
Microcline	–	–	5	25	40	10	–		20	–	–
Quartz	20	30	20	30	10	40	60	40	20	5	–
Scapolite	25	–	–	–	–	–	–	–	–	–	–
Carbonate	+	35	+	–	5	+	+	5	–	+	–
Sphene	+	+	+	+	+	+	+	+	+	–	+
Apatite	–	–	–	+	+	+	+	+	+	–	–
Biotite	–	–	–	–	–	–	–	+	–	–	–
Tourmaline	+	–	–	–	–	–	–	–	–	–	–
Magnetite	–	+	–	–	–	+	–	–	–	–	–

Proportions: – estimated to the nearest 5%; + indicates present, but less than 5%

22/9 North Ajao
22/49 Halima
22/65 Yukuala
22/95 Laga Chamu north of Moyale road
22/98 Chabicha
22/99 Chabicha
22/100 Chabicha
22/101 Chabicha
22/102 Chabicha
22/114 Roadside west of Korondil
22/115 Kubi Urgi

(c) Anthophyllite-talc-dolomite-quartz schists

These rocks were only encountered at Nyata hill, in the north-central part of the area, where brown gneisses are characterised by rough exposed surfaces due to weathering-out of carbonates. The rocks contain numerous small whitish or yellow-brown iron-stained anthophyllite fibres and have a slightly soapy feel. In the thin section of specimen 22/113, long prisms and needles of anthophyllite* make up about 20% of the rock, more than half of which is composed of anhedral plates of dolomite. Abundant small flakes of talc and anhedral grains of quartz together account for a further 20% of the gneiss, ore being a prominent accessory. Limonitic and haematitic staining is widespread.

(2) Metamorphosed semi-calcareous sediments

Dark granulites and gneisses, typically having hornblende as the chief mineral constituent, are believed to have originated by the metamorphism of semi-calcareous sediments of high quartz and chlorite content. Unlike the rocks previously described as calc-silicates, these amphibolitic types contain only accessory amounts of epidote and rarely diopside; no free carbonate is preserved. The rocks are conveniently subdivided as follows:

(a) Plagioclase amphibolites and hornblende-biotite gneisses
(b) Hornblende-diopside-biotite gneisses
(c) Hornblende-garnet gneisses.

(a) Plagioclase amphibolites and hornblende-biotite gneisses

Apart from thin bands and enclaves that occur as inclusions in granites, plagioclase amphibolites and hornblende-biotite gneisses are exposed only in the Ajao, Kijibil and Karari Guda hills, in the northern part of the Buna area.

The plagioclase amphibolites are dark, medium-grained granulites, the distribution of hornblende and leucocratic constituents often producing a finely-mottled appearance. Foliation is generally poor, though it is sometimes well defined by thin quartzofelspathic portions of the rock. Good exposures are rare, particularly towards flanking quartzites, and the extent of the outcrops is based largely on float fragments in the valley soils and in quartzite talus on the hill slopes. Estimated modes of a number of hornblendic rocks are shown in Table 3.

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* In the original script there is some confusion about the identification of anthophyllite. The thin section and rock specimens are no longer available, and further work at Nyata hill is required in order to confirm this lithological unit.

Table 3 Estimated modes of plagioclase amphibolites and hornblendic gneisses

Specimen No.	22/16	22/32	22/50	22/10	22/86	22/121	22/18	22/19	22/21	22/64
Hornblende	50	70	40	55	35	25	30	20	20	10
Biotite	+	–	+	5	+	–	20	20	20	+
Quartz	15	10	25	30	20	30	20	+	10	–
Plagioclase	35	20	25	10	20	40	25	60	50	}85
Microcline	–	–	–	–	10	–	5	–	+	
Diopside	–	–	–	–	10	–	–	–	–	–
Ore	+	+	10	+	–	}5	–	–	–	+
Garnet	–	–	–	–	–		–	–	–	–
Sphene	–	–	–	+	+	–	+	+	+	5
Epidote	–	+	+	+	5	–	–	+	+	–
Apatite	+	+	+	+	+	+	+	+	+	+
Sillimanite	–	–	–	+	–	–	–	–	–	–
Sericite	–	–	+	–	–	–	–	–	–	–
Rutile	–	–	–	+	–	–	–	–	–	–

+ indicates present but less than 5%

22/16 Plagioclase amphibolite, Kijibil
22/32 Plagioclase amphibolite, central Ajao hills
22/50 Hornblende-biotite gneiss, Karari Guda
22/10 Hornblende-biotite-sillimanite gneiss, east Ajao hills
22/86 Hornblende-diopside-biotite gneiss (mafic band), Garse Buna
22/121 Hornblende-garnet gneiss, Lesayu
22/18 Hornblende-biotite gneiss (?from inclusion in granite), Mojo hill
22/19 Hornblende-biotite gneiss (inclusion in granite), Mojo hill
22/21 Hornblende-biotite gneiss (margin of inclusion in granite), Mojo hill
22/64 Hornblende-biotite gneiss/granitoid gneiss (band in granite), north-north-east of Butei hill

In thin section, a typical specimen (22/16) of plagioclase amphibolite from the core of the Kijibil syncline shows a simple mineralogical composition with subhedral hornblende accompanied by anhedral labradorite and quartz. Magnetite and apatite are rare accessories, euhedral grains of the former often showing replacement by haematite. Biotite is present as occasional small flakes associated with the amphibole, which has maximum extinction

$c \wedge Z = 22°$ and X = pale brown; Y = brownish-green; Z = olive-green. Dark, rather friable amphibolites (22/32) exposed in the central parts of the Ajao hills contain a higher proportion of green hornblende than the Kijibil specimen. The plagioclase is apparently andesine and, in addition to ore and apatite, epidote is present as an accessory mineral. No biotite is visible in the rock examined.

With an increase in the proportion of biotite, largely at the expense of hornblende, and a common increase in the quartz content, the plagioclase amphibolites grade into better-foliated hornblende-biotite gneisses. The latter occur in mass at Karari Guda and at the eastern end of the Ajao hills and similar rocks were found as inclusions and thin bands in some of the granites in the Buna area.

In a specimen (22/50) of dark, medium-grained gneisses from Karari Guda, hornblende shows maximum extinction $c \wedge Z = 18°$ and pleochroism X = pale brown; Y = brownish-green; Z = grass-green. The felspar is andesine-labradorite and quartz is prominent in clusters of anhedral grains. Biotite is not a common constituent of the rock, occurring largely as a replacement of hornblende. Ore is evenly distributed and exhibits an interstitial or fringing habit against amphibole. Apatite, epidote and sericite are accessories, the latter appearing sparingly as an alteration product of plagioclase. An unusual, sillimanite-bearing rock (22/10) occurs as a thin band intercalated in more typical hornblende-biotite gneisses that are poorly exposed at the eastern end of the Ajao range. The coarse-grained gneiss bears large subhedral crystals of bright green hornblende, striking mauve felspar and milky quartz. In thin section, the amphibole ($c \wedge Z = 29°$ and X = very pale brown; Y = brownish-green; Z = pale grass-green or olive-green) shows patchy alteration to brown biotite and quartz, which occur mainly in lenses of interlocking grains, bearing numerous hair-like inclusions of sillimanite. Occasional crystals of epidote are visible in anhedral plates of oligoclase, and sphene occurs in clusters of small grains. Ore is a prominent accessory mineral with apatite and rutile present only in rare grains.

Numerous examples of thin bands and more irregular inclusions of hornblende-biotite gneiss were seen in the granite forming Mojo hill. The form and origin of these gneisses are discussed in a later section of the report but the petrography of the rocks is conveniently included here for comparison with similar types that occur in mass in the 'Basement System' succession, from which they differ in containing generally a higher proportion of biotite and felspars. Of the latter, oligoclase is typically the dominant type but a little microcline is frequently present and in rocks gradational towards granitoid gneisses, potash felspar becomes a prominent constituent.

Specimen 22/18, a coarsely-mottled black and off-white gneiss, was collected from a boulder on the upper eastern slopes of Mojo hill and was presumably derived from an inclusion in the granite. Subhedral crystals of hornblende (–2V large; $c \wedge Z = 20°$ and X = pale brown or greenish-brown; Y = dark brownish-green; Z = deep bluish-green) are partly replaced by biotite, dichroic from pale to dark brown. The amphibole exhibits a poikiloblastic structure, bearing numerous inclusions of quartz, the latter mineral also occurring interstitially in larger

anhedral grains together with oligoclase, which locally shows replacement by microcline. Sphene and apatite are present in accessory amounts. Farther up the slope on the same hill, finer-grained hornblende-biotite gneiss occurs as an irregular inclusion in coarse biotite granite (Plate 15). Specimen 22/19 was collected from the centre of the inclusion and 22/21 from the margin, near the gneiss-granite contact. Both rocks contain hornblende (-2V small; $c \wedge Z = 21°$) pleochroic from pale greenish-brown to deep bluish-green, together with biotite and oligoclase. The amphibole, which closely resembles an actinolitic variety found in the granitoid gneisses, encloses small grains of quartz but near the granite, quartz also appears in larger anhedral, interstitial grains and as myrmekitic intergrowths in felspar. Specimen 22/21 is also marked by the local replacement of oligoclase by microcline. Sphene, epidote and apatite are present as accessories in both specimens.

Hornblende-biotite granitoid gneiss forms a band in granite exposed three and a half miles north-north-east of Butei hill, in the centre of the Buna area. The rock (22/64) is described on p. 39 but the estimated mode is included in Table 3 to illustrate variations in mineral proportions in stages in granitization of the hornblende-biotite gneisses.

(b) Hornblende-diopside-biotite gneisses

Hornblendic gneisses in which pyroxene is preserved as a core to the amphibole are apparently rare and the feature was only observed in one specimen (22/86) of banded gneiss collected from Garse Buna, where the rocks are intercalated in a series of tough granitoid gneisses. In the mafic bands, which are generally separated by 25-mm wide quartzofelspathic layers, ragged crystals of pale green, pleochroic diopside ($+2V = c.60°$ and $c \wedge Z = 40°$) poikiloblastically enclose quartz and show common marginal replacement by hornblende ($c \wedge Z = 30°$ and X = pale brown; Y = dark brown; Z = dark bluish-green). The amphibole, which also occurs in numerous subhedral crystals lacking a pyroxene core but bearing inclusions of sphene and quartz, exhibits local replacement by biotite, dichroic from pale brown to dark brown or olive-green, and is commonly surrounded by a fringe of granular or vermicular epidote. Clusters of the ferromagnesian constituents are set in a granoblastic mosaic of quartz, oligoclase and subordinate microcline with apatite present as a rare accessory.

Leucocratic bands in the rock are composed of an inequigranular mosaic of quartz and microcline in which are scattered shreds of hornblende and biotite, and grains of sphene, epidote, ore and rare apatite.

(c) Hornblende-garnet gneisses

Like the diopside-bearing variety described above, garnetiferous hornblende gneisses are probably poorly represented in the area and only a single specimen (22/121) was collected, from a number of float boulders lying at the northern end of the main granite hill at Lesayu. It is not known whether the hornblende-garnet gneisses occur in mass flanking the granite at this locality or whether the boulders were derived from an inclusion in the granite.

The well-foliated gneiss contains hornblende ($c \wedge Z = 28°$ and X = pale brown; y = dark green; Z = bluish-green), andesine-labradorite, quartz, prominent anhedral pale pink garnets, subhedral ore and rare rounded grains of apatite.

(3) Metamorphosed pelitic sediments

Gneisses and granulites containing prominent sillimanite or garnet, or both these minerals, are thought to have formed by the metamorphism of sediments generally of high clay content. Some of the rocks now bear a very high proportion of quartz and it is possible that these types were derived from silts or clayey sandstone. For convenience, however, they are described here together with the more typical pelitic gneisses. The rocks are subdivided as follows:

(a) Biotite-sillimanite gneisses
(b) Garnet-biotite-sillimanite gneisses
(c) Biotite-muscovite-sillimanite-kyanite gneisses
(d) Biotite-garnet gneisses
(e) Garnet-quartz-felspar granulites.

(a) Biotite-sillimanite gneisses

These medium- to fine-grained purplish-grey rocks contain finely-disseminated, bronzy biotite together with lenticular patches, up to 25 mm long, of white fibrous sillimanite. They are exposed in the north-western part of the Buttelu hills and in the northern hill at Bakal, near Ali Gollo.

In thin sections, the gneisses are seen to contain abundant microcline and quartz, forming a granoblastic mosaic. Biotite, dichroic from pale brown to reddish-brown, occurs in numerous ragged plates and in trains of small shreds that fringe quartz and felspar grains. Subordinate muscovite is associated with the brown mica. Sillimanite is present of clusters of slender, prismatic crystals and occasionally occurs as needle-like inclusions in quartz, particularly in grains immediately surrounding the clusters. Granules of magnetite, sometimes accompanied by a little haematite, are present as inclusions in biotite, though the mineral is principally developed along quartz and felspar grain boundaries. Subhedral crystals of tourmaline, dichroic from pale brown to dull green, and grains of apatite are accessories in a specimen (22/69) of biotite-sillimanite gneiss from north Bakal. Estimated modes of a number of pelitic gneisses are quoted in Table 4.

Table 4 Estimated modes of pelitic gneisses

Specimen No.	22/40	22/69	22/41	22/45	22/70	22/59	22/8	22/55	22/43
Biotite	20	10	5	10	15	25	15	40	+
Sillimanite	+	+	5	+	5	25	–	–	–
Kyanite	–	–	–	–	–	+	–	–	–
Quartz	30	45	85	30	35	45	30	30	35
Microcline	50	45	+	40	20	–	–	+	60
Plagioclase	–	–	–	–	–	–	55	30	+
Garnet	–	–	5	20*	25*	–	+◇	+⊕	5
Muscovite	+	+	+	–	–	5	–	–	+
Ore	+	+	+	+	–	+	+	+	+
Tourmaline	–	+	–	–	+	+	+	–	–
Epidote	–	–	–	–	–	–	+	–	–
Apatite	–	+	–	–	–	–	–	+	+
Sphene	–	–	–	–	–	–	–	–	+
Calcite	–	–	–	–	–	–	–	–	+
Zircon	–	–	+	–	–	–	–	–	–

Proportions estimated to the nearest 5%
\+ indicates present, but less than 5%
* Higher proportions of garnet in slide than in the rock as a whole
◇ Lower proportions of garnet in slide than in the rock as a whole
⊕ No garnet cut by the thin section

22/40 Biotite-sillimanite gneiss, north-west Buttelu hills
22/69 Biotite-sillimanite gneiss, north Bakal
22/41 Garnet-biotite-sillimanite gneiss, west Buttelu hills
22/45 Garnet-biotite-sillimanite gneiss, north Datacha Mudi
22/70 Garnet-biotite-sillimanite gneiss, south Datacha Mudi
22/59 Biotite-muscovite-sillimanite-kyanite gneiss, central Ghote hills
22/8 Biotite-garnet gneiss, north Ajao hills
22/55 Fine-grained biotite-garnet augen gneiss, north-east Buttelu hills
22/43 Garnet-quartz-felspar granulite, west Buttelu hills

(b) Garnet-biotite-sillimanite gneisses

Gneisses that contain megascopic garnets, in addition to biotite and sillimanite, were found as thin bands in the western parts of the Buttelu hills and in the northern and southern parts of the Datacha Mudi range. At west Buttelu, flaggy grey and pink mottled gneisses contain prominent dark biotite flakes, numerous 5.0-6.0 mm diameter garnets, and whitish sillimanite, the latter occurring in patches of fine needles with occasional slender crystals up to 12 mm long. In thin section, specimen 22/41 is seen to be composed largely of a quartz mosaic in which are set flakes of pale to reddish-brown biotite, anhedral pale pink garnets and trains and clusters of sillimanite crystals. A little microcline is present, and ore occurs mainly as small inclusions in biotite. The garnet has inclusions of quartz, biotite and rare grains of zircon, and has an occasional plate of muscovite developed along cracks. Rather similar rocks flank a ridge of crystalline limestone at north Datacha Mudi, though the gneisses are more massive than the Buttelu variety and contain garnets measuring up to 12 mm across, and abundant microcline. The irregular garnets enclose blebs of quartz and numerous sillimanite needles, and the latter mineral is also associated with reddish-brown biotite occurring in clusters of rather large flakes.

