



COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

**GEOLOGY
OF THE
DERKALI-MELKA MURRI
AREA**

**DEGREE SHEETS 7, S.W. and S.E., and 15, N.W. and N.E.
(with two coloured geological maps)**

by

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FOREWORD

The report on the Derkali-Melka Murri area continues the revised account of the geology of north-east Kenya, which was begun in Report No. 40 on the Takabba-Wergudud area. The Derkali-Melka Murri area lies immediately north of that area, and extends to the border with Ethiopia.

The western part of the Derkali area is occupied by rocks of pre-Cambrian age. During the survey it was proved that these ancient rocks consist of two series, one of rocks of Archaean type corresponding with rocks of the Basement System of other parts of Kenya, and a second called by the authors the Ablun series, which is regarded as younger than and folded in the Basement System. The Ablun series consists of quartzites, sandstones, conglomerates, phyllites and limestones that show evidence of thermal metamorphism and may be comparable with the Embu series that was mapped a few years ago in the Embu area (see Report No. 23). Several types of granite were mapped in the Derkali area, and some of them resemble the post-Kavirondian granites of western Kenya. The granites are not seen to invade the Ablun series, but the close association suggests a comparison of that series with some of the goldfields formations of Nyanza Province. During the survey a small amount of gold was found in a breccia that lines a fault delimiting the series.

The remainder of the Derkali-Melka Murri area consists mainly of Jurassic sediments which, on the whole, form a monotonous series of limestones and offered little scope for differentiation in mapping, especially as fossils are often absent or difficult to extract in a satisfactory condition. Small-scale folding was found in the limestones at several localities, and there is a possibility that broad gentle folding also occurs.

The account of the geology given in this report is material for the appraisal of the possibility of the occurrence of oil in north-east Kenya. The area mapped is itself unlikely to contain oil, but knowledge of its stratigraphy is essential in considering as a whole the Jurassic-Cretaceous basin that extends between Wajir and Mandera.

Nairobi,
18th November, 1955.

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Scale 1:125,000	At end
Geological map of the Melka Murri area (degree sheets 7 S.E. and 15 N.E.)	
Scale 1:125,000	At end

ABSTRACT

The report describes an area of approximately 3,000 square miles in the Northern Province of Kenya, roughly half-way between Mandera and Moyale, bounded by latitude $3^{\circ} 30' \text{ N.}$ and the Kenya-Ethiopia boundary, and by longitudes 40° E. and 41° E. The area can be divided broadly into four main physiographic units: (1) a high plain in the west-central northern part of the area where it has been cut on Jurassic limestones; (2) a lower plain capping the pre-Jurassic rocks in the western part of the area, and Jurassic rocks in the eastern part; (3) the pediment area between the two plains; (4) a narrow bevel along the Daua valley, forming part of a still lower and younger surface.

The rocks of the area consist of (1) metamorphosed sediments of the Basement System, extensively invaded by at least three types of granites; (2) the Ablun Series, a group with quartzites, sandstones, conglomerates, phyllites and limestones, considered to be of post-Basement System age; (3) Jurassic Limestones which comprise the Murri Limestones and above them the Asaharbita Beds; (4) Tertiary (?) claystones and conglomerates and (5) Pleistocene to Recent surface limestones, soils and valley deposits. The petrology and stratigraphy of the rocks are briefly described and the sedimentation, metamorphism and structures are discussed.

The possibility of the discovery of oil in the area is discussed and a short description of the local water-supplies is given.

GEOLOGY OF THE DERKALI-MELKA MURRI AREA

I—INTRODUCTION

The limits of the Derkali-Melka Murri area are defined by the meridians 40° E. and 41° E., by latitude 3° 30' N. in the south, and by the Kenya-Ethiopia boundary in the north. It comprises the whole of quarter-degree sheets 15 N.E. and 15 N.W. (Kenya) and the parts of quarter-degree sheets 7 S.E. and 7 S.W. that lie within Kenya. The greater portion of the area lies within the Garri tribal land-unit, the south-eastern corner alone belonging to the Dugidea tribe. The Kenya-Ethiopia boundary shown on the geological maps prepared for this report is that agreed on by the 1951 Boundary Commission but is not as yet formally recognized. It consists of a line from a point on the western edge of the map area between the newly established Kiliwe Hiri police post and the site of the former El Roba police post, extending north-eastward to a point on the Daua Parma river just north of the Melka Murri police post. Two deviations in the boundary-line portion off Imol water-hole to Kenya and Hara-Daua to Ethiopia. East of Melka Murri, the boundary is defined by the Daua Parma river.

The field-work in the area was completed between January and August, 1953, though, during April and May, owing to the seasonal rains, mapping was temporarily suspended. The area was mapped mostly in reconnaissance style. Mapping in greater detail was possible between Melka Murri and Melka Garse, however, because of the good exposures afforded by the down-cutting of the Daua Parma drainage system.

Population.—The area is populated by Somalis of the Garri and Dugidea tribes. The Somalis are essentially nomadic and rarely remain in one locality for more than a month at a time. The density of the population is difficult to estimate as the tribesmen are seldom static, but it is considered that the overall figure is not high in proportion to the total land area. Due to the scarcity of water, the natives are obliged to follow a definite pattern of movement. At the onset of the rainy seasons, they scatter into the interior in search of new grazing for their flocks of sheep, goats, camels, and less commonly, oxen. When all the drinking-holes have dried up it is necessary to return to the sources of permanent water, either along the Daua river or at the wells of El Wak. In their movements the Somalis invariably use the same paths through the bush. Consequently, the area is cut by a widespread network of camel tracks.

Owing to the essentially nomadic, pastoral nature of the Somali, and the lack of a suitable rainfall, few attempts at crop cultivation are made. Near Kukuba and Lugh Adi, millet has, however, been grown in the valley soils. During seasons of heavy rainfall such as those in 1951 and April-May of 1953 the crop yields were considered good, indicating that more determined cultivation might produce reasonable average annual crop yields.

Climate and Vegetation.—The climate is generally dry. Two short rainy seasons occur between the months of March and May, and September and November. Rainfall figures are available only for the north and north-western extremities at Melka Murri and El Roba respectively. The figures for El Roba, which now lies in Ethiopia, can be considered as representative for the north-western corner of the area. Most of the southern portion of the area consists of low ground and the rainfall figures are probably lower than those for Melka Murri or El Roba, and the figures for the El Wak station, which is some 45 miles south of the area, are included for comparison.

The following summary of rainfall is taken from the records of the East African Meteorological Department. The figures for Mandera and Moyale are included as the area surveyed lies nearly midway between these two stations.

Station	Altitude (feet)	Total Rainfall 1952	No. of rainy days 1952	Total Rainfall 1953	No. of rainy days 1953	Annual Average Rainfall	Years Recorded
Moyale (District Office)	3,650	23.62	77	35.19	?	26.13	34
El Roba	3,300	5.30	?	14.92	35	7.05	2
Melka Murri ..	3,300	5.61	?	15.48	25	7.00	3
Mandera (District Office)	1,085	3.92	15	7.55	24	8.20	12
El Wak	1,200	13.21	?	12.54	26	10.93	3

During the dry season between the months of January and March, 1953, the temperatures in the area rarely dropped below 95° F., the maximum shade temperature recorded during these months being 103.5° F. Soon after the rains, during the months of June and July, the temperature did not rise above 95° F.

Generally the vegetation consists of low dense bush with occasional patches of grass. It is, however, subject to fairly wide variation according to the types of soil on which it grows. That growing on the broad expanses of fine-grained valley deposits usually includes a far denser grass covering with fewer and smaller thorn-bushes. The red soils derived from Basement System and Jurassic rocks are covered by a compact thorn-bush growth. In the Banissa area, dark red soils derived from Tertiary (?) sediments support fewer though larger and more leafy bushes, and an abundance of *sansevieria*. Finally, the banks of the Daua Parma river are lined with a fairly extensive belt of doum palm trees. The doum palm fruit which consists of a thin, fibrous skin covering a hard kernel, is eaten extensively by the Somali tribesmen.

Communications.—Considering the paucity of habitations and the migratory nature of the Somalis, the area is fairly well served with roads. A road runs close to the Kenya-Ethiopia border along the northern edge of the area, while another more direct road from Rahmu to Moyale passes through the centre of the area. A north-south road joins Derkali to Takabba in the area to the south. Generally the roads are in fair condition, and owing to the policy of closing them during the rainy seasons, they remain passable with a minimum amount of maintenance. Where there is a thick cover of fine red soil, gully erosion takes a heavy toll during the rainy seasons. Alternatively, the valley deposit soils are liable to widespread cracking and pot-holing when they dry up after the rains. Very little vehicular traffic apart from that of the Administration and the Police uses the tracks. The widespread network of camel tracks permitted extensive use of bicycles for geological traverses.

The police posts at Melka Murri and Kiliwe Hiri are in daily radio contact with the district station at Mandera. Apart from this, no postal or telegraphic facilities exist in the area.

Maps.—No suitable maps of the southern portion of the area were available as a base for geological survey. In the north, preliminary plots were available and were found to be reasonably accurate in most areas except for the north-eastern boundary along the Daua Parma valley. Field evidence was mostly plotted on tracings of air photographs and later transferred to maps on the scale of 1:83,333 for reproduction.

For convenience of printing the geological map of the whole area has been divided into two, the Derkali sheet and the Melka Murri sheet. In the body of the report the two are, however, considered together as a whole.

II—PREVIOUS GEOLOGICAL WORK

The area has received a fair measure of geological attention during the last thirty years. V. G. Glenday (1925)* gave a brief description of the Mesozoic rocks found in the whole of north-east Kenya, with a section at Muddo Erri, which is four miles east of the eastern boundary of the map-area, between the Rahmu-Melka Murri road and the Rahmu-Derkali road. A monograph by Weir and others (1929) was later published on the fossils collected by Glenday, and provided evidence that the rocks are Jurassic in age, ranging from Bajocian-Bathonian to Kimmeridgian, or even Tithonian. The limestones of Derkali were dated doubtfully as Kimmeridgian, those of Dedacha Korum Adau as lower or middle Kimmeridgian, while the 40-foot section at Muddo Erri was believed to be Bajocian-Bathonian at the base and Corallian at the top.

A report on the oil prospects of Kenya, including chapters on the Northern Province, was written by H. G. Busk and J. P. de Verteuil in 1938. Sandstone hills surrounded by the Jurassic limestones in the area south-east of the present map area were considered as the remains of islands that stood up in the Jurassic sea. Evidence from Derkali, where the authors stated they had found sandstones intercalated between the gneisses and the limestones, was quoted in support. The same ideas were repeated by Busk (1939). In a section given in the 1938 report the sandstones reported at Derkali are shown as continuous below the

*References are given on p. 34

limestones with the sandstones of the Marehan hills. On a map the limestones of the Derkali-Rahmu area are indicated as under 2,000 feet in thickness, and thinning both to the east and the west.

F. Dixey (1948) traversed the Derkali-Rahmu area in 1943, and recorded (*op. cit.*, p. 39) 150 feet of limestone with a thin basal pebble bed at Derkali, and 1,500 feet of limestones with calcareous mudstone and shale bands at Melka Murri. He also noted silicification of the limestones near Derkali, considering it as a surface phenomenon.

F. M. Ayers (1952) spent approximately a year in the field investigation of an area of about 17,000 square miles in the north-eastern part of Northern Province. This area included the smaller area which is the subject of the present report. Ayers described the salient features of the physiography, the geological succession of the pre-Jurassic rocks, the Jurassic and post-Jurassic sediments and the younger formations, and gave an account of the structures and geological history of the area, and finally, discussed the prospects of discovering oil. Two appendices to the report listed and dated fossils found by Ayers and by geologists of an oil company who examined the area under his guidance. An interim review of Ayers' work in Northern Province was given by Temperley (1952) in a review of the Gondwana rocks of Kenya.

The area to the south of the Derkali-Melka Murri area was mapped in 1953 by E. P. Saggerson and J. M. Miller, their conclusions being printed in Report No. 40 (1957) of the Geological Survey of Kenya.

III—PHYSIOGRAPHY

1. Topography and Drainage

The western portion of the area (*see* fig. 4 at end) consists of a gently undulating plain, the monotony of which is broken by inselbergen or granite tors, concentrated mainly in the north. The area south-west of Dugididera is devoid of notable relief. The remainder of the Basement System area consists of ground rising gently to the north-east to a higher plain.

A plain corresponding with the western plain occupies the south-eastern part of the area and continues as a bench along the flank of the Daua valley. Between the two sections of the plain the ground rises gently again to the higher plain, which stretches from Melka Murri to Derkali and occupies most of the north-western part of the area. The western part of the higher plain, near Banissa, is covered by sediments of Tertiary (?) age, which give rise to a slight plateau. The area of younger sediments is typified by an abundance of water-holes such as Banissa, Imol, Luliss, Woko and Merille. These water-holes are usually shallow circular or oval depressions of various sizes, although they are seldom more than two hundred metres in diameter. The factors responsible for the excavation of these water-holes and for the Asaharbito (Arsharbit) depression in the south-east corner of the area are probably similar to those that led to the formation of the "pans" of the Transvaal Highveld in South Africa. Du Toit (1939, p. 425) suggested that the "pans" developed largely as a result of wind erosion. The Asaharbito beds, in which the Asaharbito depression occurs, and the Tertiary (?) claystone of the Banissa area are easily weathered, soft and friable. Accumulations of rain-water disintegrate the sediments, forming clays, which when dried become fine powdery soils easily transported by wind. The continuous removal of weathered material by wind following each rainy season in time excavates the depressions. It is probable that excavation of the "pans" has been hastened by removal of mud by the wallowing of herds of wild animals in former times, and by domesticated animals in recent times. The fact that the pans in the Tertiary (?) sediments retain water for a greater length of time than that at Asaharbito, is probably due to the claystones being more impervious than the marly limestones, and to the cooler atmosphere about Banissa.

