Report No. 47

COLONY AND PROTECTORATE OF KENYA

MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
BUR MAYO-TARBAJ AREA

DEGREE SHEET 23, N.W. AND S.W. QUARTERS
(with coloured geological maps)

by

A. O. THOMPSON, M.Sc., and R. G. DODSON, M.Sc.
Geologists

1960
PRINTED BY THE GOVERNMENT PRINTER, NAIROBI
Price: *Sh.* 17/50

FOREWORD

During recent years four reports on the geology of the north-eastern tip of Kenya, where Mesozoic rocks overlie Precambrian rocks, have been published. The present report completes the accounts of the block of ground already mapped lying between the territorial boundaries and the 40th meridian and the second north parallel.

The mapping was undertaken largely with the intention of obtaining information to allow an assessment of the possibility of the occurrence of mineral oil in north-east Kenya. It was not anticipated that signs of oil or structures likely to contain oil would be found in the 2,400 square miles covered by the report, but the information gained is useful in assessing the possible value of the whole Mesozoic basin of north-east Kenya. An important feature in the area mapped is a series of sandstones, conglomerates and occasional siltstones, probably of Triassic age, that rest on Precambrian rocks and underlie a Jurassic limestone series. At the outcrops they vary from 0 to 2,000 feet in thickness, but their extent and nature under the cover of late Mesozoic rocks further east is quite unknown. It is conceivable that the beds into which they pass laterally to the east may be of importance in the search for oil.

The western part of the area contains several hills composed of Precambrian rocks, including typical Basement System rocks and rocks that more resemble thermally metamorphosed upper Precambrian types. The latter are grouped with the Basement System in the report as there are no means of determining at surface whether or not they are members of that system or of a later system. The possibility that they are infolded members of a system younger than the Basement System is a problem to be solved in the future.

Some of the limestones of the Basement System in the area contain considerable amounts of silicate minerals, including wollastonite, which has recently become of value in ceramics. The locality is so remote, however, that it is unlikely that the deposits will develop any economic interest.

Nairobi,
29th November, 1956.

WILLIAM PULFREY,
Chief Geologist.

CONTENTS

LIST OF ILLUSTRATIONS

PLATES

MAPS

ABSTRACT

The report describes an area of approximately 2,400 square miles in the Wajir and Mandera districts of the Northern Province of Kenya, enclosed by latitudes 2° and 3° N., and by longitudes 40° E. and 40° 30′ E. Three erosion surfaces have been recognized in the area, namely the end-Tertiary, a higher bevel that has been named "the Erib surface", and remnants of the sub-Miocene surface.

Descriptions of the main rock types in the area are given. They comprise (*a*) Basement System rocks, (*b*) rocks of the Mansa Guda Formation believed to be of Triassic (Karroo) age, (*c*) Jurassic limestones and associated sediments, (*d*) Tertiary claystone and sands at Erib, and (*e*) Quaternary superficial deposits.

The conditions of sedimentation of the Mesozoic rocks and the oil possibilities of the area are discussed. Economic minerals and water-supplies in the area are dealt with briefly.

GEOLOGY OF THE BUR MAYO-TARBAJ AREA

I—INTRODUCTION

This report deals with an area of approximately 2,400 square miles in the Northern Province of Kenya, lying almost due north of Wajir township. It is bounded by longitudes 40° 00′ E. and 40° 30′ E., and lies between latitudes 2° 00′ N. and 3° 00′ N.

The area largely falls within the Wajir District, administered by a district commissioner at Wajir, but the extreme north-eastern corner comes within the Mandera administrative district. The Northern Province of Kenya, which includes the present area, comes under the jurisdiction of the Provincial Commissioner, who normally resides at Isiolo.

The area mapped comprises the north-west and south-west quarters of degree sheet 23 (Kenya), corresponding with sheets 48 and 60 of the Directorate of Colonial Surveys. The results of the mapping are presented on two maps on the scale of 1 : 125,000, one of the north-west quarter, the Bur Mayo area, and one of the south-west quarter, the Tarbaj area. For convenience of description the two areas are considered together in the text of the report.

Field mapping was carried out in the area by the writers between August and December, 1954. During part of this period the "short rains" fell but, although the air was pleasantly cooled, notably at nights, the increase in humidity made work at this season more difficult as the atmosphere was very enervating. Maximum and minimum temperatures recorded during the time of the survey were 100° F. and 60° F. respectively.

Communications.—The area is fairly well served by roads. The Wajir-Takabba-Derkali road traverses it from south to north approximately in its middle and, as a result of recent work completed on the Dixey Scheme water conservation projects and Desert Locust campaigns, several camel tracks have been opened up and new roads cut. Some of the subsidiary roads in the area were initiated by the Administration. Numerous camel tracks traverse the area, but the majority run north-south. Rarely do they go east-west.

The majority of the roads were passable to vehicular traffic prior to the "short rains". Two days of heavy rain, namely on the 29th and 30th of November, rendered some of the new roads impassable—notably that from Mansa Guda to Majabau and those in the vicinity of the Ali Gollo hills.

Maps.—Field-maps were drawn from aerial photographs, with ground-control established by astronomically fixed stations at Bur Mayo and Tarbaj. The co-ordinates used for these two points were calculated by members of the Survey of Kenya in early 1953, though the station at Tarbaj had originally been established by the army in the 1939–45 war. Unfortunately the two points cannot be seen from each other, and a certain amount of plane-table resection of prominent hills in the area was necessary. It must be stressed that through lack of sufficient ground-control the accuracy of the map is reduced. Control on the eastern edge was based on data accepted from the map drawn by Messrs. Saggerson and Baker who worked in the El Wak–Aus Mandula area at the same time as the present survey was in progress. Form-lines were based on the accepted height of 867 feet for the fort in Wajir.

The area is also covered by a military map (E.A.F. No. 1719) on the scale of 1:500,000.

Rainfall.—Rain generally precipitates at two periods during the year. The earlier and heavier falls are during the months of April to June, while during the months from October to December lighter falls occur. The latter rains are generally referred to as the "short rains". During the present survey, negligible falls of rain occurred during October, but on the 13th, 29th and 30th of November, heavier showers fell. It is interesting to note the change in the maximum temperatures as a result of these rains, although the minimum (or night) temperatures were virtually unaffected (*see* Fig. 1). The following are rainfall figures for stations nearest to the area, taken from the records of the East African Meteorological Department.

Station	Total Rainfall 1953 (inches)	Total Rainfall 1954 (inches)	Average (inches)	No. of Rainy days 1953	No. of Rainy days 1954
Wajir District Office ..	16·02	7·87	8·81	31	24
El Wak	12·54	10·32	11·33	26	20

Records have been kept at these two stations for 28 and 4 years respectively.

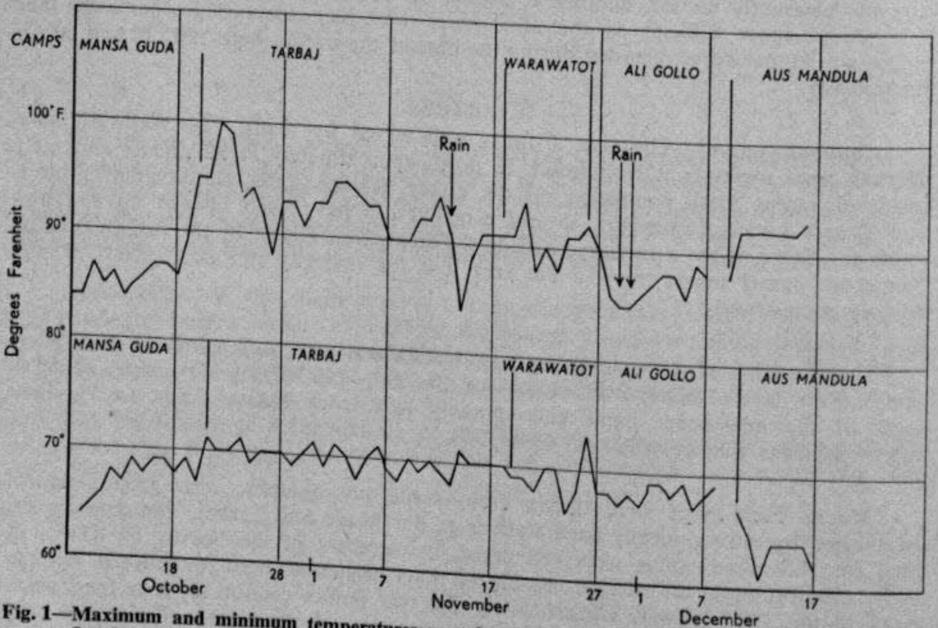


Fig. 1—Maximum and minimum temperatures recorded in the Bur Mayo-Tarbaj area between 10th October and 17th December, 1954.

II—PREVIOUS GEOLOGICAL WORK

J. Parkinson* visited the Northern Province during 1914–1915 and in 1920 published a paper describing the geographical and geological results of his visit. He devoted a separate chapter to the Basement System gneisses and schists, in which he described sillimanite-bearing gneisses and crystalline limestones from a range of hills a few miles north-west of the Ali Gollo hills. Glenday in 1925 gave a brief description of a limestone series with overlying sandstones (Marehan Series) in north-eastern Kenya. He suggested that the strip of East African coastal sediments broadened to extend eastward to at least 40½° longitude E., which is the eastern boundary of the present area. In 1929 J. Weir published a description of a fossil collection made by Glenday.

With the object of investigating oil possibilities, H. P. Busk and J. P. de Verteuil, geologists employed by the D'Arcy Exploration Co. Ltd. and the Anglo-Saxon Petroleum Co. Ltd., carried out in 1937 a reconnaissance survey of a large part of eastern Kenya that included the present area (Busk and de Verteuil, 1938). Later Busk (1939) published a paper summarising his views on the history of sedimentation in the Mesozoic basin of north-eastern Kenya. He considered the Jurassic limestones, some of which occupy a considerable portion of the present area, to be lagoonal deposits, visualising that a very shallow sea stretched across this part of Kenya from the main ocean. A report by F. Dixey was published in 1948, in which he described the geology of Northern Kenya including the area covered during the field-work for the present report. He showed (fig. 3, opp. p. 40) the sandstones at Tarbaj as equivalent to the Marehan sandstones, and believed that west of the Jurassic limestones in the Tarbaj area sediments of Tertiary age were present. He considered that two erosional surfaces are represented in the area, viz. the mid-Tertiary peneplain in the north-eastern corner, with the end-Tertiary peneplain occupying the remainder. In 1950 and 1951, F. M. Ayers, an E.C.A. geologist seconded to the Kenya Government, carried out a reconnaissance survey of an area of about 14,000 square miles in the Wajir, El Wak and Mandera area, and in 1952 a report was published in which he described the geological succession and gave his views on the possibility of the discovery of oil in north-eastern Kenya. Ayers mapped the Mansa Guda Formation, indicating that it might be Liassic or even earlier, and suggested that its sandstones were derived by erosion of Basement System rocks to the west. He concluded that the Jurassic Limestone overlies the Mansa Guda Formation unconformably. From Didimtu Ayers produced fossil evidence to prove that the Didimtu limestones are of upper Liassic age, and described them as the Lower Limestones of the (Daua) Limestone Series. In 1952, T. T. Bestow, a geologist in the Hydraulic branch of the Public Works Department, conducted geophysical and hydrological investigations in the Wajir area, in connexion with water-supplies. His findings are given in an unpublished report which includes brief geological data concerning the present area. He confirmed Ayers' observation that the Jurassic limestones do overlie the Mansa Guda Formation unconformably. He described Tarbaj hill as composed of brown and green glauconitic grits belonging to the Mansa Guda Formation and considered that at the Tarbaj wells area, north-west of the hill, there are Tertiary sandstones.

III—PHYSIOGRAPHY

The relief of the area, apart from the Ali Gollo hills, is nowhere strikingly great. Because of the monotonously flat aspect of the country as a whole, hills such as Tarbaj and Mansa Guda appear to be high by contrast, whereas in fact they stand only about 350 feet (107 m.) above the surrounding ground.

---

* References are quoted on p. 48.

The north-eastern corner of the area includes a portion of the Lugh (Lak) Suri (or Katulo). This water-course, now choked with soil and sand, receives the drainage of the eastern portion of the area, while Lugh Bor which crosses the Wajir–Habaswein road south-west of Wajir, takes the drainage from the western part.

The monotonously flat country, extending throughout the greater part of the western half of the area, is believed to constitute a portion of the end-Tertiary erosion surface (cf., Dixey, 1948, p. 16). This is bounded on its eastern edge by higher ground which bears evidence of an older bevel, the Erib surface, in the south-eastern part of the area, and the remnants of what is regarded as a still older surface (the sub-Miocene surface) at Mansa Guda and Kurawe. It is doubtful whether the summits of the highest hills in the Ali Gollo range represent the remains of an old erosion surface, but remnants of younger surfaces corresponding with the higher surfaces further east are present on the lower slopes.

1. The Erib Surface

In the Derkali area, which lies some 35 miles north of the present area, Thompson and Dodson (1958, p. 4) concluded that the claystones, grits and conglomerates of the Banissa Beds were deposited on an erosion surface, which was in existence before the beds were severed from their source by the intervention of erosion that led to the formation of a lower surface—the end-Tertiary peneplain. North-east of Tarbaj similar claystones exist which are best developed and exposed at the Erib waterholes and are believed by the writers to be congenetic with the claystones of the Banissa Beds. It is considered that the Erib claystones, like the Banissa claystones, were laid down on an erosion bevel prior to the incutting that led to the formation of the end-Tertiary surface. This bevel is referred to as the "Erib surface", and represents the maturation of an erosional phase between those that culminated in the end-Tertiary and sub-Miocene surfaces. Its main extent in the present area is at and south-east of Erib, but remnants and degraded remnants are represented at Tarbaj, Duruwe, Mansa Dika, Kabort, Alio Alem and Bur Mayo along the central meridianal part of the area, and on the Ali Gollo hills.

The Erib surface corresponds with the intermediate surface in the Derkali–Melka Murri and Takabba-Wergudud areas (Thompson and Dodson, 1958, p. 4; Saggerson and Miller, 1957, pp. 5-6) and with the Muguda surface of the El Wak area (Baker and Saggerson, 1958, p. 5), and probably corresponds with a stage intermediate between the African and Victoria Falls surfaces of South Africa referred to by Fair and King (1954, p. 19). In the present area it ranges in height from about 1,200 feet (366 m.) near the eastern boundary to about 1,600 feet (487 m.) near Erib and about 2,200 feet (671 m.) on North Ali Gollo. Of interest is its south-easterly direction of slope in this and the Takabba-Wergudud area—whereas in the Melka Murri area on the northern boundary of Kenya it declines to the east-south-east. The slope is of the magnitude of about 20 feet per mile between Erib and Wel Merere: the latter place is beyond the bounds of the present area to the south-east of Erib, and where more claystone outcrops.

West of Erib laterite pebbles are found liberally strewn on the ground surface, but no outcrops of laterite or lateritic conglomerate were found as in the Banissa area. Elsewhere massive blocks of oolitic and shelly limestones are found on the Erib surface but are believed to be considerably removed from their beds of origin.

The surface at its main extension is being attacked on the east by erosion in stream-courses that end in the end-Tertiary peneplain which flanks the Lugh Suri (Baker and Saggerson, 1958, p. 5) and by gullies that debouch on an extension of the same peneplain in its western side. As in the Derkali area the pediment between

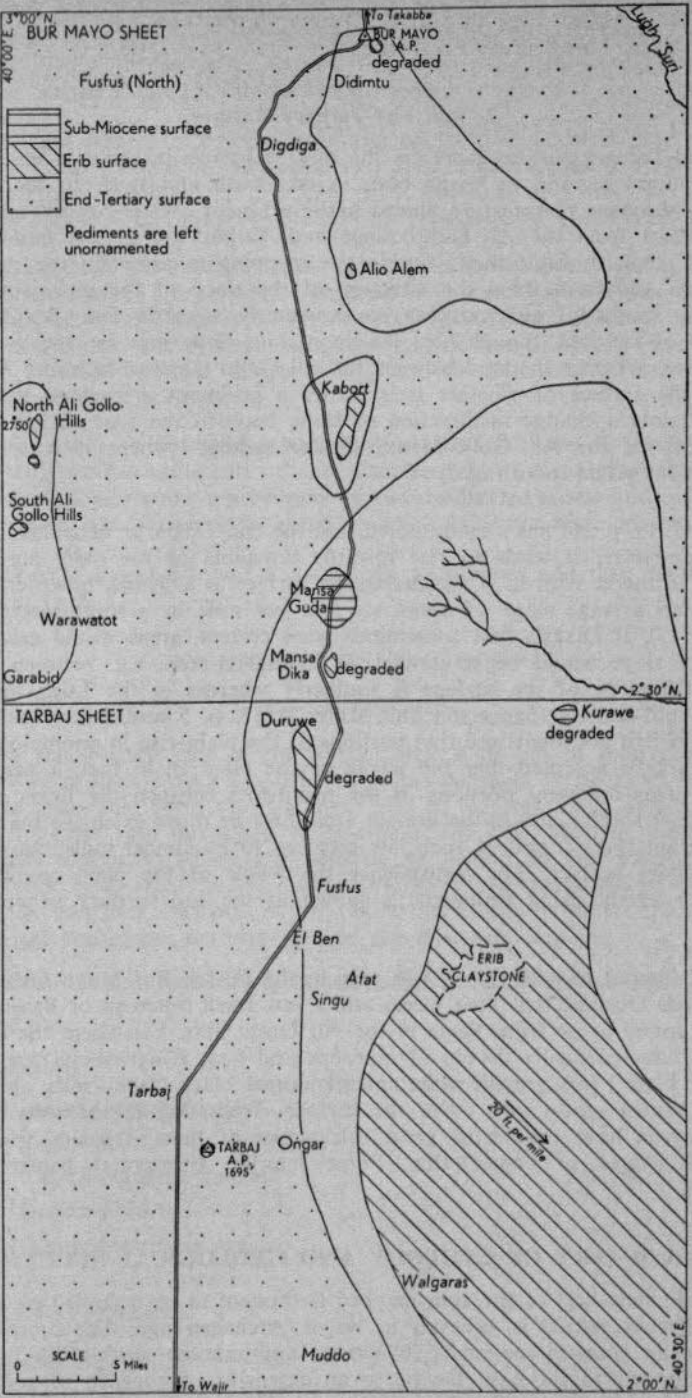


Fig. 2—Erosion surfaces in the Bur Mayo-Tarbaj area.

the end-Tertiary surface and the Erib surface is more noticeable in the west where a gentle scarp is present over the greater length of the contact between the Jurassic limestones and the Mansa Guda Formation.