In the southern part of the Datacha Mudi hills, dark grey biotite gneisses contain porphyroblastic reddish-brown garnets up to 25 mm long, around which thin but prominent bands of fibrous sillimanite show flow structures. The garnets bear numerous needles of sillimanite, rare biotite flakes and many inclusions of quartz, the latter in turn enclosing fine sillimanite. Quartz and microcline make up a large part of the rocks and tourmaline, dichroic from nearly colourless to dull green, is present in occasional subhedral grains.

(c) Biotite-muscovite-sillimanite-kyanite gneisses

Friable biotite-muscovite gneisses bearing occasional fibrous aggregates of white sillimanite and small grains of black tourmaline are intercalated in a series of biotite migmatites in the central part of the Ghote hills. In thin section, specimen 22/59 from this locality is composed essentially of anhedral quartz, pale brown to olive-green biotite and clusters of sillimanite needles and slender prisms. These clusters frequently contain a few small subhedral crystals of kyanite. Occasional flakes of muscovite are interleaved with biotite, and anhedral grains of tourmaline display dichroism from pale greyish-brown to bright green. Granules of ore are largely enclosed by biotite.

(d) Biotite-garnet gneisses

Well-foliated, friable, biotite gneisses containing numerous 2.0-mm diameter reddish garnets are exposed in the central parts of the Ajao-Kijibil range. Unlike the sillimanite-bearing rocks described above, the biotite-garnet gneisses contain an appreciable proportion of plagioclase, and potash felspar is generally absent. Specimen 22/8 from the north Ajao hills is composed mainly of sodic andesine, quartz, biotite and garnet. The mica is dichroic from yellow-brown to very dark brown and magnetite is a prominent accessory mineral. Tourmaline

and epidote occur in rare rounded grains.

Fine-grained biotite-garnet gneisses (22/55) exposed in the north-eastern part of the Buttelu hills, where they are intercalated with biotite-garnet-sillimanite gneisses, show augen textures in thin section with closely-packed flakes of biotite sweeping around small anhedral crystals of quartz, sodic oligoclase and occasionally apatite. Numerous lenticular augen of very fine-grained quartz feature prominently in the slide. Microcline and ore are rather rare constituents and no garnet is cut by the thin section, though the mineral is visible as scattered 6.0-mm diameter porphyroblasts in the hand specimen. Strain polarisation and recrystallisation of quartz, and occasional bent twin lamellae in felspar, indicate a cataclastic origin for the augen textures in these rocks.

(e) Garnet-quartz-felspar granulites

Garnetiferous quartzofelspathic rocks were encountered only in the western half of the Buttelu hills. In the south-western part of the range, the rocks form an impersistent band separating quartzite and garnet-biotite-sillimanite gneisses; farther north, they were also found flanking quartzites. Typically, the medium-grained leucocratic granulites bear numerous, evenly-distributed, 1.0-2.0-mm diameter reddish-brown garnets, and show in thin section a simple essential mineralogical composition with garnets set in an inequigranular mosaic of microcline and quartz. A little sodic andesine is visible but plagioclase has been generally replaced by potash felspar. Sphene is associated with rare grains of ilmenite, which is partly altered to leucoxene, and other accessory minerals are muscovite, sericite, biotite, apatite and finely-divided calcite that was produced during the replacement of plagioclase.

(4) Metamorphosed semi-pelitic sediments

Although only sporadically exposed along the flanks of isolated hill masses and in rare stream sections, metamorphic rocks that originated from semi-pelitic sediments are probably prominent constituents of the local 'Basement System' succession. They are characterised by a high mica and quartz content and the general absence of pyroxenes and amphiboles and are readily subdivided as follows, on the type of mica present:

(a) Biotite migmatites, gneisses and granulites
(b) Muscovite gneisses and granulites.

(a) Biotite migmatites, gneisses and granulites

Biotite-bearing rocks are far more common than types in which muscovite becomes a prominent constituent and, throughout the exposures examined, migmatitic varieties are more abundant than less intensely granitized gneisses and granulites. No differentiation of migmatites, granulites and gneisses is attempted on the geological maps since all the rocks have a similar mineralogical composition and also in view of the fact that granulites and gneisses probably appear as ribs in a migmatitic complex.

Biotite migmatites are well exposed north of Kijibil, where excellent sections show the contorted nature of the rocks and the rapid alteration of thin mafic and quartzofelspathic layers (Plate 18). The estimated mode of a specimen (22/15) from a biotite-rich band is given in Table 5, together with the modes of other semi-pelitic rocks. A thin section of the Kijibil specimen shows ragged flakes of brown biotite set in an inequigranular mosaic of quartz and felspars, in which many of the larger grains are fringed by small shreds of mica and trains of small quartz grains. The dominant felspar is oligoclase and, among the accessory minerals, apatite is prominent. Similar rocks are exposed at Karari Guda, on the south side of the range, but in the Ajao hills biotite-rich gneisses are deeply weathered and do not display convincing migmatitic structures. Dark grey migmatites were encountered in the Ghote and Yukala hills and a typical specimen (22/58) contains abundant biotite, dichroic from pale brown to olive-green, together with a small amount of accessory hornblende (X = colourless; Y = pale green; Z = pale green) and equal proportions of quartz and oligoclase. Poorly-exposed migmatitic biotite gneisses in the Ali Gollo hills contain accessory muscovite and oligoclase is largely replaced by abundant microcline. A number of biotite-rich schists and gneisses from Ali Gollo have previously been described by Thompson and Dodson (*op. cit.*, p. 11).

Friable, felspathic biotite gneisses were found flanking more resistant granitoid rocks north of El Las, in the south-western part of the Buna area. They are characterised by the prominent development of lenses and streaks of pink microcline and quartz. Similar rocks, exposed in the Laga Bor about eight miles north of Garse Buna, bear tough ribs of fine-grained pink granulite (22/96), consisting dominantly of quartz and microcline together with a little oligoclase, a few flakes of brown biotite and grains of ore. A few miles to the south, pale grey and pink fine-grained biotite granulites are exposed where the Moyale road approaches the Laga Chamu. A thin section of specimen 22/94 from this locality shows biotite, quartz and albite together with numerous small grains of magnetite and a little apatite.

Medium-grained, dark grey granulites containing small bronzy flakes of biotite were found intercalated in crystalline limestones along the crest of the northern hill at Datacha Mudi. In thin section, a specimen (22/44) shows biotite, dichroic from very pale brown to dark reddish-brown, set in an equigranular mosaic of microcline and quartz. Anhedral grains of pyrite are accompanied by subsidiary magnetite, and occasional sections of colourless, optically-positive pyroxene are fringed by pleochroic green chlorite. Scattered grains of apatite are also present.

Table 5 Estimated modes of semi-pelitic migmatites, granulites and gneisses

Specimen No.	22/15	22/58	22/74	22/44	22/94	22/60	22/106
Biotite	20	40	25	15	20	–	+
Quartz	30	30	15	10	35	45	45
Plagioclase	45	30	10	–	40	–	40
Microcline	5	–	50	75	–	40	5
Muscovite	–	–	+	–	–	5	10
Magnetite	+	+	+	+	5	–	–
Pyrite	–	–	–	+	–	–	–
Apatite	+	+	+	+	+	+	+
Epidote	+	–	+	–	–	–	+
Sphene	+	–	–	–	–	–	–
Pyroxene	–	–	–	+	–	–	–
Hornblende	–	+	–	–	–	–	–
Chlorite	–	–	–	+	–	–	–
Tourmaline	–	–	–	–	–	10	–
Garnet	–	–	–	–	–	–	+

+ indicates present but less than 5%

22/15 Biotite migmatite, Kijibil
22/58 Biotite migmatite, south Ghote hills
22/74 Biotite migmatite, three miles north of Gosieh, Ali Gollo
22/44 Biotite granulite, Datacha Mudi
22/94 Fine biotite granulite, Moyale road near Laga Chamu
22/60 Muscovite-tourmaline granulite, north Ghote hills
22/106 Muscovite gneiss, one mile east of Kuboli hill

(b) Muscovite gneisses and granulites

Muscovite is seldom an essential constituent of the metamorphosed semi-pelitic rocks. At the northern end of the Ghote hills pale pink, medium-grained granulites, containing small flakes of muscovite and numerous small black crystals of tourmaline, form a band in biotite migmatites. In thin section, a specimen (22/60) is seen to be composed largely of quartz

and microcline, together with prominent ragged flakes of colourless or very pale brown muscovite and subhedral grains of tourmaline, dichroic from pale brown to dull green. Apatite is a rather abundant accessory mineral. A continuation of the muscovite-tourmaline granulite band is probably to be found in the central parts of the Ghote hills, where tourmaline-bearing biotite-muscovite-sillimanite-kyanite gneisses are intercalated in biotite migmatites. The latter rocks have already been described as metamorphosed pelitic sediments.

About a mile east of Kuboli hill, in the north-western part of the Korondil area, a small isolated exposure reveals leucocratic gneisses, containing numerous muscovite flakes. In thin section, the rock (22/106) shows abundant quartz and saussuritized albite, with subordinate microcline. Muscovite is accompanied by a little brown or green biotite and other accessory minerals are epidote, apatite and rare pale pink garnets.

(5) Metamorphosed psammitic sediments

Thick beds of arenaceous sediments in the original sequence have given rise, on regional metamorphism, to broad bands of quartzite. Locally, the sandstones evidently contained appreciable quantities of iron which either recrystallised as magnetite or, at higher grades of metamorphism, by reaction with silica gave the amphibole grunerite.

The following two-fold subdivision is used for descriptive purposes:

(a) Quartzites, muscovite quartzites and magnetite quartzites
(b) Grunerite-(kyanite)-sillimanite-garnet quartzites.

(a) Quartzites, muscovite quartzites and magnetite quartzites

Metamorphosed arenaceous sediments are represented by bands of quartzite that vary considerably in colour, texture and mica content, though none of these features proved to be of value for general correlation purposes. Changes were observed along the strike and across the outcrops of individual bands. The outcrops usually run along or just below the tops of the ridges on account of their resistance to erosion. The quartzites form a rib or series of ribs in many of the hill masses with talus frequently concealing the flanking formations. Another quartzite is present in the valley between the main hill of Bafuf and its north-eastern ridge. This is felspathic in character so is more easily eroded; as a result it was only found at this locality where it is 100 feet thick.

The craggy summits at Ajao and Kijibil, together with most of the surrounding smaller hills, are composed essentially of quartzite; similar rocks form the main peaks and ridges in the Ali Gollo group of hills and at Ghote, Yukala, Alghe and Butei; in the Buttelu and Datacha Mudi ranges, outcrops of quartzite, that possibly constitute parts of a complexly-folded single band, form prominent features in hills composed mainly of crystalline limestones. In the Korondil area, where exposures are generally poor, dark quartzitic rocks form low rounded hills at Kuboli and Kurrbat.

Sedimentary structures, such as ripple-marks and graded quartzites and current-bedding, which were occasionally observed in quartzites in the Mara River-Sianna and Loita Hills areas of south-western Kenya (Williams, 1964; Saggerson, 1966), were not seen in the metamorphosed psammitic sediments of the present area and the structures, if present, were evidently destroyed during recrystallisation of the rocks. In many other respects, the Buna quartzites closely resemble varieties found in south-western Kenya though the frequent lateral gradation into flaggy muscovite-quartzites, so marked in many of the southern occurrences, is never a notable feature of quartzitic rocks in the present area, where mica appears to be more evenly distributed.

The quartzites vary in colour from white to shades of brown, grey, purple-grey and pink. Occasionally they contain numerous small black crystals of tourmaline or have a finely-mottled appearance due to abundant small grains of magnetite. Pale green or colourless muscovite is a common megascopic accessory mineral. The rocks vary in grain size from place to place, quartz grains ranging from 0.5 mm in the finer, compact varieties to 15 mm in some of the coarser types.

The pure, upper quartzite is exemplified by specimen 22/140 from the summit of Bafuf which is a medium-grained, off-white rock with interstitial staining by iron oxides. In thin section the texture appears highly uniform with equigranular quartz forming a compact recrystallised mosaic. There are one or two small flakes of muscovite while small grains of accessory magnetite are scattered throughout the rock. Specimen 22/151 from the same horizon at Bur Beit is generally similar but contains a few grains of diopside in place of muscovite. An impure variety was found on the north-eastern ridge of Bafuf where 22/139 was collected. It is a blue-grey rock with layers of felsic material and faint rodding. The thin section is atypical in that a higher proportion of introduced material is present than is apparent in hand specimen. The quartz mosaic contains accessory magnetite while the felsic layers contain much green and brown hornblende together with a brownish alteration product set in albite and microcline which has corroded, rounded quartz grains. Sphene and magnetite, the latter forming larger crystals than in the quartz mosaic, are accessory.

A specimen (22/12) of pale pink quartzite, collected at the western end of the Ajao hills, is composed of large translucent quartz grains that, in thin section, form an interlocking mosaic. The grains bear numerous fine acicular inclusions, thought to be sillimanite, and trails of reddish iron oxide. Muscovite and biotite are rare constituents, the latter fringing irregular small grains of ore, and epidote is present in an occasional rounded grain. Small kaolinitic patches in the rock may have been derived from rare original felspar. Towards the main summits at Ajao, these compact rocks grade into more friable, coarse granular quartzites. Fine needle-like inclusions of sillimanite are also visible in quartz in a medium-grained, white granular quartzite (22/31) from the north-central Ajao hills.

The felspathic quartzite from the valley between the summit of Bafuf and the north-eastern ridge appears to be equivalent to specimen 23/163 which Thompson and Dodson (*op. cit.*, p. 9) collected from a quartzite lens at the base of Garabid hill (named Bafuf in the present report). Specimen 22/144 from this quartzite is a fine-grained, yellowish-white rock with stringers of pure quartz. Under the microscope the quartz mosaic is seen to contain numerous grains of sericitized felspar and occasional diopside grains which are larger than the other constituents. Sphene and magnetite are fairly abundant accessories.

At Karari Guda, south of Kijibil, white quartzites (22/46) contain numerous euhedral to subhedral crystals of black tourmaline up to 10 mm in length together with occasional small clusters of biotite flakes. In thin section, the quartz shows strain shadows throughout and tourmaline is dichroic from pinkish-brown to dark green. Tourmaline is an accessory mineral in fine-grained, grey-brown muscovite-quartzites (22/71) that occur in an isolated outcrop about three and a half miles south-west of Buttelu wells. Small flakes of the colourless mica display parallel orientation and are accompanied by rare grains of sphene, and bear minute inclusions tentatively identified as sillimanite.

White, grey and reddish-brown quartzites are exposed in the Ali Gollo hills, the colour depending largely on the proportion of iron in the rocks. An ore-rich quartzite (22/73), collected from the northern slopes of Gogai, contains numerous irregular grains of magnetite, fringed with yellow-brown limonite and set in an inequigranular mosaic of quartz. Rare small flakes of biotite and rounded grains of apatite and zircon are accessories.