In sharp contrast to the surrounding plains the Daua valley in the Melka Murri area is typified by deeply dissected, youthful tributaries, frequently with small cliff faces. This is due to disturbance in recent times of the grade of the Daua, which is the only perennial river in the area. The most impressive topographical feature of the valley is the abruptness of the down-cutting at the heads of the minor tributaries, which are rapidly retreating upstream. The depth of dissection of the main valley decreases downstream, from about 1,500 feet at Melka Murri to about 500 feet at Melka Garse on the eastern boundary. In the vicinity of

Melka Garse the down-cutting is less well-defined and lateral erosion is evident along most of the major tributaries. The course of the main river is undergoing lateral erosion, and east of the area mapped wide plains have been carved between Rahmu and Mandera. A curious feature of the widened valley bottom of the Daua is the presence of three fairly large saline ponds in close proximity to the river, one at Melka Debayu, about two miles downstream from Melka Murri, one between Melka Debayu and Melka Garse, and a third at Melka Garse. Although one is as close as 80 metres to the river it is, like the others, so saline that the water is totally unfit for human consumption. Goats, sheep and camels are greatly attracted to the saline waters, as they are to dry "salt-licks". The ponds when they contain water support luxuriant growths of water-lilies, rushes and aquatic weeds, which attract thousands of birds to them. Within a month or two after the rains have stopped, however, the water in the ponds rapidly disappears with the onset of the hot weather. The high salinity of the ponds is probably the result of continuous evaporation of waters charged with salts in solution which have flowed down from the surrounding limestones into hollows beside the river. The hollows may possibly represent remains of natural hollows excavated by the river water in times of high floods.

Most of the river courses are ill-defined very shallow valleys, choked with fine-grained sediments. With the exception of the Daua it is doubtful if any of the rivers flow for more than a day at a time. Three predominant drainage trends are apparent in the area. In addition, areas of internal drainage occur in the Banissa and Asaharbita areas. The western portion of the area is traversed by the Lugh Suri which drains the entire area occupied by the Basement System rocks and the western limits of the Jurassic limestones, flowing in an approximate north-south direction towards Takabba, south of the present area.

Eastward, the predominant drainage on the Jurassic limestones follows a west-east trend as evidenced by the larger river-courses such as the Lugh Dent, Lugh Adi and Lugh Wachu. Further east, beyond the limits of the map area, these river-courses swing northwards and finally join the Daua. The main river-courses are mature. Minor river-capture can be traced at such localities as 10 miles south of Tarbe and on a tributary of the Lugh Go'gal about 10 miles south of Dedacha Korum Adau. Near Ollo, cut-off meanders are clearly visible on aerial photographs.

Few of the features commonly associated with drainage in limestone areas under humid conditions are present. A single sink-hole of notable size was discovered near Arda Garbicha just off the Melka Murri-Rahmu road. In addition, a few small sink-holes not larger than three metres in diameter occur in the vicinity of the Lugh Dent.

2. Erosion Surfaces

As indicated in Fig. 4, and as can be determined from drawing cross-sections based on the form-lines, there is a possibility of at least three erosion surfaces in the area, viz.

- (3) the Daua valley (Pleistocene) surface
- (2) the Lugh Suri-Kiliwe Hiri (End-Tertiary) surface
- (1) the Melka Murri-Merille-Ablun (Intermediate) surface

These surfaces correspond with Dixey's Pleistocene incutting (3), End-Tertiary (2) and Mid-Tertiary peneplains (1) as shown on his map (Dixey, 1948, p. 18), and probably also correspond with King's Victoria Falls, African and Post-Gondwana cycles (Fair and King, 1954, p. 25).

(1) THE INTERMEDIATE SURFACE

The Intermediate surface occupies a large part of the northern section of the area, primarily covering the limestones, but transgressing on to the Basement rocks in the west. On this surface, the Banissa claystones and conglomerates were deposited. On its eastern edges it is being attacked by the Daua drainage, while on the south and western edges, the Lugh Suri drainage is cutting into it.

It has been argued (Dixey, 1948, p. 16) that the Derkali Plateau represents a portion of the sub-Miocene surface, and that the Willeh, Raiya and Babo hills rise as residuals from it, though in a diagram (*op. cit.*, opp. p. 18) it is suggested that they may be of structural

significance only. The hill-tops would, if they are erosion bevels, represent the End-Cretaceous peneplain. The present writers believe that the Derkali plateau is part of an intermediate surface between the End-Tertiary peneplain, and residuals of the sub-Miocene surface on the Willeh, Babo and Danissa hills to the east beyond the bounds of the area mapped. This conclusion agrees with the findings of Miller and Saggerson (1957, p. 5) who mapped the Takabba-Wergudud area, which lies immediately south of the present area.

The intermediate surface slopes gently to the east-south-east at a rate of about 19 feet per mile, indicating that it has suffered some tilt. Dixey (*op. cit.*, map opp. p. 18) considered that near Derkali the surface slopes at 16 feet per mile to the east.

A feature of interest is the more pronounced scarp that has developed on the western side of the surface—that is, near Ablun and Derkali. It is believed that this is due to a structural effect—the incising streams here have to cut across the strike of the rocks, whereas on the eastern side, the Daua drainage is more or less down the dip-slope of the limestones. For this reason it is not easy to see either in the field or on cross-sections the boundary between the Intermediate surface and the pediment that lies between it and the End-Tertiary surface. Thus it may be possible that a large portion of what is shown on the figure as the pediment may largely belong to the Intermediate surface. This particularly applies to that area between Merille and Asaharbito, and between Merille and Dedacha Korum Adau.

(2) THE END-TERTIARY SURFACE

This surface is best developed in the Lugh Suri drainage area. In the eastern portion of the area it is narrow and has been largely removed during the Pleistocene erosion cycle, the noticeable effects of which are confined to the Daua river drainage area.

In the Kajaja region, probably largely because of the underlying soft Asaharbito marly rocks, degradation of the End-Tertiary surface has taken place so as to produce a “pseudo-surface” below the End-Tertiary, and which is believed not to be a part of the pediment above the Pleistocene surface. The same effect is being reproduced in human time in the Asaharbito depression, where by deflation the floor of the depression is developing into a surface of sizeable proportions.

The surface slopes in a general southerly direction at the rate of approximately 14 feet per mile.

(3) THE PLEISTOCENE SURFACE

Confined to a narrow bench along the Daua river, the Pleistocene surface can be followed by small remnants clinging to the steep sides of the valley. It increases in height from about 1,200 feet near Melka Garse to about 1,300 feet below Melka Murri.

IV—SUMMARY OF GEOLOGY AND GEOLOGICAL SUCCESSION

The area is mainly occupied by rocks of Jurassic age. Older rocks, belonging to both the Basement System and a post-Basement system, constitute about one-sixth of the area and occur in the western parts only. Rocks younger than the Jurassic sediments occur largely on the high ground in the Banissa area, and at scattered localities throughout the whole area. The succession is as follows:—

			Thickness (feet)
Pleistocene—Recent	Soils, sands, kunkar limestones, valley deposits and secondary limestones ..	variable	<100
Tertiary (?)	Banissa Beds—claystones and conglomerates	up to 100	
Jurassic (Middle) {	Callovian Asaharbito Beds	<200	
	Bathonian Murri Limestones	up to 1,700	
	Bajocian		
Precambrian (?)	Ablun Series	>5,000	
Archæan	Basement System, extensively invaded by granite	?	

Basement System.—Rocks belonging to the Basement System are scantily represented in the area. Goljo hill is composed mainly of quartzite widely invaded by granite, but in addition, a narrow lens of finely banded migmatite was found on it. Similar quartzite as well as impure crystalline limestones are exposed in the vicinity of Derkali. Quartzite float and a few pieces of banded ironstone were found in the western parts of the area and, it is thought, may be derived from the Basement System. It is noteworthy, however, that banded ironstones elsewhere in Kenya are found in the Nyanzian System, and are not known in the Basement System.

Granites.—Three main types of granite were found in the vicinity of Kiliwe Hiri, Goljo, Kukuba and Derkali. They comprise grey granites which are either fine-grained or porphyritic coarse-grained types, pink granites and a variable group including granophyric granite, fine-grained granite, and altered granites. At the margins of the intrusions, hybrid granites have developed. At Goljo the granite is seen in contact with Basement System quartzites.

Possibly associated with the granitic intrusions are pegmatites, aplites and quartz veins. Minor intrusions of unknown age, but which are believed to be younger than the granites, are lamprophyres, basalts and tremolite-bearing meta-intrusives.

Ablun Series.—Near the Ethiopian border between Kiliwe Hiri and Imol water-hole, a series of steeply folded metamorphosed sediments comprising sandstones, quartzites, conglomerates, phyllites and limestones, forms several conspicuous ridges. The sediments show evidence of thermal metamorphism.

The Murri Limestone Series.—Rocks of the Murri Limestone Series, which is known to be of Jurassic age by the fossils it yields, occupy the greater portion of the area surveyed. They are overlain by a thin layer of Tertiary (?) sediments in the Banissa area and at other places by accumulations of soils, kunkar limestones, etc. Limestones predominate in the series, though marlstones are often intercalated as narrow beds especially in the upper part. Massive limestone bands are rare. Recognizable fossils are not common in the limestones, grey varieties often being recrystallized and non-fossiliferous, while brown and yellow varieties generally contain much shell debris.

The best exposures of the Limestone Series are along the tributaries of the Daua Parma river between Melka Murri and Melka Garse.

The Asaharbita Beds.—Overlying the Jurassic limestones in the south-eastern corner of the area there are thinly bedded marls and limestones. The beds probably do not exceed a thickness of two hundred feet but since they are nearly horizontal they occupy a broad area, and as the weathered products of the marls are conspicuously white they can readily be recognized, particularly on aerial photographs. Several notable horizons occur within the series, the most extensive being a highly fossiliferous dark brownish limestone. Towards the upper part of the succession a distinctive flaggy calcareous siltstone presents a fairly reliable marker horizon.

The Banissa Claystones and Conglomerates.—In the Banissa area the Jurassic limestones are overlain by sediments believed to be of late Tertiary age, that were laid down on the Intermediate erosion surface. The total thickness of the sediments does not exceed 100 feet, (30.5m.) and they are composed mainly of fine-grained claystones with a thin layer of conglomerate, which probably does not exceed 15 feet (4.6m.) in thickness, capping the series.

Pleistocene surface limestones, valley deposits and soils.—The youngest deposits in the area include crusts of kunkar limestone, pale greyish valley-deposit soils choking the river-courses, and soils produced by the weathering of the various rock types. The soils derived from the pre-Jurassic rocks are dark reddish and usually contain fragments of quartz. The limestone soils are mostly brownish sandy types, while weathering of the Marl Series produces fine-grained, white, powdery material.

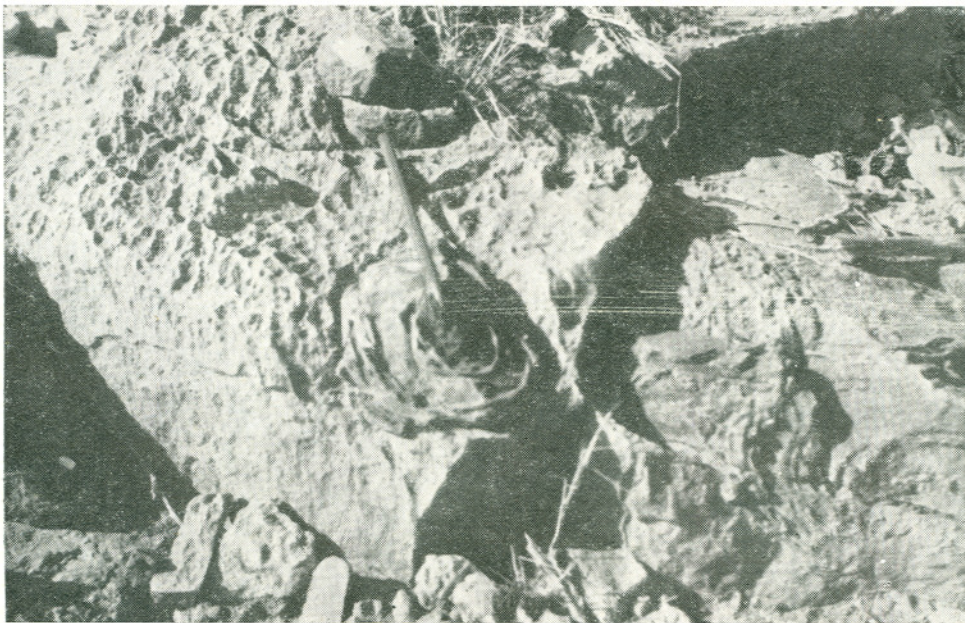


Fig. 1.—Algae (?) in the Asaharbito Beds, Ollo. (Note pencil for scale.)

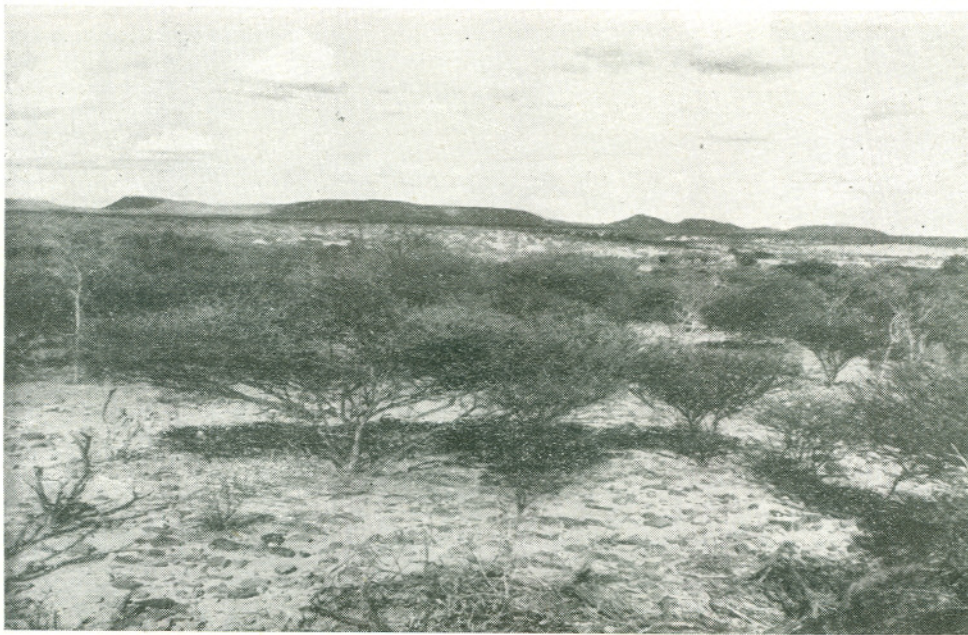


Fig. 2.—Looking across the Asaharbito depression towards the Danissa hills. Note the flaggy laminated calcareous sandstone in the foreground, the white marls in the middle distance and the hills capped by sandstone.