2. The End-Tertiary Surface

The end-Tertiary surface is by far the most extensive in the area and covers vast tracts of country beyond its limits both to the south and west. In the Bur Mayo–Tarbaj area drainage features are almost entirely absent—water-courses are ill-defined, and hills, apart from the Ali Gollo range and Tarbaj, are almost non-existent (*see* Plate I (*a*)). Thus it was difficult during the mapping to ascertain the exact position of form-lines and from them the direction of the slope of the plain surface, which is, however, southerly, and possibly south-westerly towards Lak Bor in the west central part of the area, though here the anomalous slope may be due to degradation of the surface. Whether the land between the Ali Gollo range of hills and Mansa Guda is part of the surface or whether it is rather a pediment is perhaps debatable, but there is certainly a change in direction of slope between the part of the end-Tertiary surface north of the Ali Gollo-Mansa Guda "saddle" (where it is to the S.S.E.) from that of the ground south of it.

Dixey (1948, p. 16) has already noted that the end-Tertiary "peneplain is, however, relatively immature; it tends to rise towards remnants of the older surface and in places . . . to merge with it". Considering the surface as a whole, however, he thought that it has an average slope of about six feet per mile in a south-easterly direction (*op. cit.*, p. 17). If Dixey's first contentions were correct, areas would exist where the directions of slope would be in conflict, as in fact is seen, e.g. between Fusfus and Ali Gollo the slope of the surface is southerly whereas in the Lugh Suri drainage area it is south-easterly (Saggerson and Miller, 1957, p. 5 and Baker and Saggerson, 1958, p. 5). If it is acknowledged that portions of the plain rise in anomalous directions then it cannot be accepted that the whole of the plain is, in fact, a peneplain. The anomalous areas represent portions of the pediments between the lower surface and the next higher surface and in the present area must be more extensive than are shown on the diagram (Fig. 2) and of such low relief as to be almost indistinguishable from the end-Tertiary surface. For convenience the whole of the plain country, whether peneplain or gently rising pediment, is shown as the end-Tertiary peneplain on the figure.

It is of interest to note that it was only in the Fusfus–Bur Mayo area, and southwards towards Digdiga, that float pieces and a few small outcrops of Basement System rocks were found apart from those in the Ali Gollo hills. Elsewhere the end-Tertiary surface is characteristically devoid of outcrops and float is extremely rare. Patches of kunkar (*see* Plate I (*b*)), greyish white and sometimes black clayey soils, and vast tracts of reddish brown sandy soils cover the surface. Wells dug in the soils on the end-Tertiary surface have penetrated great thicknesses of these deposits, which vary in colour and degree of cementation. Some lateritic (ferricrete) bands have been encountered.

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL SUCCESSION

Approximately half of the area mapped is thought to be occupied by rocks of the Basement System, which is believed to be of Archaean age. The junction between these rocks and younger sediments follows an approximate north-south line, with the younger sediments to the east. Owing to an extensive overburden of soils exposures of the Basement System, with the notable exception of the Ali Gollo range of hills, are rare. Minor outcrops occur between Fusfus in the north and Digdiga. The rocks represented comprise crystalline limestones, quartzites, foliated biotite and hornblende-rich rocks, which have been invaded by granites and minor basic intrusions, now mostly reduced to a highly altered state. Banded ironstone was discovered *in situ*, but its stratigraphical relationship to the Basement System could not be established.

The Basement System is overlain unconformably in the central part of the area by the Mansa Guda Formation, which is composed of arenaceous to rudaceous rocks of variable texture (*see* Plate II (*b*)). Owing to the lack of fossils, the age of the Mansa Guda rocks is unknown, but they are provisionally considered as Triassic.

Representatives of the Jurassic Daua Limestones of north-east Kenya, namely the Didimtu and Bur Mayo limestones, transgress over the Mansa Guda rocks north of Didimtu hill on to the Basement System rocks and are exposed over much of the eastern half of the area. The Didimtu limestones are of Toarcian age (lower part of the upper Lias) whereas the Bur Mayo limestones are believed to range from the Bathonian to the upper Callovian.

A small remnant of claystone around Erib is believed to be of Tertiary age, and comparable with similar sediments at and near Banissa in the Derkali-Melka Murri area. Quaternary deposits are represented by unconsolidated sands and clays, kunkar and lateritic soils, which cover the greater portion of the surface in the area.

The geological succession and a list of the rock types and their features in the area is given in Table I.

V—DETAILS OF GEOLOGY

1. Basement System

Although the western part of the Tarbaj area is devoid of hard rock outcrops and even devoid of float blocks it is believed to be underlain by rocks of Precambrian age similar to those that form the Ali Gollo hills in the Bur Mayo area and outcrop sporadically, together with intrusions, north-east of the hills. Most of these rocks are metamorphosed sediments which are believed to belong to the Basement System. Some of the rock types are, however, unlike any previously recognised in the Basement System, but as they are enclosed in crystalline limestones typical of the Basement System they are considered to form part of the Basement System.

The Basement System rocks are described under the following headings:—

(1) Quartzites

(2) Limestones

(3) Para-gneisses and schists

- (*a*) Biotite schists and gneisses
- (*b*) Chlorite-epidote gneisses
- (*c*) Quartz-sericite schists
- (*d*) Quartz-muscovite schists
- (*e*) Quartz augen gneisses
- (*f*) Knotenschiefer

(4) Amphibolites

Some banded ironstones were found in the area and, although there is doubt that they form part of the Basement System, they are described in sub-section (5) for convenience.

TABLE I

THE GEOLOGICAL SUCCESSION, ROCK TYPES AND THEIR FEATURES IN THE BUR MAYO-TARBAJ AREA

Era		Period	Stage	Formations	Lithological Characteristics	Thickness ft.	Environment of Deposition	Climatic Condition	Events
Cain-ozoic	Quaternary	Recent Pleistocene		Superficial deposits	Red and black soils, kunkar and gypsum.	>100	Terrestrial	As present day to cold.	Erosion.
	Tertiary	Pliocene?		Erib Claystones	Claystones and indurated clayey sands.	>100	Terrestrial, lacustrine.	Warm?	Erosion. Deposition. Erosion.
Mesozoic		Cretaceous							Deposition.
		Jurassic. U	Callovian	Bur Mayo Limestones.	Grey and fawn oolitic limestones, calcite mudstones, marls and rare dolomites. Fossiliferous.	2,000–5,000?	Marine—shallow-water	Warm.	Erosion.
		M	Bathonian Bajocian						Deposition.
		L	Toarcian.	Didimtu Beds.	Limestones and marls, essentially non-oolitic but fossiliferous.	200–1,000	Marine—shallow-water	Warm.	Deposition.
		Trias.		Mansa Guda Formation.	Grits, conglomerates, sandstones.	0–2,000	Deltaic.	Arid.	Erosion. Deposition.
Palaeozoic									Erosion.
Eozoic	?				Meta-dolerite, intrusive basalt, lamprophyre, ortho-schists.				Intrusions in the Basement System.
	Archaean			Basement System.	Crystalline limestones quartzites, para-gneisses and schists.				

The total thickness of the Basement System is not known, but it appears that a succession some 10,000 feet in thickness may be present in the Ali Gollo hills. Considerable lateral changes are probably present in the hills, and sequences from one hill group to another cannot be readily matched. It appears that the succession on the north group may be:—

4. Crystalline limestones
3. Para-gneisses and schists
2. Quartzites with bands of crystalline limestone
1. Crystalline limestones with para-gneisses and schist bands

(1) QUARTZITES

Quartzites form a small hill north-east of Digdiga and are also exposed at certain horizons in the Ali Gollo hills (*see* map, at end). The quartzites near Digdiga are characterized by a high mica content. In the hand-specimen they are cream to reddish, varying from highly micaceous types with well-defined partings to more massive saccharoidal varieties. Slabs of mica-rich quartzite lying around on this hill and also near the Didimtu wells, where they have been used for covering native graves, contain as much as 55 per cent of muscovite. Specimen 23/41,* from the hill, is a medium-grained micaceous felspathic quartzite in which the mica is mainly concentrated in seams a few millimetres thick. In thin section the component minerals exhibit recrystallization and most of the quartz shows strain polarization. The rock is composed of quartz, muscovite, felspar, and green biotite, together with accessory magnetite and zircon. The muscovite occurs as irregular medium-sized colourless flakes, some intergrown with green biotite. Both microcline and orthoclase felspar are present, the microcline replacing orthoclase and quartz. Some of the quartz is shot through by needle-like muscovite flakes, often in radiating clusters, which demonstrate the mode of emplacement of the mica.

Specimen 23/163, from a quartzite lens at the base of Garabid hill, is a compact, fine-grained, whitish quartzite containing megascopic diopside. In thin section this rock reveals an intensely recrystallized quartzose sutured mosaic with preferred orientation. The diopside is much more coarse-grained than the other constituents and occurs in clusters which exhibit the effects of slight rotation. Smaller irregular grains of calcite are also present, and are generally aligned along the common orientation. Small grains of magnetite are sparsely distributed through the rock. The crest of Garabid is composed of massive compact quartzite which forms a prominent marker horizon in the Garabid syncline. In specimen 23/171 the texture of this quartzite is coarse and indicates complete recrystallization. The rock is dark reddish brown due to the presence of numerous euhedral grains of magnetite and extensive interstitial iron oxide staining.

Along the western slopes of Warawatot hill a narrow band of nearly vertical grey quartzite forms a prominent ridge. In a thin section of specimen 23/187 from the south-eastern slopes of Warawatot the texture appears highly uniform, equigranular quartz forming a compact recrystallized mosaic. The grey colour is due to abundant rod-like magnetite grains scattered through the rock. A few flakes of muscovite and small grains of microcline are minor constituents. Speciment 23/344 from Dunto in the North Ali Gollo hills has a similar texture, but contains a high proportion of mica, including small flakes of a pale brown variety.

---

* Specimens referred to are in the regional collection of the Geological Survey in Nairobi.

(2) LIMESTONES

There is a number of broad bands of crystalline limestone in the Ali Gollo hills. Some of the hills, such as Garabid and Warawatot, are composed almost entirely of limestones and it is considered probable that in the area between these hills and those of the Mansa Guda beds to the east, there are extensive limestone bodies. This conclusion is based on the fact that the fine, whitish, powdery soils, which cover large tracts of that area, have been repeatedly found to be the product of eroded limestones such as result from the weathering conditions of the Northern Province.

The limestones vary greatly in composition and to a lesser extent in texture. Some are white, coarse-grained and relatively free from impurities. The most common non-calcareous impurity is iron ore which, if sufficiently concentrated, colours the limestones in various shades of grey. Specimen 23/179, from Warawatot hill, is a dark grey limestone consisting of roughly equidimensional anhedral grains of calcite liberally sprinkled with small irregular grains of magnetite. Secondary vein calcite, which can be seen in this specimen, though slightly tinted by hydrated iron oxide is not coloured by the primary magnetite and sometimes forms a complex white network in darker massive limestone. Concentration of the iron ores in narrow zones sometimes produces a strong banded effect, as can be seen at Garabid and Warawatot. A few grains of quartz are present in some of the limestones but generally quartz is a rare constituent. It is frequently present only as a vein mineral. On the slopes of Garabid quartz "fins" on weathered limestone surfaces present a striking appearance. These fins are seldom more than quarter of an inch thick but protrude up to two inches from the limestones, frequently in close parallel arrangement.

The most common calcareous impurities are wollastonite and diopside. They are present in most of the limestone horizons of the Ali Gollo hills and less commonly in calcium-rich horizons bordering the limestone bands. On the central eastern slopes of Warawatot, wollastonite and diopside account for over fifty per cent of the volume of the limestones, and certain horizons up to fifteen feet thick are almost devoid of calcite (*see* Plate III (*a*) and (*b*)). When wollastonite is present as a minor constituent it occurs as evenly distributed, commonly orientated prisms up to one inch long, or as composite, radiate crystal aggregates as much as four inches across. In the hand-specimen the wollastonite usually appears as dirty whitish to bluish grey, vitreous blades. White wollastonite such as occurs in specimen 23/336 is rare. On weathered surfaces the (100) and (001) cleavages are frequently etched. Most of the wollastonite is partly altered to calcite, the alteration being most pronounced along the edges and cleavages of the crystals. *Diopside* occurs as greenish to bluish, or rarely white crystals (specimen 23/336) up to four inches long. It is frequently partly replaced by calcite along crystal edges or cleavages. A partial analysis of massive diopside from Warawatot gave the following results:—

	Per cent
SiO_2	51.91
Fe_2O_3	1.52
MgO	14.53
CaO	26.18

Analyst: W. P. Horne

Hornblende is a rare constituent in the limestones and was discovered only along massive horizons on the western slopes of Warawatot. Here, rare, isolated hornblende prisms attain a length of about half an inch.

(3) PARAGNEISSES AND SCHISTS

(*a*) *Biotite Schists and Gneisses*

Two exposures of biotite-rich schistose rock types, separated by about thirty feet of banded quartzo-felspathic metamorphic rocks, were discovered on the south-eastern slopes of North Ali Gollo. The two bands are narrow and, as Ali Gollo is well covered by bush, outcrops are difficult to find except in gullies. There is little or no grading from the adjacent bands through to these horizons.

The lower of the two horizons is a dark grey medium- to fine-grained fairly homogeneous rock with well-defined partings. In specimen 23/345 from this horizon, the micas are aligned along a common orientation and are mostly concentrated in folia. The principal mica is brown biotite, commonly including zircons with pleochroic haloes. While moderately sized muscovite flakes are rare, the felspar is extensively replaced by sericite. The felsic constituents include quartz and microcline felspar. The quartz, like the biotite, is chiefly segregated in narrow lenticular seams where it forms compact equigranular mosaic textures with coarser grain than the remainder of the rock, and in which biotite is much less abundant. The microcline occurs as smaller variably shaped grains often replacing the quartz. Slight crushing can be observed along the edges of some of the grains. The microcline is almost confined to the biotite-sericite-rich seams and is often concentrated along the margins of the quartz segregations. Accessory minerals are zircon and fine skeletal structures of iron ore associated with the larger sericite aggregates.

The upper horizon of biotite schist is a greyish finely banded rock composed of alternating biotite-rich and felsic layers seldom exceeding a quarter of an inch in thickness. The banding is frequently wavy and a number of tight folds can be observed. Few of the individual bands can be traced for more than a few inches as they tend to lens out. In a thin section of specimen 23/342, it is seen that the quartz-rich bands contain only a small amount of mica while the micaceous layers are composed of biotite, muscovite, quartz, microcline and the alteration products of felspar, sericite and kaolinite. The presence of large sericite aggregates possibly indicates original felspar porphyroblasts. The biotite is again a brown variety, with abundant zircon inclusions with pleochroic haloes. Accessory minerals are medium-sized tourmaline grains dichroic from neutral to brownish, zircon mainly included in the biotite, and sparsely distributed specks of iron ore.

Several minor bands of gneissic variably biotite-rich rocks are exposed on the slopes of South Ali Gollo hill. They differ from the biotite schists in that they are more massive and contain a high percentage of felsic minerals. Gradations between the schists and gneisses are common, the gneissose rocks grading into schistose types and bands of schistose rock being sometimes partly gneissic.

Specimen 23/326, from the north-western slopes of South Ali Gollo, is a fine-grained grey biotite gneiss. The felsic constituents are microcline, orthoclase and quartz, and medium-sized brown biotite and larger crystals of muscovite are present, the latter replacing both the biotite and the felspars. Zircon, apatite and iron ore constitute the accessory minerals. In common with most rocks of that area, specimen 23/326 exhibits strain polarization of the quartz grains and slight crushing of the felspars.

(*b*) *Chlorite-epidote Gneisses*

A small unrelated occurrence of chlorite and epidote-bearing gneissic rock was discovered in the area west of Digdiga. As it consists merely of a few scattered boulders in an area covered by a thick mantle of soil, field relationships were not apparent.

Specimen 23/77 is a medium- to coarse-grained, greenish grey, moderately gneissic rock from the more northerly of the two occurrences. In thin section it is seen to consist of a compact unsutured simple mosaic composed of quartz, felspar which is partly altered to sericite, chlorite, epidote and magnetite. The chlorite is present as weakly pleochroic bluish green flakes and aggregates, while the epidote occurs as pale yellowish green to colourless euhedral prisms or granular aggregates, the prisms often occurring in trains that traverse the rock in various directions. The chlorite is arranged at right-angles to a weak foliation in the rock and to trains of sericite that cross it in a direction parallel to the foliation.

(*c*) *Quartz-sericite Schists*

A band of steeply inclined quartz-sericite schist, approximately 20 feet (6 m.) thick forms a prominent jagged crestline on South Ali Gollo hill. Similar rock is also exposed on North Ali Gollo and on the eastern slopes of Warawatot. Typically the schist is pale bluish grey to fawn-coloured and is composed of curved quartz lenses set in a fine-grained groundmass of sericite and quartz. Narrow micaceous seams tend to accentuate the schistose texture.

Specimen 23/195 from South Ali Gollo, is composed mainly of quartz, sericite, a few medium-sized flakes of muscovite, and small amounts of tourmaline and iron ore. The quartz occurs as irregular medium-sized grains frequently elongated parallel to the foliation and invariably exhibiting strain polarization. Aggregates of fine sericite flakes are directionally orientated, sometimes curving around quartz grains. A small amount of kaolinite is associated with the sericite and it is considered that both minerals were derived from potash felspar. The tourmaline is strongly dichroic from pale brown to dark brown and is probably the iron-tourmaline schorlite. It occurs as medium-sized euhedral prisms usually with quartz inclusions. Small irregular specks of iron ore are mainly confined to the sericite aggregates. Minute crystals of apatite and zircon represent the other accessory minerals. Specimen 23/174, from North Ali Gollo, is generally similar but, in addition to the white mica, greenish brown biotite is present and there are some unusually large crystals of muscovite. The biotite varies from medium-sized flakes to fine shreds and some of the larger flakes contain zircon crystals with pleochroic haloes.