(b) Grunerite-(kyanite)-sillimanite-garnet quartzites

At Kuboli and Kurrbat hills in the north-western part of the Korondil area, the only rocks exposed are dark brown and black mottled ferruginous quartzites. At both localities, the quartzites contain grunerite, sillimanite and garnet; kyanite is also present in the Kuboli rocks. In a typical specimen (22/112) collected at the top of Kuboli hill, the dark quartzite is characterised by numerous 4.0-5.0 mm long, brown, silky crystals of grunerite, having parallel orientation and being particularly noticeable on foliation planes. In thin section, grunerite, kyanite, sillimanite, small rounded pink garnets and occasional grains of ore are set in a medium-grained quartz mosaic in which individual grains are often coated with a film of brown iron oxide. Grunerite, the identification of which was confirmed by X-ray analysis of extracted material, is colourless or neutral in thin sections, shows perfect (100) cleavages at 124° in basal sections and displays very common multiple twinning with (100) as the twin plane. Maximum extinction ($c \wedge Z$) is 13° and $-2V$ was estimated to be 80° to 85°. The following refractive indices (± 0.002) were determined on grains:

(i) $\alpha = 1.685$; $\gamma = 1.724$; $\gamma - \alpha = 0.039$
(ii) $\gamma = 1.721$

These figures show that the mineral contains 95%-97% of the $(OH)_2\,Fe_7\,(Si_4O_{11})_2$ molecule (Bowen and Schairer, 1935, p. 547). Kyanite occurs in occasional bladed crystals, enclosing



PLATE 1 Reita and Mojo Hills

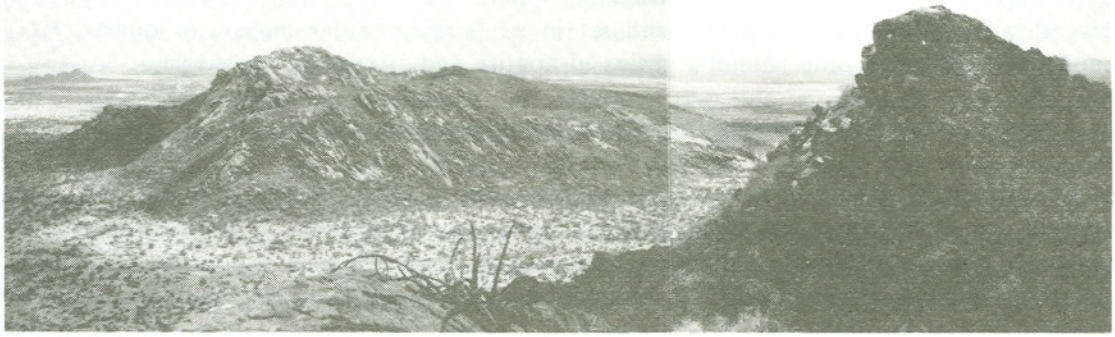


PLATE 2 El Las range



PLATE 3 Police patrol at Buna

1 Reita (left) and Mojo (right) granite hills from Daka Lawa, which is also composed of biotite granites. Sala and the Ghote hills are visible in the distance.

2 A view from the south of the largest hill in the El Las range. Note the steep eastward dips in the granitoid gneisses. Other granitoid gneiss outcrops are visible in the middle distance to the left, with Garse Buna in the background. Mojo and Ajao hills are visible in the distance at the extreme right. A number of east-west faults are postulated to explain the stepping of the granitoid gneiss outcrops at El Las.

3 A Kenya Police patrol at Buna. In the background, craggy outcrops of granitoid gneisses forming the feature known as Garse Buna. (Plate 2)



PLATE 4 Ajao-Kijibil range



PLATE 7 Bar Chuma and Sala Hills



PLATE 5 Southern Ali Gollo Hills



PLATE 8 Waterholes, and **adadi**, Lesayu



PLATE 6 Southern El Las range



PLATE 9 Lesayu Hill

4 The Ajao-Kijibil range from Mojo. Daka Lawa and Reita granite masses in the middle distance.

7 Bar Chuma and Sala from the summit of Mojo hill. All are formed of biotite granites.

5 The southern part of the Ali Gollo hills from Gogai. The ridge is formed of a central rib of quartzite, flanked by crystalline limestones.

8 Deep natural cavities in biotite adamellites on the south side of the largest hill at Lesayu. The holes fill with water during periods of rain and, because of the small surface area, evaporation losses are low. Low concrete parapets on the bare rock surface a little higher up the hillside increase the catchment area. The earth bund at the foot of the hill is well situated to trap surplus runoff during heavy rain.

6 The southern end of the El Las range. A view from the north showing the eastward-dipping granitoid gneisses.

9 Biotite adamellites forming the main hill at Lesayu. A view from Kiliwe Heri.



PLATE 10 Sala Hill



PLATE 13 Mojo Hill



PLATE 11 . Korondil and Urgi Hills



PLATE 14 Reita and Kijibil Hills



PLATE 12 Western Ajao Hills



PLATE 15 Xenolith in granite, Mojo Hill

10 Sala granite hill from Sofio.

13 Mojo granite hill from Sala. Bar Chuma is in the right middle distance. The cut-line at the left is the Wajir-Moyale district boundary.

11 Korondil and Kubi Urgi (left centre), from one of the biotite adamellite hills at Kiliwe Heri.

14 The granites at Reita with Kijibil in the background. A view from the summit of Mojo hill. The cut-line marks the Wajir-Moyale district boundary .

12 The western parts of the Ajao hills from the north-east. The main summit (3,690 feet) on the right is composed of massive quartzites. At the hill on the left, quartzites preserve the closure of a synclinal fold. A major north-south fault is situated between the hills.

15 A xenolith of hornblende-biotite gneiss in coarse biotite granites on the eastern flank of Mojo hill.



PLATE 16 Olivine basalt lavas, western Korondil area

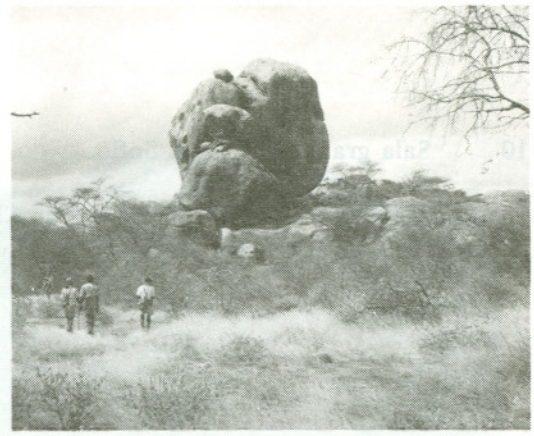


PLATE 19 Erosional features in granites, Sofio

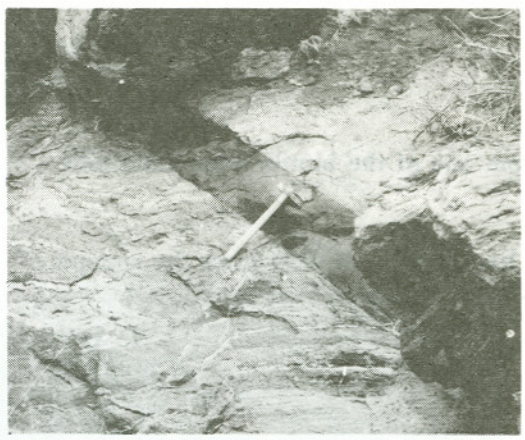


PLATE 17 Basalt dyke, Kijibil Hill



PLATE 20 Basalt dyke, Garse Buna



PLATE 18 Migmatites and dyke, N.orth Kijibil Hill



PLATE 21 Band of granite gneiss in granite, Sala Hill

16 A flow of vesicular olivine basalt of Late Pleistocene or Recent age in the western part of the Korondil area. Note the columnar jointing, lack of soil and the sparse vegetation.

19 Typical erosional features in granites at Sofio. The rounded masses are perched on rocks of similar composition.

17 A basalt dyke cutting biotite migmatites on the northern slopes of Kijibil.

20 A dyke of fine-grained basalt cutting granitoid gneisses at Garse Buna. Note the small xenoliths of gneiss enclosed by the dyke.

18 Biotite migmatites at north Kijibil. A thin basalt dyke is visible in the right half of the photograph.

21 A sharp contact between coarse biotite granite and porphyroblastic biotite granitoid gneiss on the southern slopes of Sala hill. Foliation in the gneiss is at right angles to the contact and parallel to thin granitic veins that show displacement by a small fracture.

grains of grunerite and sillimanite. It is most easily distinguished from grunerite by maximum extinction angle ($c \wedge Z$) of 30° and lower birefringence. Kyanite has $\beta = 1.720$. Sillimanite is present in subhedral crystals and slender fibres; where displaying the former habit, it is readily distinguished from kyanite by a small optic axial angle and positive sign.

At Kurrbat hill, compact brown quartzites (22/108) bear 2.0-mm long, pale brown, silky fibrous aggregates of grunerite. In thin section, the rock is rather similar to the Kuboli specimen described above. Kyanite, however, was not identified and small rounded garnets are less prominent. Sillimanite occurs in occasional clusters of radiating needles, and apatite and zircon are present in rare small grains, twinned subhedral grunerite crystals are abundant, showing $-2V = 80°\text{-}85°$ and maximum extinction $c \wedge Z = 12°$. The refractive index $\gamma = 1.719$ indicates about 92% of the $(OH)_2\ Fe_7\ (Si_4O_{11})_2$ molecule in the amphibole.

(6) Granitoid gneisses

Apart from small exposures at Kamor Kiliwe and Chipder, in the north-western and central parts of the Korondil area respectively, and rare bands in unfoliated granites, outcrops of granitoid gneisses are confined to the country between the El Las range, Buna, Ingrir and Nafsid, the occurrences defining the Buna anticline. The rocks generally form rugged hills in which foliation and direction of dip in the gneisses can be appreciated, even from a distance. The strike of foliation is usually clearly visible on air photographs and the feature distinguishes hills of granitoid gneiss from those composed of unfoliated granites.

The granitoid gneisses are typically pale brown, pinkish-brown or grey medium-grained rocks containing small flakes of biotite and often a dark amphibole. The following subdivision, which is based largely on the content of ferromagnesian constituents, is adopted for descriptive purposes though no differentiation is attempted on the geological maps:

(a) Biotite-(actinolite) granitoid gneisses
(b) Quartzofelspathic granitoid gneisses
(c) Hornblende-biotite granitoid gneisses.

(a) Biotite-(actinolite) granitoid gneisses

The commonest granitoid gneisses are well-foliated rocks containing about 5% or 10% of ferromagnesian minerals; biotite is always present though the mica is frequently accompanied by varying proportions of an amphibole having unusual optical properties. Microcline is abundant in all the rocks, generally exceeding in amount combined quartz and plagioclase, the latter invariably being albite or sodic oligoclase. The accessory minerals are shown in Table 6 which gives the estimated modes of a selection of granitoid gneisses.

Table 6 Estimated modes of granitoid gneisses

Specimen No.	22/77	22/78	22/89	22/76	22/82	22/84	22/85	22/88	22/97	22/105
Quartz	30	40	40	30	40	10	30	30	10	50
Microcline	60	40	50	50	40	70	55	55	80	}40
Plagioclase	10	20	10	10	15	10	15	10	10	
Actinolite	+	–	–	5	–		+	–	–	5
Biotite	+	+	+	5		}10	+	5	+	5
Sphene	+	–	+	+	}5	–	–	+	–	+
Ore	+	+	+	+		+	+	+	+	+
Muscovite	–	+	–	–	+	+	–	+	+	–
Epidote	+	–	+	+	–	+	+	+	–	+
Apatite	–	–	–	+	+	+	–	+	–	–
Zircon	–	+	+	+	–	–	–	–	–	–
Calcite	–	+	–	–	–	–	–	–	–	–
Chlorite	+	–	–	–	–	–	–	–	–	+

+ indicates present but less than 5%

22/77 Quartzofelspathic granitoid gneiss, south hill El Las
22/78 Quartzofelspathic granitoid gneiss, north of El Las
22/89 Quartzofelspathic granitoid gneiss, north Garse Buna
22/76 Actinolite-biotite granitoid gneiss, summit El Las
22/82 Biotite granitoid gneiss, Ingrir
22/84 Biotite-actinolite granitoid gneiss, north Nafsid
22/85 Biotite-actinolite granitoid gneiss, south Nafsid
22/88 Biotite-granitoid gneiss, east Garse Buna
22/97 Biotite-granitoid gneiss, south hill Buna
22/105 Biotite-actinolite granitoid gneiss, Kamor Kiliwe

In thin section, the rocks exhibit an inequigranular, granoblastic texture with quartz frequently showing strain shadows. In some specimens, microcline occurs as porphyroblasts measuring up to 5.0 mm across as well as in smaller anhedral grains replacing quartz and plagioclase. Fine perthitic intergrowths of albite are sometimes visible in the potash felspar and more rarely, as in specimen 22/105 from Kamor Kiliwe in the Korondil area, microcline is present as antiperthitic intergrowths with albite. Microcline microperthite frequently exhibits a replacive relationship towards plagioclase and quartz with inclusion of these minerals in optical

continuity.

Biotite is present in small flakes and usually shows pleochroism from pale brown or pale greenish-brown to dark greenish-brown. In some rocks (e.g. specimen 22/97 from the southern small hill at Buna) a pale brown biotite, pleochroic to distinct green, is interleaved with flakes showing pleochroism from pale to dark brown. The amphibole occurs in subhedral or rather ragged crystals seldom more than 2.0 mm long and X-ray analysis of material extracted from specimen 22/76, collected near the summit of El Las, produced a photograph identical to that of actinolite. In this rock, the mineral has X = olive-green; Y = dark green or dark brownish-green; Z = dark blue-green. The maximum extinction ($c \wedge Z$) measured in the slide was 20° and -2V was estimated to be 20°-30°. Actinolite in specimen 22/105, from an isolated exposure at Kamor Kiliwe, shows pleochroism with X = pale yellow-green; Y = dark green; Z = bluish-green. The maximum extinction seen in the slide is 16° and -2V was estimated to be about 30°. Pale pink sphene is often prominent among the accessory minerals, occurring in rounded grains up to 1.0 mm across in some specimens. Sometimes the sphene is developed as a fringe around grains of ore. The latter mineral is never abundant in the granitoid gneisses and usually shows subhedral or irregular outlines. Epidote and apatite are found in small grains in some of the rocks; zircon and chlorite are rare.

Only one exposure of muscovite-biotite gneisses was found in the valley between the summit of Bafuf and the north-eastern ridge, where it crops out on the south-western side of the felspathic quartzite. Specimen 22/146 which was collected from it is a fine-grained, well-foliated grey rock with reddish-brown weathered surfaces. Some fairly large plates of muscovite are visible on the foliation planes. In thin section the rock is seen to be formed of quartz, felspar and mica but the foliation is not apparent on account of the orientation of the slide. The quartz occurs in rounded grains set in albite and microcline and some of the felspar is sericitized. Muscovite is more abundant than biotite, but a brown alteration product may represent some of the latter. Zircon grains are enclosed in the mica and magnetite is accessory.

The rock appears similar to that (23/345) described by Thompson and Dodson (*op. cit.*, p. 11) from the south-eastern slopes of north Ali Gollo hill, but with an increase in the muscovite content. They found two bands separated by quartzofelspathic metamorphic rocks which are probably equivalent to the felspathic quartzite. At Bafuf the sequence on either side of the muscovite-biotite gneiss and the felspathic quartzite is similar, being limestone, quartzite, limestone. It therefore seems probable that the felspathic quartzite forms the core of a fold with the muscovite-biotite gneiss sheared out along the north-eastern, inverted limb.

(b) Quartzofelspathic granitoid gneisses

Pink or brown, well-foliated quartzofelspathic rocks occur as bands intercalated in more typical granitoid gneisses from which they differ in containing a smaller proportion of ferromagnesian constituents. They contain quartz, microcline and albite or sodic oligoclase and, occasionally, microcline-microperthite. Biotite, which is always present, is generally pleo-

chroic from brown to dark brown though flakes pleochroic from pale brown to bottle-green are visible in some slides. A specimen (22/77) from the southern hill of the El Las range contains actinolite in small subhedral crystals, in addition to biotite. The amphibole has a small -2V, $c \wedge Z = 16°$ and is strongly pleochroic with X = pale yellow-green; Z = dark bluish-green. The accessory minerals in this rock are rather common, small rounded grains of pale pink sphene together with epidote, ore and chlorite. Sphene, pleochroic from pale pink to pinkish-brown, is also an accessory in specimen 22/89 from the northern part of the Garse Buna hills and zircon was identified in the same rock. Zircon is also present in a quartzo-felspathic granitoid gneiss (22/78) that crops out in a small hill north of El Las.

A small outcrop of quartzofelspathic gneiss was discovered on the eastern side of Tosi just before the underlying crystalline limestones rise to form the hill itself. Specimen 22/148 from this locality is a fine-grained, poorly-foliated, pale grey rock. In thin section, it is composed mainly of albite, together with some microcline and subordinate rounded quartz grains. There are some flakes of muscovite while magnetite and zircon are accessory. Specimen 22/160 from the isolated southern hill is only faintly foliated because of the low content of ferromagnesian minerals which do not form distinct bands. Under the microscope the mafic minerals are represented only by alteration products and there is a greater proportion of microcline than in the other specimens.