Plate II



Fig. 1.—Gentle folds in the Murri Limestones in Lugh Dent, approximately 5 miles S.S.W. of where the Rahmu-Melka Murri road crosses Melka Garse.



Fig. 2.—A close-up of one of the folds in Fig. 1. Note the gentle plunge of the fold towards the viewer, that is to W.N.W.

V—DETAILS OF THE GEOLOGY

1. The Precambrian Rocks

Less than one-quarter of the area surveyed is occupied by rocks of Precambrian age. They occur along the length of the western boundary and extend eastwards until they are overlain by Jurassic limestones. The Precambrian rocks comprise representatives of the Basement System, extensively invaded by granites, and probably a group of much more weakly metamorphosed beds which will be referred to as the Ablun Series. The general paucity of outcrops prevents interpretation of the structural relationships of the two groups but it is believed that the Ablun Series is of post-Basement System age.

(1) BASEMENT SYSTEM

Three Basement System rock types were recognized in the area surveyed, viz. quartzites, crystalline limestones and migmatites. In addition several large blocks of banded ironstone float were discovered and, whilst there is doubt that such rocks form part of the Basement System, the ironstone occurs in a part of the area where no trace of the Ablun Series or similar series was found, and is described here for convenience.

(a) *Quartzites*

Ignoring the presence of float and boulders of doubtful origin, three exposures of Basement System quartzite were discovered. A small hill, alongside the Derkali-Moyale road, about three miles west of Derkali, is composed entirely of quartzite. This hill appears to be the western extension of an outcrop which occurs in an embayment of the Jurassic limestone junction south-south-west of Derkali. Further west, the eastern peak of Goljo hill, south of the Kukuba-Kiliwe Hiri road, is composed chiefly of quartzite, and may conceivably represent the same horizon as the quartzites nearer Derkali.

The quartzites are typically fine-grained with equigranular, saccharoidal textures. The colour is subject to wide variation. A thin section of specimen 15/254*, a pink quartzite collected from south of Derkali, shows a compact mosaic chiefly composed of quartz lightly dusted with fine flakes of muscovite, and associated with a few scattered iron ore grains. The quartzite forming the small hill west of Derkali, though of similar texture, is dark bluish with unevenly distributed reddish patches. The bluish colour of the quartzite appears to be due to the presence of finely disseminated grains of iron ore. The thin section of specimen 15/314 from this hill contains about seven per cent of iron ore, which appears to be chiefly magnetite, and reveals the presence of scattered muscovite crystals, blue tourmaline grains and zircon. The grains of ore vary greatly in size and the smaller grains tend to crowd the borders of quartz grains. A thin section of specimen 15/315, from the same locality but taken from a slightly sheared zone, shows directional orientation. The effect is clearly marked by the alignment of the grains of magnetite, often producing "flow" structures around the quartz grains. Reddish patches in the hand-specimen are due to localized oxidation of the magnetite and dispersion of the oxidation products.

Goljo hill consists predominantly of quartzite invaded by granite. Within about ten feet of the contact the quartzite is completely recrystallized, and beyond that distance partial recrystallization is frequently apparent. Specimen 15/320, a greyish vitreous-looking quartzite from Goljo hill, shows the recrystallization resulting from the effect of the granitic intrusion. The quartz grains have lost their equigranularity and now form a generally coarse-grained irregular mosaic, through which are scattered abundant flakes of brown biotite and scanty flakes of muscovite. No tourmaline was observed, which is perhaps detrimental to the correlation of this quartzite with that nearer Derkali.

Between Kukuba and Goljo hill a few scattered specimens of quartzite were discovered though it was considered probable that most of them originated from the three exposures described. Further south but a single boulder of quartzite float was discovered, in the extreme south-western corner of the area. Microscope examination of the specimen (15/307) revealed that it is a sheared muscovite-bearing type, and that it contains a few tourmaline grains like the quartzite near Derkali.

*Numbers prefixed by 15/ and 7/ refer to degree-sheet specimens in the regional collections of the Geological Survey of Kenya

(b) Crystalline Limestones

Due west of Derkali a band of Basement System limestone extends from the edge of the overlying Jurassic limestones to the vicinity of Kukuba, where the outcrops are concealed by an overburden of soils. The southern margin of the band is exposed on the Derkali-Kukuba road. Further north-westwards, near Ablun water-hole, a few small exposures of limestone may be of similar age, though it is considered more probable that they belong to the younger Precambrian series of that locality.

The exposures on the Derkali-Kukuba road include both pink marble relatively free of impurities and lenses of impure limestone. The pink marble is coarsely crystalline and only rarely includes small grains of iron ore. The impure limestones are in part serpentinized, i.e. they are ophealcites. In the hand-specimen they are bluish-green, mottled with reddish-brown iron-oxide staining, and an irregular network of narrow white calcite veins gives the rocks an attractive appearance. Specimen 15/317 from the side of the Derkali-Kukuba road shows serpentine replacement of dolomite (?). The constituent minerals include serpentine, dolomite, patches of partly limonitized dolomite, and strongly pleochroic bluish-green chlorite.

(c) Banded Ironstone

Approximately three miles north of Dugididera a large boulder of finely banded ironstone was discovered. Later, several smaller specimens were found in the immediate vicinity, but none was found *in situ* so that the field relationships of the ironstone remain obscure. Judging from its comparative resistance to weathering, the small amount of float found indicates that the body of ironstone from which it was derived is probably small. Though such rocks are unusual in the Basement System it is possible that the float was derived from a small lens or inclusion of banded ironstone in the system.

The ironstone is finely banded, the average thickness of the bands seldom exceeding 5 mm. On a freshly fractured surface the banding consists of alternating metallic-lustred and cinnamon-coloured layers. However, after a few weeks of exposure the metallic bands are oxidized to a reddish brown colour, while the cinnamon-coloured layers remain unchanged. In an advanced state of weathering, a ribbed effect is produced by the greater resistance of the non-metallic layers.

The metallic-lustred mineral is feebly magnetic and has reddish brown streak, and it is concluded that it is probably martite. Spot tests failed to reveal the presence of titanium. Microscope examination of specimen 15/377 shows parallel alignment of elongated martite aggregates and grains, which have sometimes been fractured and parted by quartz veinlets, while the intervening space is occupied by quartz. Needly crystals of pale-reddish limonite are scattered through the rock but are chiefly concentrated along the margins of the limonite grains (see Fig. 2a).

(d) Migmatites

Migmatites, i.e. rocks which are obviously derived from the mixing of introduced material with older formations, are poorly represented in the area. The rocks most liable to migmatization are pelitic to semi-pelitic types as described in southern Kenya by Bear (1952, p. 19), Dodson (1953, p. 7) and Schoeman (1951, p. 11), etc. The rocks that are least likely to suffer as a result of the process have been found to be quartzites and limestones.

The single exposure of migmatite found in the present area occurs as a band in the quartzite of Goljo hill. Unfortunately weathering has reduced the exposure to a soft, friable condition but it can be seen that it is finely banded, consisting of alternating quartzo-felspathic and biotite-rich laminations. It is concluded that the existence of this migmatite is due to protection afforded by the surrounding quartzite, which, while permitting the introduction of metasomatic material, prevented complete assimilation by the intrusive granites.

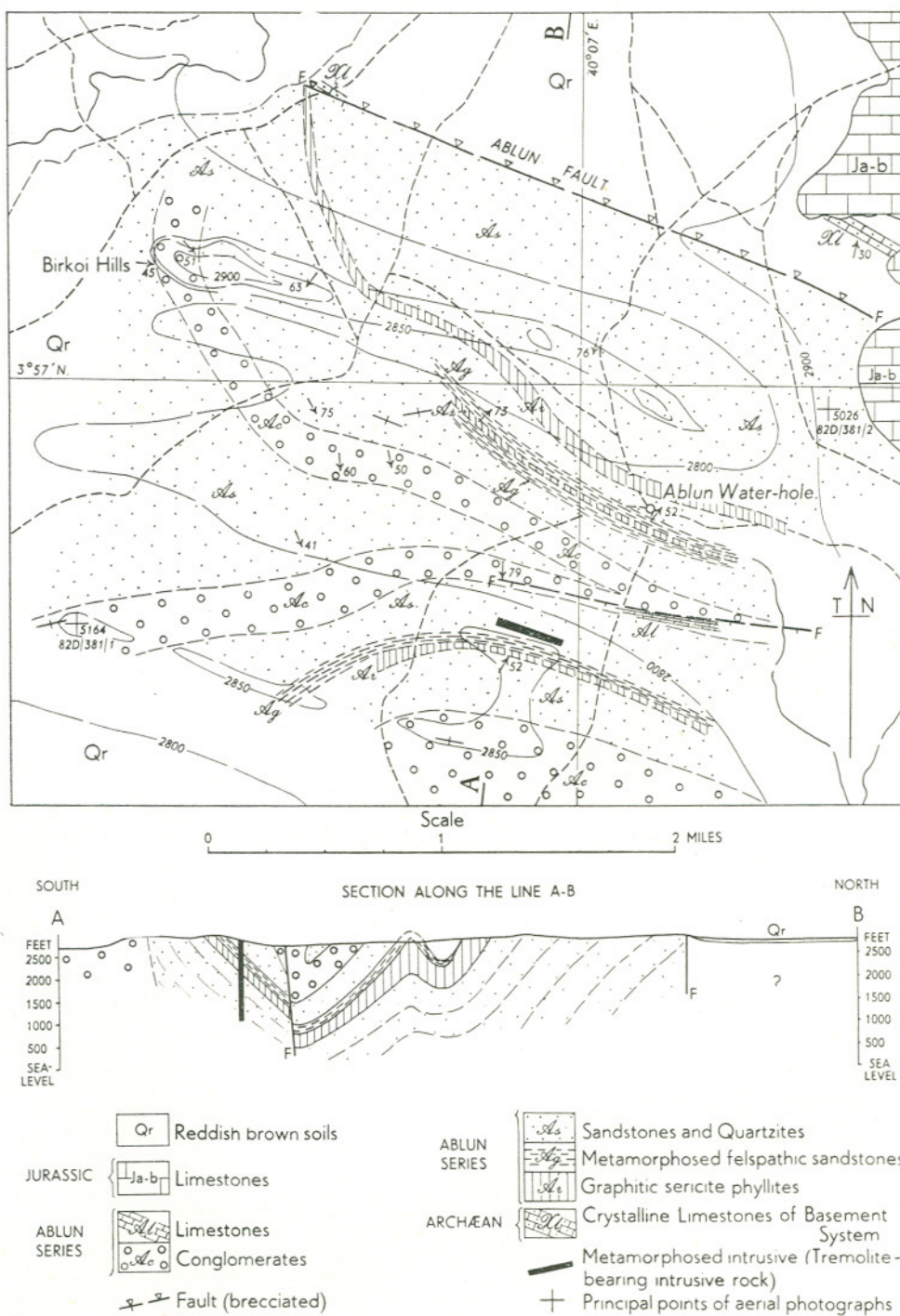


Fig. 1.—Geological map of the Ablun water-hole area.

(2) ABLUN SERIES

In the vicinity of Ablun water-hole a number of hills collectively known as Birkoi are composed of compactly folded, steeply-dipping sediments (Fig. 1 and Plate III, Fig. 2). The field relationship of this series and the surrounding granites is not clearly seen but there are indications that the sediments have suffered thermal metamorphism. The following rock types were recognized in the series—limestones, conglomerates, quartzites and sandstones, metamorphosed feldspathic sandstones and graphitic sericite phyllites. The thickness of beds represented must be greater than 5,000 feet, and the succession appears to be:—

								<i>Estimated thickness (feet)</i>
7. Sandstones	..	..	..	..	..	..	..	>200
6. Conglomerates	..	..	..	..	..	..	..	500
5. Sandstones	..	..	..	..	..	..	..	600
4. Metamorphosed feldspathic sandstones				..	..	..		200
3. Graphitic sericite phyllites	..	..	..	..	..	..		300
2. Sandstones and quartzite	..	..	..	..	..	..		>2,000
1. Conglomerates	..	..	..	..	..	..		>2,000

—Base not seen—

(a) *Limestones*

Several exposures of limestone were discovered in the Ablun area. In contrast to the medium-grained crystalline limestones of the Basement System, they are invariably fine-grained.

The limestones were found to vary but little texturally, though they show an appreciable variation in composition. The purer types are pale greyish to pale pink, while the impure types vary from dark grey to dark brown, containing impurities both disseminated through them and as segregation clots. The clots are composed mainly of iron-stained quartz. Specimen 15/342 from south of Ablun water-hole is a fine-grained dark bluish grey limestone. The exposure is cut by numerous narrow calcite veins and, less commonly, by quartz veins. Microscope examination of a thin section revealed that the rock has equigranular texture and is composed almost entirely of calcite. Quartz is mainly present in veinlets, but occasional grains are isolated among the carbonate and may possibly be allogenetic. The calcite of the rock has recrystallized more coarsely along the line of some of the veinlets. Sporadic small crystals of muscovite are scattered throughout the slide.

(b) *Conglomerates*

Several good exposures of the conglomerates occur in the Ablun area. Bear (1952, p. 29) has described an intraformational conglomerate in an area occupied by apparently pre-Cambrian but post-Basement System rocks in the Embu district of central Kenya. There is an appreciable similarity between the Embu conglomerate and the Ablun type. Typically, the Ablun conglomerates are pale grey and consist of a medium- to fine-grained pelitic matrix supporting ill-sorted, but usually rounded pebbles orientated along the strike. The conglomerates are associated with pebble-free bands, though sporadic concentrations of pebbles occasionally occur in such bands. Beds with a high percentage of pebbles are frequently bounded by barren layers. The matrix shows variation both according to the amount of mica present and the constituent grain size. Weathering of the conglomerate produces a lumpy effect, the more resistant pebbles projecting from an irregular furrowed surface.

The pebbles are usually elongated and reach a maximum length of about 100 mm., although the average length is about 15 mm. While the pebbles constitute about thirty-five per cent of the composition of the rocks, large pebbles account for only about eight per cent. The pebbles are usually composed of quartz, less commonly of quartzite and the large

pebbles are invariably rounded, the most common form being cylindrical. The smaller fragments are frequently only sub-rounded and rarely crystal faces can be seen. Where the conglomerate has been subjected to directed pressures, augen-textures have been produced. Weathered surfaces of the rocks show the directional orientation of the constituent minerals, while in thin section signs of shearing can usually be detected.