(*d*) *Quartz-muscovite Schists*

On the eastern slopes of North Ali Gollo a band of soft, friable schistose rock is exposed in the more deeply cut gullies. Although the limits of this horizon are obscured by overlying soils and talus, it is unlikely that the band is thicker than 15 feet. The rock is highly conspicuous, being characterized in hand-specimen by its almost pure white colour and a schistose platy texture in which the partings are accentuated by the presence of narrow micaceous seams. Since jointing is well-developed, flaggy slabs are scattered around the exposures.

Specimen 23/343 is a fine-textured rock in which signs of stress are strongly manifest. It is composed of narrow, alternating bands of quartz and fine-grained bands rich in mica, the bands being a millimetre thick. The larger quartz grains are lengthened parallel to the foliation and show strain polarization. Crushing of the quartz is apparent along the margins of the coarser-grained bands and occasionally on narrow zones inside them, and in the finer-grained layers. The mica-rich bands are composed of medium-sized flakes of muscovite, small granulated quartz grains and seams and aggregates of minute sericite flakes. Accessory minerals include abundant yellowish brown tourmaline, rare magnetite octahedra, apatite and small zircon prisms.

(*e*) *Quartz Augen Gneisses*

A narrow band of highly foliated fine-grained augen gneiss is discontinuously exposed on the south-eastern slopes of Warawatot. Because the rock is not particularly resistant, the exposures are mainly indicated by flaggy slabs aligned along the strike, though there are also rare almost vertical projecting outcrops. Typically the rock is a mottled greyish colour, consisting of alternating quartz and micaceous bands with included quartz augen of variable size. The bands at a minimum are about one-eighth of an inch in thickness and are frequently lenticular, particularly near the augen, where they curve around the quartz. The augen occur both as short, roughly oviform bodies and as greatly elongated rod-like forms, but in either case they retain the typical augen shape in cross-section. (*See* Plate IV (*a*).)

In specimen 23/126, the groundmass consists of a compact recrystallized suture mosaic of quartz with small amounts of magnetite, both as octahedra and irregular elongated grains, and patchily distributed sericite flakes. The iron ore and sericite both tend to be concentrated along seams parallel with the foliation. The augen are composed of clusters of larger recrystallized quartz grains showing strain polarization and are usually bordered by a peripheral concentration of sericite. A few grains of accessory zircon and rutile (?) are present.

The structure of the rock suggests that the augen were formed by the disruption and rolling of highly quartzose bands in the original sediment.

(*f*) *Knotenschiefer*

Two examples of knotenschiefer, or schistose rock spotted with sub-spheroidal mineral aggregates, were discovered on the south-eastern slopes of North Ali Gollo. The two bands appear to be unrelated stratigraphically, and texturally they differ widely, the aggregates in one being several times coarser than those in the other, though the groundmass textures do not differ greatly.

The coarser rock, represented by specimen 23/337, (Plate IV (*c*)) forms a low ridge at the base of the main hill slope. In the hand-specimen it is a medium-grained pale greyish moderately schistose rock with a number of well-rounded dark grey projecting knobs about three-eighths of an inch in diameter. A thin, pale brown, weathered crust covers most of the exposures. In one thin section made none of the aggregates were cut. The slide is a medium- to fine-grained equigranular interlocking mosaic of microline, orthoclase and quartz with micas, biotite and muscovite, and accessory minerals. The microcline replaces quartz and orthoclase and frequently occurs interstitially as semi-crescent-shaped replacive grains between quartz and orthoclase. Although quartz is less abundant than the microcline, the grains are larger and sometimes occur in clusters. Most of it shows strain polarization to a certain extent. Brown biotite is far more abundant than muscovite and is mostly aligned along a common direction. The muscovite occurs as small variably sized flakes. Small octahedra and subhedral grains of magnetite are plentifully scattered through the rock. The accessory minerals are a few grains of apatite, zircon, sphene and rutile (?). A thin section made of one of the aggregates (23/337 (*a*)) shows that it is composed almost entirely of sericite with plumose and crudely spherulitic arrangement. The sericite is presumably pseudomorphous after some metamorphic aggregate or metacryst, but there is no evidence of the nature of the original mineral.

The finer-grained knotenschiefer is a dark, highly schistose rock containing small white micaceous aggregates rarely more than one-eighth of an inch in diameter (*see* Plate IV (*b*)). A thin section of specimen 23/351 indicates that the rock is medium-grained and composed essentially of quartz, microcline, biotite, muscovite and accessory minerals. The quartz grains are lengthened along the foliation and moderate strain effects are apparent in a few of them. Microcline grains are smaller and less common than the quartz and often replace it. They tend to be concentrated in fine-textured patches of the rock. Brown biotite is abundant, but is often slightly altered, the chief alteration product being iron oxide as aggregates of small reddish specks. Muscovite is less abundant and appears as variable-sized flakes scattered through the rock. Accessory zircon crystals with strongly pleochroic haloes are included in the biotite and medium-sized tourmaline prisms, dichroic from neutral to reddish or brown in different parts of the crystals, are distributed through the rock. The micaceous aggregates of the hand-specimen are seen to consist of well-crystallized muscovite that exhibits slight strain polarization.

The knotenschiefer appear to owe their nature to thermal metamorphism followed by slight retrogressive metamorphism.

(4) Amphibolites

A few boulders of plagioclase amphibolite were found on the northern slopes of Warawatot, and it is believed that they were not far removed from their source. The amphibolite is a fine-grained, mildly schistose greyish banded rock with well-defined alternating felsic and hornblende-rich bands not more than half an inch thick. Larger ovoid or lenticular felsic bodies that occur among the bands are believed to be due to subsequent deposition. Specimen 23/152 is composed of hornblende, quartz, plagioclase, epidote, sphene, iron ore and apatite. The hornblende is moderately pleochroic from yellowish green to bright green and the grains are aligned lengthwise along the foliation. Quartz is abundant and occurs as clear elongated grains occasionally with slight strain polarization. The plagioclase occurs both as albite-twinned and as untwinned grains, and is sodic oligoclase. Sphene is abundant as small- to medium-sized rounded subhedral to euhedral grains. Iron ore, small prisms and occasional large grains of apatite and irregular grains of epidote are the common accessory minerals.

A band of friable dark green hornblende schist is exposed in one of the deeper Digdiga wells, at an estimated depth of about 50 feet. Blocks of the rock are heaped around the sides of the well and a few lie scattered about in the immediate vicinity. Specimen 23/333 consists of narrow, alternating hornblende-rich and felsic bands. The hornblende-rich bands are composed of strongly pleochroic green hornblende and granular aggregates of epidote, with smaller grains of quartz and felspar. The felsic bands are composed of microcline and plagioclase felspar, with small quartz grains and a few medium-sized hornblende grains. The rock is a member of the amphibolite group.

Another amphibolitic rock, specimen 23/115 from the area west of Digdiga, is a medium- to fine-grained greenish gneiss and unlike other rocks in that area is comparatively fresh, the felspars being almost unaltered. Microcline is the predominant felspar and replaces both orthoclase and quartz. The hornblende is a moderately pleochroic bluish green variety. Epidote occurs as medium-sized granular aggregates. Accessory minerals are sphene, zircon, iron ore and apatite.

Amphibolites are commonly formed by the alteration of basic intrusions and by the metamorphism of calcareous pelitic sediments. While the origin of the amphibolites of the present area is not clear, it is considered that they are probably para-amphibolites of sedimentary ancestry.

(5) Banded Ironstones

Approximately six miles south-west of Digdiga a small outcrop of banded ironstone forms a slight ridge. The exposure is about 40 feet (12 m.) long and has an average breadth of about eight feet (2.4 m.) In the north-western portion of the area isolated banded ironstone pebbles are fairly commonly found on the surface, but no other ironstone was discovered *in situ*. Since no other outcrops occur near the banded ironstone exposure, its relationship to the Basement System could not be established—it may be part of the system, but equally well might be a member of an infolded system of different age.

The scattered pebbles vary in size and composition but generally consist of alternating bands of metallic-lustred iron ore and iron oxide-stained quartz. The bands are seldom more than half an inch thick. Most of the iron ore is magnetite, although a certain amount is the non-magnetic oxide, martite, and the magnetite is often replaced by limonite. The ironstone outcrop occurs as a steeply dipping discontinuous layer of rough brownish rocks coated with a limonitic crust about half an inch thick. The ironstone is a dark brown, medium-textured banded rock, composed of translucent quartz, limonite and dark brown iron oxides containing small crystals of iron ore with metallic lustre. Within a few weeks of exposure to the atmosphere, the metallic-lustred ore is covered by a reddish brown oxidized coat. A thin section of specimen 23/113 shows that it consists of medium-sized quartz grains with quartzitic texture, iron ores and bands or veins of fine-grained recrystallized silica. The bulk of the iron oxide is dull brown limonite, with metallic-lustred cores which are probably hematite, though metallic-lustred ore seen in the hand-specimen is magnetite. Goethite (?) is associated with the limonite. It is, in part, slightly fibrous, orange to reddish coloured, weakly pleochroic, and probably optically negative. Accessory minerals are muscovite (?) and zircon.

2. Mansa Guda Formation (Triassic?)

The Basement System rocks are overlain by an unfossiliferous sedimentary sequence of sandstones, quartzites and conglomerates, described by Ayers (1952, p. 6) as the Mansa Guda Formation. It is probable that the formation corresponds with the Adigrat Sandstones of Ethiopia, described by Dacqué and Krenkel (1909, p. 152) which Stefanini (1925, p. 1061) correlated with what he called the Lugh Group in Italian Somaliland and which he also considered as the equivalent of the upper part of the Duruma Sandstones of Kenya. Dacqué and Krenkel described the Adigrat Sandstones as overlying Basement System rocks and overlain by Jurassic limestones of Bathonian to Kimmeridgian age; Stefanini ascribed the Lugh sandstones to the Trias.

The formation is exposed discontinuously from near Didimtu, in the north of the area, to Tarbaj in the southern part. The outcrop is largely concealed by superficial deposits and is believed to be considerably wider than the exposures suggest at first sight. The base can be traced to a certain extent by the nature of sandy soils overlying the formation, which contrast with the finer soils covering the older rocks, and by a change of vegetation that can usually be recognized on aerial photographs. The inferred basal boundary is shown on the maps by a dotted line. The outcrop progressively widens southwards to a maximum of about eight miles in the vicinity of Tarbaj. The thickness of the formation also increases to the south, ranging from less than 20 feet at Didimtu to an estimated thickness of about 2,000 feet at Tarbaj. Dacqué (1910) described the Adigrat Sandstones of Abyssinia as being 300 m. in thickness.

Owing to lack of continuity of outcrop, the variability of the beds and lack of knowledge of the effect of faulting no certain succession can be made out for the Mansa Guda Formation, but it appears that the general sequence as exposed is as follows:—

Rock Types	Localities	Estimated Thickness *ft.*
3. Pale mauve to buff grits, coarse conglomerates, quartzites, occasional fine-grained laminated sandstones.	Didimtu, Alio Alem Mansa Guda	500
2. Coarse mauve sandstones with rare conglomerates ..	Kabort Mansa Guda	400
1. Mauve to buff sandstones, conglomerates, quartzites and fine-grained laminated sandstones.	Mansa Guda Mansa Dika Tarbaj	400

Sections of the lower part of the formation can be seen at Mansa Guda, Mansa Dika and at Tarbaj hill. In general it consists of pale mauve to buff, often cross-bedded sandstones, a few conglomerates and at least two quartzite horizons. In addition to the conglomerates, individual quartz pebbles are extensively scattered through the upper beds of sandstone and quartzite. Lenses of fine-grained laminated rock occur in the succession at Mansa Guda hill. In the hand-specimen such rocks are usually pale mauve to whitish and feel like chalk. Specimen 23/137 from Mansa Guda is composed of variable-sized quartz grains showing a moderate amount of rounding, set in a cement of the weathering products of felspar. Abundant small rounded grains of red hematite colour the rock dark mauve. Towards the summit of Mansa Dika hill a dark mauve, medium-grained sandstone (specimen 23/36) contains abundant pellets of material strongly resembling the fine-grained rocks, haphazardly scattered through it. The pellets vary from about half an inch to about two inches in length. Similar rock at a lower horizon was exposed at about 80 feet below the surface during excavation of the El Ben wells.

Mansa Guda and Mansa Dika hills have two quartzite horizons, one of which accounts for the step in their escarpments and the second caps them. The lower of the two quartzites at Mansa Guda is a fine-grained mauve highly resistant rock. The mauve colouring is normally uniform but locally it becomes blotchy, due to the irregular distribution of clouds of minute hematite specks, giving a highly attractive effect. In thin section the quartzite (specimen 23/147) is seen to consist of ill-graded coarse- to fine-grained quartz and rare quartzite grains, cemented by secondary silica. The larger grains are rounded, but the finer grains are sub-rounded to angular. The upper quartzite is a coarser-grained buff-coloured type showing well-defined bedding and containing occasional quartz pebbles. Specimen 23/145, from Mansa Guda, is composed of rounded to irregular, well-sorted, medium-sized grains cemented by silica, some of which is stained by iron oxide. The high degree of irregularity of some of the grains appears to be a result of corrosion by the matrix.

The lowest exposed sediments of the Mansa Guda Formation are best seen on Tarbaj hill where there is a section of 240 feet of beds. The succession is as follows:—

(Top of the hill approximately 1,695 feet O.D.)	*Feet*
7. Light grey coarse-grained felspathic sandstones containing scattered quartz pebbles and a few chalcedony infillings ..	50
6. Grey cross-bedded sandstones containing abundant quartz pebbles	40
5. Grey cross-bedded sandstones and fine grits; weathering produces small flattened biscuit-like rock slabs, unlike the massive blocks produced from the underlying sediments	50
4. False-bedded heterogeneous greyish beds ranging from coarse grits to pebble bands. The upper beds tend to be finer-grained, becoming purplish laminated sandstones ..	40
3. Greenish grey soft, fine- or even-grained sandstones ..	40
2. Even-grained grey to whitish sandstones	10
1. Coarse, cross-bedded, felspathic grit, including scattered quartz pebbles and clay pellets	10
(Base of the hill)	

The lower sediments of the formation are succeeded by pale mauve to grey coarse-grained sandstones, best exposed in the Kabort hills. Conglomeratic bands are rare among these beds and when present the pebbles in them are generally smaller than those of the lower conglomerates. No fine-grained lenses were recorded.

The best exposure of the higher horizons that are seen is at Alio Alem where the Mansa Guda sediments form an escarpment about 350 feet high. The foot of the escarpment is covered by an extensive carpet of pebbles of chalcedony, quartz and rarely quartzite, which appear to have been derived from the Mansa Guda beds. The uppermost beds in the scarp consist of coarse mauve grits interbedded with ill-sorted conglomerates which, apart from the included pebbles, are of similar composition to the associated sediments. The sediments contain abundant kaolinite and sericite which it is believed were derived from felspars in the original eroded rock material that was deposited as the Mansa Guda Formation. Conglomerates occur haphazardly throughout the exposed sediments (*see* Plate II (*b*)) but tend to become finer-grained, less felspathic and better sorted, with better rounded pebbles in the upper horizons. In the conglomerates from the lower horizons the pebbles range from about half an inch to about three inches in diameter and are poorly rounded. They are mainly quartz and vary from clear to milky types and, rarely, are rose quartz. Quartzite from the Basement System is considerably less common than quartz. Chalcedony infillings of cavities in the conglomerates are fairly common. The absence of granite or other felspar-rich pebbles which might be expected in sediments derived from the Precambrian rocks, may be due to their greater susceptibility to weathering. The smaller grains which make up the matrix of the conglomerates and associated beds are chiefly angular clastic quartz grains between one-eighth of an inch and one-tenth of an inch in length.

Lenses of fine-grained laminated rock, similar to those of the lower horizons, occur throughout the beds in the Alio Alem area, but are not confined to any particular horizon. Specimen 23/65 from Alio Alem, is similar to the sample from Mansa Guda, the chief difference being a finer-grained texture.

Alio Alem is capped by a fairly compact quartzite band about 20 feet thick. It is a medium-grained pale mauve, highly resistant rock and forms the greater part of the dip-slope east of Alio Alem. Pebbles are not common in this horizon and appear to be confined to small lenses of coarser material. Specimen 23/67 is, in thin section, found to be composed of medium-sized angular quartz grains firmly fixed in a siliceous matrix. A slight porosity in the rock is probably due to the dissolution of felspar grains.

Heavy mineral separations were carried out on representatives of the Mansa Guda Formation from the upper half of the formation, from the lower sediments and from the fine-grained lenses. For the upper horizons, specimens were collected from the Didimtu, Alio Alem and Kabort areas, for the lower sediments specimens from Mansa Guda, Mansa Dika and Tarbaj were used, while representatives of the fine-grained rocks were collected from Alio Alem and Mansa Guda. The following results were obtained: —

	Lower beds	*Fine-grained lenses*	*Upper beds*
Iron ore (magnetic)	xxx	xx	xx
Non-magnetic iron ores (incl. ilmenite)	xxx	xxx	xxx
Tourmaline	xxx	xxx	xxx
Zircon	xxx	x	xx
Biotite	xx	—	x
Muscovite and sericite	xxx	x	xx
Sphene	xx	x	x
Hornblende	xx	—	xx
Epidote	xx	xx	x
Rutile	—	x(?)	x

xxx = Abundant. xx = Present. x = Rare.

Stefanini (1925, p. 1062) described the presence of monazite in the Lugh Group, which might correspond with the Mansa Guda Formation, but no monazite was recognized in the heavy residues examined from the present area.

The sediments of the formation are apparently as a whole inclined in an east-south-easterly direction at about four degrees. Highly resistant quartzite bands form well-defined dip-slopes extending from the escarpment at Mansa Guda towards the Jurassic limestones. The difference between the inclination of the outlying Jurassic limestones and that of the Mansa Guda beds indicates unconformity between the two series. The formation extends as a wedge from the Tarbaj area where it probably reaches its maximum thickness, tapering off to the Didimtu area where only a few feet remain. North of Didimtu the Jurassic limestones have been mapped as far as the Kenya-Ethiopia boundary, and throughout that distance they overlie Precambrian rocks directly. The restricted occurrence of the Mansa Guda Formation, the lensing habit of many of the beds and extensive cross-bedding suggest deltaic conditions of deposition.