(c) Hornblende-biotite granitoid gneisses

Granitoid gneisses in which common hornblende is a prominent constituent are rare; most amphibole-bearing rocks contain the bluish-green actinolite described above. However, in a specimen (22/64) of coarse-grained grey to pinkish-grey gneiss, collected from a thin band in a granite three and a half miles north-north-east of Butei hill, the amphibole has -2V large, $c \wedge Z = 30°$ and X = pale green; Y = brownish-green; Z = dark green, rarely with a bluish tinge. The subhedral crystals of hornblende are often fringed by a fine development of brown biotite and are set in an interlocking mosaic of antiperthite, composed of fine potash felspar intergrowths in albite. Grains of pinkish, weakly-pleochroic sphene are rather abundant and other accessories are ore and apatite. The estimated mode of this rock is shown in Table 3, for comparison with the approximate modes of a number of plagioclase amphibolites and hornblendic gneisses. Specimen 22/159 from the highest point of the large outcrop contains the greatest proportion of ferromagnesian minerals and so is probably nearest to the composition of the original host rock before granitization. It is a well-foliated rock consisting of alternating layers of yellowish-brown felsic material and darker bands of ferromagnesian minerals. In thin section the felsic minerals are rounded quartz grains and crystals of oligoclase with some microcline. A dark green hornblende is the chief mafic mineral but there are some small plates of biotite. Magnetite, epidote and zircon are accessory. The same minerals are present in 22/158 from the small eastern hill but the ferromagnesian bands are thinner and more widely spaced so that the foliation is slightly less pronounced.

(7) Pegmatites

Pegmatites are uncommon in the area and the few occurrences encountered are conveniently described with the 'Basement System' rocks in which they are emplaced. Rare pegmatitic veins were also seen in some of the granites and are best described with the unfoliated rocks.

Thin pegmatites occur as auto-segregations in the migmatites exposed north of Kijibil and are essentially quartz-microcline rocks. Similar thin concordant pegmatitic bands are present in calc-silicate gneisses at Chabicha, south-west of Buna, rarely attaining a width of more than 30 cm. Associated with the pegmatites are 25-mm wide quartzitic bands.

At two localities, pegmatites probably occur in discordant bodies though exposures are too poor to permit a thorough investigation of the relationships with surrounding 'Basement System' rocks. Coarse biotite-garnet pegmatite crops out in a valley on the western side of the Buttelu hills, and a magnetite-bearing pegmatite apparently cuts across the foliation in hornblende-biotite gneisses and quartzites in the south-western hill at Karari Guda. Fragments of tourmaline found between Karari Guda and Kijibil may have been derived from pegmatites, though the latter are unexposed.

2. Unfoliated granitic rocks

Unfoliated granitic rocks usually form prominent craggy hills that often bear a dense vegetational cover between massive joint blocks and fallen boulders. On some hills, vegetation is only patchily developed and many excellent bare rock surfaces are available for study. The smaller occurrences of granitic rocks take the form of minor hills and inselbergs or accumulations of large rounded boulders. Flanking rock types are never convincingly exposed so that the nature of the contact between granitic rocks is consequently regarded as the final stage in the sequence: gneisses⇒migmatites⇒granitoid gneisses. The evidence leading to this conclusion is summarised in a later section of the report.

All the unfoliated granitic rocks are of medium to coarse grain, varying in colour from pink to shades of brown and grey. At many localities, they enclose numerous bands, streaks and lenses of microgranite, granitoid gneiss, biotite gneiss and hornblende-biotite gneiss. More rarely, angular xenoliths of gneiss are enclosed by the granitic rocks.

The following classification depends on the ratio of potash felspars to plagioclase in the rocks and corresponds generally to colour changes that are of value for subdivision in the field:

(1) Biotite granites
(2) Biotite adamellites
(3) Biotite granodiorites.

(1) Biotite granites

In most of the granitic rocks examined, the proportion of alkali felspars to plagioclase exceeds 2:1 and these types are accordingly classified as granites. They are typically pink to pinkish-brown, coarse-grained rocks and most are porphyritic, though only rarely do the phenocrysts show up prominently against the coarse groundmass. Most of the phenocrysts, which sometimes attain a length of 25 mm, are of pink or pale brown microcline, and simple Carlsbad twins are often visible in hand specimens. Occasional small phenocrysts are composed of white plagioclase. Biotite occurs in clusters of aggregates of small flakes, accentuating the mottled appearance of the rocks. Rarely, the mica is more evenly distributed.

Table 7 Measured modes of granitic rocks

Specimen No.	22/3	22/104	22/117	22/119
Quartz	23	45	30	25
Microcline/perthite	58	42	36	32
Oligoclase (partly sericitized/kaolinized	15	10	26	36
Biotite	2	3	7	6
Muscovite	–	+	–	–
Ore	1	+	1	+
Sphene	1	–	+	1
Apatite	+	+	+	+
Epidote	+	+	+	+

+ indicates present but less than 1%

22/3 Biotite granite, Reita hills
22/104 Biotite granite, Korondil
22/117 Biotite adamellite, Kiliwe Heri, northern part of Lesayu hills
22/119 Biotite adamellite, central part of Lesayu hills

Examination of thin sections of the granites showed little variation in texture or constituent minerals from rock to rock. Modes of two specimens of granite are quoted in Table 7, together with figures for other granitic rocks. Quartz, frequently showing strain shadows, occurs in large anhedral grains up to 5.0 mm long or in aggregates of smaller grains that tend to develop along the margins of felspar crystals. Small inclusions of quartz in felspars are common. Microcline, which occurs in prominent subhedral and anhedral crystals, often bears numerous streaky perthitic intergrowths of albite. Clear evidence of replacement of

plagioclase by microcline is often visible, inclusions of oligoclase appearing in optical continuity with a neighbouring crystal. The microcline occasionally displays anomalous optical properties. For instance, (100) sections of the felspar in specimen 22/61, from a small outcrop of granite at Yukala, shows fine twinning and -2V was estimated to be about 50°. The unusually small optic angles may be due to interference from the fine twin lamellae in these sections. (010) Cleavage flakes from the pink microcline phenocrysts in specimen 22/61 show extinction angles of 7° and twinning is rarely visible. The refractive indices are lower than 1.530. The more common (001) flakes all show fine cross-hatched twinning and a maximum extinction angle of 13°. Refractive indices are equal to and lower than 1.530. Spectrographic analysis of the same material showed that the felspar has the following approximate composition: K_2O 12%; Na_2O 4%; CaO up to 5%.

(2) Biotite adamellites

All the granitic rocks forming the Lesayu-Kiliwe Heri group of hills are marked by a higher ratio of plagioclase to alkali felspars than the types described above and are classified as adamellites. Biotite adamellites also crop out south-south-east of Tuli Roba hill in the western Korondil area. In contrast to the coarse-grained pinkish-brown rocks, they often bear pale felspar phenocrysts up to 6 mm long and all contain abundant, evenly-distributed biotite.

In textures and mineralogical composition the adamellites closely resemble the granites. The modes of two specimens of adamellite are shown in Table 7, for comparison with granites, from which they differ not only in the proportions of microcline and plagioclase but also in containing more biotite. The plagioclase in the adamellites is oligoclase, ranging in composition from Ab_{78} to Ab_{87} and locally exhibiting sericitization. Microcline typically bears perthitic intergrowths of clear untwinned albite, and crystals generally exhibit more regular outlines and more frequent twinning than in the granites. Biotite, pleochroic from pale brown to dark brown or dark greenish-brown, is accompanied by a brighter green variety in most of the rocks examined. Ore and sphene are prominent accessories, the latter occurring in euhedral to subhedral crystals, and apatite and epidote are present in small grains.

(3) Biotite granodiorites

Unfoliated granitic rocks in which the ratio of alkali felspar to plagioclase is less than 1:2 are evidently rare in the Buna area and only a single occurrence was mapped. Large boulders of very dark grey, coarse-grained granodiorite, encountered at a locality between the Ajao and Buttelu hills, are unlikely to have been transported and are considered to indicate an outcrop of these rocks beneath the soil cover. Granodiorites are more common in the Gurar-Kubi Halo area, north of the Buna sheet (Walsh, *op. cit.*).

A thin section of biotite granodiorite (22/51) from the present area shows quartz, oligoclase, albite, microcline, biotite, ore and apatite. The oligoclase occurs in poorly-twinned anhedral crystals, some bearing intergrowths of untwinned albite, and is accompanied by subordinate microcline. Quartz displays strain shadows throughout the slide and biotite is strongly pleochroic from pale to dark brown.

(4) Bands and inclusions in the granites

A variety of rock types, ranging from biotite and actinolite-biotite gneisses through granitoid gneisses to poorly-foliated or unfoliated microgranites, occur as thin bands, streaks, lenses and xenoliths within many of the granite masses; on the other hand, no inclusions were seen in the adamellites, and the granodiorites are insufficiently exposed to justify comment. The inclusions are on too small a scale to permit differentiation on the geological maps but, where foliation is discernible, structural details were recorded and plotted within the granite mass.

At Mojo hill, in the west-central part of the Buna area, inclusions in the granites are predominantly of actinolite-biotite gneisses, the mafic patches generally displaying irregular outlines with interdigitation of granite and gneiss parallel to the foliation in the latter (Plate 15). The petrography of these actinolite-biotite gneisses has already been described (pp. 36-38) and attention has been drawn to an increase in quartz and the appearance of microcline, replacing plagioclase, towards the contacts with the granite. It is noteworthy that the amphibole in these inclusions is a bluish-green actinolitic variety with a small optic angle, very similar to that found in most of the granitoid gneisses and unlike the olive-green or grass-green hornblende of plagioclase amphibolites and hornblende-biotite gneisses exposed in the Ajao-Kijibil range. In addition to the occurrences in irregular inclusions, amphibolitic gneisses form a number of thin streaks and bands in the granites at Mojo but, near the summit of the hills, 25-50-mm wide darker bands in the granite are composed of biotite-rich microgranite and poorly-foliated granitoid gneiss.

The granites exposed at Bar Chuma, south-east of Mojo hill, bear numerous 70-80-mm wide bands of biotite gneiss, locally containing microcline porphyroblasts, and 30-60-cm wide bands of biotite granitoid gneiss. Even the narrowest bands can be traced for many metres through the granite and lack the irregular outlines that characterise many of the inclusions at Mojo. In thin section, a specimen of pale brown, well-foliated granitoid gneiss (22/36) shows a granoblastic mosaic of quartz, microcline and partly-sericitized oligoclase. Biotite is pleochroic from pale to dark brown or in shades of olive-green. Sphene is associated with ore, the latter occurring in anhedral grains, and apatite and epidote are present in tiny euhedral to subhedral crystals. Apatite, ore and sphene are the commonest inclusions in biotite. A specimen (22/37), taken from the margin of a band of fine-grained biotite granitoid gneiss at the western end of the outcrop, shows a gradation from grey gneiss through microgranite to coarse pink biotite granite over a distance of about 50 mm. In mineralogical composition, the granitoid gneiss closely resembles specimen 22/36 described above though olive-green biotite is accompanied by subordinate muscovite.

On the lower slopes in the north-western part of the Sala hills, south of Bar Chuma, typical coarse biotite granites contain bands of pinkish-grey microgranite that are all aligned parallel to the length of the hill and dip southwards at steep angles. The contacts between coarse and fine granitic rocks are usually rather sharply defined. A specimen (22/23) of the microgranite contains quartz, microcline, oligoclase and green and brown biotite together with

ore, sphene, apatite, muscovite and a little calcite. The quartz bears numerous unidentified needle-like inclusions, oligoclase is locally sericitized, and some of the microcline contains microperthitic intergrowths of albite. Similar rocks are exposed at the western summit, though the upper northern slopes are composed predominantly of coarse granites. Microgranites are interbanded with coarser varieties in the valley separating the two conical peaks, and a specimen (22/25) collected from a contact shows no significant change in mineral composition between the two varieties. Coarse biotite granites bear few inclusions on the bare northern slopes of the eastern hill at Sala but an occasional band of granitoid gneiss shows the strike or foliation to be parallel to the length of the range (WNW-ENE). Midway down the southern slopes of the same hill, 70-80-mm wide bands of finely-foliated granitoid gneiss dip into the hillside and, nearby, the granites are traversed by occasional pegmatites. Near the foot of the hill an inclusion of porphyroblastic biotite granitoid gneiss displays sharp contacts against coarse granite, with the latter truncating foliation planes in the gneiss (Plate 21).

A number of irregular-shaped xenoliths of biotite granitoid gneiss were encountered in the coarse granites forming a small hill west of the track at Sofio. The largest is some 40 feet long and about ten feet wide, with foliation striking parallel to the length. A felspathic selvedge is present along the greater part of the contact with enclosing granite, which locally penetrates the xenolith at a large angle to the foliation. Thin quartz veins cut both xenolith and host rock. The grey granitoid gneiss (22/28) from one of the inclusions differs from the Bar Chuma rocks only in the zoning exhibited by plagioclase, with oligoclase cores surrounded by a thin rim of albite.

Biotite gneisses, containing porphyroblasts of microcline about 6.0 mm long, occur as small lenses in the granites at Daka Lawa. Rare inclusions of biotite gneiss were also seen in the granites forming the Reita hills where granite-aplite and quartz veins were encountered. A specimen of pink aplite (22/1) shows a microgranitic texture in thin section and is composed of quartz, microcline, oligoclase, muscovite, subordinate biotite and grains of ore. The potash felspar is characterised by numerous graphic intergrowths of quartz.

Bands of hornblende-biotite granitoid gneisses occur in the coarse granites exposed in the centre of the Buna area, about three and a half miles north-north-east of Butei hill. A specimen (22/64) of the gneiss from one of these bands is described on p. 39 and the mode of the rock is quoted in Table 3. It is of interest to note that the gneiss contains no quartz and that the amphibole is predominantly common hornblende, in contrast to the actinolite with an unusually small optic angle that characterised most of the granitoid gneisses in the area and the inclusions in granite at Mojo hill.

A small granite outcrop between Yukala and Alghe is marked by streaks and lenticular bands of fine-grained, dark grey biotite granulite and gneiss. In thin section, a specimen of the granulite (22/62) shows small porphyroblasts of quartz, microcline and partly sericitized oligoclase set in a fine granular mosaic of quartz, felspars, apatite, ore and epidote, bearing shreds of biotite and muscovite. The oligoclase is occasionally zoned and biotite is pleochroic from pale brown or greenish-brown to dark brown.

Inclusions are extremely rare in the Korondil granites and none were seen displaying convincing foliation. A finer-grained patch at one locality consists of prophyritic biotite microgranite, specimen 22/103 showing phenocrysts of microcline set in a mosaic of quartz, microcline and oligoclase, the latter displaying sericitization. Flakes of biotite, pleochroic from pale to dark brown and from pale brown to green, are accompanied by subordinate muscovite, and epidote, apatite, ore and rutile are accessories, the latter occurring as rare inclusions in ore grains. In mineralogical composition, the rock differs from the surrounding coarse granites in containing occasional crystals of near-colourless amphibole (-2V large and $c \wedge Z = 30°$).

(5) Petrogenesis of the unfoliated granitic rocks

The unfoliated granitic rocks all occur in isolated hill masses and inselbergs and contacts with the surrounding 'Basement System' metamorphic rocks are never exposed, so that conclusions regarding the origin and method of emplacement of the granites and associated types are necessarily based largely on the form and composition of inclusions and banding and the distribution of the granitic masses within the area.

Thin but extensive bands of gneiss, granulite and microgranite are common features in many of the granite outcrops. The foliated rocks in these bands range from biotite gneisses, frequently containing microcline porphyroblasts, to granitoid gneisses and very similar types and gradations are present in the 'Basement System' succession. Microgranites, with or without faint foliation, are often developed between gneisses and adjacent coarse granites, the sequence being completely gradational; elsewhere, bands are composed entirely of microgranite and, since the finer variety was never encountered in masses of more irregular form, these are considered to represent modified bands of gneiss. The thin nature of individual bands, compared to their length, parallelism of banding over small areas, and sub-parallelism of banding (as indicated by recorded foliation strikes) between Reita and Sofio, are considered to be more easily reconcilable with an origin for the granite largely by the metasomatic alteration of pre-existing rocks, rather than by large-scale magmatic intrusion. The 'Basement System' rocks surrounding the main granite outcrops in the Buna area display frequent sharp changes in foliation strike, related to complex major structures, so that more than sub-parallelism of banding and foliation in remnants of gneiss within the granite cannot reasonably be expected over a distance of several miles.

Microtextures in most of the granite specimens examined are very similar to those observed in granitoid gneisses forming part of the 'Basement System'. The widespread replacement of plagioclase by microcline microperthite is indicated by the irregularity of boundaries between crystals; by the common inclusion within the potash felspar of small patches of plagioclase, often in optical continuity with each other and with adjacent plagioclase crystals; and by the rarity of inclusions of microcline in plagioclase. A similar relationship exists between potash felspar and quartz, and the textural features closely match those described by King (1947, pp. 45-50) from the Singo granite of Uganda, for which a metasomatic origin is claimed.