The matrix of the conglomerates is composed mainly of quartz, mica, feldspar and accessory minerals. The quartz grains are normally a little larger than the other constituents and frequently exhibit strain effects. Sometimes they occur in lenticular aggregates or veinlets, and obviously in parts the quartz has been rendered mobile. The micas consist of muscovite and green biotite, and are associated with a few flakes of chlorite or partly replaced by it. Of the feldspars, microcline is the most abundant in parts although in other parts grains of sodic plagioclase are abundant, and small grains of orthoclase do occur. The most frequent accessory mineral is iron ore which occasionally forms large sieved grains up to a millimetre across. In addition small amounts of calcite, zircon and rare apatite were recognized.

Examination of specimens 15/338 and 15/355, which are conglomeratic and in part schistose biotite-bearing rocks, revealed evidence of mild granitization. Small amounts of replacive feldspar occur interstitially to the more abundant quartz, though it is considered that some of the muscovite present may have been formed by thermal metamorphism of the sediments. There are also large feldspar porphyroblasts, mainly of microcline, that are considered to be of metamorphic origin though it is possible that some of the largest may have originated as detrital minerals. The green biotite is probably not detrital.

(c) *Sandstones and Quartzites*

Sandstones are the most widely occurring rock-types of the Ablun Series, forming the greater part of the low-lying ground. They vary greatly both in texture and composition but are typically medium-grained and faintly banded. Small amounts of mica are present, usually in thin pockets a few millimetres long. Cleavage is usually well-developed, giving the sandstone a slightly flaggy appearance in the field. Specimen 15/354 from the north-western limit of the outcrop is composed mainly of quartz with a small amount of microcline feldspar. Microscope examination shows directional orientation and that recrystallization of both the quartz and feldspar has taken place.

Eastward, near the junction with the Jurassic limestone, black quartzite forms a discontinuous outcrop immediately south of a small water-hole. The outcrop consists of rounded brown boulders, not unlike weathered dolerite. In the hand-specimen the quartzite is fine-grained and where unaltered is black, but the weathered crust is frequently as much as twenty millimetres thick. Microscope examination of specimen 15/335 revealed a fine-grained mosaic composed almost entirely of interlocking quartz grains associated with scattered muscovite and occasional apatite grains. The colour of the fresh quartzite is due to the presence of minute grains of iron ore evenly disseminated through the rock.

(d) *Metamorphosed feldspathic sandstones*

Metamorphosed feldspathic sandstones form prominent bouldery ridges near Ablun water-hole. They are usually dark grey medium-grained rough rocks. While they normally appear to be homogeneous, faint banding is sometimes visible on freshly fractured surfaces.

The sandstones are composed mainly of quartz and feldspar. Microscope examination of specimen 15/365 from near Ablun, revealed a compact mosaic of interlocking quartz and feldspar grains with small amounts of mica, the whole patchily dusted with minute specks of iron ore. The specks of ore form clouds in association with aggregates of fine-grained feldspar crystals. Specimen 15/364 from the same vicinity contains an appreciable amount of orientated brownish green biotite and colourless muscovite. In addition there is accessory calcite and rare zircon.

Junctions between this distinctive rock-type and the adjacent sandstones are invariably gradational.

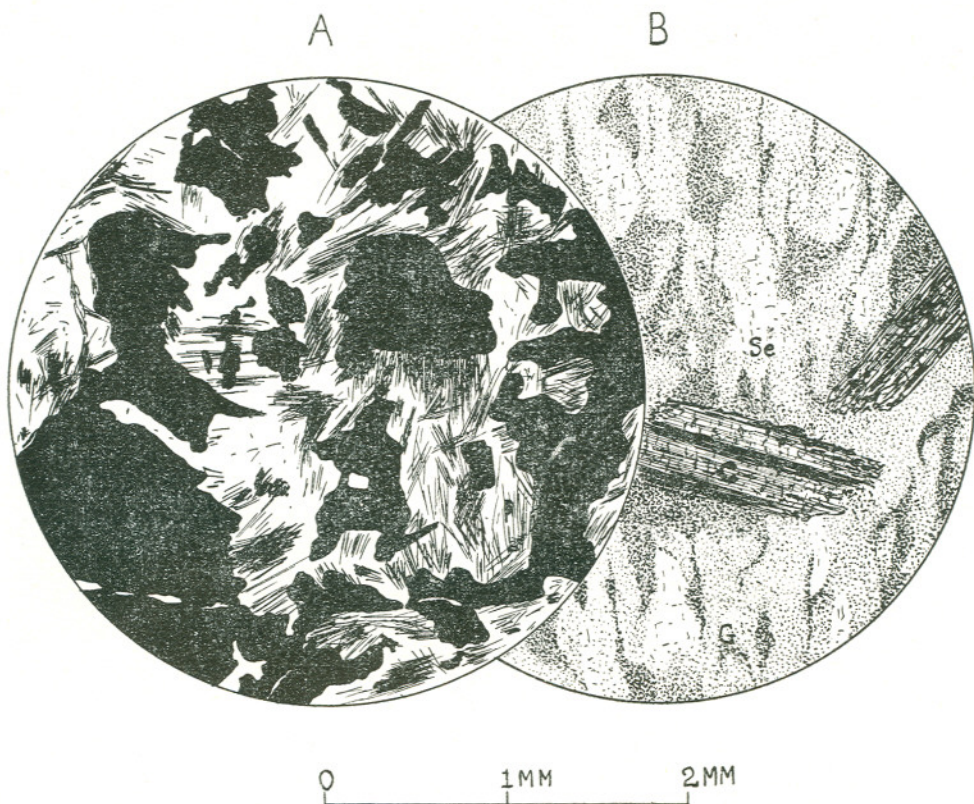


Fig. 2.—Microscope drawings of thin sections from the Derkali area.

A.—Banded ironstone, 15/377. Ordinary light. Black=martite; fibrous mineral=limonite; colourless=quartz.

B.—Sericite-graphite phyllite, 15/278. Ordinary light. Se=flakes of sericite; C=pseudomorph after cordierite (?); G=fine flakes of graphite, in part concentrated in clusters.

(e) *Graphitic sericite phyllites*

Narrow beds of phyllite consisting essentially of sericite and graphite are best exposed near Ablun water-hole. As they are especially prone to weathering, their exposures consist of discontinuous lines of friable rock-brash. The phyllites are the most distinctive looking rock-types of the Ablun series. They are characteristically silver-grey to dark grey and, owing to their graphite content, are greasy to the touch. Although they are subject to local textural and compositional variation they remain highly foliated throughout.

Microscope examination of specimen 15/341 shows that it consists mainly of small flakes of sericite, aggregates of quartz, iron ore, biotite and graphite dust. The sericite aggregates curve sinuously around quartzose lenticles and occasionally around the biotite. The quartz lenticles usually consist of several grains which are sometimes elongated along the foliation, but only rarely show slight strain polarization. The iron ore is mainly hematite and is frequently replacive. It occurs both as highly irregular grains and as replacive streaks interlaminated with sericite or biotite. The biotite is a greenish-brown variety and is often intimately associated with the iron ore or, less commonly, is replaced by medium-sized grains of muscovite. The graphite is finely disseminated through the rock with a slight tendency to form nebulous segregations. It occurs in such minute specks that flotation methods failed to separate them from a carefully crushed sample. Tourmaline in stout prisms up to 0.5 mm. in length and dichroic from dull brown to pale brown, is a common accessory. Specimen 15/366 from south-west of Ablun is porphyroblastic and exhibits marked

strain-slip cleavage. The porphyroblasts are now completely altered, being replaced by kaolinitic and micaceous minerals, but from their shape it is suggested that originally they may have been cordierite. Tourmaline is again an abundant accessory, though here it tends to be rather bluish in some crystals. In specimen 15/278 (Fig. 2*b*) from south-east of Ablun, which is more heavily graphitic, scattered prismatic iron-stained pseudomorphs up to 2.5 mm. in length are arranged in all directions across the planes of foliation. The pseudomorphs now consist principally of aggregates of biotite and muscovite and it is possible that the original mineral was cordierite. Tourmaline prisms are once more in evidence, but are not so frequent as in the two specimens first described.

2. The Younger Rocks

(1) JURASSIC

The Jurassic rocks of the Derkali-Melka Murri area belong to the middle division of the system, ranging from Bajocian to Callovian in age. They can be separated into two parts, viz.

- | | |
|---------------------|-------------|
| 2. Asaharbita Beds | Callovian |
| 1. Murri Limestones | { Bathonian |
| | { Bajocian |

The Murri Limestones and the Asaharbita beds are part of the Daua Limestone Series of Weir (1929, p. 9). The Jurassic limestone and associated beds of north-east Kenya were originally called "The Limestone Series" by Glenday (1923, p. 29), who was followed by Dixey (1948, p. 34) and by Ayers (1952, p. 5), but in the most recent publication on this part of Kenya (Saggerson and Miller, 1957, p. 10) Weir's term has been resuscitated.

The stratigraphically lowest part of the Jurassic limestone sequence cannot be seen in the area surveyed, but it is believed that the oldest Jurassic rocks there are those exposed in the Daua valley at the Kenya-Ethiopia border, below Melka Murri police post. It is also believed that the Jurassic sediments were deposited in a basin that was gradually filled up, so that the beds seen at the junction with the pre-Jurassic rocks, e.g. near Birkoi, Derkali, and Dugididera, are younger than those below Melka Murri police post—a feature also observed by Dixey (1948, p. 39). It is also considered that the limestones along the junction with the Basement System rocks become progressively younger towards the southern boundary of the area surveyed. Apart from minor folds or ruffles (Plate II, Fig. 1) and dislocations due to minor faulting, the Jurassic limestones lie almost horizontally, but with a slight dip towards the east. Thus the Jurassic rocks become younger towards the eastern boundary of the area also.

(a) The Murri Limestones

The generalized succession exposed in the flanks of the Daua valley is as follows:

	feet
4. Compact grey oolitic limestone with marly and sandy intercalations, and with thin bands of fine-grained non-fossiliferous limestone, marly limestone and marl in the upper part. Horizons of yellow limestones also present	c. 200
3. Vari-coloured coarsely crystallized oolitic limestones containing many shell fragments, and with a yellow porous oolitic and shelly limestone at the top	c. 300
2. Yellowish often coarsely crystallized limestones containing shell fragments, and with intercalations of grey, fine-grained, non-fossiliferous limestone	c. 400
1. Grey thin-bedded sandy limestones with intercalated bands of fine-grained limestone. Rarely oolitic and containing shell fragments	c. 800
Total	1,700
(Base not seen)	

In the northern part of the area near Imol and Birkoi water-holes the limestone overlying the older rocks is yellowish in colour, oolitic, and contains small fossils and shell debris as well as pellets of grey non-fossiliferous limestone. A few miles further south, in the vicinity of Ablun water-hole, a thin bed of yellowish fossiliferous limestone occurs associated with friable red and purplish shales. South-west of Derkali, grey dappled brown fossiliferous limestone overlies Basement System quartzite. At Dugididera grey non-fossiliferous limestone associated with a yellow fossiliferous detrital limestone is in close proximity to the pre-Jurassic rocks, while at Burashum, in the extreme south of the area, a yellow oolitic limestone with pellets of grey non-fossiliferous limestone forms the lowest bed of the succession.

The oldest Jurassic rocks seen in the area are the grey sandy limestones of the Daa valley section. They are generally thinly bedded, with occasional thicker strata up to 2 metres thick. Their colour varies from light grey to dark grey and, less commonly, to pale yellow. The sandy limestones are on the whole non-fossiliferous and only slightly oolitic—specimen 7/31 from Lugh Debaiyu is an example of the more oolitic and more fossiliferous type belonging to this group. The ooliths in this specimen range up to about 0.4 mm. in diameter and are accompanied by abundant shell fragments and algæ (?); angular quartz grains of about silt size constitute less than 5 per cent of the rock. Recrystallization of the calcite of the rock is marked so that original structures in the fossils and in the ooliths have been to a large extent destroyed. Usually few concentric zones can be seen in the ooliths. In other cases recrystallization has almost completely destroyed the ooliths and fossil remains. Allothigenous minerals constitute up to 20 per cent of these limestones, small angular quartz grains being the chief. Often impurities are concentrated along the laminae, a feature that can be observed in the hand-specimen as well as under the microscope. Specimens 7/31 and 7/45 are typical of such impure banded types. The fine banding is often pale greenish, as in specimen 7/35.

The fractured surfaces of the sandy limestones are generally rough, but the thin beds of fine-grained limestones, often intercalated with marls, that occur with them have remarkably smooth fracture surfaces. These fine-grained limestones rarely show signs of lamination, and in general they are non-fossiliferous and light to dark grey in colour, though sometimes they are yellowish. The yellow coloration is due mainly to iron-staining around ooliths and rare fossil fragments.

The grey sandy limestones and associated rocks comprise about 800 feet (244 metres) of the exposed section in the Melka Murri tributary of the Daa. Near the top of this group of limestones coarser-grained oolitic limestones are to be found, and are represented by specimen 7/35. Fossils and shell fragments are absent from this horizon, and the ooliths are frequently stained by iron-oxide. Fragments of oolitic limestone are present, and together with the ooliths themselves are an indication of the conditions prevailing at the time the limestones were deposited. It appears to be generally agreed that ooliths grow freely suspended in turbulent waters (Pettijohn, 1949, p. 77) and that calcitic ooliths grow in waters that are salt and not very cold (Twenhofel, 1950, p. 632). Twenhofel, however, qualifies his statement by saying "It seems probable that no generalization has general application to all ooliths, and that ooliths of the same or different composition form as consequences of different combinations of conditions". The evidence in the present area suggests that the ooliths formed in a shallow neritic environment in which rocks formed by the cementation of ooliths could be fragmented and included in later-formed oolitic rocks. The turbulent conditions are also indicated by the frequency of the occurrence of broken ooliths. Varying conditions of deposition are, in addition, indicated by the colour of the ooliths. They are often darker than the surrounding groundmass, and the concentric bands in the individual ooliths vary in colour also (e.g. specimen 15/325). Frequently the ooliths are yellowish or brown, probably due to iron-staining as in specimen 15/259, whereas the calcite of the matrix is clear and colourless. Fringes of brown calcite, which probably also owe their colour to iron-staining, were observed on many ooliths (e.g. specimen 15/325). These features suggest that the ooliths developed in environments different from those in which they were eventually deposited and cemented to form oolitic limestones, as might be expected in the changing conditions of a neritic locale.