Since the Didimtu Beds overlying the Mansa Guda Formation contain fossils of the Toarcian stage of the Jurassic, it is probable that the Mansa Guda sediments are of Triassic age.

3. Jurassic Limestones

The Jurassic limestones within the area form part of the Daua Limestone Series of north-east Kenya (Saggerson and Miller, 1957, p. 10). They can be divided into essentially oolitic and non-oolitic groups (Fig. 3) the separation being effected at a marly horizon. The non-oolitic limestones, following on Ayers (1952, p. 5) are referred to as the Didimtu Beds, and the oolitic limestones that overlie them are here named the "Bur Mayo Limestones". The succession can be tabulated as follows: —

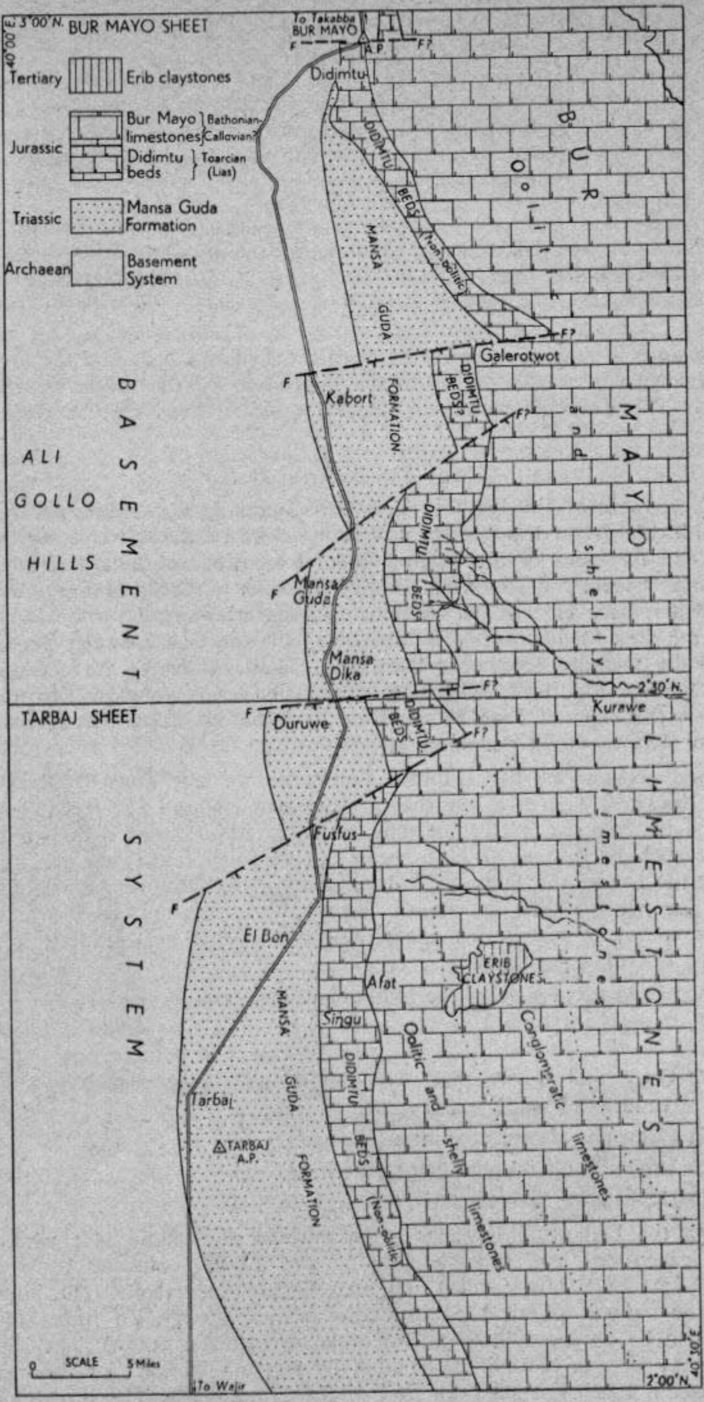


Fig. 3—The solid geology of the Bur Mayo-Tarbaj area.

System	Series	Stage	Name	Types
Jurassic.	Daua. Limestone. Series (part).	Callovian to Bathonian.	Bur Mayo Limestones.	Grey and fawn oolitic limestones, grey calcite mudstones, intra-formational conglomerates and marls.
			Marl horizon.	Marls.
		Toarcian.	Didimtu Beds.	Essentially non-oolitic limestones, calcite mudstones and marly partings.

The change in type of sediment between the Didimtu beds and the marls is abrupt and no evidence of erosion prior to the deposition of the marls was found during the survey. The Toarcian-Bathonian interval appears, therefore, to represent a non-sequence.

(*a*) *The Didimtu Beds*

The limestones of the Didimtu Beds are essentially non-oolitic on the whole and rest unconformably on the Basement System rocks in the extreme northern part of the area, and on rocks of the Mansa Guda Formation southwards from Didimtu to the southern boundary of the area. Equivalent beds north of Didimtu have not been found and it is believed that the Didimtu beds are overlapped by the Bur Mayo limestones in the area further north. Nowhere has the junction between the Mansa Guda rocks and the Didimtu limestones been seen. Their exposures are closest around the base of Didimtu hill itself, where brown-mottled grey non-fossiliferous limestones, which form the exposed base of the Didimtu beds, are found 20 feet (6 m.) above boulders of Mansa Guda conglomerate.

Exposed sections of the Didimtu limestones do not normally exceed 200 feet (61 m.) in thickness, and as a rule they are between 100 and 150 feet (30–46 m.) thick. Intercalated in them are marly horizons, probably never more than two feet (0.6 m.) thick. One such horizon at Didimtu bears a rich fossil fauna (see p. 22). The marly horizon at the top of the Didimtu beds separating the Didimtu non-oolitic limestones from the Bur Mayo oolitic limestones, is probably much thicker. It was not possible during the survey to record the exact thickness of this horizon, but it is estimated to be about 20 feet (6 m.) thick.

A generalized succession of the Didimtu beds is as follows:—

	Thickness (feet)
(4) Grey and fawn shelly limestone, and grey calcite mudstones with marly partings	30–80
(3) Grey and fawn coquinoid limestone	20–35
(2) Brown mottled pale grey limestone	10–65
(1) Dark grey unfossiliferous limestone	20

Though the Didimtu limestones are essentially non-oolitic as a whole, there are occasional exceptions, e.g. specimens 23/56 and 23/88, collected from about three miles south-east of Fusfus (south) and near Ongar respectively. The latter specimen contains iron-stained spherical ovoid bodies which, though no radial or concentric structures can be observed in them, resemble ferruginized ooliths. The lack of oolith structures may be due to their destruction by recrystallization, for the calcite mosaic in the pellets is much coarser than that of the groundmass. The brown bodies range up to about 1.5 mm. in diameter and in some there are the remains of organic nuclei.

Another exception to the generally non-oolitic character of the Didimtu limestones is represented by specimen 23/60, collected about 1½ miles east of Abdigani along the Hagardulun track. The best developed ooliths in this rock are small and have both concentric and radiate structures, but there are also other numerous larger and elongated ooliths with large nuclei of shell fragments. Quartz grains also form nuclei in some cases, but are scarce compared with the number of quartz grains that occur in the matrix of the rock.

The lowest horizon of the Didimtu beds seen is a dark grey, generally non-fossiliferous, fine-grained limestone, which was probably a lime mud before consolidation. It is generally about 20 feet (6 m.) thick. Rarely are macro-fossils to be seen in it. When they are visible they are usually whole, but resist removal without fracture from the enclosing rock.

Overlying the lowest bed is a bed of brown-mottled pale grey fine- to coarse-grained limestone, which is sometimes fossiliferous, and is characteristic of the basal beds of the Didimtu limestones. Often it is a calcite mudstone which rarely contains fossils. The mottling is due to iron-staining in patches. Specimen 23/106 (Plate IV (*d*)), collected from near Singu, is an extreme example of this limestone where the iron-staining has taken place to such an extent that the specimen almost has a reticulated pattern of yellowish brown markings. Under the microscope it is seen that the rock is traversed by anastomosing veinlets of iron-stained calcite that are coarser-grained than their host. On weathered surfaces the iron-stained blotches often stand out, as in specimen 23/86 which was collected from near Ongar and which also contains occasional fossils. This layer of blotched limestone is about ten feet to 20 feet (3–6 m.) thick in most places, but near Ongar it is nearly 65 feet (19.8 m.) thick. Detrital fragments derived from it are widespread. At Didimtu sub-angular quartz grains varying in size from 0.1 mm. to one mm. are to be found in it (specimen 23/35), and a few felspar grains are also present. These impurities, however, do not exceed one per cent of the content of the rock.

A bed of coquinoid limestone which also contains whole fossils overlies the blotched or speckled calcite mudstones. This horizon varies greatly in colour—at Didimtu and Mansa Guda it is grey; grey speckled and brown east of Abdigani, yellowish brown in the hills between Abdigani and Fusfus, while further south at Ongar it is fawn-coloured. As with many of the limestones in the Bur Mayo-Tarbaj area it varies in thickness, ranging from about 20 feet (6 m.) in the Didimtu area to 35 feet (10.6 m.) near Fusfus. Specimen 23/40 from near Abdigani, in which some of the macro-fossils have been partly replaced by iron-stained calcite, is typical of this bed. The iron-staining in some extreme cases has spread throughout the greater part of the rock. Intercalated in this horizon in the Fusfus area is also a dark purplish highly fossiliferous limestone which is only a few feet thick.

The uppermost beds in the Didimtu limestones are shelly limestones with bands of grey calcite mudstones. These beds are about 30 feet (9 m.) thick at Didimtu and up to 80 feet (24.4 m.) thick in the locality of Fusfus and Abdigani and southwards. They are thin-bedded—rarely do beds exceed three feet (0.9 m.) in thickness. Some oolitic horizons are present and are typified by specimen 23/37, from the southern end of the Didimtu hills, in which compound ooliths can be seen, and the nuclei of some of the ooliths are shell fragments. Grey and fawn colours are typical of the shelly types, and generally are not blotched like those in the lower part of the sequence. These shelly limestones are often highly fossiliferous, but rarely exceed six inches (15 cm.) in thickness. Specimen 23/112, a slab of such limestone from about two and a half miles east of Ongar, is typical of these thin-bedded limestones, and on it Dr. L. R. Cox of the British Museum (Natural History) has recognized *Nuculana* (*Praesaccella*) cf. *juriana* Cox and indeterminate forms of *Trigonia* and *Corbula*. Marly material often occurs as partings in these beds.

It is not common to see the marly partings in the field as they are more often than not covered by debris from higher horizons that has been cemented to form sheets of calcrete. Where erosion has outstripped the formation of the calcrete, depressions in the land-surface often develop and shallow water-holes sometimes form on the marly bands. Should gully erosion encounter these soft, marly partings, strike valleys develop—a feature commonly seen on the western-facing limestone scarps overlooking the end-Tertiary surface in the western portion of the limestone country.

The results of chemical analyses of the limestones of the Didimtu beds are given in Table II (p. 30).

Within 20 feet (6 m.) of the base of the Didimtu limestones at Didimtu hill, a large collection of fossils has been made from a marly horizon. The fossils collected here during the present survey were sent to the British Museum (Natural History), and the lamellibranchs and gastropods were identified by Dr. L. R. Cox and listed as follows:—

LAMELLIBRANCHIA

Nuculana (*Ryderia*) sp.
Nuculana (*Praesaccella*) sp. nov.
Grammatodon sp.
Gervillia sp.
Pecten (*Weyla*) *ambongoensis* Thevenin
Modiolus (*Inoperna*) *plicatus* J. Sowerby
Lopha sp. nov. aff. *costata* J. de C. Sowerby
Astarte spp.
Protocardia sp.
Corbula sp. nov.
Pholadomya sp.

GASTROPODA

Discohelix sp.
Amberleya sp.
Cirrus sp.
Cloughtonia sp.
Allocosmia ? sp.
Cylindrites sp.

Dr. Cox writes that *Pecten* (*Weyla*) *ambongoensis* Thevenin is a species which was described from the Upper Lias of Bekodia, Madagascar, and is said to occur also in the Upper Lias of Pakistan, although no detailed description of specimens from that area has been published. He comments that *Modiolus* (*Inoperna*) *plicatus* J. Sowerby is a long-ranging species which first appears in the Upper Lias, and that the *Lopha* is a species found in the Upper Lias of the Ikahavo plateau, Madagascar, which was misidentified by Thevenin as *Ostrea subserrata* Goldfuss, which is said to be a *Plicatula*. Dr. Cox further comments that the *Protocardia* sp. is probably identical with a species occurring in the Upper Lias of Madagascar and recorded by Thevenin as *Protocardia* cf. *striatula* Sow. and that the *Pholadomya* sp. is probably the species which Thevenin records from the Upper Lias of Madagascar as *Pholadomya* cf. *idea* d'Orbigny. He notes that the *Astarte* represent at least five species, most of which are probably new.

A brachiopod tentatively identified by Dr. Muir-Wood of the British Museum as *Spiriferina rostrata* var. *madagascarensis* but which she thinks may possibly be a new species, was collected by P. Joubert in March, 1955, at Didimtu, after the completion of the survey. A spiriferina like *S. rostrata* var. *madagascarensis* in its elongate forms has already been collected from limestones close to the base of the limestone series north-east of Tarbaj hill (Ayers, 1952, p. 26). This genus became extinct in the Lias.

A slab of limestone (specimen 23/112) containing numerous shells, collected along the camel-track east of Ongar and about five miles from Singu, contains fossils which Dr. Cox identified as follows:—

Nuculana (*Praesaccella*) cf. *juriana* Cox
Trigonia sp. indet.
Corbula ? sp. indet.

Dr. Cox writes that *Nuculana juriana* was described from the Divesian of Cutch, N.W. India.

The limestone that contains these fossils occurs stratigraphically at the top of the Didimtu beds and beneath the Bur Mayo limestones, which contain fossils that Dr. Cox believes are certainly Bathonian or later Jurassic in age, although there is insufficient evidence to indicate their exact stage.

Dr. J. W. Arkell has identified an ammonite from Didimtu hill as *Bouleiceras nitescens* Thevenin (*see* Fig. 4), which is characteristic of the Toarcian (upper Lias). *Bouleiceras arabicum* has been identified previously from the same beds.

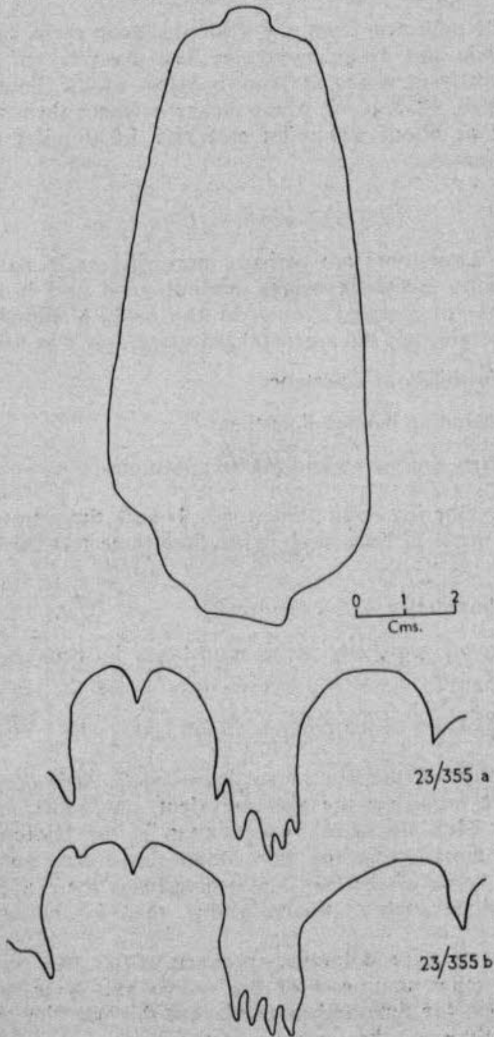


Fig. 4—Outline and sutures of *Bouleiceras* cf. *nitescens* from Didimtu.

Two nautilids collected by Joubert in March, 1955, have also been identified by Dr. Arkell as probably—

Cenoceras cf. *orbigny* (Prinz)
Paracenoceras anomphalum (Pia).

The latter nautilid is mainly a Toarcian species. Dr. H. D. Thomas of the British Museum (Natural History) has also identified the following corals from the Didimtu beds;

Montlivaltia sp.
Chomatoseris sp.

The former has a range from the Middle Triassic to the Cretaceous period, and the latter occurs in the Lower and Middle Jurassic. *Galeolaria*, a worm with slender, parallel aggregated tubes from the beds has also been identified by Dr. Thomas.

From the fossils collected from the Didimtu Beds there can be no doubt that they are upper Liassic and Toarcian in age. The discovery of beds of such age in north-east Kenya greatly increases the known extent of the Toarcian sea in this part of the world (cf. Arkell, 1952, p. 30, where on the evidence then available the Toarcian shore-line is shown as about 600 miles east and 1,000 miles north of the Liassic beds of north-east Kenya).

(*b*) *The Bur Mayo Limestones*

The Bur Mayo Limestones are perhaps more diverse in nature and colour than the underlying Didimtu Beds. Exposures are not good and it is rare to find more than 200 feet (61 m.) of exposed section in the field. A complete succession could not, accordingly, be established but a generalized succession is as follows:—

6. Grey oolitic fossiliferous limestones
5. Limestones, including banded limestones
4. Marls with marly limestones and calcite mudstones
3. Grey, fawn-weathering oolitic limestones in beds three to five feet thick, calcite mudstones, marls in beds rarely more than three feet thick, and conglomeratic limestone
2. Fawn oolitic limestones with a few fossils
1. Grey and brown blotched calcite mudstones in beds rarely more than five feet thick.

The estimated total thickness of the group is about 5,000 feet.