In contrast to the thin bands of gneiss and microgranite that characterise many of the outcrops, the granites at Mojo and Sofio also contain more irregular-shaped inclusions of actinolite-biotite gneiss (Plate 15) and biotite granitoid gneiss respectively. These may represent true xenoliths and indicate that, locally, the granites attained a certain degree of mobility. The lack of bands and inclusions in the adamellites of the Lesayu-Kiliwe Heri hills, in the Korondil area, together with a general tendency for the potash felspar to adopt a more euhedral form, to display more frequent evidence of twinning and less prominent replacement textures, all suggest the possibility of a local magmatic stage having been attained during or after emplacement. On the other hand, sufficient replacement phenomena are preserved in the adamellites, and in granites near xenolith contacts, to show that all the rocks were formed principally by metasomatic processes. The presence of pegmatitic and aplitic veins in some of the granites is not necessarily indicative of the intervention of a magmatic phase, for King (1948) has described numerous examples of dykes and veins of similar composition with criteria showing a nondilational mode of emplacement. Processes of metasomatic replacement, termed 'pegmatization' and 'aplitization', were envisaged to explain the development of the bodies. During the present work, insufficient evidence was encountered to prove the mode of emplacement of pegmatites and aplites and their examination, particularly of intersecting veins, must remain a subject for further study.

Slight additional evidence in favour of a metasomatic origin for the granites in the Buna area is provided by their distribution in relation to the disposition of 'Basement System' rocks. Outcrops of biotite migmatites south of the Ajao-Kijibil range and the occurrence of similar rocks in the northern part of the Ghote hills suggest that the granite masses between Sofio and Daka Lawa are situated in an unexposed zone of migmatites. A small occurrence of granite in the southern part of the Ali Gollo hills is similarly located in a band of migmatitic biotite gneisses. It is perhaps significant that no inclusions of quartzite or limestone have been encountered in the granites, though these are the commonest 'Basement System' rocks.

3. Intrusive rocks

In addition to pegmatites mapped in the 'Basement System' rocks, which have already been described and some of which probably represent intrusions, a number of more basic intrusive bodies were encountered during the survey. The latter comprise a boss of basic and ultrabasic rocks and associated ortho-amphibolites, a few minor intrusions of metadolerite, and thin basaltic dykes. The metamorphosed plutonic and hypabyssal rocks are provisionally assigned to the Precambrian whereas the basalt dykes are considered to be late-Tertiary or early-Pleistocene intrusions.

(1) Basic and ultrabasic intrusives and associated plagioclase amphibolites

A small boss composed essentially of basic and ultrabasic hypersthene-bearing rocks form

Tuli Roba hill, which rises some 350 feet above the plains in the west-central part of the Korondil area. Exposures are poor, but the bouldery surface suggests that the summit and the western half of the hill are underlain largely by hypersthenic gabbros, whilst the eastern slopes are formed of olivine-bearing pyroxenites. Numerous boulders of amphibolitic rocks around the lower northern slopes are believed to have been derived from a metamorphosed marginal zone of the intrusion rather than representing remnants of the country rocks.

For descriptive purposes, the Tuli Roba rocks are classified as follows:

(a) Olivine-bearing augitic hypersthenites
(b) Hypersthenic gabbros
(c) Plagioclase amphibolites.

(a) Olivine-bearing augitic hypersthenites

The ultrabasic rocks are medium-grained, dark brownish-grey pyroxenites. Thin sections show that they contain no felspars and consist essentially of anhedral crystals, 1.0-2.5 mm across, of pyroxenes and olivine. Smaller grains of the same minerals are frequently present along crystal boundaries. The pyroxenes display slight marginal alteration to hornblende and small grains of ore and small apatite euhedra are the only accessories.

Hypersthene forms about 70% of specimen 22/122 and is marked by numerous inclusions producing characteristic schiller structures and by thin lamellae of clinopyroxene. The optic angle is large. Clinopyroxene, which accounts for a further 20% of the volume of the rock, is generally colourless though numerous minute inclusions locally produce a brownish tinge in thin section. The maximum extinction angle recorded was $c \wedge Z = 49°$, though some crystals are zoned with the cores having $c \wedge Z = 38°$ and rims $c \wedge Z = 49°$. Strong (100) diallage parting is prominent.

The presence of about 10% of olivine causes difficulty in the naming of the rock and according to some schemes would preclude classification as a pyroxenite. The olivine is clear, marked by a series of irregular cracks and the optic angle is about 90°, indicating a magnesium-rich variety.

The amphibole which develops marginally to some pyroxenes is hornblende with $c \wedge Z = 17°$ and showing pleochroism from pale brown or colourless to brown. Both magnetite and pyrite are present in the ore grains.

(b) Hypersthenic gabbros

The felspar-bearing intrusives at Tuli Roba are medium-grained, brownish-grey and white mottled rocks. In thin section, specimen 22/124 from the summit of the hill shows about 60% pyroxenes and 40% plagioclase together with acessory hornblende and ore.

The pyroxene is dominantly a monoclinic variety having a prominent parting parallel to (100), $c \wedge Z = 46°$ and $+2V$ commonly about 40°. Crystals are often fringed by hypersthene, the latter locally bearing vermicular intergrowths of colourless or very pale green spinel. Both pyroxenes are neutral or very pale brown in thin section. Hornblende occurs as a thin marginal alteration of pyroxenes, has $c \wedge Z = 20°$ and is pleochroic with X = colourless; Y = pale brown; Z = pale brown.

The plagioclase is labradorite and occurs in broad subhedral and anhedral, well-twinned crystals. Small grains of ore are present largely as inclusions in pyroxenes.

(c) Plagioclase amphibolites

Medium-grained, dark greenish-grey and white mottled plagioclase amphibolites, encountered as boulders around the lower northern slopes of Tuli Roba hill, contain approximately equal proportions of amphibole and felspar. In specimen 22/126, tremolite, pleochroic from very pale green to nearly colourless and having the optic plane parallel to the cleavage, contains cores of colourless, optically-positive pyroxene. The plagioclase is andesine-labradorite. Rare biotite and ore grains are associated with the amphibole, and a little calcite replacing tremolite is also visible in the slide.

In contrast to 'Basement System' calc-silicates, derived from calcareous sediments, and plagioclase amphibolites and hornblendic gneisses that originated from semi-calcareous sediments, the Tuli Roba rocks lack epidote, quartz and sphene; they also differ from most of the metasediments by the absence of microcline and green hornblende. The plagioclase amphibolites at Tuli Roba are therefore considered to be metamorphosed gabbroic rocks, forming an envelope around the intrusion. Ortho-amphibolites of similar origin have been described from a number of areas north-east of Mount Kenya, principally the Chanler's Falls area (Williams, 1966), the Barchuma-Kom area (Dodson, in press) and the Kora-Kalimangilu area (Jennings, in press). Although all these areas are more than 100 miles from Tuli Roba, they are all characterised by occurrences of basic and ultrabasic hypersthene-bearing plutonic rocks similar to those described above, so that a comparison is justified.

(2) Dykes

Only at three localities are basic dykes well exposed. Elsewhere, similar minor intrusions were mapped on occurrences of boulders or float fragments littering small areas of hill slopes.

The dykes are subdivided as follows:-

(a) Metadolerites and epidiorites (of presumed Precambrian age)
(b) Basalts and olivine basalts (?Upper Tertiary or Pleistocene).

(a) Metadolerites and epidiorites

Metamorphosed minor intrusions are evidently confined to the Ajao and Karari Guda hills in the northern part of the Buna area. The western occurrence at Karari Guda was mapped from numerous boulders, up to 60 cm in diameter, lying across outcrops of biotite migmatites. The dark grey, fine-grained rocks (22/75) display a doleritic texture in thin section with a criss-cross arrangement of plagioclase laths that are commonly about a 0.5-1.0 mm long. The felspar shows Carlsbad, and combined Carlsbad-albite twinning with some individuals also twinned on the pericline law. The composition is andesine (An_{34}) and crystals are marked by a distinctive pale brown colour. Zoned and twinned neutral pyroxene, which occurs both in the groundmass and also as occasional phenocrysts up to 2.0 mm long, has $+2V = c.30°\text{-}40°$ and maximum $c \wedge Z = 46°$. The crystals are largely replaced in a patchy fashion by biotite showing pleochroism with X = very pale brown; Y = Z = medium brown. Ore occurs in small irregular grains and as inclusions in pyroxene and biotite, and apatite is present in tiny prisms.

In the south-eastern part of the Karari Guda hills, a metadolerite dyke is inferred from numerous float fragments and is also emplaced in biotite migmatites. The fine-grained intrusive rocks bear occasional dark phenocrysts of felspar up to 6.0 mm long. The thin section of a specimen (22/48) from this locality shows rare plagioclase microphenocrysts about 2.0 mm long in a fine doleritic groundmass in which felspar laths rarely attain a length of more than 0.5 mm. The pale brown plagioclase in both phenocrysts and groundmass is sodic andesine. Pyroxene, which is largely replaced by colourless to greenish-brown biotite, is probably hypersthene. Dendritic ore is abundant and secondary quartz occurs in small rounded patches resembling amygdales.

On the eastern limb of the Bafuf syncline, just below and north-east of the quartzite forming the crest of the ridge, there is an irregular basic intrusion. It varies considerably in thickness, being 95-125 cm wide in places but in others being pinched out. It is also emplaced along different foliation planes in the crystalline limestone, so at first appears to be earlier than the folding and metamorphism.

The rock is soft and rubbly on account of weathering when it is brownish-green in colour. A faint schistosity is apparent in the weathered rock but this is not distinguishable in the fresh core which is hard, dark and fine grained. In thin section, specimen 22/145, an example of the fresh rock, has a fine-grained granular texture with recrystallised felspar which appears to be oligoclase. The most abundant mineral is a moderately-pleochroic, light green hornblende. Irregular grains of magnetite are a common accessory and epidote is also present, while some patches of calcite are secondary. The rock therefore appears to be best termed an epidiorite since it has suffered only a moderate degree of metamorphism and was probably emplaced during the closing stages of the orogeny.

Epidiorites are represented by a single specimen (22/11) collected from the eastern end of the Ajao hills where the intrusion probably cuts hornblende-biotite gneisses. No exposures

were found but small fragments of fine-grained, grey rock occur on the slopes below a prominent saddle separating quartzite hills. In thin section, the specimen is seen to be composed of a very fine granular mass of biotite, felspar and ore with occasional grains of quartz. The felspar, which also occurs as microphenocrysts, exhibits a pale brown coloration similar to that observed in the metadolerites; it is probably andesine.

(b) Basalts and olivine basalts

Most dykes in the area lack evidence of metamorphism and are clearly younger than the metadolerites and epidiorites. They cut 'Basement System' rocks, and fragments found on the slopes of Tuli Roba hill suggest that these younger dykes postdated the basic and ultrabasic intrusives there. In composition and freshness of the constituent minerals, the dykes show affinities with the Pleistocene-(?)Recent lavas in the area. They are also very similar to dykes mapped in the Chanler's Falls area (Williams, *op. cit.*) which were provisionally dated as Upper Tertiary-Lower Pleistocene and a similar age is suggested for the minor intrusives in the present area.

On the lower northern slopes of Kijibil hill in the Buna area, dykes from 30-95 cm in width cut cleanly across contorted 'Basement System' migmatites (Plate 17). A specimen (22/14) of the dark grey, fine-grained intrusive basalt contains titanaugite, labradorite and ore together with a little interstitial calcite. Fine-grained basaltic dykes, the largest about 45 cm wide, cut granitoid gneisses in the eastern part of Garse Buna hill (Plate 20). In thin section, specimen 22/87 is identical to the basalt described above.

At Ingrir, south-west of Garse Buna, a dyke about 23 cm wide also intrudes granitoid gneisses but the basalt differs from the Kijibil and Garse Buna rocks in having a porphyritic texture and in containing prominent olivine. The thin section of specimen 22/83 shows phenocrysts of olivine about 2.5 mm long and numerous laths of plagioclase up to 1.0 mm in length, set in a groundmass of titanaugite, plagioclase, ore and granules of altered olivine. The olivine phenocrysts have $2V = c.90°$ and display all stages of alteration to antigorite and calcite. In many crystals olivine is surrounded by colourless antigorite which is in turn rimmed by a zone of calcite. The plagioclase in the rock is labradorite.

All other dyke occurrences were mapped on the presence of float fragments of basalt. In a small specimen (22/123), collected from Tuli Roba hill and evidently derived from a dyke cutting hypersthenic gabbros, granules of reddish-brown iddingsite are considered to be altered olivines. The rock, which is composed largely of titanaugite and labradorite, is notable for the abundance of dendritic ore.

4. The Wajir Beds

Sedimentary rocks, largely calcareous, are best exposed in the northern part of the Giriftu well area, and extend northwards in three zones in the Dela area. Their character is similar to that of the Wajir Beds at Wajir (Parkinson, *op. cit.*, p. 11) and so they are regarded as a northern extension from the type locality, although their extent in the intervening Giriftu sheet has yet to be traced. A full description of the beds at Wajir has been given by Joubert (1963, *op. cit.*) and by Bestow (*op. cit.*). Although the Wajir well area was Bestow's primary concern he also sank several pilot wells in the present area during the investigation of water supplies for the Degodia pastoralists. As surface outcrops of the Wajir Beds are usually poor, his records have been used in this report.

Where the Wajir Beds crop out at the surface they have been altered to kunkar limestones which can be distinguished from those originating from crystalline limestones by their irregular shape of outcrop. The outcrops of kunkar limestones derived from metamorphic rocks roughly follow the strike and there are occasional outcrops of solid rocks. The Wajir Beds yield a red soil which is finer and lighter in colour than the red sandy soil derived from 'Basement System' rocks. Whenever this occurs it is presumed that Wajir Beds are present under the soil cover which, on aerial photographs, can be distinguished by their spotted appearance from the soils overlying the 'Basement System'. Drainage also indicates the boundary between the 'Basement System' and the Wajir Beds, including their soils, because small *laga* flow on the surface on the 'Basement System' but terminate at the boundary with water moving underground through the porous Wajir Beds.

Bestow (*op. cit.*) came to the conclusion that although the Wajir Beds vary greatly in thickness and lithology both laterally and vertically, a fairly uniform succession exists within the well area at Wajir as follows:

	feet
4. Semi-friable laminated impure limestones	0-12
3. Greenish or reddish, calcareous or ferruginous sandstones	5-20
2. White or grey calcareous loams and marls	10-30
1. Grey arenaceous clay (at Waghalla, 8 to 9 miles west of Wajir)	30

The above succession is given in order to compare it with those in the present area, which are illustrated in tabular form in Fig. 2.