The nuclei of the ooliths are composed of a variety of objects. By far the greatest number are composed of fragments of calcite crystals, but shell fragments, including foraminiferal tests, are also frequent. Quartz grains have also been observed, and rarely fragments of other ooliths have been noted forming the nuclei of some ooliths, as in specimen 15/259.

Dissolution of the limestones has taken place to a small degree, and in specimen 7/35 chalcedony partly replaces the calcite of the matrix and occasionally parts of oololiths in small patches. Localized dissolution of the oololiths has produced "pin-point" porosity in the rocks. This is best seen in the hand-specimens, e.g. in specimens 15/242 and 15/285. When viewed under a microscope, the nuclei appear to be the parts of the oololiths that have been dissolved out first.

Silicification of the Jurassic limestones has proceeded to varying degrees in different parts of the area. The greatest development has taken place in the limestones around the edge of the Banissa conglomerate—a good example being near Ogonishu, to the east of the Luliss water-hole, as exemplified by specimens 7/23 and 7/25, which are completely replaced by opaline and chalcedonic silica. As these limestones occur near the Tertiary conglomerate, it is believed that this intense silicification may be derived from the quartzose conglomerate, and therefore only local in extent.

Local and selective pene-contemporaneous silicification of the limestone as well as silicification of joint-planes and fossils has been recorded by Dixey (1948, p. 40). He also, however, noted the presence of silicified surface layers at various places (*op. cit.* p. 41) and concluded that they represent surface silicification that took place on erosion bevels, rather than that they indicate a temporary halt of erosion at a layer of pene-contemporaneous silicification. Ayers (1952, p. 16) records silicified limestones and chalcedony fragments from various localities in this part of the Northern Province.

Both Dixey and Ayers record the presence of pebbles of quartz, quartzite, and gneiss and chalcedony fragments on the tops of the Marehan sandstone hills between Mandera and El Wak, where their presence is interpreted by Dixey as indicating a former erosion surface bevelling these hilltops. The other examples of silicification quoted by Dixey and Ayers, it is now known, are connected with more than one erosion surface, and it is believed that the silicification is not a result of the cycles of erosion but of the transference of silica from originally siliceous material in the sediments or possibly, in some cases, of the infiltration of silica from overlying siliceous rocks. Dixey, for example, refers to several small plateaux, 48 miles from Derkali on the Rahmu road, containing silicified fossils and joints 50 feet below the tops of the plateaux. This locality is at Ollo, where horizons of sandy limestones in Asaharbita Beds (*see* p. 19) have been observed, and are regarded as a possible source of silica. Silicified limestones and cherty bands were found by the writers in the Asaharbita Beds at Asaharbita. Their origin is not certain, but they are believed to represent horizons of pene-contemporaneous silicification or beds silicified by the percolation of silica from sandstones of the Marehan Series like those of the nearby Danissa hills, when the series extended further west. In addition, it is believed that the occurrences of silicified limestones in the Derkali and Melka Murri areas are due to silicification by silica derived from associated beds that were intrinsically siliceous.

Above the grey sandy limestones of the Melka Murri section there is a group of limestones about 400 feet (122 metres) thick. These limestones are usually light yellowish and frequently coarsely crystalline, and resemble the lower horizons of the series in being thin bedded. They are usually oolitic and commonly bear numerous fragments of shells, though there are many intercalations of grey fine-grained, non-fossiliferous bands, some of which show faint traces of banding. Quartz grains are noticeably absent from these limestones. The only common impurity is limonite which is frequently associated with oolitic grains. Marls and marly limestones become more common towards the upper levels of this group until the Asaharbita Beds are reached. A coarsely crystalline grey limestone (specimens 7/19 and 7/17) including coarse shell debris and oolitic grains forms a prominent horizon in this group of light-coloured limestones.

Overlying this group of light-coloured limestones is a group of vari-coloured limestones about 300 feet (91 metres) thick. The beds composing this group are more variable, both in colour and texture, than those below them. They are generally yellowish, but grey, reddish and drab-coloured beds are also present. They are usually coarsely crystalline, contain many shell fragments, and are more oolitic than the underlying limestones. Fossils, too, are more common but are generally so firmly encased in the rocks as to prevent their separation for identification. A characteristic horizon forming the highest bed in this group is a light yellow porous oolitic limestone containing lamellibranch shells and much shell

debris, of which specimens 7/18 from Moski, and 15/284 from south of Lugh Wachu are typical examples. Echinoid spines are common in this bed and stand out characteristically on the weathered surfaces.

Overlying the yellow porous limestone are compact grey oolitic limestones about 200 feet (61 metres) thick. They are more massive than the underlying group of vari-coloured limestones but nevertheless contain marly and sandy intercalations. Examples can be seen in the gullies along the Melka Murri-Rahmu road where it crosses the Melka Garse river-bed. A thin section prepared from specimen 7/29 from two miles south of Lugh Dent along the Helgudo camel-track shows shell fragments, a few whole fossils (foraminifera and gastropods) and ooliths, cemented together in what appears to have been originally a lime mud. In addition to the calcite, a small amount of angular quartz and limonitic staining is present. The thin section has cut the junction of two bands of different kinds of limestone, one a more fine-grained oolitic type with few fossils and few shell fragments and the other a coarser limestone rich in shell fragments. A pellet of a very fine-grained limestone containing numerous small quartz grains, and scattered ooliths and shell fragments, rests on the upper surface of the fine-grained band. Shell fragments of the succeeding band are impressed in its surface and obviously it was in a soft condition when the later band deposited.

Ripple-marks were seen in these grey limestones in a river-bed just south of the Rahmu-Melka Murri road, near the eastern boundary of the area. The measurements and index of these wave ripple-marks are tabulated below:—

Wave-length (W.L.)	Amplitude (A)	Ripple-mark Index (W.L./A)
<i>cm.</i>	<i>cm.</i>	
36.5	3.7	9.88
27	2.5	10.8
36.5	4.2	8.7
53.7	5.5	9.72
		} Average 9.8

Among the upper horizons of the grey oolitic limestones are bands of grey non-fossiliferous limestone, seldom more than six inches (15 cm.) thick. These bands are often intercalated with bands of marls and marly limestones which are slightly fossiliferous. Brachiopods, such as rhynchonellids, and some lamellibranch fragments (*Pinna* sp.?) were found in the marly limestones in a shallow gully south of the Rahmu-Melka Murri road near the eastern boundary of the area.

Yellowish limestones, such as specimen 15/253, which include pellets of grey non-fossiliferous fine-grained limestone, were observed at several localities in the area. It is believed that these conglomeratic limestones may occur at several horizons but most generally near the top of the Murri Limestones.

Palaeontology and Age of the Murri Limestones. Unfortunately extensive fossil collections from the Murri Limestones have as yet not been made, nor were any localities observed during the present survey where such collections could be made, with the possible exception of the uppermost horizons near the Asaharbitto Beds in the vicinity of Melka Garse. Although fragments of fossils can be seen in various microscope slides, it is doubtful if they are suitable for specific identification.

Of the collections of fossils that have been made and described, most have been taken from localities near the junction with the Asaharbitto Beds in the vicinity of Dedacha Korum Adau, and probably from the uppermost horizons of the Murri Limestones. Some rather poorly preserved fossils were collected, however, by Glenday from Derkali and were identified (Weir, 1929, pp. 11 and 14) as follows:—

- Plagiostoma* cf. *semicircularis*
- P.* cf. *astartina* Thurm.
- Acrosalenia* sp. indet.

Weir accordingly provisionally regarded the slaty grey limestone at Derkali as Kimmeridgian in age. Both Weir (1929, p. 14) and Ayers (1952, p. 27) record fossils from near Dedacha. Weir listed the following species:—

Stolmorhynchia (?) *azaisi* (Cottreau) var.

Plagiostoma harronis Dac.

P. notata de Loriol

P. cf. astartina Thurm

Cf. *Somalirhynchia stefaninii*.

He considered that the beds in this locality are probably lower or middle Kimmeridgian in age (Upper Jurassic), and that beds further east at Muddo Erri, beyond the limits of the present area, range in a compressed succession from Bajocian-Bathonian (Middle Jurassic) at the base of the section to Oxfordian and what he calls Corallian at the top. It is recorded in Ayers's report that near Melka Murri the lowest beds of the Murri Limestones yielded *Bakevella* (*Gervillella*) sp. resembling the Bathonian *B. Waltoni* (Lyc.), but that about 1,200 feet (366 metres) higher an upper Bathonian fauna was collected including:—

Pseudomonotis aff. *braamburensis* (Phil.)

Brachydontes (*Arcomytilus*) *bathonicus* (Mor. and Lyc.)

Anatina (*Cercomya*) *silicus* Ag.

Trigonia pullus Sow.

Exogyra fortaui Stef.

Corbula sp.?

The list is given, however, under the heading "Bathonian-Bajocian Limestones", so it appears that Weir's findings at Muddo Erri were accepted.

Other fossils were collected from Dedacha (locality 5326) which appears to be the Dedacha Korum Adau of this report. The fossils listed from the locality are:—

Lima (*Plagiostoma*) *subcardiiformis* Greffin

Burmihynchia subversalis Weir

Kutchirhynchia aff. *morieri* (Dav.)

Thus, disregarding Weir's determination of some beds as Kimmeridgian, which has not been supported by later work, the age of the Murri Limestones must continue to be considered as Bajocian-Bathonian, until more conclusive evidence becomes available.

(b) The Asaharbito Beds

In the eastern portion of the area a group of sediments composed largely of marls and marly limestones with horizons of other types of calcareous sediments, such as sandy limestones, conformably overlies the Murri Limestones. As members of the group are well-exposed at Asaharbito, it is named the Asaharbito Beds. On aerial photographs of the northern parts, the Asaharbito Beds appear whiter than the Murri Limestones, presumably because of the rapidity with which the marls weather, giving rise to fine-grained white soils. In the Asaharbito depression a similar feature is vividly depicted on the photographs, although in the south generally, the marl soils are less obvious as the marls have not been exposed to the same rapid erosion as at Asaharbito, and contain a higher proportion of foreign material. Ant-hills in the same part of the area are composed of material derived from below the crust of darkened soil and always present conspicuous features as small white dots on the aerial photographs.

The Asaharbito Beds are not thick, and probably do not exceed 200 feet (about 61 metres) in thickness. The beds are best exposed in the isolated outliers in the vicinity of the Rahmu-Melka Murri road-crossing at the Melka Garse river-bed, and in the Asaharbito depression (Plate I, Fig. 2).

The complete section of the part of the Asaharbito Beds exposed in the Asaharbito depression is as follows:—

	Approximate Thickness	
	ft.	in.
Plain level, approximately 2,150 feet O.D.		
Red sandy soil	0-3	—
7. Silicified chalcedonic limestone (e.g. 15/290)	3	—
6. Drab to dirty white gypsiferous marls	20	—
5. Brown fossiliferous limestone (15/291)	—	6-9
4. Drab to dirty white marls with chert bands and nodules ..	12	—
3. Brown laminated calcareous (15/297 and 15/371) and green siltstones (15/306)	1-2	—
2. White fossiliferous marly limestone	5	—
1. Drab and grey slightly fossiliferous faintly laminated limestone (15/299)	?	

Floor of Asaharbito depression (approximately 2,110 feet)

The marls are soft and friable, and occur as narrow bands of calcareous muds between the limestone bands. They are rarely seen in the field, except in their weathered and disintegrated state. Often fine clusters of gypsum crystals can be found in them at Asaharbito.

The marly limestones on weathering give rise to marl-like debris and surface exposures are easily confused with marls. At Asaharbito, where denudation by wind action is proceeding at a greater rate than superficial limestone can develop, exposures of the marls are more readily available.

Intercalated in the marls are narrow yellowish to brown horizons of limestones which are normally highly fossiliferous—specimen 15/373 is a typical example. They are invariably oolitic and most of the shell fragments have not been recrystallized. In addition to the larger fossil fragments a micro-fauna of foraminifera and embryonic gastropods is common. The limestone bands are usually less than three feet (1 metre) thick, whereas the marls and marly limestone interbeds are up to six feet in thickness. The weathered surfaces of the limestone bands are generally rough on account of the coarse shell debris they contain. Whole fossils too are far more common than in the limestones of the Bathonian beds, and it is notable that many of the fossil localities in the north-east part of Kenya described in previous reports are in the Asaharbito Beds. Brachiopods (*Rhynchonella* and *Terebratula*) have been found both in the marls and in the intercalated limestones. Specimen 15/257 from near Ollo is an example of one of these highly fossiliferous limestones. Some of the limestones here contain algæ-like bodies (see Plate I, Fig. 1).

Numerous fluctuations of sea-level and perhaps of climate are evidenced by the alternations between the marls, marly limestones, limestones and laminated sandy limestones. A shallow-water environment of deposition is suggested by the presence of ripple-marks and what may be fossil rain-prints in specimen 15/305. A single measurement of a doubtful ripple-mark exposed in the limestone on the camel-track in the south-western corner of the Asaharbito depression gave the following values:—

Wave-length (W.L.) (cm.)	Amplitude (A.) (cm.)	Ripple-mark Index (W.L./A.)
76	15.2	5

Within 46 feet (14 metres) of the base of the Asaharbito Beds, highly conspicuous laminated slabby calcareous siltstones can be seen at and around the Asaharbito depression. On the weathered surfaces the laminæ are clearly visible (15/371) but on fresh surfaces they are hardly discernible. The siltstones are in beds about one inch (2.5 cm.) thick, and the laminæ in the beds are about 1/12th inch (2 mm.) in thickness. Mica flakes are frequent along the laminæ. On the southern side of the depression green siltstones (15/306) were

found in close association with the normal brown siltstones. A thin section of specimen 15/371 shows that it is of siltstone grade, consisting mainly of angular grains of quartz, other mineral grains, shell fragments, and whole fossils cemented by fine-grained calcite. The non-carbonate constituents comprise about 70 per cent of the rock. Besides the quartz grains, feldspar, weathered biotite, zircon, chlorite, iron ore and some interstitial limonite are present in specimens 15/371 and 15/297. Coral (?) fragments, gastropods and sponge spicules were observed in specimen 15/297 and some foraminifera were seen in 15/371. In the hand-specimen of 15/371 lamellibranchs are visible.

The weathering of these calcareous siltstones is highly characteristic. Hillocks are often littered with flaggy rectangular slabs with well-defined joint faces, the slabs being up to four feet long and one foot wide and are generally less than one foot thick. A little east of Rahmu on the Rahmu-Mandera road such slabs have been extensively used as gravestones by some riverine tribe of natives.