The essential feature of the Bur Mayo limestones is their oolitic nature. Although bands of grey calcite mudstone are also prevalent, non-oolitic horizons play a subordinate role. Marly beds are more frequent than in the Didimtu beds and there is more evidence of lamination in the Bur Mayo limestones. Judging from the thin sections prepared of some of the Bur Mayo limestones there appears to be a higher proportion of impurities, such as quartz grains, than in the underlying limestones.

What is virtually a pure dolomite, specimen 23/53, was collected from a low hill two and a half miles south-east of Bur Mayo hill. Nine samples from various localities were analysed for lime and magnesia but this was the only one of dolomitic composition. The analyses of the samples together with analyses of limestones of the

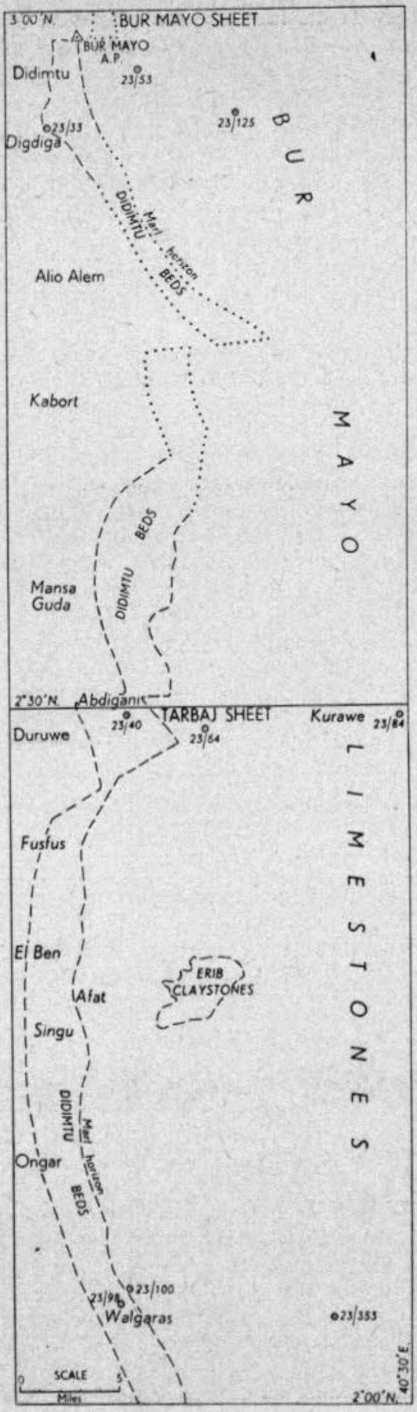
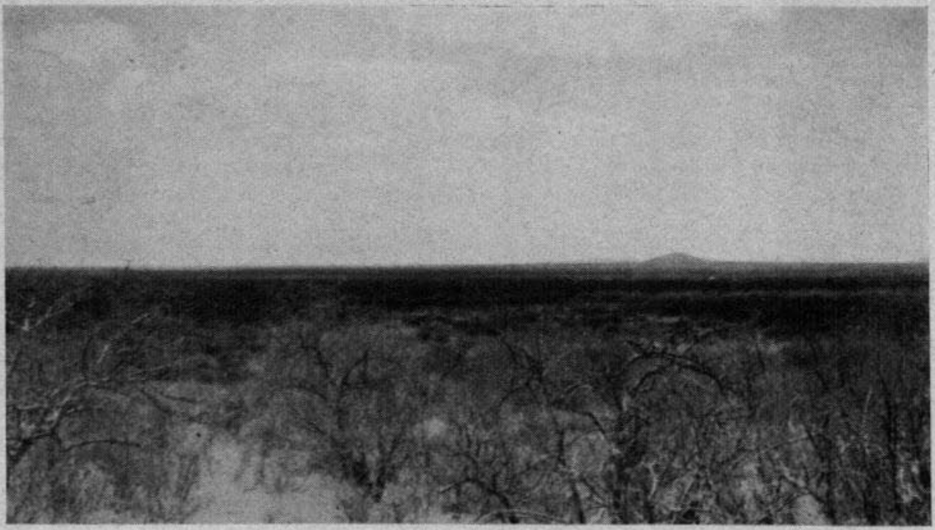


Fig. 5—Map of the Bur Mayo-Tarbaj area showing the localities from which the analysed samples of limestones of the Daua Limestone Series were taken.

Didimtu beds are listed in Table II. They are placed in groups of three in relation to their provenance from the northern, middle and southern parts of the area (*see* Fig. 5).

Plate I



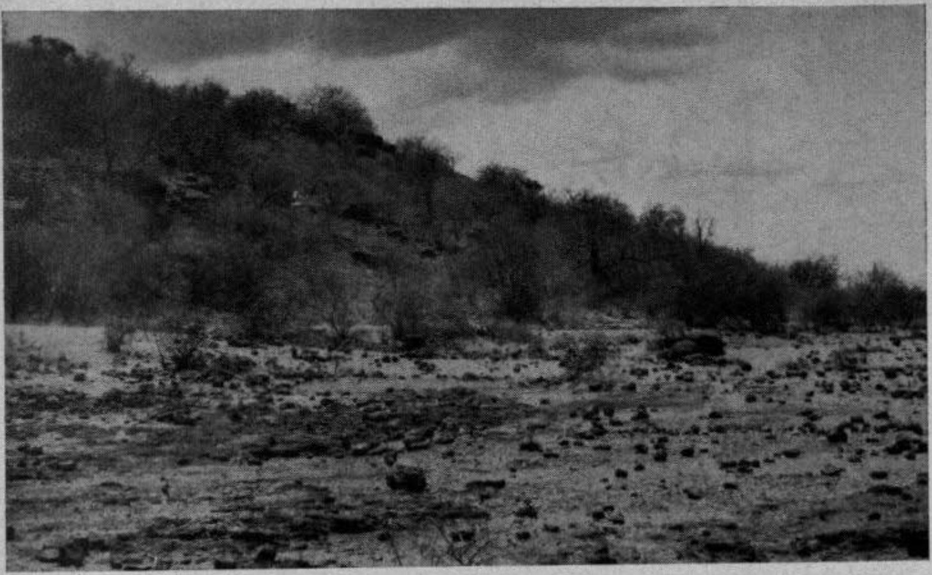
[*Photo*: *A. O. Thompson*

(*a*) The end-Tertiary erosion surface viewed from Ongar, looking west. Tarbaj hill on the right.

[*Photo*: *R. G. Dodson*

(*b*) Kunkar limestone on the end-Tertiary erosion surface in the Digdiga area.

Plate II



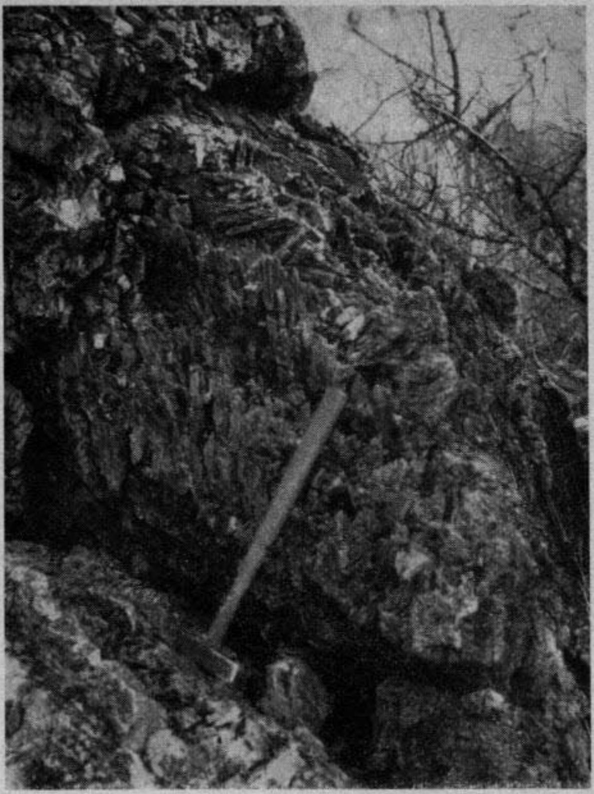
[*Photo*: *R. G. Dodson*

(*a*) **The Mansa Guda Formation at Kabort hill, with consolidated clayey sands and pebble gravels in the foreground.**

[*Photo*: *A. O. Thompson*

(*b*) **Sediments of the Mansa Guda Formation at Tarbaj hill, illustrating their cross-bedding and heterogeneous nature.**

Plate III



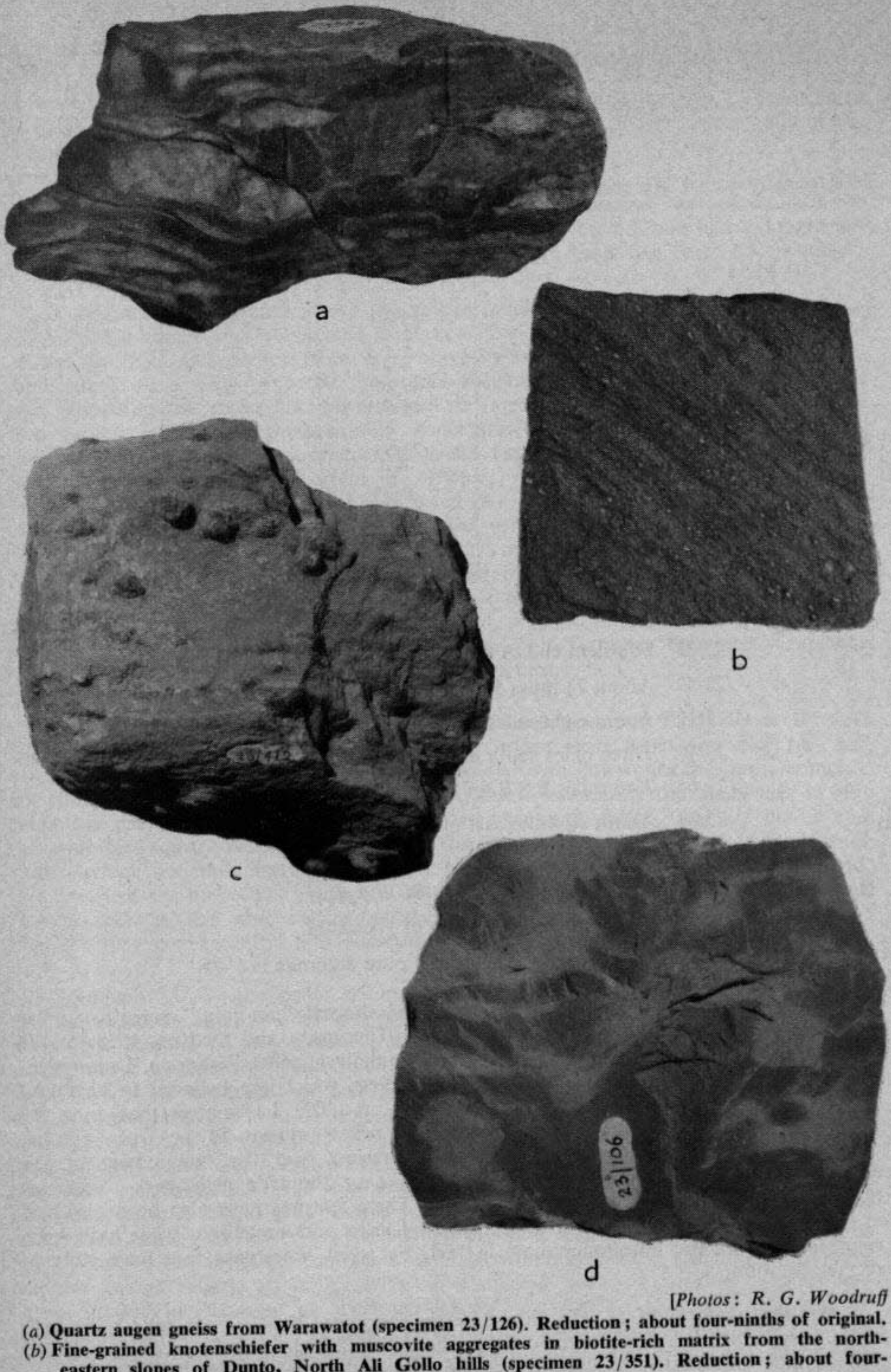
[*Photo*: *R. G. Dodson*

(*a*) **Aggregates of wollastonite and diopside crystals on the eastern slopes of Warawatot hill.**

[*Photo*: *R. G. Dodson*

(*b*) **Limestone bands containing wollastonite and diopside, Warawatot hill. The dip of the beds is to the south-west.**

Plate IV



[*Photos*: *R. G. Woodruff*

(*a*) Quartz augen gneiss from Warawatot (specimen 23/126). Reduction; about four-ninths of original.

(*b*) Fine-grained knotenschiefer with muscovite aggregates in biotite-rich matrix from the north-eastern slopes of Dunto, North Ali Gollo hills (specimen 23/351). Reduction; about four-fifteenths of original.

(*c*) Coarse-grained knotenschiefer with sericite aggregates in a fine-grained micaceous quartzo-felspathic matrix from the north-eastern slopes of Dunto, North Ali Gollo hills (specimen 23/337; the number written on the specimen is an original field number, since replaced by a regional collection number). Reduction; about two-fifths of original.

(*d*) Brown-blotched grey limestone of the Didimtu Beds, from Singu (specimen 23/106). The iron-stained patches are the lighter coloured. Reduction; about one-half of original.

TABLE II—CHEMICAL ANALYSES OF LIMESTONES OF THE DAUA LIMESTONE SERIES FROM THE BUR MAYO-TARBAJ AREA

	Didimtu Beds	Bur Mayo Limestones	
NORTHERN PART OF THE AREA	23/33 %	23/53 %	23/125 %
MgO	0·98	19·26	0·05
CaO	51·25	28·12	51·66
CaO/MgO	52·2/1	1·46/1	1001/1
CENTRAL PART OF THE AREA	23/40 %	23/64 %	23/84 %
MgO	3·35	1·31	0·42
CaO	49·86	50·69	50·69
CaO/MgO	14·9/1	39·1/1	120/1
SOUTHERN PART OF THE AREA	23/98 %	23/100 %	23/353 %
MgO	0·75	0·45	0·39
CaO	51·53	52·08	49·86
CaO/MgO	68·8/1	116/1	128/1

Analyst: Mrs. R. A. Inamdar.

23/33 Southern end of the Didimtu hills.

23/53 About 2½ miles E.S.E. of Bur Mayo hill.

23/125 About eight miles south-east of Bur Mayo hill.

23/40 Three miles south of Abdigani.

23/64 Two miles E.S.E. of Abdigani.

23/84 About 3½ miles east of Kurawe.

23/98 Walgaras.

23/100 About 1 mile north-east of Walgaras.

23/353 About three miles north of Weldebbi.

Note.—The ratio of lime to magnesia in pure dolomite is 1·40:1.

It is interesting to note that specimen 23/53 showed "pin-point" porosity similar to limestones in the Derkali-Melka Murri area (Thompson and Dodson, 1958, p. 17). The specimen is also an example of what was initially a pellet limestone. Dolomitization has all but destroyed the outlines of the pellets, which are believed to be faecal pellets of mud-feeding animals. George (1954, p. 307) has noted that in some pellet limestones in Breconshire "some of the pellets appear to be truly detrital, consisting of granular material rounded by abrasion, and that winnowing of the finer detritus has cleaned the granular mudstone or the true pellet-rock to give it the appearance of an oolite (a "false oolite")". These features have also been observed in some of the oolitic limestones of north-east Kenya and sometimes what have been referred to as oolitic limestones may, in fact, be pellet limestones that have suffered recrystallization.

Another example of a pellet limestone is specimen 23/82, from four miles east of Kurawe, which is a finely banded rock. The pellets are elongated as well as rounded and angular and consist of granular calcite darker than the matrix. They are rarely greater than 0.2 mm. in diameter and are commonly less than 0.1 mm. in diameter.

The pellets tend to be concentrated in laminae, in which numerous foraminifera are also present. Angular quartz grains, which are mostly less than 0.05 mm. across, are abundantly present and tend to be concentrated in intervening laminae. On weathered surfaces the fine laminations show up in relief as a result of the etching out of the less quartz-rich laminae.

The lowermost horizons of the Bur Mayo limestones are not much different from those of the underlying Didimtu beds. Grey and brown blotched calcite mudstones are present in thin beds—they are rarely more than five feet (1.5 m.) thick.

A characteristic horizon above the calcite mudstones is composed of fawn limestones which are highly oolitic and contain a few fossils. Specimen 23/45 is typical of this horizon and comes from Bur Mayo, where about 120 feet (36.6 m.) are represented. In a slide prepared from this specimen small veins of calcite can be seen traversing the rock. The fawn colour is imparted to the rocks by fine-grained iron oxides which are preferentially concentrated in the ooliths. On weathered surfaces siliceous masses are frequently to be found in relief, largely in the upper part of the horizon. Their origin is obscure; in the Derkali-Melka Murri area Thompson and Dodson (1958, p. 17) believed that although some general silicification took place in the limestone there were also certain fossils, such as algae, which had been replaced by silica. Specimen 23/127, an oolitic limestone collected from about eight and a half miles south-east of Bur Mayo hill, has such siliceous bodies on its weathered surface and they have the appearance of fragments of bone. In thin section they show structures suggestive of organic origin. There has been replacement of the original material by calcite which in turn has been partly replaced by chalcedonic silica, without destroying the structure.

Overlying the fawn limestones is a group of limestones and marls about 100 feet (30.5 m.) thick, in which marl bands seldom more than three feet (0.9 m.) and often only a few inches in thickness are interbedded with limestones that are commonly not more than three feet to five feet (1.5 m.) thick. Essentially the limestones in this group are grey, but the weathered surfaces are commonly fawn. They are oolitic and the contained macro-fossils are unevenly distributed throughout. Grey calcite mudstones, which generally have a thin light grey weathered surface, are frequent and, as a result of the numerous joints, are found as cobbles on the surface of the ground. As with most of the other calcite mudstones, fossils are rarely to be found in them; they fracture conchoidally, and sometimes have a porcellanous appearance.