At Giriftu a pilot well (D.W.7) which was probably near the southern boundary of the area on the banks of the Laga Bor where the most important wells are situated, gave the following succession (Bestow, *op. cit.*, appendix K):

	Feet
6. Sand	0-2
5. Friable limestone, silicified	2-18
4. White limestone, porcellaneous	18-22
3. Hard white limestone	22-36
2. Soft sandstone	36-40
1. Soft sand with mica and calcareous nodules	40-48

Bestow recorded a water level of 45 feet but after the very heavy rains of 1961-62 the level was high enough to obscure the lower, arenaceous part of the succession

The eastward continuation of the Giriftu outcrop of the Wajir Beds on the Wajir-Buna road was investigated at Gel Goulbis (D.W.11) with the following results (Bestow, *op. cit.*, p. 40):

	Feet
8. Sand	0-5
7. Red sandstone passing into grey loam	5-9
6. Hard white arenaceous limestone	9-20
5. Arenaceous white clay	20-28
4. Pebbly sandstone	28-32
3. White pebbly clay	32-47
2. Loam	47-52
1. Pinkish gritty non-calcareous loam	52-65

A somewhat similar succession was found at Hashinleh (D.W.12) farther north along the Wajir-Buna road in an isolated patch of Wajir Beds (Bestow, *op. cit.*, p. 40):

	Feet
9. Sand	0-3
8. Calcareous sandstone	3-7
7. Sandy limestone	7-20
6. Hard limestone	20-26
5. Friable sandstone	26-28
4. Hard non-calcareous pebbly clay	28-48
3. Friable arenaceous limestone	48-58
No sample	58-67
2. Grey calcareous friable loam	67-77
No sample	77-81
1. Pebbly loam	81-83
Quartz-mica granulite	83

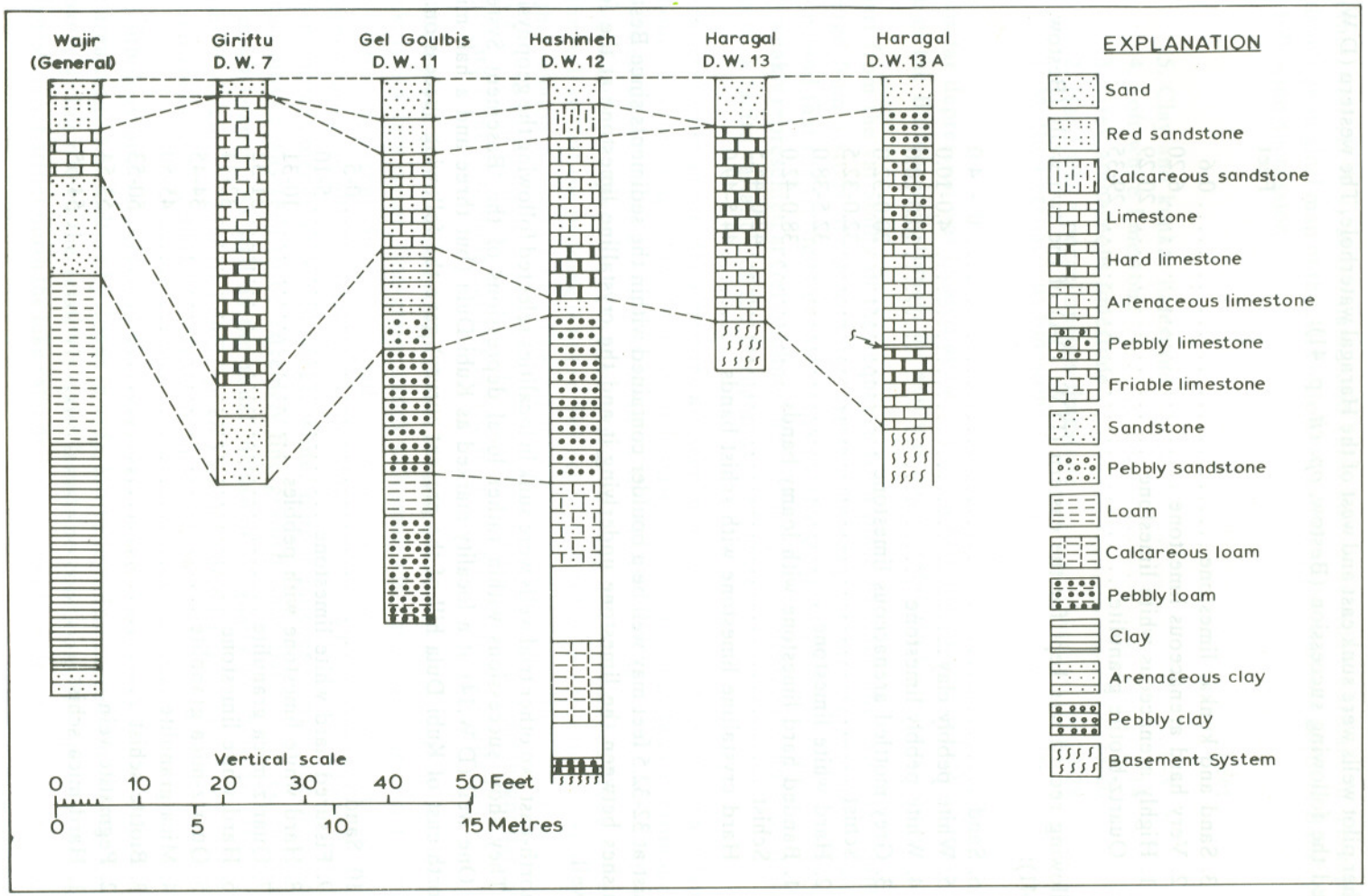


Figure 2 Geological Successions from Boreholes in the Wajir District

Two other pilot wells were sunk east and west of the Haragal waterhole. The western (D.W.13) disclosed the following succession (Bestow, *op. cit.*, p. 41):

	Feet
3. Sand and kunkar limestone	0-6
2. Very hard arenaceous limestone	6-20
1. Highly arenaceous white limestone	20-29
Quartz-biotite granulite	29-35

The following record was kept for the eastern (D.W. 13A) of the two wells (Bestow, *op. cit.*, p. 41):

6. Sand	0 - 4.0
5. White pebbly clay	4.0-10.0
4. White pebbly limestone	10.0-20.0
3. Grey mottled arenaceous limestone	20.0-32.0
Schist	32.0-32.5
2. Hard white limestone	32.5-38.0
1. Banded hard limestone with loamy bands	38.0-42.0
Schist	42.0-44.5
Hard crystalline limestone with schist bands	44.5-49.0

The schist at 32-32.5 feet may well be a boulder contained within the sediments since Bestow distinguishes between the limestone underlying it and the crystalline limestone at the foot of the well.

To the north-east two other trial wells were sunk in localities selected following the geophysical survey. They show successions within rather local depressions of the 'Basement System' surface. One well (D.W.14) at a locality marked as Kubi Dula (but three and a half miles north-north-east of Kubi Dula hill of the present survey) gave the following succession:

10. Sand	0-5
9. Fissured hard white limestone	5-10
8. Hard white limestone with pebbles	10-31
7. Quartz-mica granulite	31-32
6. Hard white limestone	32-34
5. Quartz-mica granulite	34-45
4. Mica granulite	45-50
3. Biotite schist	50-53
2. Pegmatite vein	53-54
1. Hard mica schist	54-65

Another well (D.W.9) at Sarmant Adin (also known as Adair Sarmant in Thompson and Dodson's geological map of the Ali Gollo hills, 1960), by the roadside north of Bafuf, provided the following succession:

	Feet
5. Clay and kunkar limestone	0-3
4. Soft white limestone	3-14
3. Grey arenaceous limestone	14-20
2. Hard white porcellaneous limestone	20-28
1. Mottled arenaceous limestone	28-?

A similar depression was located about ten and a half miles north of D.W.14, near the first rise of the Buttelu hills, though no well was dug to establish the succession.

Apart from the variability of the sequence from place to place, the two main points which emerge from a study of the well-logs are that limestone is more thickly developed than at Wajir; and that the ferruginous sandstones overlying the Wajir Beds at the type locality are only weakly represented at Gel Goulbis. The top four feet of calcareous sandstone at Hashinleh may be a facies variation of the ferruginous sandstones.

When fresh exposures of the limestone are seen in wells, they are chalky-white and laminated, although the bedding takes the form of a series of lenses rather than continuous planes. Specimen 22/165 from a well just north of the Giriftu trading centre is a buff, nodular, fine-grained rock. There has been some alteration to superficial limestone because of exposure in the well so that the bedding is not so distinct as it would be in a freshly-quarried specimen. In thin section it consists of a fine calcite mosaic with some inclusions of quartz, felspar and a brownish alteration product, presumably originating from ferromagnesian minerals. There are some exsolution cavities in which calcite has been redeposited.

An example of the more altered type found in surface outcrops is 22/137 from the Dela-Dunbas track. It is a dark cream, fine-grained rock with small white porous patches in which bedding is no longer apparent. Small sub-angular inclusions of quartz and felspar are again present. Another variety of altered limestone is illustrated by 22/169 from east of Giriftu. It is a pale brown, porcellaneous rock with large, white, porous patches. Under the microscope the calcite mosaic was seen to be extremely fine grained while patches of redeposited calcite are much coarser. As well as the usual inclusions of quartz and felspar there are a few grains of magnetite. Joubert (1963, *op. cit.*) quotes chemical analyses illustrating that these altered rocks show a marked increase in lime near the surface.

The lithology and variability of the lower part of the Wajir Beds in the southern part of the area suggest deposition by floods in wide, low valleys. The channels probably then became choked, giving rise to the relatively quiet lacustrine conditions required for the formation of limestones. Farther north the lake extended in a series of low depressions in the end-Tertiary

peneplain to give limestones where the sandstones and clays had not been previously deposited. The ferruginous sandstones were probably formed under terrestrial conditions; their absence in the west and north of the Dela sheet may well be due to denudation by the Laga Bor and its tributaries. Unfortunately no diagnostic fossils have been found in the Wajir Beds, but Dixey (1948, *op. cit.*, p. 10) ascribed a Miocene age to them and to the El Wak Beds which appear to represent the northern extension of the Wajir Beds. He based this on their correlation with the undoubted Miocene sediments in Turkana, believing that they were all bevelled by the end-Tertiary peneplain. Recent mapping, however, has disclosed that the El Wak Beds occur in depressions in the end-Tertiary peneplains which dates them as Pleistocene and an Upper Pleistocene age was tentatively put forward (Baker and Saggerson, 1958, p. 34). Joubert (1960, *op. cit.*, p. 48), while agreeing that they are Pleistocene, suggested that it was possible that the deposits may have been initiated as early as the Lower Pleistocene. After mapping the Wajir-Wajir Bor area, Joubert (1963, *op. cit.*) thought it was reasonable to correlate the Shangalla limestone in the Daua valley, which also has conglomerates and grits at its base and is overlain by gypsum, with the limestones and gypsum of the Wajir Beds. The clays and sandstones underlying the limestones in the Wajir Beds were the first deposits laid down after the maturation of the end-Tertiary peneplain, so it may well follow that they belong to the first Pleistocene pluvial and interpluvial periods respectively, i.e. the Lower Pleistocene. The obvious corollary is that the limestones and gypsum of the Wajir Beds and the Shangalla limestones represent the succeeding Kamasian pluvial period, with the grits and conglomerates at the base of the Shangalla limestones indicating its onset. If the El Wak Beds were initiated in the Lower Pleistocene it would appear that all the calcareous and gypsiferous deposits in the Northern Frontier District belong to one period of deposition.

5. Pleistocene-(?)Recent volcanic rocks

The only volcanic rocks in the area are olivine basalts which crop out in one of the more easterly tongues extending from the vast plain stretching westwards to Marsabit and Lake Rudolf [Turkana]. Flows of olivine basalts rest on the end-Tertiary peneplain along the western edge of the area, attaining a total thickness of some 70-100 feet. No vents occur within the present area, but evidence from air photographs indicates the existence of a number of cones both north and west of the map area. One or two of the smaller hills immediately west of the area display more rounded outlines than most of the volcanic features, and the likelihood of their being composed of basic or ultrabasic plutonic rocks, similar to those at Tuli Roba, should be entertained. The flows thin to the south and near Aden Wale area reach a thickness of only about 45 feet.

At least two flows of olivine basalt were recognised though no distinction is apparent in thin sections of the rocks. The earlier lavas bear a thin soil and vegetation cover in contrast to the bare surfaces that characterise overlying rocks. Poorly-developed columnar jointing is everywhere typical of the upper flow (Plate 16).

The lavas are medium-grey, highly vesicular rocks usually containing small phenocrysts of

green olivine. The vesicles are never filled though they are frequently lined with calcite. The rocks show remarkably little variation in thin section, the only difference being the size of olivine phenocrysts and plagioclase laths, the latter locally attaining phenocryst proportions. Slight changes in the habit of pyroxene were also noted; most commonly, the mineral displays an ophitic relationsip towards plagioclase, for example in specimen 22/125 from a locality about a mile north-west of Tuli Roba; rarely, as in specimen 22/107 from the lavas some four miles west of Kurrbat hill, the pyroxene exhibits a subhedral-granular habit. Specimen 22/162 from the edge of the lower flow on the eastern side of Bule Sabor is a fine-grained, dark, bluish-grey rock which is highly vesicular. The slide cut from it is composed of fresh olivine crystals with somewhat less abundant titaniferous augite set in a mosaic of labradorite laths. Magnetite is a common accessory and some grains of epidote and zircon are present. An example of the non-vesicular type of basalt is 22/164 from the centre of the same flow a little farther west, which is identical to 22/162 in its mineralogy, except that some of the olivine crystals show slight alteration to iddingsite at their edges.

The most striking feature of the rocks in thin section is the complete absence of alteration of any of the constituent minerals. Neutral or colourless, subhedral to rounded crystals of olivine occur both as phenocrysts up to 1.5 mm long and as smaller granules in the groundmass. The optic angle is about 90°. Brown to purple-brown, very weakly pleochroic titanaugite, with $+2V = c.60°$ and $c \wedge Z = 47°$, is generally anhedral, with individual crystals up to 2.5 mm long ophitically enclosing plagioclase laths. The felspar is labradorite and ore occurs in small irregular grains.

The lavas rest on the end-Tertiary peneplain and are therefore post-Middle Pliocene in age. The lack of alteration of constituent minerals mentioned above suggests a Quaternary rather than Tertiary age and the generally fresh appearance of the upper flow may indicate extrusion during Recent times.

6. Quaternary deposits

Quaternary deposits in the Buna area comprise a variety of soils, rare occurrences of poorly-consolidated grits and developments of superficial limestones. The soils have been subdivided into types broadly associated with outcrops of 'Basement System' rocks, commonly red or red-brown and of a sandy nature; clayey and dusty soils that vary in colour from grey and brown to reddish-brown, best developed in the western half of the area; dark, clayey alluvial soils grading into a reddish-brown variety, generally related to the present drainage system; and dusty volcanic soils that occur in the western part of the area.

Red and red-brown sandy soils cover the greater part of the flat ground surrounding hill masses composed of 'Basement System' rocks. Towards many of the outcrops, particularly those of quartzites, the soils become pebbly and bouldery. Around crystalline limestones, on the other hand, reddish superficial deposits grade into brown varieties bearing fragments of kunkar limestone. Near some of the granite hills, notably at Mojo and Korondil, a superficial

apron is composed of poorly-consolidated quartzofelspathic grits, and many of the stream-beds on the lower flanks of the hills are occupied by sands. Sands near the track at the south-eastern part of Mojo hill contain quartz, felspar, magnetite, hornblende, sphene and apatite - minerals derived from the granites and inclusions in the granites. In the Korondil area, red and red-brown sandy soils occur as irregular patches across the plains, separated by an extensive development of deposits of a more clayey or fine dusty nature. With very few exceptions, outcrops of 'Basement System' rocks are found only within the reddish sandy soils. In the central and south-central parts of the area, these deposits are often characterised by sheets of rounded quartz pebbles up to 75 mm in diameter. All the above superficial deposits are combined on the geological maps and are indicated by the symbol Qr.

The north-western corner of the Buna area and a large part of the northern half of the Korondil area is covered by grey and brown clayey soils that grade into reddish-brown dusty varieties as traced southwards. Even in the north, the clayey soils frequently bear a thin patchy veneer of pale reddish-brown material probably deposited by wind action. Small fragments of kunkar, tiny pellets of iron ore and small quartz pebbles are often found in the clayey soils, and midway between Garse Buna and Lesayu, sheets of 50-75-mm diameter quartz pebbles overlie similar deposits over an area of about a square mile. Dusty reddish-brown soils in the southern half of the Buna area frequently contain rounded and subrounded quartz pebbles up to about 25 mm in diameter. These deposits are never as brightly coloured as the sandy soils previously described and they differ from the sandy varieties in supporting a less dense vegetational cover. The clayey and dusty soils are together indicated by the symbol Qb on the geological maps.

In the northern half of the area, black and grey clayey alluvial soils occupy the courses of the Laga Jara, Laga Bor, Laga Jarti Guda and the upper stretches of the Laga Chamu. Sections in the alluvial deposits are exposed in the wells at Buna where 20 feet of grey clayey soils overlie secondary limestones and weathered hornblende-biotite gneisses. Immediately around Buna, the deposits are completely devoid of vegetation and during the dry months of the year the surface breaks down into a pale fine dust. South of the latitude of Buna, the alluvial deposits become progressively redder and spread beyond the confines of the shallow drainage systems to merge with surrounding soils. The plain extending westwards from El Las is notable for the stunted nature of its vegetational cover, and reddish-brown dusty soils are believed to have been derived from a barren alluvial fan between the Laga Bor and Laga Chamu. The western boundary of alluvium is recognisable near Garse Buna and Ingrir but, farther south, no distinction in soil types could be made during a traverse between the Aden Awale and Arba Jahan tracks, and the line shown on the map is taken largely from air photographs. Black and grey clays, very similar in appearance to alluvial deposits north of Buna, occupy two marked depressions near the lavas in the western part of the Korondil area. These are clearly seasonal swamps.