Owing to lack of exposures for several miles on either side of the mutual boundary the Asaharbito beds cannot be traced from the present area to the Takabba-Wergudud area, which lies immediately to the south of it (Saggerson and Miller, 1957). When exposures do become available again, on the northern side of the Ogar Wein hills, there is apparently no sign of the Asaharbito Beds, and it is presumed that there is a facies change as one goes southwards, so that in the Takabba-Wergudud area the Asaharbito Beds will be represented by limestones in the Bathonian-Oxfordian range as mapped by Saggerson and Miller.

Palaeontology and Age of the Asaharbito Beds. Fossils collected from the Asaharbito depression by Ayers and identified by Dr. L. R. Cox at the British Museum were inconclusively dated as Bathonian (Ayers, 1952, pp. 22-23). The fossils comprised:—

- Palaeoneilo* sp.
- Nuculana* sp.
- Grammatodon* cf. *bathonicus* Cox and Arkell
- Trigonia stefaninii* Venzo
- Astarte* sp.
- Eomiodion angulatus* (Morris and Lycett)
- Platymya* sp.
- Sphaeriola oolithica* Rollier
- Corbula* cf. *lulliana* Morris

Fossils recorded as "Bathonian-Bajocian" are also reported in Ayers (*op. cit.*, p. 27) from locality No. 5325 which appears to correspond nearly with Ollo of the present survey, which is considered to be on the Asaharbito Beds. The fauna recovered comprised:—

- Pygurus* cf. *depressus* Currie
- Eligmus rollandi* Douville
- Burmishynchia subversalis* Weir
- Terebratula* indet

Callovian fossils were obtained at locality No. 5329, midway between Rukesa and Murri, which is believed to correspond with the Melka Garse of the present report, from an outcrop that is believed to be an outlier of the Asaharbito Beds. The fossils included (Ayers, 1952, p. 28):—

- Burmishynchia subversalis* Weir
- ? *Cymatorhynchia quadruplicata*
- Pholodomya carinata* Goldf.
- Lopha solitaria* (J. de C. Sow)

A Callovian age was also ascribed to the sediments at Melka Addi (locality No. 5324) which is presumably the same place as Lugh Adi on the present map, or close to it, where the beds are characteristically white (hence the use of the Somali word *addi*, meaning "white"). The fossils recorded are (Ayers, 1952, p. 28):—

Lima (Plagiostoma) harronsis Dac.

L. (P.) subcardiiformis Greffin

Velata abjecta Mull.

Eligmus rollandi Douv. (abundant)

E. rollandi var. *laevis* Douv.

Burmishynchia subversalis Weir (one only)

(c) *Sedimentation during the Jurassic period*

Consideration of the distribution and type of the Jurassic sediments in northern Kenya and Italian Somaliland suggests that they were deposited in a trough or basin. Within the limits of the area surveyed for the present report the dip is eastward, towards the axis of the trough, which must run close to the border between El Wak and Mandera. The width at surface of the sediments between Derkali and the eastern margin of the basin, where the limestone junction with the underlying Precambrian rocks is exposed, is approximately 200 miles (320 km.). As no outliers or other indications of a former extension of the series are known from west of the present area, it is unlikely that the Jurassic sediments extended much beyond the present-day limits. Southwards, towards Wajir, the width of the basin appears to diminish. The thickness of the limestones increases northwards, and thus it appears that the trough in which the sediments were deposited deepens and widens to the north.

Troughs are either deep orogenic, or of shallow foreland type. Pettijohn (1949, p. 455) has tabulated diagnostic features of the respective conditions of deposition in the two kinds of trough, so that it is only necessary to mention obvious features observed in the area mapped which indicate that the Jurassic beds of northern Kenya are the result of deposition under shallow foreland conditions:—

- (a) Ripple-marks were observed in the Asaharbito area.
- (b) No signs of contemporaneous deformation such as folding and brecciation were seen.
- (c) Detrital quartz is fairly widespread; feldspar grains are virtually absent from the limestones.
- (d) Limestones and marls are common; conglomerates were not discovered.
- (e) The presence of chert is rare; its occurrence is confined to small nodular inclusions in the limestones and marls.

It is probable that the sediments were slowly deposited in a shallow trough under fairly stable conditions. The main phase of deposition included the formation of the Daua valley limestones. Towards the close of the foreland infilling phase, successive layers of sediment transgressively overlapped one another southwards and westwards. At the close of this phase it appears that there was a regression of the sea towards the centre of the trough when the deposition of the shallow-water Asaharbito Beds took place. As has already been noted, what are thought to be fossil rain-drop imprints were found in some beds, indicating at least temporary raising of the unconsolidated sediments to sea-level at some period.

Although a skeleton geophysical survey was carried out over north-east Kenya a few years ago, the results did not provide reliable information on the profile of the trough in which the sediments were deposited. Consequently, estimations with regard to both the profile of the trough and the thickness of the sediments must be based on the broadest assumptions. There is every indication in the present area that the trough sides initially slope fairly steeply, but there is no data to provide indications as to the behaviour of the profile towards the centre of the trough.

The most northerly junction between the Jurassic limestones and the underlying pre-Jurassic rocks in the area surveyed occurs north of the Ablun water-hole, at an altitude of about 3,000 feet. To the north-east, the limestones at the Daua river below Melka Murri occur at an altitude of approximately 1,300 feet. Thus the sub-Jurassic floor drops *at least* 1,700 feet over a distance of approximately 45 miles, or at a minimum rate of 36 feet to the mile. Pettijohn (1949, p. 452) has pointed out, however, that in foreland sequences quartzites or sandstones usually constitute up to 1,000 feet of the lower strata. If this figure is accepted as possible for the basal beds at Melka Murri, the overall slope is increased to about 60 feet to the mile. If the profile slope continues for about 80 miles before levelling towards the axis which lies approximately 100 miles east of the exposed unconformity near Ablun, the floor in the middle of the trough would lie at a level between 2,900 feet and 4,800 feet lower than its shoulders. There is, however, no direct evidence of the nature of the profile of the trough, nor of the thickness of sediments below Melka Murri.

A different approach to the problem is offered by the fact that throughout the area, the nearly horizontal strata have an overall gentle eastward inclination. The average easterly dip is about 2° , and it may continue as an overall figure of between 1° and 2° towards the axis of the trough. If this dip continues for a distance of 80 to 100 miles the total thickness of the strata will be between, 8,000 feet and 16,000 feet. It is considered that the total thickness of the sediments of northern Kenya is probably between 6,000 feet and 9,000 feet.

(2) TERTIARY (?)

In the north-western portion of the area the Jurassic limestones are covered by a relatively thin layer of sediments believed to be of Tertiary age. The outcrops extend from just south of Merille water-hole to the Kenya-Ethiopia boundary near Imol water-hole in the west and to the Darken Sedeni area in the east. While the surface extent of the sediments increases progressively northwards, there is no indication of a proportionate thickening, the maximum thickness from the Banissa area northwards remaining at approximately seventy feet.

Two phases of sedimentation are recognizable, and broadly speaking, correspond with the upper and lower strata in the succession. The lower sediments vary from the finest claystones near the basal unconformity to fairly coarse grits. They are usually buff-coloured although the coarser grits tend to be darker. Typically, the claystones consist of sub-rounded to rounded quartz grains set in a finelimonitic matrix, and on weathering yield impervious clay. Localized porosity and pale discoloration on some outcrops indicate leaching of what might possibly have been calcareous material. The upper horizons include grits and discontinuously developed conglomerate. The conglomerate is not more than about fifteen feet thick at a maximum and consists of rounded quartz pebbles held in a matrix of small quartz grains and limonite. The average length of the pebbles is about 30 mm.

Ayers (1952, p. 16) interpreted the Banissa sediments as fluvial deposits derived from the highlands to the west. This is considered to be the most likely origin of the sediments.

(3) PLEISTOCENE TO RECENT

Throughout the area, young deposits believed to be of Pleistocene to Recent age are unevenly developed as cappings to the older rocks or as river deposits, and include surface limestones, salt encrustations and soils. Surface limestones or "kunkar" cover both Jurassic limestones and the Precambrian rocks. In the Melka Murri area crusts of kunkar limestone resemble the underlying older limestones and often give a misleading impression of the dip. The crusts are usually composed of homogeneous fine-grained pale grey limestone, seldom more than about three feet thick. The kunkar limestones overlying the Precambrian rocks are usually more heterogeneous. They frequently include pebbles derived from the older rocks and are usually more or less stained with iron oxide. Specimen 15/353 from north-west of Derkali is a reddish-brown conglomeratic surface limestone, consisting of numerous small included pebbles cemented by a compact calcareous iron-stained matrix. The included pebbles were derived from both Basement System rocks and Jurassic limestones.

Along the courses of most of the tributaries of the Daua river and along the banks of the river itself occasional patches of salt encrustations were discovered. The salt in such cases occurs as a thin discontinuous layer covering highly weathered limestone, but in addition small quantities of salt, not discernible to the eye, can be detected in nearly all the weathered limestones. Qualitative analysis of the salt revealed that it contains nitrates and chlorides but does not contain sulphates or carbonates. The concentration of this salt on the surface appears to be due to capillary action in an arid climate. In addition, small rare accumulations of salt composed mainly of potassium nitrate, derived from excreta, are found on the rocks frequented by hyrax.

With the exception of the Daua drainage system, the river-courses in the area are choked with valley deposits. The courses consist of plains, frequently over a mile wide, and the deposits in them are typically dark brown fine-grained silts. During the rainy seasons the silts become highly glutinous and the valley bottoms are impassable to camels or motor vehicles. Following the rainy seasons the valley deposits dry out and contract, with the formation of large cracks.

Four distinct types of soils produced by the weathering of the various rocks in the area are recognizable. In the western portion the soils overlying the Basement System rocks are typically red and frequently gravelly, containing abundant quartz pebbles. Overlying the Jurassic limestones are grey to buff-coloured sandy soils showing little variation of texture or composition. The soils originating from the Asaharbitto Beds are characteristically white and usually extremely fine-grained. The Asaharbitto depression in the south-east corner of the area is covered by a mantle of this fine material. Owing to its minute grain-size it is easily transported by wind, and there is every indication of intense wind erosion in that area. In the immediate vicinity of Asaharbitto, clusters of gypsum crystals were discovered in the white soil. The soils produced by the weathering of the Tertiary (?) sediments in the Banissa area are dark red and contain abundant ironstone nodules. As the sediments form a low-lying plateau, the soils have also been transported into the valleys draining the plateau.

3. The Major Intrusives

(1) GRANITES

Intrusive rocks were found only in the western part of the area, i.e. among the Precambrian rocks. Owing to blanketing by superficial deposits a sure determination of their age cannot be made but since the Ablun Series exhibits thermal metamorphism and, in common with the other Precambrian rocks, contains an appreciable amount of tourmaline which was probably formed by the introduction of boron during a plutonic phase, the granites are probably of post-Ablun Series age. They may be of similar age to the post-Kavirondian granites of western Kenya. The major intrusives comprise several types of granite which differ chiefly in their textures. Their outcrops consist almost entirely of low-lying tors which are concentrated mainly in the north-western corner of the area. The extent of the intrusions is largely obscured by the widespread overburden of soils and alluvial deposits. The granites can be divided on field appearance and constitution into grey types, pink types, and a general class including a myrmekitic granite, a fine-grained granite and an epidotic granite. The grey granites are older than the pink types.

(a) Grey Granites

Grey granites occupy a relatively small area in the vicinity of Kiliwe Hiri police post, the exposures being confined to the Kiliwe Hiri hills, Omur hill to the south, and the Daka Khalla hills to the north-east. Evidence of the relative ages of the pink and grey granites is furnished at Kiliwe Hiri and Omur where the grey granites are invaded by the pink. The contacts are well-defined and the presence of xenoliths of the grey granite within the pink indicates that the intrusion of the latter took place after consolidation of the grey granite.

Two types of grey granite, possibly representing different phases of the intrusion, were recognized—a porphyritic pale grey type and a fine-grained dark grey type. Despite the fact that no clearly defined contacts were observed, narrow embayments in the porphyritic granite indicate that the fine-grained type probably invaded it during the later stages of the grey granite phase. Examination of the fine-grained granite proved a relatively high apatite content suggesting that at the time of emplacement it probably contained a fair amount of volatile material, as is normal in the later stages of igneous intrusion.

Plate III

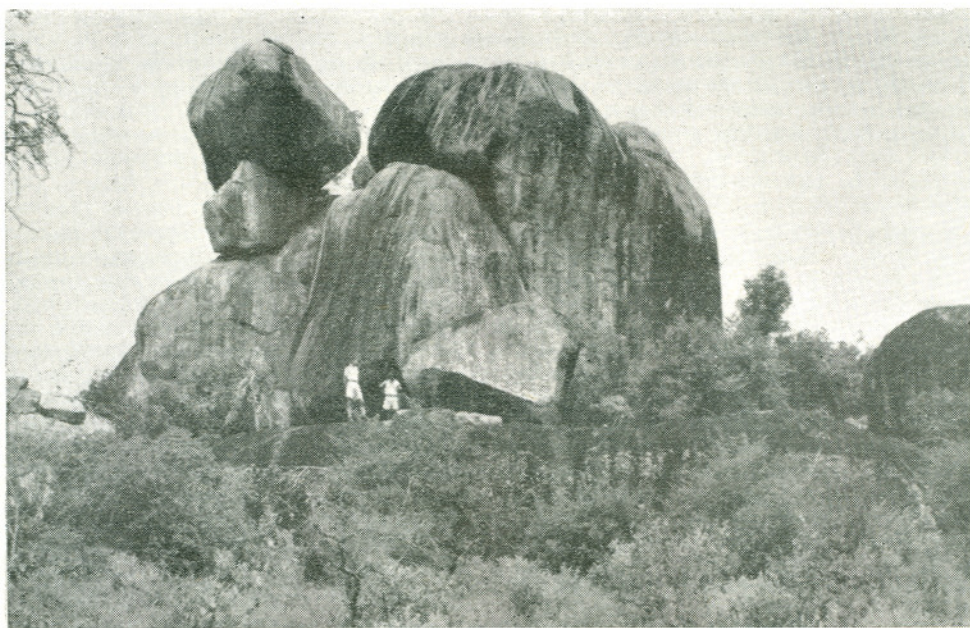


Fig. 1.—Granite tor north-east of Kiliwe Hiri.



Fig. 2.—Compact folding of Ablun Series sediments at Birkoi.