Specimen 23/53—the pellet dolomite, already mentioned—belongs to this group of limestones. Included in the group there are also intra-formational conglomeratic limestones. Pebbles of grey calcite mudstones generally about half an inch (1.2 cms.) across, occur in shelly or coquinoidal limestone bands. Specimen 23/51, from a hill about two miles south-east of Bur Mayo, is an example of this type of limestone, and like specimen 23/53 it is dolomitic. Other examples of these intra-formational conglomerates are specimen 23/153 from three miles east-south-east of Erib, and 23/350 from a mile and a half north of Weldebbi. In the hand-specimen, the included fragments in specimen 23/153 can be clearly recognised as angular dark grey calcite mudstone set in a lighter grey matrix which, however, under the microscope, appears darker and heterogeneous. Many shell fragments and quartz grains are present in the host, whereas the included fragments are more homogeneous, although one pellet contains faecal pellets, an oolith with an elongated piece of shell as nucleus and quartz grains. In the case of specimen 23/350 the foreign fragments are seen in relief as rounded lumps of various shapes on the weathered surface only. On the fresh surface it appears much like a grey calcite mudstone and under the microscope the outlines of the fragments are sometimes difficult to detect. The matrix of the specimen, however, contains more angular quartz grains than the inclusions and aids distinction. It is believed that the included fragments in this rock were still plastic when they were incorporated in the matrix in which they finally consolidated, whereas the fragments represented in specimen 23/153 were already hard when they were deposited. It is apparent that at the time the calcite mudstones were being deposited the floor of the sea was sometimes brought within the range of wave or current action, before the sediments on it had become indurated.

At Hagardulun there are intercalated with the marls bands of fawn limestones (specimen 23/64) rich in macro-fossils which resist extraction complete. Specimen 23/125 from eight miles east-south-east of Bur Mayo is a similar type. There are also at Hagardulun bands of crushed shells and shell fragments which give the limestone a coarse appearance and which are found as large slabs about three feet long, one foot six inches wide, and six inches thick (90 cms. × 46 cms. × 15 cms.). Specimen 23/66 is an example of this type of limestone composed of shell debris.

A group of marls, marly limestones and calcite mudstones overlies the preceding group of limestones and marls. The marls appear to be more dominant and the limestones thinner than in the underlying beds.

Slabs of grey fossiliferous limestone which weather to a characteristic yellow ochreous colour are found interbedded in the marls at Hagardulun and Kurawe. Dr. Cox of the British Museum (Natural History) has identified the following fossils in specimen 23/116 from Hagardulun:—

LAMELLIBRANCHIA

Nucula sp.

Nuculana sp.

Brachidontes (*Arcomytilus*) sp.

Lima (*Plagiostoma*) sp.

Camptonectes sp.

Trigonia sp.

Ceratomya sp.

Pholadomya cf. *ovalis* (J. Sowerby)

GASTROPODA

Procerithium (*Rhabdocolpus*) sp.

The gastropod is prolific. The *Ceratomya* has concentric ornament only, and Dr. Cox considers it is close to *C. concentrica* (J. de C. Sowerby), a species that ranges from Bajocian to Callovian. Dr. Cox has recognized the following fossils in specimens from the same group of marls and limestones but about 400 feet (122 m.) higher in the succession at Kurawe:

Specimen 23/72

Lima (*Plagiostoma*) or *Inoceramus* sp.

Thracia cf. *depressa* (J. de C. Sowerby)

Specimen 23/78

Lima (*Plagiostoma*) sp.

Dr. Cox remarks that the doubtful *Lima* is without radial ornament but with concentric growth-stages imbricating at intervals in a manner suggestive of *Inoceramus*, but that the preservation is too poor for him to be certain of the genus. The definite *Lima* is a large crushed specimen of a species devoid of radial ornament. The *Thracia* is an obscure cast but is interesting as *T. depressa* is stated to range from Bathonian to Portlandian. Dr. Cox lists all these fossils under the heading of upper Jurassic.

From an horizon about 60 feet (18.3 m.) higher, associated with grey, highly fossiliferous limestone which weathers a yellow ocherous colour, a poor specimen of an ammonite was collected during the survey. Dr. W. J. Arkell of the Sedgwick Museum, Cambridge, suggests that it is *Peltoceras* and perhaps comparable though not quite identical with *Peltoceras ngerengerianum* Dacqué of the Pendambili Limestone in Tanganyika, which is Upper Callovian.

In the Kurawe area and eastwards the succeeding 600 feet (183 m.) of limestones are poorly exposed. A characteristic horizon, however, is a grey fossiliferous, oolitic limestone which weathers a fawn colour and shows laminae in relief. Other specimens of this type have been collected as float samples on the laterite pebble-strewn surface at Erib. Specimen 23/80, collected about two miles east of Kurawe, is an example of these laminated limestones though the laminae are not clearly visible on the weathered surface. In thin section it is seen to contain numerous micro-fossils and shell fragments, foraminifera, polyzoa and corals being fairly plentiful. Quartz grains are rare.

Overlying the laminated limestones are more grey oolitic limestones, essentially fine-grained, fossiliferous and with irregular siliceous patches which, on weathered surfaces, show up in relief. The limestones are porcellanous in appearance and sometimes highly oolitic, as in specimen 23/84 from five miles east of Kurawe. Along the Aus Mandula camel-track from Harakoro, about three miles west of the border of the area, a float piece of light-grey ripple-marked limestone (specimen 23/108) was found, which shows grading of the particles. The ripple troughs are filled with coarser material which gradually becomes finer towards the crests of the ripples. The ripples appear to be asymmetrical, suggesting current ripples, and with a fairly high ripple-mark index (about 17). These limestones appear to represent almost the highest horizon in the Bur Mayo–Tarbaj area. Outcrops, however, are poor in the eastern parts of the area and float pieces are not abundant, as well as being sometimes misleading as to the nature of the underlying rocks, so that no detailed information was obtained on the uppermost part of the succession.

Age of the Bur Mayo Limestones.—The beds underlying the Bur Mayo limestones, the Didimtu beds, are known to be Toarcian in age, i.e. they are upper Lias, forming the uppermost part of the lower Jurassic of north-east Kenya. No trace has yet been found of the Aalenian stage, the highest part of the lower Jurassic, nor have any fossils been discovered that would suggest that the Bajocian stage, the lower part of the middle Jurassic, is present, though further north, in the Melka Murri area, a fossil suite has been dated as Bajocian-Bathonian (Thompson and Dodson, 1958, p. 19). The fossils recovered from the Bur Mayo limestones suggest that they are upper Jurassic and probably Callovian (i.e. the lowest part of the upper Jurassic) in age but, in view of the fact that they are an extension of limestones further north that are in part Bathonian (upper middle Jurassic), it is likely that their lower beds are also Bathonian in age. The Bur Mayo limestones are accordingly considered to embrace the Bathonian and Callovian stages of the Jurassic System.

4. Sedimentation during the Mesozoic era

Probably in Triassic times earth-movements in north-east Kenya initiated a vigorous cycle of erosion during which the arenaceous ill-sorted, chiefly rudaceous, and commonly cross-bedded sediments of the Mansa Guda Formation were deposited on a floor of Basement System rocks.

The nature of the sediments of the Mansa Guda Formation is suggestive that they were deposited in a deltaic environment. Their strong cross-bedding, lenses of fine-grained sandstones, and the restricted extent of the various beds are indicative of this type of sedimentation, but the marked absence of fossils and the general coarseness of the sediments suggests a hinterland environment subject to energetic erosion and probably extremely arid conditions.

When dealing with the Jurassic sediments in the Melka Murri–Derkali area Thompson and Dodson (1958, p. 23) considered that they were probably deposited slowly in a shallow trough under fairly stable conditions, and that the trough deepened and widened northwards.

All workers in the north-east part of Kenya are in agreement about the shallow-water environment in which the Jurassic sediments were deposited. Fluctuations of the sea-level took place, for there is evidence that at certain times sediments were exposed and eroded, fragments from them being redeposited in overlying beds. The intra-formational conglomerates in which pellets of grey lime mud are incorporated in beds of oolitic or shelly limestones, and the occurrence of fragments of lime muds in later beds of lime mud, as in specimen 23/350, exemplify this process.

The generally non-oolitic, less fossiliferous aphanitic grey limestones, which are in fact calcite mudstones, and which are most abundant in the Didimtu beds, suggest quiet conditions of deposition. Narrow bands of these rocks are found in the Bur Mayo limestones but are not so frequent as in the underlying group.

The Bur Mayo limestones provide evidence of more vigorous movement of the sea water, by the presence of ooliths and comminuted shell fragments—the latter often acting as the nuclei of the ooliths. The shallow-water conditions that prevailed during the deposition of these limestones are indicated by the intra-formational conglomerates, and by the fact that laminated limestones are fairly frequent. A higher proportion of impurities, such as quartz grains also appears to be present in the Bur Mayo limestones than in the Didimtu beds. Nowhere, however, were sandstones found intercalated in the limestones.

5. Tertiary—Erib Claystones

Claystones, believed to be of Tertiary age, unconformably overlie the Jurassic limestones to form a limited outcrop at Erib east of Tarbaj. The occurrence is about five miles long and three miles wide, and is situated in what appears to be a broad shallow valley in the Jurassic limestones. Several wells sunk at Erib, some of which are within 20 yards of the claystone-limestone junction, extend to a depth of about 20 feet without reaching Jurassic limestone. One well dug by the Public Works Department to a depth of 90 feet, largely through the claystone, suggests that deposition of the claystone probably took place in a sink-hole in the Jurassic limestones.

The claystone series in the area of the wells consists of a basal arenaceous bed at least ten feet thick, followed by nearly 80 feet of claystone. The arenaceous bed consists of mottled yellow to whitish loosely bound sandstone. Judging from a few fragments of marly material found in the waste heaped around the unsuccessful well dug by the Public Works Department it would appear that the underlying Jurassic sediments had just been reached. The claystone is generally similar to the Banissa claystone described by Thompson and Dodson (1958, p. 23) and claystones in the Aus Mandula area described by Baker and Saggerson (1958, p. 32), but does not include any iron-cemented conglomeratic horizons such as are found at Banissa. It is composed mainly of quartz and ironstone nodules set in a buff limonitic clay matrix.

From "spoil" around one of the shallow wells dug by Africans near the limestone-claystone junction on the eastern edge of the claystone outcrop, blackened lumps of calcite were found to contain 12.72 per cent of manganese (Analyst: W. P. Horne). The calcite appears to be in anastomosing veins through the claystone.

6. Quaternary Deposits

The youngest sediments of the area consist of gypsum, secondary limestones and soils. These formations cover the greater portion of the area mapped and frequently obscure the underlying older rocks. Well excavations in the Tarbaj area near Warafaria, at Digdiga and El Ben prove that the Quaternary sediments are, at least locally, over 100 feet thick. In an unpublished report to the Public Works Department in connexion with a hydrological survey of the Wajir area, T. Bestow briefly described the logs of several wells in the present area and concluded that the water-table, in what he believed are Tertiary lacustrine sediments, was dropping at a rate of about two to four inches annually. Since much of the material excavated from these wells has been disposed of by various agencies, and well D.W.3, situated about 11 miles south of Tarbaj alongside the Tarbaj–Wajir road, has been filled in, it was not possible for the writers to examine the excavated material.

The only gypsum discovered in the present area occurs as isolated pinkish to dirty white crystalline clusters, usually about six inches long, which are sparsely distributed on the surface of the fine *lugga* soils south-east of Digdiga. Shallow excavation in this part of the area might reveal the presence of more continuous gypsum beds. In the vicinity of Digdiga, kunkar or secondary limestone occurs which resembles massive gypsum such as that found in the El Wak area to the east, but chemical tests prove that it is free of sulphate.

Secondary limestones occupy a narrow tract extending from Bur Mayo south-westwards to where the deposit widens to form the open plain south-west of Digdiga (*see* Plate I (*b*)). So far as can be deduced the average thickness of the kunkar limestone is about ten feet. It varies from a massive pale grey type to nodular reddish limestone, and towards the edges of the deposits occurs as nodules about three inches across, in the soils. In most of the wells in the present area, irregular horizons of kunkar limestone are traversed within 30 feet of surface. Secondary limestone crusts cover large areas of the Basement System crystalline limestone in the Ali Gollo hills.

Nodules of brown concretionary barytes are sparsely scattered on the ground below the outcrops of weathered fossiliferous marly limestone at Didimtu. It is not clear whether the barytes has been derived from the limestone but it is believed that the Jurassic limestones of the Northern Province contain a relatively high percentage of sulphate. The nodules (specimen 23/352) appear to consist of sub-fibrous radiate crystals in crude bands which are sometimes separated by thin layers of white calcite.

Extensive tracts of the area are covered by deep, mostly residual, mantles of soil. To a certain extent, the soils are representative of the underlying rocks and geological boundaries can often be roughly predicted by their distribution. The Basement System gneisses produce reddish soils which are often characterized by the presence of megascopic quartz fragments. Soils derived from the Precambrian quartzites, however, are far more sandy and usually lighter coloured, and resemble soils formed from the Mansa Guda beds in the Tarbaj area. The crystalline limestones of the Basement System usually form fine whitish powdery soils. In most localities soils derived from the Mansa Guda beds can be recognized by the presence of quartz pebbles and chalcedony fragments. They are of two types—the sandy buff-coloured type found in the Tarbaj area, and a fine-grained red clay-like soil, which occurs in the Mansa Guda and Mansa Dika areas (Plate II (*a*)) where it forms resistant highly impervious layers.

The soils produced by the decay of the Jurassic limestones are generally fine-grained, pale greyish to pale buff types, but the marly limestones produce a distinctive dirty white soil.

The weathering product of the Erib claystones is a highly characteristic soil, similar to the soils in the Banissa area near the Abyssinian border and at Wel Merere east of the present area. The soils are dark red and invariably include abundant ironstone pellets and nodules.

Fine-grained dark grey soils, formed in areas of low relief or local internal drainage, occur extensively throughout the Northern Province. These deposits are locally known as "lugga" and are easily recognizable in the field and on aerial photographs, as they support a far denser grass cover and fewer bushes than the surrounding country. The soil resembles black cotton soil but is generally finer grained and paler in colour.

During the course of mapping, artifacts were discovered at Ali Gollo and near Tarbaj, most being fashioned from quartz, chert and rarely fine-grained quartzite. A single artifact of Jurassic limestone discovered east of Harakoro, five miles north of Erib, is believed to have been used as a result of the discovery of a fortuitously shaped fragment which lent itself to reshaping. At Ali Gollo the artifacts belong to two cultures, according to Dr. L. S. B. Leakey of the Coryndon Museum, Nairobi. The better preserved belong to the Stillbay Culture which is representative of the Gamblian pluvial of upper Pleistocene age, and a few less well-preserved fragments may represent the Hope Fountain culture which was contemporary with the hand-axe culture. Artifacts found at Tarbaj water-holes on the Dombas road, are believed to be the Northern Province representatives of the Wilton culture.

7. Intrusives

(1) GRANITES

Rare exposures including outcrops of granite are sporadically distributed in widely separated localities between Garansabos, north-east of the Ali Gollo hills, and the Digdiga area. The exposures are either small bare slabs of rock just protruding from the soil or consist of a few scattered, rounded granite boulders. Owing to the poor exposures, relationships between the granites and the local Basement System rocks could not be established. Most of the granites differ in texture and composition from outcrop to outcrop.

About four miles south of the derelict Digdiga wells, a few boulders composed of two distinct types of granite are exposed alongside the Takabba-Tarbaj road. The predominant type is a coarse-grained, reddish brown granite, flecked with dark green ferromagnesian minerals. Specimen 23/57, representative of this rock, has a granitic texture and is composed essentially of microcline, orthoclase, plagioclase, quartz and biotite. The microcline replaces the orthoclase and the plagioclase (oligoclase) and is often perthitic. Microcline-quartz intergrowth is on a limited scale. The ferromagnesian mineral is brown biotite. It occurs as medium-sized flakes, and where unaltered is pleochroic from deep brown to greenish brown. It is, however, extensively altered, being partly converted to a green biotite or replaced by chlorite, epidote and iron ore. The accessories are zircon, some of which is included in the biotite, and octahedra of magnetite. The red colour of the rock is due to extensive interstitial staining by iron oxide. A few boulders of fine-grained leucocratic granite are associated with those of red granite at this locality. This granite (23/59) is pale greyish to dirty white and is almost free from dark minerals. The felspars consist of microcline, orthoclase and plagioclase (oligoclase). The microcline replaces the quartz and myrmekitic intergrowths replace the microcline. Most of the orthoclase is clouded with sericite. The accessory minerals are a few small grains of iron ore, small rare zircon prisms and aggregates of epidote.

About four and a half miles west-north-west of Digdiga, fine-grained biotite-rich granite is exposed as a series of flat slabs. In the hand-specimen (23/85) it is a dark grey rock, spotted with pink felspar aggregates. In thin section it is seen to be composed mainly of orthoclase and quartz with smaller amounts of microcline and plagioclase. Some of the orthoclase is partly altered to sericite. Green biotite is the ferromagnesian mineral and contains zircon inclusions, usually with pleochroic haloes. The accessory minerals are zircon, both included in the biotite and "free", sphene, and ilmenite. Secondary epidote, both as small individual grains and as granular aggregates is patchily distributed through the rock. Specimen 23/97, from about eight miles south-south-west of Digdiga is generally similar in composition but is coarser grained. In composition the chief differences are the paucity of microcline with corresponding abundance of orthoclase, and the prominence of oligoclase, which is present in such amount as to give the rock an adamellitic composition.

The metamorphosed sediments exposed on the south-eastern slopes of North Ali Gollo are invaded by medium-grained, leucocratic, grey granite. Rock exposures are poor thereabout and no outcrops of the granite were discovered. The granite (23/340) is composed of quartz, much microcline, some of which is replaced by sericite, orthoclase, primary and secondary muscovite and specks of iron ore. Between Gosieh hill and South Ali Golo a few boulders of finer-grained, but generally similar-looking, granites are barely exposed through a covering of soils and secondary limestone. The most striking feature of this granite (specimen 23/331) is the granulation along the margins of the larger mineral grains which has obviously been caused by post-intrusion stress. The granite contains unaltered microcline, slightly altered orthoclase, and more highly altered plagioclase. The ferromagnesian mineral is biotite, pleochroic from dark brown to pale brown, which occurs in small plates and fine shreds confined to the seams of crushed material. Bright green chlorite replaces some of the biotite.