Brown, greyish-brown and pale reddish-brown soils are developed on some of the lavas and the main occurrences are shown on the geological map.

Occurrences of kunkar limestone are common across outcrops of 'Basement System' crystalline limestones, in many cases effectively concealing the exposure. The existence of slight topographic relief has been taken to indicate an outcrop of marble beneath the superficial limestone. South of the Ali Gollo hills, however, an extensive sheet of kunkar forms no topographic feature and its orientation is not conformable with the local 'Basement System' strike so that the possibility of the limestones overlying calcareous sediments must be considered.

7. Superficial deposits

The greater part of the area is covered by thick soils, some of which indicate the underlying rock type. It is not known, however, what rock underlies the red-brown clayey soils of the west. Although it is a distinctive soil it may be formed by a mixture of other soils or may be formed from a rock not exposed in the region. Because of this doubt it is proposed to describe the soils as being derived from the underlying rocks during the one period and not attempt to place them in stratigraphical order.

The red sandy soil surrounds and appears to be derived from outcrops of 'Basement System' rocks. It is a loose soil largely composed of quartz fragments while the bright red colour is given by iron oxides derived from the destruction of primary ores and ferromagnesian minerals. Bestow recorded thin sandstones at Dela (*op. cit.*, p. 40) and Kisirip (p. 41) which he considered to be ferruginous sandstones overlying the Wajir Beds. In the present report these are regarded as local occurrences, being possibly formed by the induration of red sandy soils in the pans. The main reason is that the type of soil is that found overlying the 'Basement System' and not that derived from the Wajir Beds, which shows a distinctive spotted appearance on aerial photographs. The numerous quartz pebbles in the red sandy soils of the Aden Awale area are believed to be derived from the weathering of quartzites which farther east were less intensely eroded and so form hills.

On the lower exposures of crystalline limestone, kunkar limestone is well developed, but on the higher hills a thin, powdery, white soil was derived from the country rock. It occurs only in small patches between solid outcrops.

The Wajir Beds are overlain by another red soil which, however, is finer and lighter in colour than that derived from 'Basement System' rocks. As noted before, they have a distinctive spotted appearance on the aerial photographs and usually carry a thicker growth of thorn trees than the soils derived from the 'Basement System', although this is not the case at Giriftu. They may have been derived from a thin layer of the ferruginous sandstones overlying the Wajir Beds which has been completely broken down by weathering. On account of the thickness of the soils, however, it is believed more likely that they were formed by leaching of the limestones as described by Robinson (1949, pp. 427-429). Joubert (1963, *op. cit.*) places the ferruginous sandstones of Wajir in the Kamasian-Kanjeran interpluvial period, by correlating them with similar deposits belonging to the second interpluvial period of the

Mandera area (Joubert, 1960, *op. cit.*, p. 47).

The western red-brown clayey soils present a problem because no rocks from which they could be derived are exposed. Bestow (*op. cit.*, appendix K) gives the following succession for a pilot well (D.W.8) dug on the Giriftu-Arba Jahan track near the Laga Har:

	Feet
3. Clay	0-7
2. Red-brown calcareous loam	7-24
1. Pinkish-grey friable loam	24-27

Northwards around Korondil, the red-brown clayey soils pass into grey and black soils but this may be due to different weathering conditions in the southern area of lower rainfall. It is also possible that the grey and black soils were produced by poor drainage on the 'Basement System' in the north. A third possibility is that the red-brown clayey soils are formed by an admixture of red sandy soil from the 'Basement System' with the grey and black soils, the southern flow of the drainage causing the red soils to be found in the south of the region. Joubert (oral communication) states that the red-brown clayey soils are similar to the red-brown and yellowish-brown clays he found near Wajir. There they are associated with the drainage system, being best developed on the western side of the channels, probably indicating an easterly migration of the flow. Joubert (1963, *op. cit.*) stated that these soils are impermeable to water, forming good foundations for pans, and that they are probably post-Middle Pleistocene in age from their stratigraphical position. Southwards the red-brown clayey soils pass into the non-cohesive, fine silty soils of the Boji plain.

From the above it would appear that these soils could have one or more of several origins and it is impossible to determine which in fact was responsible for their formation. If unexposed rocks were the source of the red-brown clayey soils, it is possible that they belonged to the Jurassic since Dodson (in press) found Oxfordian limestones in the Matasade hills some 45 miles south-west of the south-western corner of the Aden Awale area. Deep boreholes south-west of Wajir at Ndege's Nest and Habaswein disclosed a thick sequence of clays and sandstones of possible Miocene age and they may extend northwards to underlie the red-brown clayey soils.

Although alluvium and valley soils have been mapped along most of the western watercourses, it is only along the Laga Bor and, to a lesser extent along the Laga Har, that true alluvium has been developed. The soils along other smaller western watercourses and most of the soils along the Laga Har are somewhat browner in colour than the surrounding red-brown clayey soils and their junction is gradational. The former therefore appear to have been formed from the latter by leaching of some of the components or by illuviation. The soils along *laga* on the 'Basement System' also show only slight modification of the surrounding red sandy soils so it is believed they were formed by a similar process.

VI. METAMORPHISM AND GRANITIZATION

The rocks in the Buna area have evidently undergone two periods of regional metamorphism. An earlier phase, which converted a thick series of sediments into high-grade metamorphic rocks, was accompanied by widespread granitization producing migmatites, granitoid gneisses and unfoliated granitic rocks. Following the intrusion of basic and ultrabasic plutonic rocks and a number of dykes, the area suffered a second period of metamorphism. Gabbros and pyroxenites of a major intrusion were converted marginally to amphibolitic rocks and the dykes to metadolerites and epidiorites.

Pelitic gneisses of the 'Basement System' contain sillimanite, kyanite and garnet and indicate a grade of metamorphism corresponding to the almandine-amphibolite facies (Turner and Verhoogen, 1960, p. 544). The following mineral assemblages are typical:

(a) quartz-sillimanite-muscovite-biotite-microcline
(b) quartz-sillimanite-garnet-muscovite-biotite-microcline
(c) quartz-sillimanite-kyanite-muscovite-biotite
(d) quartz-garnet-plagioclase-biotite-microcline(-muscovite).

(a), (b) and (c) indicate a grade of metamorphism probably equivalent to the sillimanite-almandine-muscovite subfacies (Turner and Verhoogen, *op. cit.*, p. 549), though the association in (b) could indicate a transition to the sillimanite-almandine-orthoclase subfacies, with microcline proxying for orthoclase. The plagioclase in (d) is oligoclase or andesine and since the rocks contain negligible epidote, the assemblage is more likely to represent the sillimanite-almandine-muscovite subfacies rather than the kyanite-almandine-muscovite subfacies.

Typical assemblages in the metamorphosed calcareous sediments are:

(a) calcite/dolomite-forsterite-diopside-tremolite(-spinel-phlogopite-quartz)
(b) calcite/dolomite-diopside-tremolite(-phlogopite-quartz).

A common mineral association in the metamorphosed semi-calcareous sediments is:

quartz-diopside-hornblende-epidote-plagioclase-calcite-sphene
(-tremolite-microcline-scapolite).

All these assemblages conform to the almandine-amphibolite facies though the recognition of a precise subfacies is difficult. The presence of spinel in many of the calcareous rocks suggests the highest grade of metamorphism within the facies (sillimanite-almandine-

orthoclase subfacies) whereas abundant epidote in the semi-calcareous metasediments indicates a grade lower than that represented by the sillimanite-almandine-muscovite subfacies.

Mineral assemblages in the 'Basement System' rocks thus show that the grade of metamorphism attained corresponds generally to the higher parts of the almandine-amphibolite facies, with temperatures approaching 750° C and pressures up to 8,000 bars.

Evidence of granitization is found both in microtextures, with microcline commonly adopting a replacive habit towards plagioclase and quartz, and in the range of rock types constituting the 'Basement System'. Potash metasomatism is insignificant in the quartzites and crystalline limestones; it becomes more noticeable in semi-calcareous and pelitic gneisses but the best examples occur in rocks of semi-pelitic origin. Many of the latter are now represented by migmatites, an intermediate stage in the production of more homogeneous granitoid gneisses. Unfoliated granitic rocks, that are all characterised by the replacive habit of microcline, are considered to be the end stage in the process of granitization where the metamorphic fabric has been almost completely obliterated. Locally, there is evidence to suggest the intervention of a mobile phase in the formation of the unfoliated rocks.

The origin of the Haragal granite could not be discovered from its scanty exposures but Walsh (*op. cit.*) believes that similar granites farther north are metasomatic, whereas Thomson and Dodson (*op. cit.*, p. 40) postulated that the granites of the Bur Mayo-Tarbaj area were intrusive.

VII. STRUCTURE

Apart from southerly dips of one or two degrees in the Wajir Beds, which appear to parallel the surface on which they were deposited, structures are only found in the rocks of the 'Basement System'. They are best displayed in the hilly north-east quadrant of the map area, and a structural map containing synoptic stereograms for this quadrant is given in Fig. 3. Descriptions of major folds lying outside the structural map are given for the Bafuf to Bur Beit area.

The following discussion of structure is confined to a study of the major folds and faults in the 'Basement System' rocks in the area, with brief reference to inferred folds in unfoliated granites. Structures in the basic and ultrabasic intrusives and associated plagioclase amphibolites are unknown and the lavas occur in nearly horizontal flows with no evidence of faulting.

1. Folds

'Basement System' structures are extremely complex over most of the area and details recorded during the survey indicate more than one period of folding. The complexity is best illustrated by a study of lineations which show a marked spread that is not merely related to swings in the axes of the major folds, though this undoubtedly occurs. The majority of the lineations measured are shown both on the geological map and also on a structural map of the area (Fig. 3). On the latter, two sets of lineations have been distinguished:

(a) Those related to folds having axes trending approximately NE-SW, though swinging locally to a more N-S direction.
(b) Those related to folds with axes trending approximately NW-SE.

The direction of plunge of the axes of minor folds are also shown on the map and they show a general parallelism with one or other set of lineations. At many localities, both sets of minor structures are present but in a few sub-areas a dominance of one trend, to the virtual exclusion of the other, is indicative of an approach to structural homogeneity and it is only in these sub-areas that the major structures can be convincingly demonstrated.

Complexity in the foliation pattern is best appreciated from stereographic plots of the poles to foliation planes. Apart from the marked scatter shown by the stereograms, structural inhomogeneity is also obvious from a study of the strike of vertical foliation which must be parallel to the axis of the fold with which it is associated. Numerous examples of sharp changes in the strike of vertical or near-vertical foliation are found at the intersections of postulated earlier and later folds, and it is significant that the strike is parallel to the trend of one or the other set of lineations described above.

It is unwise to deduce the form of major folds only on the orientation and dip of bands in the local 'Basement System' succession. For example, bands of quartzite and marble display a general NW-SE strike at some localities, e.g. Buttelu, closures demonstrating the existence of major folds that are often apparently simple anticlines and synclines. However, although these open folds frequently do exist and are accompanied by lineations parallel to their axes, the occurrence of other lineations parallel to the banding remain to be explained. Lineations at an appreciable angle to banding and foliation strike are indicative of overturned or recumbent folds. The main difficulty in the present area lies in determining whether the orientation of a particular outcrop is a result of complex early structures or whether the present banding is related to later folds of a more open nature.

A detailed discussion of some of the major folds in the area is best carried out by an examination of structures mapped in the various sub-areas.

Sub-area 1 (Buna-El Las-Korondil)

In the eastern parts of this sub-area, the lineation pattern is simple and shows that fold axes trend approximately N-S. The sub-horizontal attitude of lineations alternating with shallow plunges to N and S prove the existence of gentle culminations and depressions on the axes. The culminations correspond, however, to anticlinal NW-SE folds and the depressions to synclines. That these transverse folds belong to a separate system is indicated by cross-lineations developed in the N-S set at Garse Buna. The NW-plunging folds are apparently dominant elsewhere in the Korondil area, though exposure is poor. The stereogram for sub-area 1 shows that both sets of folds are simple open structures. The most important N-S fold is the Buna anticline and, on the NW-SE trend, the Ingrir syncline probably dominates 'Basement System' structures in the Korondil area. East of the Buna anticline, in sub-area 4, NW-SE lineations plunge to the SE so that the folds with which they are associated evidently display a major culmination where they cross the axis of the Buna anticline. This mutual interference of both sets of folds provides no clue to the relative ages of the structures involved.

Sub-area 2 (Ajao-Kijibil range)

In the Ajao hills, lineations plunge consistently to the SW and WSW, though the angle of plunge is variable. The stereogram shows that open anticlines and synclines are present but stratigraphic repetitions suggest that the open folds might be superimposed on a recumbent structure (see section D-E-F published with the geological map of the Buna area). Critical closures of the quartzite bands required to prove the recumbent fold at Ajao are not exposed. A similar lineation trend to that seen at Ajao is present at Kijibil but, in addition, vertical foliation striking NNW-SSE and minor folds plunging to the SSE indicate the existence of subordinate folds on this trend. The NE-SW folds at Ajao and Kijibil are correlated chronologically with the N-S set of structures in sub-area 1, so that a 45° swing in the axes occurs between Ajao and Buna. Better evidence of the swing is found in sub-area 4. Postulated recumbency on the NE-SW trend suggests that these folds are earlier than NW and NNW structures.

Sub-area 3 (Buttelu-Kuro-Butei-Karari-Guda)

WSW-plunging lineations are prominent in the Buttelu hills, showing that some folding occurred about axes approximately parallel to those recognised in the Ajao-Kijibil range. The plunge of lineations at Buttelu is somewhat steeper than that measured at Ajao. Other lineations at Buttelu trend approximately NW-SE and are clearly related to the cross-trend recognised in sub-areas 1 and 2. Plots of poles to foliation planes in sub-area 3 tend to confirm two distinct directions of folding, but the stereogram does not illustrate fully the styles of folding on the two trends. An examination of banding and the stratigraphic succession in the 'Basement System' rocks at Buttelu provides further critical evidence of the major structural features involved. In the southern parts of the Buttelu hills, sillimanite-bearing gneisses overlie a prominent band of quartzite, the gneisses in turn being overlain by crystalline limestones. Farther north, the succession is reversed and the rocks adopt a strike that is approximately parallel to the ENE-WSW lineation pattern. It is considered unlikely that more than one band of quartzite and flanking pelitic gneiss is involved, and the reversed succession is indicative of a major overturned or recumbent fold (probably the latter). Foliation in the central parts of the Buttelu hills proves the existence of an open syncline trending approximately NW-SE and evidently refolding the recumbent fold. In the south-western part of the Buttelu hills, a syncline having an axis trending NE-SW is related to the earlier period of folding and was superimposed on the lower limb of the recumbent fold, since sillimanite-bearing gneisses overlie quartzites. Other early open folds on the lower limb of the recumbent structure are indicated by culminations and depressions in the lineation pattern of later folds. At Kuro, foliation dips consistently to the NW, and any folding there must be isoclinal and related to early NE-SW structures.

Sub-area 4 (Ghote-Yukala-Alghe)

Evidence of the swing in fold axes from NE-SW to approximately N-S (i.e. from the trend mapped at Ajao and Buttelu to that recognised in the Buna anticline) is found in the lineation pattern in the Ghote, Yukala and Alghe hills, plunges being dominantly to the S and SW. Lineations belonging to another set of folds plunges SE and ESE. Vertical foliation is found on both trends. Overturned structures plunging S and SW are seen in the northern part of the Ghote range, where banding and foliation strike is at an angle to the lineation pattern. Similar non-parallelism of banding and lineations farther south is probably also indicative of overturned or recumbent structures, though there the banding and foliation strike is parallel to later lineations and the intensity of refolding is difficult to assess. The stereogram for sub-area 4 shows that, in contrast to the near-horizontal first fold axes in sub-area 1, early structures often plunge steeply to the SW or S. Again in contrast to sub-area 1 where second folds plunge to the NW, the later folds in sub-area 4 plunge to the SE, illustrating a major culmination across the Buna anticline.