Outcrops of the *grey porphyritic granite* are massive, forming low, yet prominent, tors composed of large, rounded blocks (see Plate III, Fig. 1). Although there is no evidence of direct connexion between the isolated outcrops it appears likely that they form part of a single body. With the exception of marginal alterations against intrusions of the pink granite, the granite is uniform over the series of outcrops. In exposures and in hand-specimens it closely agrees with the numerous descriptions of younger granites throughout East and southern Africa. So far as Kenya is concerned it agrees to a great extent with the descriptions of the post-Kavirondian granites given by Pulfrey (1945), Shackleton (1946), Huddleston (1951) and Gibson (1954). The chief point of difference is that the Kiliwe Hiri grey granite is free of the dark xenoliths and schlieren referred to by Pulfrey (1936, p. 19; 1945, p. 14), Huddleston (1951, p. 37) and Gibson (1954, p. 26). This may be due to the fact that the recorded country-rock in this area is mainly quartzite. In the hand-specimen the granite is a coarse, strongly porphyritic rock with abundant mafic minerals. The feldspar phenocrysts, which largely determine the colour of the rock as a whole, vary slightly from pale grey to equally pale greenish or bluish, and they attain a length of about 1 cm. At contacts with the younger pink granites the phenocrysts are more numerous and pink. In thin section the rock (15/346 from the small hill north-east of Kiliwe Hiri) was found to have an allotriomorphic matrix consisting essentially of often turbid feldspar, smaller grains of quartz, biotite and accessory minerals. The feldspar phenocrysts are euhedral grains of microcline while the matrix feldspars are orthoclase, plagioclase (oligoclase) and microcline in approximately equal proportions. The microcline phenocrysts often poikilitically enclose grains of quartz and plagioclase, and usually forms marginal intergrowths with plagioclase or orthoclase. The biotite is a dark green or dark brownish variety, commonly containing zircons with pleochroic haloes. It occurs as fairly large flakes sometimes showing alteration or replacement. The chief accessory minerals are abundant octahedra of magnetite, anhedral to subhedral sphene, small needles of apatite and a few crystals of zircon. Secondary minerals are sericite from the alteration of feldspar, chlorite replacing biotite, and epidote.

Exposures of the *fine-grained grey granite* are much less extensive than the porphyritic type, being confined to the Kiliwe Hiri and Omur hills. In the hand-specimen, the fine-grained granite is much darker grey than the porphyritic variety and appears to contain a higher proportion of mafic minerals. Examination of a thin section (15/345, from Kiliwe Hiri hill) showed a compact inequigranular, allotriomorphic texture and that the rock is composed of quartz, feldspar, biotite, hornblende and abundant accessory minerals. The quartz grains are large but of highly irregular form and contain abundant poikilitically enclosed grains of feldspar. Similarly, their margins are deeply embayed by the feldspars. Orthoclase is the most abundant feldspar and with microcline it occurs as small, often rounded, grains, while plagioclase occurs as larger anhedral to subhedral prisms. Some of the plagioclase crystals show faint zoning. The proportionate amounts of biotite and hornblende vary from specimen to specimen. In specimen 15/345 from Kiliwe Hiri, dark green hornblende is subordinate but it appears to have been partly replaced by biotite. Of the accessory minerals, both small octahedra of magnetite and numerous fine needles of apatite are scattered through the rock. The less common accessory minerals are sphene and zircon.

(b) *Pink Granites*

The pink granites probably form the major portion of the Precambrian rocks in the area surveyed. The outcrops vary from small flat exposures such as are found west of Kukuba and south of Derkali to prominent hills such as the Korgola group, the Birka group, Dakadiema and Kothkota. Textural variations were noted but generally the granites are fairly uniform throughout. As already mentioned, exposures showing intrusion of grey granite by pink granite were noted at Kiliwe Hiri and Omur hills. At Omur the pink granite includes xenoliths of the grey type. The xenoliths vary in size but are usually not more than 3 cm. long. They are aligned along a strike of about 240° , which indicates the probable direction of the margin of the intrusion at that point.

In the hand-specimen the pink granite is typically coarsely porphyritic and varies from pale pink to reddish. The mineral composition and texture are subject to only slight variation. In thin section the pink granites are found to consist of large grains of microcline-microperthite, smaller grains of orthoclase, plagioclase, quartz, and medium-sized crystals of biotite. The microcline is frequently turbid and where the granite is darker coloured, as in specimen 15/348 from Dakadiema hill, fine iron-staining can often be detected along the crystal cleavages. The plagioclase content varies greatly, and frequently forms marginal

ntergrowths with microcline and orthoclase. In the field, what appeared to be rapakivi structures consisting of orthoclase grains mantled by plagioclase were noted, but no confirmation of this was obtained from the thin sections prepared. The biotite is dark greenish-brown, patchily distributed, contains abundant zircons with pleochroic haloes and is not infrequently altered to chlorite. In specimen 15/356, a fine-grained reddish granite from Korgola hill near the Kukuba-Moyale road, in addition to the normal sporadic distribution of biotite, there are segregations of larger flakes giving a spotted appearance to the rock. Apart from an abundance of microcline-quartz intergrowths this rock is in other respects similar to the pink granites.

(c) Other granites

No field-relationship could be established between the remaining granite types and those already described. Two distinct types differing from the pink and grey granites were recognized in outcrops and, in addition, float fragments of a third type were found.

South of Kukuba, Horkiri hill is composed of myrmekitic granite, which in the hand-specimen resembles the pale pink porphyritic granite. In thin section (15/332) it is found to consist mainly of large grains of microcline, orthoclase and plagioclase, with a sparse quartz-feldspathic matrix of much finer grain, in which myrmekite figures prominently. The mafic constituents are represented by crystals of brown biotite and a little green hornblende. Large, irregular grains of sphene and small crystals of zircon and apatite constitute the accessory minerals. Pyrite is a constant secondary mineral, and can be seen on the granite faces of Horkiri hill.

At Goljo hill Basement System quartzite is invaded by homogeneous *fine-grained granite*. Immediately east of Goljo three small hills and several flat exposures are composed of a similar rock. As is the case in the hills composed of porphyritic granite, systems of vertical and horizontal jointing tends to isolate large rounded blocks of granite resting on granite sheets. In the hand-specimen the fine-grained granite is an even-grained, fine-textured, massive rock rarely showing directional orientation of the constituent minerals. The colour varies from brownish grey to reddish. In a thin section of specimen 15/318, from Goljo, the rock is seen to be roughly equigranular, and to consist of anhedral to subhedral grains of turbid, often altered and stained feldspar, quartz, biotite and accessory minerals. Microcline is not as abundant as in the porphyritic granites, while the amount of plagioclase is slightly greater. The larger grains of quartz show marked strain polarization. The mafic minerals comprise rare hornblende and biotite, which is abundant in small crystals in specimen 15/319 from the same locality. In specimen 15/318 some of the biotite is partly or entirely replaced by chlorite. Iron ore is the only well-distributed accessory; sphene and apatite are both rare.

South of Korgola a few specimens of greenish-coloured granite float were discovered. The source of the float is not known but it is considered that it may represent fragments originating from granite now hidden by overlying soils in that area. In the hand-specimen the granite consists of medium-sized pink feldspars, with yellowish-green veins and streaks. A thin section of specimen 15/277, from south of Korgola, reveals that the rock consists mainly of feldspar, quartz and secondary minerals. Of the feldspars, plagioclase is most abundant, orthoclase is less abundant, while microcline, which is the predominant feldspar of the porphyritic granites, is absent. A few flakes of green biotite and some pale green replacive chlorite are all that remain of the micas. The yellowish-green streaks of the hand-specimen are composed of secondary epidote which has been deposited either in irregular veins or as granular clusters.

4. The Minor Intrusives

(1) PEGMATITES AND APLITES

Although pegmatite and aplite veins were found to cut most of the granites described, they are mainly concentrated in the north-western portion of the area. They vary from narrow bands a few millimetres thick to broader sheets up to about four metres across. The pegmatites show little variation in texture or composition. Typically, they are coarse-grained bright pink types, composed largely of quartz and feldspar, usually with small quantities of biotite, tourmaline, hornblende or muscovite. The feldspar, which is normally microcline, forms large pink crystals with graphic intergrowths of quartz. At Kiliwe Hiri hill, a fairly broad pegmatite contains abundant needles of tourmaline with a few small books of musco-

vite. On the northern peak of Goljo hill a coarse-grained pegmatite contains flakes of biotite and a few crystals of hornblende interstitial to large euhedral microcline-quartz intergrowths.

At Katsi the pink porphyritic granite is cut by a narrow body of fine-grained aplite. In the hand-specimen the aplite is pale pinkish with a fine, even-grained texture. It is mainly quartz-felspathic but a few specks of ferromagnesian minerals are just discernible megascopically. In thin section (15/258) the texture is found to be micro-porphyritic. It is composed of a fine-grained mass of equi-dimensional grains of microcline, orthoclase, quartz and rare plagioclase, with larger intergrowth clusters of microcline/quartz and microcline-perthite (?). Small flakes of altered biotite and hornblende are scattered through the rock and nearly all the felsic mineral grains are crowded with minute inclusions of iron ore (?).

(2) LAMPROPHYRES

In the Kukuba area lamprophyre forms a small discontinuous outcrop, consisting of large slightly rounded boulders aligned along a strike of approximately 290° . No contacts between the dyke and the adjacent Basement System rocks were observed, and it was not possible to establish the extent of the body. The rock is coarsely crystalline and melanocratic, and in the field strongly resembles dolerite. Where weathered the outcrops develop a thin, reddish, iron oxide-stained coating.

In thin section specimen 15/331, from Kukuba, is seen to be composed of feldspar, biotite, pyroxene, hornblende, quartz and accessory minerals. The feldspar is albite-twinned plagioclase and forms an allotriomorphic mosaic in which the minerals are set. The twinning extinction in the symmetrical zone indicates that it is a sodic andesine (An_{33}). The biotite is dichroic from dark brown to light yellow, occurring in irregular poikilitic crystals, and is sometimes partly intergrown with hornblende. The poikilitic inclusions are small crystals of apatite, and medium-sized grains of pyroxene and iron ore. The hornblende is green and is partly replaced by the biotite. The pyroxene is colourless to greenish diopsidic augite and hypersthene exhibiting typical pale green to pink pleochroism. Many of the hypersthene grains are crowded with schiller inclusions. A few interstitial grains of clear quartz are present. The accessory minerals are octahedra and anhedral grains of magnetite and abundant small prisms of apatite. The rock may be considered as intermediate between spessartite and kersantite.

About 10 miles south of Derkali a small dyke of highly weathered dark rock may be an altered lamprophyre. In the hand-specimen it is fine-grained and holocrystalline, with a slight greenish tint on freshly fractured surfaces. The weathered surfaces are covered with a brownish crust up to 3 mm. thick. In thin section the rock (15/309) displays alteration, the ferromagnesian minerals having been almost completely replaced by flaky hornblende. The feldspars, however, which include plagioclase (An_{30}) and a little orthoclase, though they are patchily clouded by minute inclusions, show relatively little alteration. As in the Kukuba lamprophyre, quartz is present as a minor interstitial constituent. Latticed aggregates of iron ore included in some of the hornblende pseudomorphs probably represent original schiller structures. Biotite is present in scattered small flakes and aggregates.

(3) BASALTS

Ten miles south-south-west of Derkali, west of the Muda-Dugididera road, a discontinuous row of dark, slightly rounded, slabby outcrops just protrudes from the red soils which cover the older rocks of that area. No field relationships could be established, but in view of the fact that no other exposures of this apparently highly resistant rock were discovered, it is considered probable that it is part of a small intrusion. It is a tough rock with a fine porphyritic texture and consists of medium-sized feldspar phenocrysts in a fine-grained dark groundmass (15/249). The presence of evenly distributed pyrite cubes gives the rock a striking appearance. In a thin section it is seen that the groundmass consists of a fine granular intergrowth of plagioclase, green hornblende (?) and small aggregates of secondary sphene. The feldspar phenocrysts are plagioclase with the composition of sodic labradorite (An_{55}) and a few are well zoned. They have both carlsbad and albite twinning. In addition, there are phenocrystic aggregates consisting of idiomorphic epidote, large apatites, and green hornblende. The rock is sparsely sprinkled with large crystals of pyrite and disseminated with smaller grains and octahedra of iron ore. Apatite is an abundant accessory mineral

and is sometimes of phenocryst size. Medium-sized grains of calcite associated with quartz probably represent later infilling of cavities. There are also patches of quartz that may represent xenocrysts.

(4) TREMOLITE-BEARING META-INTRUSIVE ROCKS

South-west of Ablun water-hole a discontinuous line of boulders indicates what originally was probably an intrusive body. The rock is so altered that its original composition is masked by secondary minerals and unfortunately its relationships to the surrounding Ablun Series rocks could not be established. It is considered probable, however, that it is intrusive into the Ablun Series. In the hand-specimen the rock varies considerably. It is usually a granulose, tough, buff-coloured type with haphazardly arranged tufts of whitish tremolite, or rarely with the tremolite in large stellate tufts. Less commonly, dark reddish iron oxide-staining gives a mottled appearance. Specimen 15/368 is composed largely of stellate tufts of tremolite and patches of jasper. Several cavities are only partly infilled with jasper or chalcedonic quartz. In thin section it is apparent that the tremolite has developed as a replacement of pyroxene. A few small grains of original pyroxene remain but exhibit partial replacement. The greater portion of the rock consists of a fine felted, iron-stained mass of tremolite. The quartz infilling is mainly chalcedonic and usually contains fine blebs of red iron oxide, symmetrically arranged in the depositional banding.

About 8 miles north-west of Dugididera a specimen of float (15/248) consisting largely of tremolite was discovered. No related rocks were found *in situ*, but it is considered possible that the float originated from an occurrence now obscured by the deep overburden of soils in that area. In the hand-specimen the rock does not resemble the tremolite rock from near Ablun water-hole. It is dark greenish-grey, soft, and has a faint greasiness to the touch. Examination of a thin section revealed that it consists almost entirely of tremolite, patchily intergrown with actinolite. The few residual grains of pyroxene appear to be hypersthene. The greasy feel of the hand-specimen is probably caused by the partial alteration of the tremolite to talc.

These tremolite-rich rocks are obviously derived from ultra-basic rocks, probably from pyroxenites.