Further south, on the north-eastern slopes of Warawatot, a pink granite occurs intermittently as boulders. In the hand-specimen it is a pale pinkish, medium-grained rock spotted with small grains of ferromagnesian mineral and iron ore. A thin section of specimen 23/148 is composed of quartz and nearly equal amounts of microcline, plagioclase and orthoclase, the plagioclase and orthoclase being highly altered. Original biotite has been almost entirely replaced by chlorite. The pink colour of the rock is due to an overall staining by reddish iron oxide.

(2) AUGEN ORTHOGNEISS

A small lenticular body of gneissose granitic rock apparently invades the metamorphosed sediments exposed on the south-western slopes of North Ali Gollo. The outcrop is narrow and appears to be more or less concordant with the surrounding rocks. In the hand-specimen the rock is dark greyish, and contains numerous ovoid pink felspar "augen" up to half-an-inch in length. Specimen 23/347 is strongly porphyritic, the larger felspar augen contrasting with the finer-grained matrix of felspar, quartz and mica. The matrix felspars consist of grains of orthoclase and plagioclase (oligoclase) of variable size, and a small amount of myrmekite. Both biotite and muscovite are present but the white mica is rare and occurs as small flakes, probably of secondary origin. Most of the constituent minerals of the matrix show a certain amount of crushing, the granulation being mainly confined to grain margins and seams of crushed material. The augen consist of microcline, poikilitically including quartz, biotite and accessory minerals. The accessories are iron ore, apatite and zircon. Granular aggregates of epidote are concentrated along the seams of crushed material and are often associated with the biotite.

The rock appears to have been originally a porphyritic granite that suffered sufficient shearing to crush its more fine-grained matrix, the phenocrysts being reduced to characteristic augen shape.

Another augen rock is represented by specimen 23/178, from North Ali Gollo. It is a coarse-grained gneissic rock with small quartz and felspar augen. In the hand-specimen, fairly large, widely separated biotite flakes in a white quartzo-felspathic matrix produce a spotted effect. The biotite is orientated in parallel arrangement, accentuating shearing which the rock has undergone. The gneiss is composed of orthoclase, microcline, plagioclase, quartz, biotite, magnetite and the secondary minerals sericite, epidote and calcite. Most of the primary minerals show a certain amount of brecciation.

(3) Basalt

An occurrence of basalt, approximately seven miles west of Alio Alem, consists of a number of rounded fragments, seldom more than about six inches long. Similar rock occurs in the Derkali area farther north where it is apparently an intrusion (Thompson and Dodson, 1958, p. 28), and it is believed that the boulders here are derived from an intrusive body. In the hand-specimen the rock, specimen 23/93, is a dark bluish grey fine-grained type usually covered by a reddish-brown weathered crust. In thin section it is micro-porphyritic, with pyroxene and felspar phenocrysts in a fine-grained matrix consisting of felspar, pyroxene, yellowish green biotite, and iron ore. The iron ore occurs either as small dense aggregates of minute specks, as irregular to subhedral grains and as a complex criss-cross network of needles throughout the thin section. The pyroxene phenocrysts are augite, and the felspar labradorite.

(4) Lamprophyre

A number of small blocks of lamprophyre, seldom more than four inches long, were found on the north-eastern slopes of Warawatot. No outcrops were discovered, but it is considered unlikely that the blocks were transported for any great distance.

The hand-specimen (23/150) is a tough medium-grained dark bluish grey rock coated with an olive-greenish weathered crust. In thin section it is seen to consist of an interlocking hypidiomorphic aggregate composed mainly of plagioclase felspar and ferromagnesian minerals. The plagioclase is sodic labradorite and occurs with both Carlsbad and albite twinning. The ferromagnesian minerals are somewhat altered. Stout prisms of augite are more or less altered to actinolite, and biotite, pleochroic from dark brown to yellow, is rarely unaltered and is frequently replaced by chlorite. Iron ore occurs both as irregular primary grains or as aggregates of minute specks derived from the alteration of the ferromagnesian minerals. Narrow prisms of accessory apatite are patchily distributed through the rock. The composition of the rock suggests that it is a biotite-bearing augite lamprophyre, i.e. a spessartite.

(5) Epidiorite

An irregular dyke-like body of metamorphosed intrusive rock is exposed on the eastern arm of the Garabid syncline. Although the weathered outer crust of the rock is in a soft rubbly state the core remains as a highly resistant fine-grained, dark coloured crystalline rock. The weathered crust is not so dark coloured and shows schistosity not normally apparent in the fresh hand-specimens.

Specimen 23/173, an example of the fresh rock, has a fine-grained granular texture. The felspar has recrystallized as a fine-grained mosaic and is probably albite. The ferromagnesian mineral is moderately pleochroic dull-green amphibole. Irregular granules of iron ore and a few grains of secondary calcite are present.

(6) CHLORITE SCHISTS

Some of the intrusive rocks are highly altered to such a state that recognition of their original composition is difficult or impossible. These rocks are usually dull greenish and frequently have a schistose texture. Their weathered surfaces are either pale green or reddish from iron oxide staining. Specimen 23/79 from about four miles west of Digdiga and 23/101 from about six miles south-west of Digdiga are examples. Specimen 23/79 is composed of quartz, albite felspar, chlorite, calcite, primary and secondary iron ore and accessory apatite. Specimen 23/101 is composed of quartz, chlorite, calcite, plagioclase felspar (andesine), most of which is saussuritized, orthoclase and secondary iron ore. The chlorite is concentrated in shear-zones.

(7) AMPHIBOLITES

About six miles west-south-west of Digdiga, a number of rock fragments scattered about a small area are believed to be derived from an amphibolite body concealed by overlying soils. The fragments are angular and seldom more than about five inches long. In the hand-specimen (23/107) the rock is dark green and coarse-grained, with a chocolate-coloured oxidized crust on the weathered surfaces. It is composed of abundant green hornblende, plagioclase in which only faint twinning is recognizable, quartz grains and abundant iron ore. Secondary sphene occurs in discontinuous veinlets aligned obliquely across the preferred orientation of the rock.

The texture suggests to the writers that the amphibolite was formed by metamorphism of a basic intrusive body.

(8) ISOLATED BOULDERS OF BASIC INTRUSIVE ROCKS

Two isolated boulders of igneous rock, totally unrelated to any other rocks in the area were discovered during the course of mapping. In both cases the rocks were rounded boulders weighing between 10 and 20 lb. and were found resting on the ground. There is little doubt that they had been brought to their localities fairly recently as neither were covered by soil. The Somali tribal habit of carrying rocks by camel to place on graves in areas naturally devoid of rocks may possibly account for the presence of these boulders. Ultra-basic rocks have been recorded near Dobel about 15 miles north-west of the present area, and the two boulders found may possibly have been derived from an undiscovered suite of basic and ultra-basic rocks related to the Dobel intrusives.

Specimen 23/133 was found in the kunkar limestone region at the site of the former Digdiga wells. It is a greyish medium-textured rock mottled with greenish ferromagnesian minerals. The rock is composed of plagioclase felspar, hornblende, zoisite, and accessory sphene, zircon, and pyrite. The plagioclase is sodic andesine. The rock is an epidiorite. Specimen 23/183, a coarser-grained dark rock, was found slightly north-east of Warawatot hill in the Ali Gollo range. It is composed almost entirely of pyroxene with a small amount of plagioclase, hornblende, a few flakes of biotite, occasional sphene, specks of accessory iron ore and secondary minerals. The pyroxenes include both augite and enstatite. The plagioclase is labradorite. The biotite is pleochroic from nearly colourless to brown. Secondary products are chlorite replacing biotite and calcite.

VI—METAMORPHISM AND METASOMATISM

The Precambrian rocks of the Bur Mayo–Tarbaj area have been affected by regional metamorphism, thermal metamorphism, and to a certain extent metasomatism. There is evidence of some retrogressive metamorphism which has produced rocks of secondary low-grade metamorphism. The metamorphic history of the area is complex and accurate interpretation is made difficult by the rarity of rock exposures.

Few of the rocks mapped can be considered as having been closed systems during metamorphism which, because of their texture and composition, remained unaffected by metasomatism. On the other hand metasomatism has not been extensive in the area, and where it has left its effects it is invariably associated with granite intrusions and is of potassic nature.

The mineral assemblages of the amphibolites indicate that the rocks attained the grade of metamorphism of the amphibolite facies (Turner, 1948, p. 61). Parkinson (1920, p. 27) recorded the index mineral sillimanite from Butellu hill about 12 miles north-west of North Ali Gollo, indicating the presence of rocks of the higher temperature range of the amphibolite facies. Sillimanite was not recognized in the many specimens collected from the Ali Gollo hills, but it is possible that the sericite knots in specimen 23/337 from Ali Gollo may be replacements of sillimanite *faserkiesel.*

Turner (1948, p. 70) states that temperatures of 700° to 750° C. prevail at the transition from amphibolite to the pyroxene hornfels facies in contact zones but the overall temperature of the facies is undoubtedly lower. Barth (1952, p. 347) considers 500° C. as the maximum temperature of the amphibolite facies. In an open system Barth estimates that wollastonite is formed at 450° C. The presence of wollastonite in the Ali Gollo limestones confirms that the temperature range of the amphibolite metamorphic facies was attained.

Intrusive granite outcrops comprise the majority of the exposures in the area occupied by Precambrian rocks between Ali Gollo and Kiliwe Hiri police post, about 90 miles farther north. It is probable that all the ancient sedimentary rocks of this region have been invaded by granites and have, accordingly, undergone a certain amount of thermal metamorphism. The effects of thermal metamorphism are most obvious in the suite of rocks exposed on the south-eastern flanks of North Ali Gollo. Although only a few poorly exposed minor granitic bodies are visible in that locality, the metamorphism was probably caused by a nearby major granite intrusion.

Several of the rock types described on earlier pages are composed of low-grade mineral assemblages and in some cases, notably the replacement of metacrysts by sericite in specimen 23/337, the low-grade pseudomorphs are obviously derived from high-grade minerals.

Potash metasomatism is evident in some of the rocks of the present area. The more obvious indications of the introduction of potash are the development of interstitial microcline and the replacement of plagioclase, orthoclase and quartz by microcline. Specimens 23/342 and 23/345 exhibit the effects of metasomatism. The extensive granite intrusions and the mildness of granitization suggest that the potash was probably introduced during the granitic igneous phase, which may have included a deep-seated intrusion. The abundance of tourmaline in the Precambrian sediments suggests contemporaneous boron metasomatism.

VII—STRUCTURES

The most prominent structures that can be mapped in the area are those in the Basement System rocks of the Ali Gollo group of hills. Intense folding and faulting has undoubtedly taken place but it must be stressed that some of the structures shown on the maps and on Fig. 6 are inferred, for example the fault between North Ali Gollo and South Ali Gollo is conjectural.

Major structures were not observed in the Mansa Guda Formation and the Jurassic limestones. Faults and folds seen in them are of a minor nature, although gentle folds on a broad scale are believed to occur in the limestones, and presumably would also affect the Mansa Guda beds.

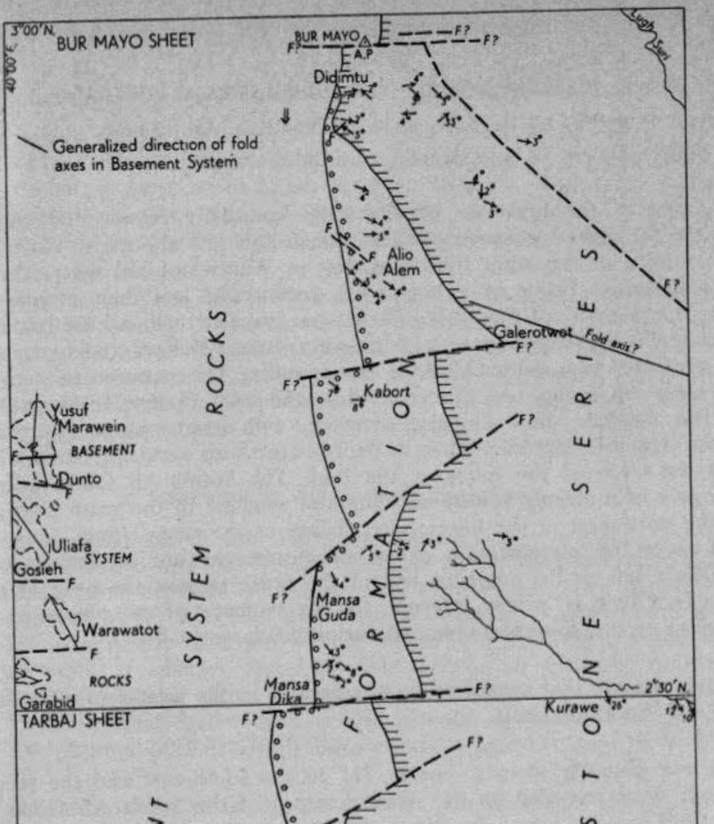


Fig. 6—Structural map of the Bur Mayo-Tarbaj area.

1. Structures in the Basement System

Folds.—There are three main trends in the fold structures in the Ali Gollo hills, namely:—

(1) N.W.-S.E., for example in the Warawatot and South Ali Gollo hills.

(2) Approximately north-south, as in the North Ali Gollo hills.

(3) Approximately W.N.W.-E.S.E., as in the Garabid hills.

The limbs of the folds are usually steep—generally between 60° and 80°. The traces of the anticlinal and synclinal axes often follow one another in close succession—the best example of this tight folding is that in Warawatot hill where three synclines and three anticlines occur in a horizontal distance of less than a mile and a half (2.4 km.). The mapping of the other hills has not revealed such intense folding, although South Ali Gollo approximates it, with possibly three synclines and two anticlines in a distance of about two miles (3.2 km.) horizontally. The extreme hills of the group, namely North Ali Gollo and Garabid, show the least intense folding. Garabid is a near perfect example of a plunging syncline, with axial plunge approximately 10° to the west. The thin quartzite band in the hill forms an excellent marker horizon and delineates the trace of the limbs of the fold. The South Ali Gollo hills appear to consist largely of a steeply folded anticline and syncline in the main ridge, with more folds to the north-east in the lower hills. Owing to the steep slopes, heavy vegetation and talus cover the interpretation of the structures may not be entirely correct. The dips on Uliafa hill, at the southern end of the range suggest the nose of the syncline but its western limb is largely inferred, for no evidence of the presumed outcrop of the paragneiss on that limb was obtained during the survey.

It would appear that compression was greater in the southern parts of the South Ali Gollo and Warawatot hills.

Lineations plunging steeply, one at 31° to the south-east and the second at 52° to the south, were recorded on the western slopes of the South Ali Gollo hills north of Gosieh hill.

Faults.—Faults were observed only in the South and North Ali Gollo hills. Between Gosieh hill and the spine of the South Ali Gollo hills brecciation in the paragneisses was observed, and was taken to indicate the presence of a fault with approximately north-west-south-east strike. A mappable fault, with east-west strike, also separates Dunto from Yusuf Marawein in the North Ali Gollo hills. No signs of brecciation were seen along the fault-line, and the fault appears to be a tear-fault. There is an apparent displacement of about 6,000 feet (1,830 m.) along the fault. A fault is inferred in the area between the northern part of the South Ali Gollo hills and Dunto. This is shown on the maps as having an approximately east-west bearing on analogy with the fault separating Dunto from Yusuf Marawein. There appears to be displacement of about 10,000 feet (3,050 m.).

Faults are postulated between the various hills of the range. There is an apparent displacement of about 10,000 feet between the South Ali Gollo hills and Warawatot, and a still greater apparent displacement between Warawatot and Garabid—probably in the region of about 25,000 feet (7,625 m.). The apparent displacement between North Ali Gollo and South Ali Gollo is of the order of 12,000 feet.

A breccia (specimen 23/194) collected from the eastern slopes of Yusuf Marawein indicates that strike-faulting has also taken place within the metamorphosed sediments Unfortunately the exposure is rather limited.

The faults, mapped and inferred, fall into three groups: east-west tension faults, north-west–south-east shear faults, and north-south shear faults.

2. Structures in the Mansa Guda Formation

Folds.—There is no specific evidence of folding in the Mansa Guda Formation. As the succeeding rocks, namely the Didimtu beds and Bur Mayo limestones, appear to be gently folded, it must be deduced, however, that the Mansa Guda Formation is similarly affected. A poor exposure of laminated silty sandstones at the Muddo water-hole revealed a dip of 60°, but this anomalous dip is probably due to slumping.

Faults.—At two localities, Alio Alem and Kabort, faults cutting the formation were observed, the trends being north-west–south-east and north-east–south-west respectively. At Kabort a purplish silicified rock (specimen 23/46) has developed. The trend at Kabort approximates that of the strike of the formation, whereas the faults in the Alio Alem area are dip-faults. Displacement in the region of about 4,000 feet has probably taken place in the latter.

3. Structures in the Jurassic Limestones

Folds.—Broad flexuring of the sediments appears to have taken place. In the region between Bur Mayo and Galerotwot the strike of the limestones approximates a N.W.-S.E. direction, but between Galerotwot and Kurawe the strike appears to have assumed a more N.E.-S.W. direction, especially at Kurawe. Further south the strike changes to a more northerly direction and at Walgaras it has swung round to nearly N.W.-S.E. once more. It appears, therefore, that there is an anticlinal flexure in the region of Galerotwot, though alone it cannot entirely explain the anomalous features of that area. It is believed that a fault is also present. A synclinal flexure can also be traced in the vicinity of Erib. Both flexures have approximately N.W.-S.E. axes.

South and south-east of Walgaras the strike of the sediments changes noticeably towards an east-west direction and particularly so south of the present area, as can be seen on the aerial photographs.

Minor folds and puckers affect the Jurassic limestones in the Bur Mayo–Tarbaj area, but they are not so common as in the Derkali-Melka Murri area (Thompson and Dodson, 1958, p. 31). Two small synclinal puckers were noticed—one at Singu and the other about 5 miles (8 km.) north of Erib. In neither case do the folds exceed 200 feet (61 m.) in wave-length. The fold up-stream from the Singu dam plunges gently, about 2° on a south-east bearing, and that north of Erib about 10° on a bearing slightly west of south. Small distortions, probably due to compaction and slumping of the sediments, were also observed.