Sub-area 5 (Gogai-Ali Gollo-Hawal Ben-Bakal-Datacha Mudi)

The south-eastern quarter of the Buna area is marked by strong NW-SE folding. This trend was described by Thompson and Dodson (*op. cit.*) in the Ali Gollo hills and some of the structural information shown in sub-area 5 is taken from maps and notes compiled by these authors. Closer examination of the structure during the present survey showed that lineations

associated with NW-SE folding are accompanied by others plunging to the SSW and clearly related to the early trend recognised at Buttelu and Ghote. By comparison with the other sub-areas, it is inferred that NW-SE folds mapped at and around the Ali Gollo hills are superimposed on earlier structures having axes trending approximately SSW. A clear example of the earlier trend is preserved at north Datacha Mudi where vertical foliation strikes NE-SW.

Major folds mapped immediately to the south of the area covered by the structural diagram include the main hill of Bafuf which is a near-perfect example of a plunging syncline, with an axial plunge of 10° to the WNW given by lineations in the quartzite which forms a marker horizon in the limbs. The same quartzite reappears at the west of the north-eastern ridge of Bafuf, with felspathic quartzite and muscovite-biotite gneiss in the intervening valley separating the crystalline limestones on the sides of the hills. As the SSW dip in the north-eastern ridge is similar to that in the north-eastern limb of the Bafuf syncline, it is believed that the two ridges are separated by an isoclinal anticline. Its plunge is also to the WNW, because the limestones close in that direction round the felspathic quartzite and the muscovite-biotite gneiss which is sheared out on the north-eastern inverted limb. West of Bafuf the quartzite reappears as a discontinuous lens in a small hill where the dips are SSW so an anticline separating the hills is inferred. The same anticline was also recognised at Tosi, south of Bafuf, where no quartzite is exposed and the trend of the fold axis is NNW-SSE. The limestones south and west of Bafuf are therefore regarded as the same horizon as that exposed there, with the quartzite missing through facies variation. The limestones are folded in another anticline and two synclines, the axes of which exhibit the same swing from WNW-ESE to NNW-SSE. Farther west the quartzite reappears in plunging synclines at Bur Beit where the trend is WNW-ESE and at Deto where the trend is also exposed but is not associated with limestones; the dips are variable but generally easterly.

2. Minor structures

As limestones form the bulk of the exposures minor structures are not well displayed, being confined to the quartzites and granitoid gneiss. In the quartzites lineations roughly parallel the axes of the major folds, trending between NNW-SSE and WNW-ESE with low plunges corresponding to the plunge of the particular fold in which they occur. On the isolated hill east of Halati, however, there are two lineation directions. One compares with those found in other quartzite outcrops, plunging ESE at 5° but the other plunges NNE at 35°. The occurrence of two mutually perpendicular b-lineations confirms that two fold directions are involved.

The granitoid gneisses also contain lineations trending NNE-SSW but in this case the northerly plunges are low. They are accompanied by minor folds on the same axis which are tight in style, but somewhat less than isoclinal.

3. Faults

No definite faults are exposed in the area, and most of the faulting is inferred. Two principal fault directions occur: one is WSW-ENE and the other is NW-SE, each parallelling one of the fold directions in the 'Basement System'. WSW-ENE faults are inferred cutting the eastern limb of the Buna antiform on the west bank of the Laga Bor, giving rise to *en echelon* segments of the granitoid gneiss hills, of which El Las is the most prominent. In the Ali Gollo and Buttelu hills, NW-SE faults are intruded by basalt dykes. Thompson and Dodson (*op. cit.*) also mark a prominent fault separating Gosieh hill from the immediately adjacent hill of Uliafa to the east. It seems likely that many of the separated hill outcrops in the whole area owe their existence to concealed faults between them, and that faulting parallel to the SW-NE or WSW-ENE fold axes is a common occurrence, though difficult to recognise because of the superficial cover.

VIII. ECONOMIC GEOLOGY

1. Minerals

Sillimanite and kyanite

Few minerals of possible economic importance were encountered during the survey and the traces found are unlikely to arouse interest in view of poor communications. Sillimanite occurs in lenticular patches up to 25 mm long in gneisses at Buttelu. The presence of the mineral at this locality was reported many years ago by Parkinson (*op. cit.*, pp. 26-27) and it was the first recorded occurrence of sillimanite in Kenya. In the course of the present survey, a band of sillimanite-bearing gneisses was traced intermittently around the Buttelu hills, and similar rocks were encountered in the northern and southern parts of the Datacha Mudi hills and intercalated in crystalline limestones at north Bakal. All the occurrences may form part of a single band. Biotite-muscovite gneisses exposed in the central parts of the Ghote hills bear occasional fibrous aggregates of sillimanite and subordinate kyanite. Sillimanite was identified in ferruginous, grunerite-garnet quartzites that outcrop at Kurrbat and Kuboli hills near Korondil; a little kyanite is present in the rocks at the latter hill. Sillimanite was not confirmed in quartzites in other parts of the area, but microscopic inclusions in constituent quartz grains in rocks from the Ajao, Karari Guda and Buttelu hills were provisionally identified as sillimanite.

Limestone

Limestones are abundantly developed in the eastern and north-eastern parts of the Buna area. The remoteness of the localities makes it unlikely that any demand for limestone will arise in connection with the manufacture of cement, and many of the rocks would probably prove unsuitable in view of the suspected high magnesia content. The highest magnesia values are likely to be found in marbles cropping out around Buttelu.

The limestone from the Wajir Beds has been used as a source of dimension stone at Wajir and Giriftu because its softness and fissility facilitate working and its proximity cuts transport costs to a minimum. Its poor quality is shown by the considerable damage done to buildings in Wajir during the heavy rains of 1961. Part of the damage, however, may have been due to the use of calcined gypsum as lime mortar, for little burning of limestone has taken place.

In addition to the production of lime both the Wajir limestone and the crystalline limestones of the 'Basement System' appear to be fairly free of dolomite so could be used in the manufacture of cement. The availability of gypsum would prove an advantage and other necessary components are within easy reach but local demand appears unlikely to become sufficient to warrant cement manufacture. The remoteness of the area would probably preclude transport to more developed centres.

Pegmatites

The general paucity of pegmatites is considered to be related to the essentially metasomatic origin of masses of unfoliated granitic rocks. The few pegmatites encountered showed no encouraging signs of mineralization. Panning of sands derived from the granitic rocks at one or two localities yielded no minerals of economic value.

Magnesite

A little magnesite was found veining the gabbroic rocks at Tuli Roba hill. Low-grade chromite occurs at Dobel, north of the Buna area, but no indications of chromite deposits were seen at Tuli Roba, though it must be stressed that exposures are poor.

?Wollastonite

Wollastonite is not present in any of the specimens collected from the Buna area. The occurrences of wollastonite described from the crystalline limestones of the Ali Gollo hills (Thompson and Dodson, *op. cit.*, pp. 10 and 44) may well have resulted from a misidentification of the metasilicate, though the best exposures mentioned in that report were not revisited.

2. Water supplies

The most vital problem for the population is an adequate supply of water. Surveys of existing water supplies were carried out and recorded by Bestow (*op. cit.*) and Messrs. Howard Humphries and Sons (*op. cit.*). Bestow's work, which included numerous geophysical investigations, was confined to the Wajir district whereas a broader water development scheme was undertaken by Howard Humphries. This project involved implementing the proposals put forward by Dixey (1944), commonly referred to as the 'Dixey Scheme'. For convenience, the following discussion of water supplies is subdivided on an administrative district basis.

Wajir administrative district

Details of the geological successions of the pilot wells sunk during Bestow's survey have been given in the section on the Wajir beds and all the sites of the wells are marked on the geological map, except for D.W.14 and D.W.9. Bestow concluded that wells should be made at Yakho, Maddo and Gel Goulbis.

The best permanent water supply at present is provided by the Buttelu wells, which are situated in crystalline limestones, and wells in the northern part of the Giriftu area. Although lying within the Wajir district, the Buttelu wells are frequently used by Adjuran pastoralists from the Moyale district.

Howard Humphries and Sons (*op. cit.*, pp. 39-40) recorded a water level of between 45 and 50 feet in the six wells they constructed near Giriftu in December 1954, but this had risen by about 10 feet in February 1962 after the exceptionally heavy short rains of 1961. All except one of the wells produced water with yields varying between 80 and 150 gallons per hour. The productive wells were steined and provided with tops and drinking troughs; the

tops of the wells were high enough to be above likely flood water from the Laga Bor, on the banks of which most of the wells are situated. No mechanical pumps were fitted to any of the wells and water is raised by a team of two men using a goat skin bucket on a rope. The water is relatively pure, and on account of the lack of gypsum in the Wajir Beds at this locality does not possess the well-known laxative qualities of the Wajir water. Farther north, Howard Humphries and Sons (*op. cit.*, pp. 38-39) found well sites suggested by Bestow along the Laga Bor disappointing, so instead constructed *dololo* at Maddo and Yakho to supplement the existing tanks at Dela and Halati. The Maddo *dololo* had a capacity of $1^1/4$ million gallons at the time of construction and the one at Yakho 1 million gallons, but silting may have reduced their capacity since then. The *dololo* at Jeruko on the Laga Har is not mentioned by Howard Humphries and Sons so is presumably of later date, having been constructed by the Government or the local people. Other tanks are small and of local construction so hold water for only a short period after rain.* Smaller supplies of water are obtained from wells beside the granite outcrops at Bar Chuma and Sofio. Dams at Ali Gollo and Gosieh, constructed in 1954, have capacities of $5^1/2$ and $5^3/4$ million gallons respectively. These fill rapidly during heavy rain but the supplies are inadequate to support the large numbers of pastoralists that converge on them to take advantage of good local grazing. Another dam has been constructed north-east of Buttelu, beside the Gogai-Kubi Makagaad road, but the site was visited during a long period of drought and no indication of its water-retaining potential was available. The clayey soils at this locality should, however, prove suitable though perhaps subject to cracking during dry spells. About three miles away, west of the road, a tank was excavated. This was also visited only during extremely dry weather. At this locality, brown soils underlie a few feet of superficial reddish-brown sandy deposits and are likely to provide a good floor to the tank. Small natural shallow waterholes in a granite outcrop between Yukala and Alghe provide a limited, temporary water supply after rainstorms. It is of interest to note that wild animals, including elephant, visit these shallow ponds when water is available.

Bestow's pilot wells D.W.9 and D.W.14 were dry, but D.W.9 south of the Ali Gollo hills near the Tarbaj road (Adair Samant) proved the existence of fluviatile deposits beneath superficial limestones, probably infilling an old river valley. It is likely that sites for successful wells could be found farther south along the line of the kunkar if its distribution proves to be indicative of old drainage courses from the Ali Gollo hills. In the event of further failure to locate water in wells, additional surface works are desirable in this part of the area.

Moyale administrative district

A borehole (C.2440) beside the Laga Bor at Buna was drilled to 57 feet in 1955 and produces excellent water. Samples taken during the drilling of the borehole, which is situated on the eastern side of the *laga*, indicate that granitoid gneisses are overlain by about 25 feet of pale calcareous soils, marls and limestones. In the Buna wells, a little west of the borehole, about 20 feet of grey and brown calcareous soils overlie weathered hornblend-biotite gneisses

* A pan is of natural origin while a tank is an artificial excavation to store water.

and associated secondary limestones, with the water level at some 34 feet from the surface. The hornblende-biotite gneisses seen in the wells are evidently intercalated with westward-dipping bands of granitoid gneisses. A similar relationship between hornblendic and granitoid gneisses was seen in the Garse Buna outcrops, west of the trading centre. It seems likely that the success of the Buna borehole may have been largely due to the local 'Basement System' structure, with softer bands in the succession having been picked out by old drainage courses that were subsequently infilled. Such an explanation should be borne in mine if other boreholes are sited in the vicinity of the Buna anticline.

In addition to those at Buna, other wells provide limited supplies of water at Ajao, Sofio, El Las, Ingrir and in the Laga Chamu. The Ajao well apparently taps water in a syncline of biotite migmatites overlying quartzites, whereas those at Sofio, El Las and Ingrir are of the *adadi* type, dug at the foot of rocky outcrops of granite and granitoid gneiss. An earth dam at the southern end of the Lesayu hills (Plate 8) was constructed to retain runoff from bare rock surfaces. Natural waterholes occur in the biotite adamellites forming the hillside above the dam site and provide a limited supply of water for many weeks after rain. Pools exist for a shorter period in the upper stretches of the Laga Bor, near its point of divergence from the Laga Jarti Guda and Laga Chamu, where the bed is formed of outcrops of migmatites. Tanks have been excavated west of El Las ($1^1/_2$ million gallons), at Kuboli ($2^3/_4$ million gallons) and north of Ajao.

The most likely sources of underground water in parts of the area lying within the Moyale district are in the neighbourhood of the main *laga*, though Bestow has noted that the aquifer may not everywhere be associated with the present drainage system. The spread of alluvial soils south and south-west of Buna is indicative of a flood plain in which underground water might be too widely dispersed to permit tapping by boreholes. Generally, additional surface works are recommended in the Korondil area in preference to wells and boreholes.

Bestow (*op. cit.*, p. 33) concluded that the water table at Wajir was falling by between two and four inches per year due to a southerly seepage. Joubert (1963, *op. cit.*) pointed out that the wells have not been deepened since the Somalis entered the region around the beginning of the century, and if the fall was as much as Bestow postulated all the wells would be dry by now. At the time of the present survey the water in the Giriftu wells was higher than at the time of their construction but this may be a seasonal variation. The number of dead trees can more probably be attributed to overgrazing consequent on the increase in livestock since the coming of the Somalis, and so the problem appears to be the retention of water near the surface rather than a fall in the water table itself. Accordingly, the most pressing need seems to be some form of grazing control, together with the supply of new watering points in presently-unused good grazing areas. Many of the grazing areas near existing water supplies would then have a chance to recover.

If and when new construction works are envisaged in the area, their nature should depend more on the underlying rocks than has hitherto been the case. Howard Humphries and Sons (*op. cit.*, pp. 38-39) stated that wells along the Laga Bor were disappointing, but the trouble

appears to have been that they were dug in rocks of the 'Basement System' whereas the Giriftu wells are located in the Wajir Beds. The aquifer in the Wajir beds is the soft sandstone below the limestones, probably corresponding to the upper of the two aquifers at Wajir (Bestow, *op. cit.*, p. 11). The sandy soil overlying the 'Basement System' on the other hand appears too loosely consolidated to form a good aquifer. It is therefore recommended that wells should be sunk in the Wajir Beds only at localities where a considerable surface flow appears to percolate into them, recognisable from the disappearance of the surface *laga*. The best sites would appear to be situated in the extensive outcrop running south from the Ali Gollo hills, although this probably contributes to the recharge of the Wajir wells. The two most convenient localities are the southern end of the outcrop west of the hills and on the Giriftu-Tarbaj track in the larger eastern outcrop. It should be emphasised, however, that the aquifer at Wajir varies both in lithology and thickness and affects the yield of wells, as well as the quality of the water, from one well group to another and sometimes between wells of the same group (Bestow, *op. cit.*, p. 23). This probably also applies in the present area, so pilot wells would have to be dug at several points before a permanent site could be established.

Because of the lack of a good aquifer in the soils overlying the 'Basement System', wells sunk in them are unlikely to produce much water. Boreholes reaching the 'Basement System' may yield water lying in depressions on solid rock but their siting would require geophysical work. On account of the high cost of boreholes it is believed that surface works would be more suitable. Howard Humphries and Sons (*op. cit.*, p. 22) found that, for unit volume of water impounded, dams were the cheapest form of surface works. Only at Bafuf are there streams large enough to warrant investigation as possible sites for earth dams, and even they would probably not obtain enough water to justify their cost. The location of new tanks would depend on local needs but two favourable sites would be south of Bur Beit and east of Hagargoh. In both these localities there are several small *laga* indicating that there is sufficient surface water to fill tanks.

On the western plains there is abundant grazing, which is largely unused because of lack of water. It would therefore seem worth investigating possible sites for tanks, but *dololo* would be ruled out since *laga* are few. The critical factor would be the depth of red-brown clayey soil which appears impermeable enough to retain water, but may not be thick enough for the construction of a tank sufficiently deep to allow for evaporation losses. The region appears to have been neglected in the past because the soil passes southwards into fine silty soil on the Boji plains, which Howard Humphries and Sons (*op. cit.*, p. 19) describe as non-cohesive and having no water-retaining properties.

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