Faults.—The faults depicted on the maps and figures have largely been inferred. It was not possible in the field to determine the nature of the faults or their throws but the apparent horizontal displacements of those that cut across the Mansa Guda Formation are between 10,000 and 15,000 feet (3,050–4,575 m.). It is believed that the throws on the faults are, in fact, probably small. The faults trend in the main directions:—

(1) East-west.

(2) North-east–South-west.

(3) North-west–South-east.

VIII—ECONOMIC GEOLOGY

1. Oil

In a report dealing with the Derkali–Melka Murri area, Thompson and Dodson (1958, p. 32) dealt with the possibility of the occurrence of oil in part of north-east Kenya and the conclusion reached was as follows: "In view of the fact that no visible signs of the presence of oil were found, and as the stratigraphical and structural conditions do not seem favourable within the area mapped, it is considered unlikely that drilling for oil in the area surveyed would meet with any success".

Conditions in the present area are generally similar and it is considered unlikely that natural oil occurs below it. The area must, however, be considered as a unit of the whole basin of Mesozoic sediments in north-east Kenya, and the study of its geology is of importance in assisting the assessment of the basin as a whole. The presence of the Mansa Guda Formation may be perhaps of some importance as indicating the probable occurrence of pre-Jurassic marine sediments below parts of the basin further east, where more suitable conditions for the generation and preservation of oil may have existed.

2. Wollastonite

Within the last 15 years attention has been focused on the extensive possibilities of the calcium metasilicate mineral wollastonite. Its two most important uses are in the paint industry and in ceramics, for example, for the manufacture of rock wool and insulating porcelains, while several other uses, including the manufacture of tiles, have been considered. The properties of wollastonite considered desirable by industry are its whiteness and high proportionate length of the ground material, which is 13 to 15 times that of the diameter.

In the present area, all the crystalline limestones of the Ali Gollo hills include a certain amount of wollastonite which, together with diopside, accounts for up to 80 per cent of some of the rocks. The highest concentration found occurs on the eastern slopes of Warawatot hill, where there is a lens about one hundred and forty yards long and thirty yards wide containing about 20 per cent wollastonite.

The difficulty of separating the wollastonite from its host rock and the remoteness of the outcrops make the occurrences valueless at present.

3. Barytes

A small deposit of barytes, or heavy spar as it is often commercially known, occurs in the Didimtu area as scattered fragments and nodules on an eroded surface of the Didimtu beds.

Barytes is barium sulphate and is utilized in the paint industry, and due to its weight and chemical inertia, it is also used as a filler by the paper, rubber, linoleum and cloth industries. Yet another use is in the preparation of heavy flushing fluids for use in oil-drilling. A high percentage of limonitic impurities and limitation of the deposit, however, make the Didimtu barytes occurrences valueless in present circumstances.

4. Limestone

Both as building-stone and for making cement, certain of the Jurassic limestones in the Bur Mayo-Tarbaj area may be found to be satisfactory, should a demand arise for such purposes. Before choosing material it would be necessary for more detailed investigations to be made into the properties of the limestones and it must be stressed that the following statements are only of a preliminary nature.

The limestones of the Didimtu beds and the Bur Mayo limestones are compact, well-bedded, and relatively pure in certain beds. Apart from the dolomitic samples collected at Bur Mayo, none show any high proportion of cavities. Under the microscope the percentage of impurities—chiefly angular quartz grains—is seen to vary greatly in specimens from the less pure beds, but is often less than 20 per cent. The thin bedding should render quarrying easy, and it is believed that blocks could be trimmed easily.

Apart from any local needs, however, it is unlikely that the limestones would be of economic importance as a building-stone in the Colony.

Cement.—Nine partial analyses of limestones in the area have been made (*see* p. 30) and the majority show percentages of calcium carbonate in excess of 90 per cent and percentages of magnesium carbonate less than two per cent. Such limestones could probably be used for the manufacture of British Standard portland cement by careful selection of magnesia-poor beds. The remoteness of the area, however, renders it most unlikely that the limestones would ever be used for such a purpose.

Lime.—The limestones in the area could be burnt for the production of lime to be used for building purposes and as white-wash. No large scale use has been made of the limestones for these purposes, however, reliance being placed more on the calcining of gypsum—particularly in parts of Northern Province east of the present area.

5. Water-supplies

Water in the Bur Mayo-Tarbaj area is the most precious commodity, and at the same time the most precarious. Permanent supplies are very limited and there is an acute danger that what might be considered permanent now, may in the near future fail. It is stated that some wells have dried up within the memory of living men, such as those at Erib, and others, like those at Abdigani, seem to be near exhaustion. The large quantity of dead trees in the area and the falling water-levels in the old established wells are indicative of a falling water-table. Bestow (1954, p. 33) has concluded tentatively that the present rate of fall of the water-table in the Wajir basin is between two and four inches (five to 10 cm.) per year, but without careful measurements it cannot be stated that the same rate applies in the present area.

The apparently permanent supplies known in the area are those at El Ben and Tarbaj. The water available at the latter place is almost unfit for human consumption due to its high salinity, but unfortunately no chemical analyses are available. The quality of the water at El Ben is good by standards in the Northern Province, though it is a little hard, and its value has been enhanced recently by the construction of concrete parapets over some of the wells, under the Dixey scheme for water-supplies in the Northern Province. Analyses of waters from three wells in the El Ben area are given below:—

Analyses of Waters from the El Ben Wells

No. of well	3C	5	1
Turbidity	None	None	None
Colour	Clear	Clear	Clear
Odour	None	None	None
Suspended matter	Slight	Small amount of organic matter	None
pH	7·3	7·3	7·8
Alkalinity (as $CaCO_3$)		Parts per 100,000	
Carbonate	Nil	Nil	Nil
Bicarbonate	41·0	32·4	32·7
Ammonia— Saline	0·006	0·01	0·012
Albuminoid	0·064	0·008	0·01
Oxygen absorbed (4 hrs. at 80° F.)	0·49		
Chlorides (as Cl)	8·4	165·0	8·6
Sulphates (as SO_4)	8·5	9·6	5·2
Nitrites (as NO_2)	Present	Heavy	Present
Nitrates (as NO_3)	Present	Heavy	Heavy
Calcium (as Ca)	11·5	47·6	14·1
Magnesium (as Mg)	3·4	15·4	3·2
Iron (as Fe)	Trace	Trace	Trace
Silica (as SiO_2)	4·0	3·2	5·2
Total Hardness	42·7	182·4	48·4
Permanent Hardness	1·7	153·8	17·2
Temporary Hardness	41·0	28·6	31·2
Total Solids	81·0	521·5	77·0
Fluorides (as F) parts per million	1·5	0·2	0·2

Commenting on the analyses the Government Chemist writes: "The high ammonia and oxygen absorbed figures (of well 3 C) indicate organic pollution of an animal origin and therefore the water will have to be treated. The fluorides also exceed the limit of 1.0 parts per million for potable waters. The samples from wells one and five are hard waters showing signs of organic contamination and would have to be boiled or chlorinated to render them suitable for human consumption.

Both samples are unsuitable for washing purposes". The Government Chemist's remarks are, of course, based on comparisons with the quality of water demanded in more developed parts of the world.

Dr. F. Dixey, at present Director of the Overseas Geological Survey, put forward the scheme named after him in 1943 with the intention that by the establishment of more water-supplies by means of tanks and bore-holes, the nomadic tribes in the Northern Province could become more static. The change would bring about a reduction of tribal feuds and would relieve the strain on over-grazed areas, as well as being a safeguard against recurring droughts.

A tribute to the Dixey scheme should be paid, and its long-term effects will be achieved if works carried out under it are not abused by the tribesmen. The dams erected will require careful supervision and strict control may have to be applied to see that branches of trees are not put in them—a custom frequently adopted by the Somalis when watering their camels; the dam walls, too, must be protected from the tread of the camels, cattle and goats that throng these water-points during the dry months after the rains. Overgrazing, too, about these permanent supplies will be a hazard—particularly about El Ben.

Under the Dixey scheme, water-supplies, by means of dams, have been inaugurated at Tarbaj, Singu, Afat, Fusfus (South), Mansa Dika, Mansa Guda and Kabort (where two dams were erected). Two dams, just beyond the limits of the present area, have been constructed at Gosieh and Ali Gollo in the Ali Gollo hills. The short rains in November, 1954, were the first that could affect these dams as a whole, but owing to the rather patchy nature of the precipitation some of the dams remained almost dry. The majority, however, were successful and some filled to a depth of about six feet or more. The Mansa Dika dam had already been of great assistance in relieving the water shortage in these parts for several months, as at its middle a sump had been excavated in the partly cemented detrital sands about the base of the Mansa Guda Formation scarp nearby. Such cemented sands (*see* Plate II (*a*)) are quite common along the base of the Mansa Guda scarps, and it is recommended that more of these sumps or "tanks" should be dug in the area. Similar areas of this type of sandstone are found at the base of Tarbaj hill and along the base of the Ali Gollo hills. The construction of tanks is believed to be feasible, too, in the limestone areas in the Ali Gollo hills where the soil cover is very scanty, and large bare patches of rock act as catchments. Likewise small tanks could possibly be constructed on the scarps in the Jurassic limestone country where outcrops of the limestones or calcrete could serve as catchments.

Natural ponds are scattered throughout the area, largely on the end-Tertiary peneplain west of the Jurassic limestones and Mansa Guda Formation, and if deepened would probably be useful for augmenting the limited water-supplies in the area. Depressions at places such as Tarbaj, Dombas, Waragura, Warafaria and Majabau collect a few feet of rain-water and run-off water during the rains and the water remains for a few weeks afterwards. If these places could be deepened—perhaps by a few feet so as to reduce the ratio of surface of water to depth and thereby the percentage losses by evaporation, their reserves of water would last longer.

It is doubtful if there are sites where large-scale masonry or concrete dams could be constructed, but it might be possible to construct further large earth dams in some of the gullies issuing from the Mansa Guda scarps and in the Ali Gollo hills. The construction of a dam at Erib on the claystone is thought to be feasible.

The digging of wells for sub-surface water in the area has not been very successful. Trial wells were dug by the Public Works Department in 1953 at Tarbaj, Harau, Erib Majabau (D.W. 10) and about 11 miles south of Tarbaj, alongside the Wajir road (D.W. 3). Bestow (1954, p 43) states that in the Tarbaj well some 40 feet (12.2 m.)

of red and green grits rest on a pebbly grit, which here forms the aquifer, but an examination of the well in October, 1954, revealed no water at a depth of about 45 feet (13.7 m.). The grits referred to in this well are believed to belong to the Mansa Guda Formation. The wells on the end-Tertiary peneplain, namely wells D.W. 10 and D.W. 3, although dug to 109 feet (33.2 m.) and 98 feet (29.9 m.) respectively, did not encounter any solid rock. Only partly consolidated cream or red sands, gravels, clays and laterites were pierced.

It is doubtful if the deepening of the existing wells or the drilling of bore-holes can be considered as likely to be successful in improving the water-supplies in the area. This particularly applies to the part underlain by the Jurassic limestones. Greater attention, it is considered, should be focused on the surface water-supplies, and attempts should be made to conserve them as much as possible.

IX—REFERENCES

Arkell, W. J., 1952—"Jurassic ammonites from Jebel Tuwaiq, Central Arabia." *Phil. Trans. Roy. Soc.*, London, Vol. 236B, No. 633, pp. 241–313.

Ayers, F. M., 1952.—"Geology of the Wajir-Mandera District, North-east Kenya." Report No. 22, Geol. Surv. Kenya.

Baker, B. H. and E. P. Saggerson, 1958.—"Geology of the El Wak-Aus Mandula area." Report No. 44, Geol. Surv. Kenya. (Published 1959.)

Barth, J. F. W., 1951.—"Theoretical Petrology."

Bestow, T. T., 1954.—"Report on the Geology and Hydrology of Wajir District." Hydraulic Branch, P.W.D., Nairobi (unpublished).

Busk, H. G. and J. P. de Verteuil, 1938.—"Notes on the Geology and Oil prospects of Kenya Colony." D'Arcy Exploration Co. Ltd., and Anglo-Saxon Petroleum Co. Ltd. (unpublished).

Busk, H. G., 1939.—"Notes on the Geology of the North-eastern extremity of the Northern Frontier Province, Kenya Colony." *Geol. Mag.*, Vol. LXXVI, pp. 263–269.

Dacqué, E. and E. Krenkel, 1909.—"Jura und Kreide in Ostafrika." *Geol. Pal.*, Beil. Bd. 28, pp. 150–232.

Dacqué, E., 1910.—"Dogger und Malm aus Ostafrika." *Pal. Geol. oester. ung. und Orient*, Vienna, 33, pp. 1–63.

Dixey, F., 1948.—"Geology of Northern Kenya." Report No. 15, Geol. Surv. Kenya.

Fair, T. J. D. and Lester King, 1954.—"Erosional Land-surfaces in the Eastern Marginal Areas of South Africa." *Trans. Geol. Soc. S. Africa*, Vol. LVII, pp. 19–26.

George, T. N., 1954.—"Pre-Seminulan Main Limestone of the Avonian Series in Breconshire." *Quart. Journ. Geol. Soc.*, London, Vol. CX, pp. 283-317.

Glenday, V., 1923.—"A short account of the Sedimentary rocks found in the Northern Frontier District, Kenya Colony." *Journ. E.A. and Uganda Nat. Hist. Soc.*, Ser. No. 18, pp. 27–31.

Parkinson, J., 1920.—"Report on the Geology and Geography of the Northern Part of the East African Protectorate." Col. Rep. Misc. No. 91.

Saggerson, E. P. and J. M. Miller, 1957.—"Geology of the Takabba-Wergudud area." Report No. 40, Geol. Surv. Kenya.

Stefanini, G., 1925.—"Sur la Constitution Géologique de la Somalie Italienne Meridionale." Comptes Rendus, Int. Geol. Congress, Session XIII en Belgique, 1922, pp. 1059–1072.

Thomson, A. O. and R. D. Dodson, 1958.—"Geology of the Derkali-Melka Murri area." Report No. 43, Geol. Surv. Kenya.

Turner, F. J., 1948.—"Mineralogical and Structural evolution of the metamorphic rocks." Mem. 30, Geol. Soc., America.

Weir, J., 1929.—"Jurassic fossils from Jubaland, East Africa, collected by V. Glenday." Mono. No. III, Hunterian Museum, Glasgow University.

G.P.K. 2991—800—12/57

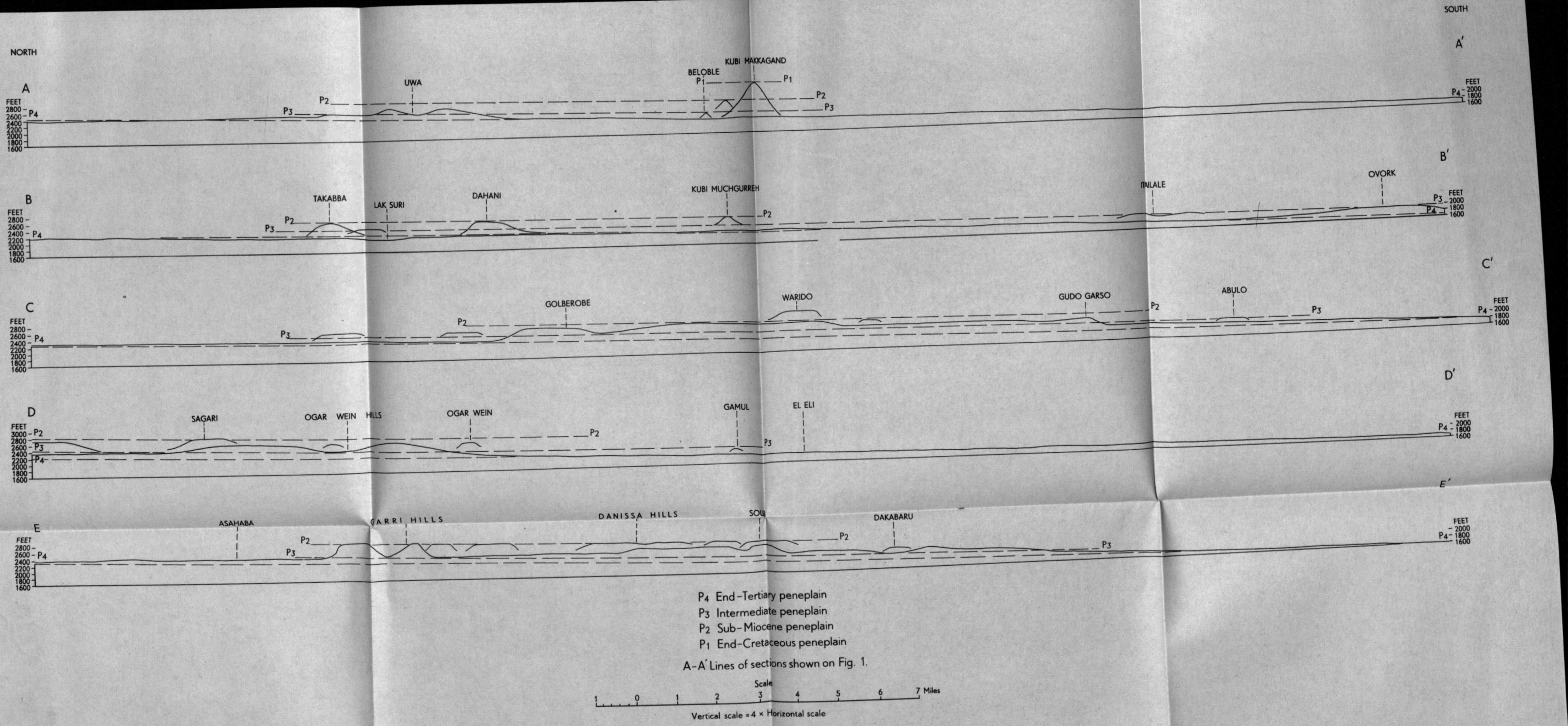


Fig. 6.—Sections showing erosion surfaces in the Takabba-Wergudud area.

GEOLOGICAL MAP OF THE ALI GOLLO HILLS

Based on aerial photographs

Magnetic declination 1°28'W.

TO ACCOMPANY "GEOLOGY OF THE BUR MAYO-TARBAJ AREA" BY A.O. THOMPSON & R.G. DODSON

Del. J.F. CASTELLO

Photo-Litho, Government Printer, Nairobi.