(5) QUARTZ VEINS

Although small quartz veins and lenses are numerous throughout the area, no large quartz veins were observed. Small quartz veins cut all the granites, and the Ablun Series rocks. They are usually colourless to white and exhibit a variety of forms from stout ellipsoids less than a metre long to long cross-cutting, though narrow, veins. With the exception of small erratically distributed grains of iron ore, the veins are free of mineralization.

5. Metamorphism

The exposed Basement System rocks in the area are mainly quartzites and limestones, practically free of impurities, and hence of little value in assessing the degree of metamorphism they have undergone. Parkinson (1920, p. 27), however, described the occurrence of sillimanite faserkiesel in micaceous gneisses from near Butteli, some 45 miles south-south-west of the south-western corner of the present area. It is possible that unexposed Basement System rocks in the Derkali area may also contain sillimanite.

The post-Basement Ablun Series exhibits low-grade metamorphism, including thermal effects of a later (?) phase. The strata are mainly arenaceous with relatively narrow intercalated argillaceous bands, the sericite-graphite phyllites affording the best medium for assessing the metamorphism. The mineral assemblages include the following:—

Sericite—Biotite

Sericite—Biotite—Cordierite (?)

With the exception of mild recrystallization in parts, the Jurassic limestones do not exhibit any noticeable post-depositional alterations.

6. Structures

(1) MAJOR STRUCTURES

The exposures of the Basement System rocks are too few to permit the determination of the structures in which they are involved.

The present-day extent of the Ablun Series gives no indication of the dimensions of the basin in which it was deposited. The outcrops represent a remnant preserved because of infolding in the Basement System. The beds are tightly folded, the axes of the folds running approximately west-north-west. Lineation was observed only in rocks of the Ablun Series, and normally plunges westward to north-westward at an average inclination of approximately 20° . With the exception of the apparent boundary fault on the north side of the outcrops, no major faulting was noted in the series.

The Jurassic sediments in the area surveyed dip gently to the east. No major structures were recognized in them but in view of the fact that small-scale folding is widespread (Fig. 5 and Plate II, Fig. 1 and Fig. 2), it is possible that broad, though very gentle, folding may be present. Ayers (1952, p. 18) described the existence of an arch whose axis passes through the Dedacha area in a N.N.E.-S.S.W. direction. No conclusive field evidence was found in the area during the present survey to verify this anticlinal structure, but the presence of the

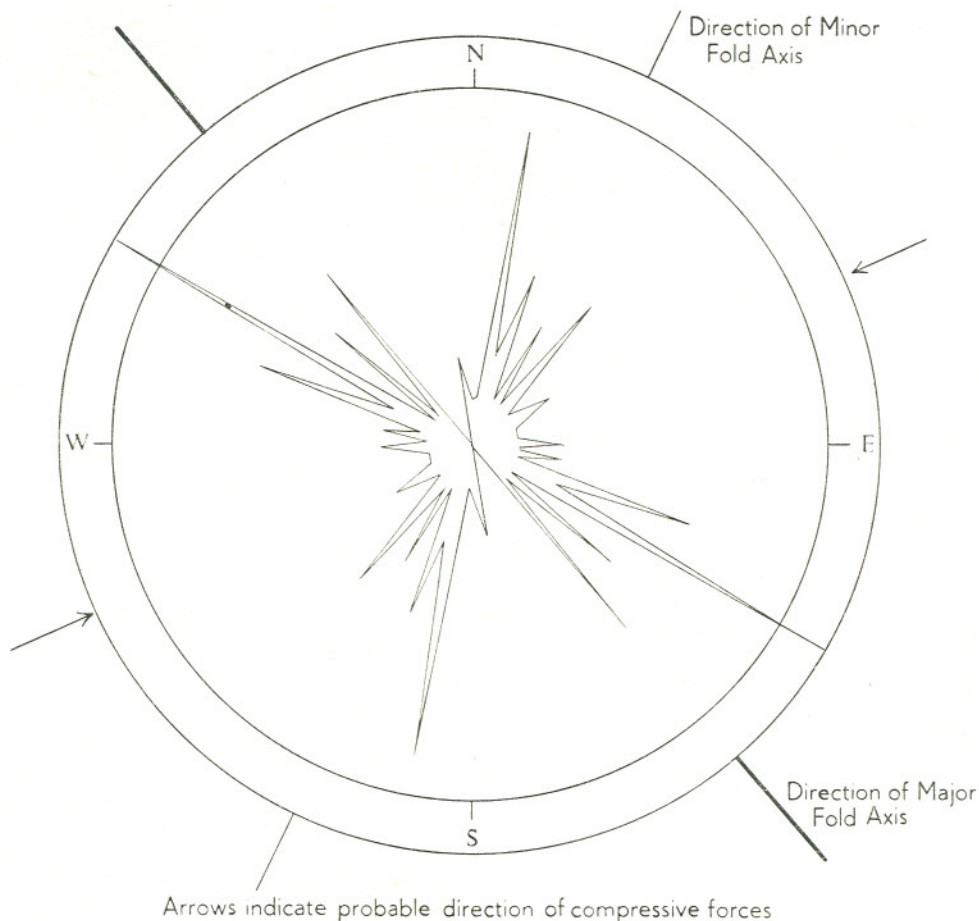


Fig. 3.—Joint-frequency diagram.

arch is not denied. There is the appearance of gentle arching of the Dawa limestones in Abyssinia when viewed from high ground in Kenya in the Melka Garse area. No major faulting was discovered.

(2) MINOR STRUCTURES

The minor folds or ruffles of the Murri Limestones have already been mentioned. They vary in size but are usually not more than about 100 feet (approximately 30 m.) between crests. Two chief directions of the fold axes were recorded, the predominant direction being about 320° - 140° , and the secondary direction approximately 25° - 205° . The directions along which stresses acted on the limestones can be estimated by a study of the distribution of the jointing found in the area (Fig. 3), from which it appears likely that gentle compression forces acted in an E.N.E.-W.S.W. direction, a suggestion that is confirmed by the most marked direction of folding.

Horizontal and vertical jointing is well-developed in the granites in the west part of the area. It is generally regular, the vertical jointing following two main alignments at 112° - 292° and 35° - 215° respectively.

VI—ECONOMIC GEOLOGY

1. Oil

On several occasions during the past 20 years the possibility of the occurrence of oil deposits in north-eastern Kenya has been considered, by both official and non-official bodies. Before considering the pros and cons of the local argument it will perhaps be useful to give an account of the nature and occurrence of oil deposits in general.

(1) THE ORIGIN OF MINERAL OIL

Opinions have differed widely concerning the origin of mineral oil—Russel (1951, p. 163), for example, discusses three theories. The least acceptable theory postulates an abyssal origin, the oil being derived inorganically, and migrating from the depths of the earth to overlying sediments. Another theory involves the generation of petroleum from the combination of natural gases and organic matter in sediments to form petroleum. The most likely and the generally accepted theory, however, is that petroleum in economic quantities is derived from the organic content of marine sediments. Pratt and Good (1950, p. 7) have pointed out that chemists are able to demonstrate the ready transformation of organic material into petroleum. Russel (*op. cit.* p. 168) suggests that the transformation is carried out by anaerobic bacteria which obtain oxygen for their life processes from the combined oxygen of organic matter. He cites as an example of this process, the production of methane from decaying matter in swamps. He considers that the matter remaining after decomposition depends on the nature of the original organic material.

It has been established that the percentage of organic material in a sediment does not necessarily affect the ability of the sediment to serve as a source of oil, provided that a minimum of marine organic material was originally present. Pratt and Good (*loc. cit.*, p. 9) consider that the most likely supply of organic material is from the various types of plankton found in the seas. They believe that only a small fraction of the organic material represented by the present-day plankton living in the seas, could supply the entire quantities of organic material found in marine sediments.

In the presence of an assured supply of organic matter which can accumulate under suitable condition in the muds of sea beds, it is believed that bacteria reduce it by extracting the combined oxygen. It is considered essential for the formation of oil, that the organic material so transformed is subjected to compacting pressures and a suitable temperature range. The pressures applied are normally due to the continued accumulation of younger sediments on the marine floor, and it appears that petroleum is formed only in sediments that have been buried deeper than 2,000 feet. Opinions are divided on whether traces of rare metals such as vanadium and nickel, which have been detected in oil, act as catalysts in the process of oil formation. Tiratsoo (1951, p. 36) points out that the energy released during the decay of small amounts of included radio-active minerals with the formation of helium probably assists the conversion of lower hydrocarbons to more complex hydrocarbons.

The final stage of the development of petroleum deposits consists of migration of the oils and gases. Normally they migrate upwards to accumulate in overlying porous sands or in various types of structural or stratigraphical traps.

(2) FEATURES ASSOCIATED WITH THE PRESENCE OF OIL

(a) *Surface Indications*

Oil seepages are the most favourable surface indication of the probable presence of oil underground. The seepages issue from the ground or under water, when the oil floats to the surface. When collected on water, the oil is brownish to greenish, and if thin the surface film may resemble the iridescent iron oxide-rich scum found in stagnant pools, which is often mistaken for oil. Oil from seepages is generally detectable by its appearance, odour and inflammability. Gas seeps are less easy to detect unless they occur in water, in which case bubbles are noticeable. Most gaseous mixtures associated with petroleum deposits have well-defined characteristic odours.

Surface accumulations or stainings of asphalt and similar substances often indicate the presence of asphaltic oils. Asphalt is usually fairly easily detected and is readily recognized by heating, when it yields drops of oil and a pronounced odour of asphalt. Mud volcanoes extruding mud, saline water, oils and gases are often characteristic of petroleum areas.

(b) *Subterranean Features*

An important aspect in the assessment of a sedimentary sequence with regard to the possibility of the occurrence of oil is the establishment of the presence of oil traps. Traps are caused by local structures, by variations of lithology or by combinations of both structure and lithological variations. With the aid of a suitable sealing rock they check or prevent the migration of the oil, causing accumulation in subterranean reservoir rocks.

Russel (1951, p. 112) and Tiratsoo (1951, p. 77) give detailed descriptions of the various oil traps. The most important structural traps are sealing against fault-planes, closed anticlines and monoclines, and accumulations in fractures produced by deformation. The more important traps produced by both lithological and structural causes include the truncation of reservoir beds at angular unconformities where the younger beds can act as a seal, and anticlines with traps sealed by lithological or stratigraphical variations. The purely lithological traps consist chiefly of porous zones in non-porous rocks. The most common "host-rock" of oil is sandstone; porous zones in dolomites and limestones are less common.

(c) *Salt-domes*

In various parts of the world oil has been obtained from the immediate vicinity of salt-dome structures. Briefly, salt-domes are normally large but variable-shaped, dome-like bodies which have been squeezed upwards through sediments. The sediments penetrated are usually uptilted against the sides of the domes and sometimes strongly contorted. Various theories have been offered concerning the mode of emplacement but it is generally agreed that the rock in the domes is ultimately of sedimentary origin. The domes are often composed of about 90 per cent salt with up to 10 per cent anhydrite as a capping, though in some cases the capping contains rich deposits of sulphur. Rarely, shale and sandstone are included in them.

The topographical features produced by salt-domes exposed at the surface depend on the nature of the particular dome and the local climatic conditions. Differential erosion in humid conditions produces depressions or lakes, while in arid climates such as that of Iran, salt-domes sometimes rise high above the surrounding sediments. Many domes do not, however, penetrate to the surface.

Salt-domes frequently afford good oil traps, both around their flanks and in the domed-up beds above them, when the beds around them include suitably permeable beds in which the oil can be stored and satisfactory sealing beds.

(3) THE POSSIBILITIES OF THE OCCURRENCE OF OIL IN NORTH-EASTERN KENYA

Surface Indications.—No surface indications of oil were discovered throughout the area mapped. In the *Social Credit Review of East Africa* of June 11th, 1937, J. Dejean

stated "East of Asharbit (Asaharbito) at the foot of the Willeh hills, the coloration of the sands changes when dug up and they become wet. If washed with boiling water, one obtains petroleum". Although samples of soils were collected within the limits of the area, including the Asaharbito depression, none yielded any trace of petroleum on boiling. A slight greasiness was commonly experienced in such cases but this was mainly due to salt in the sediments.

Subterranean Conditions.—Stratigraphical and structural analysis of the area surveyed could not be expected to reveal conclusive evidence of the possibility of the discovery of oil in the Mendera-Wajir basin. The area surveyed for the present report is a small part of the whole Mesozoic basin, and any conclusions drawn from the investigation of its geology must be considered in association with results obtained from the whole area when they become available. The part likely to be played by the rocks of the Derkali-Melka Murri area may, however, be conveniently discussed now. Tiratsoo (1951, p. 93), describing areas offering the highest chances of success, stated . . . "those areas of the earth where there are thick marine sediments containing in their sections dark shales and porous sands; where there are plenty of gentle folds but no violent fractures, and where there is adequate impermeable cover". These criteria, as applied to the present area, are considered in succeeding paragraphs.

The Murri Limestones, consisting of perhaps well over 2,000 feet of sediments, are of marine origin and include abundant fossil fragments, among which are large numbers of foraminifera, believed by many to be the chief source of organic matter that can yield petroleum. The area surveyed, however, was found to be devoid of dark-coloured, pyrite-bearing mudstones or shales, such as often provide ideal conditions for the formation of oil. In addition, no horizons capable of acting as reservoir rocks were found in the exposed sections of the limestones. The ideal reservoir rocks are ill-consolidated sandstones, though porous limestones are also suitable. It is possible, however, that dark mudstones and lenses of sandstones may occur beneath the exposed limestones or further towards the centre of the basin, perhaps corresponding with Ayers' (1952, p. 61) Mansa Guda beds. If such were the case, it is not impossible that oil might have been generated and stored at levels in the basin of which it is not possible to obtain evidence at surface.

In the area surveyed there is little indication of oil traps. The area is almost free of faulting, the sediments are almost horizontal and the strata exposed are all conformable. It is possible, however, that the stresses responsible for the small-scale folding may have caused gentle archings on a larger scale, which could perform as anticlinal oil traps, so far as the Bathonian-Callovian sequence is concerned. Finally, an impermeable capping to prevent the escape of migrating oil is lacking.

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. Such a conclusion does not, however, rule out the possibility of the discovery of suitable conditions nearer the centre of the basin, in the region of Mendera.

Perhaps the most important requirement for further investigation of the sediments, is the establishment of the complete profile of the basin, by geophysical means.

2. Other Mineral Deposits

Although no mineral deposits were discovered during the survey of the area, it is possible that occurrences of the minerals often associated with granitic intrusions, such as tin, tantalum, tungsten, gold and mica might be found near the contact zones of the granites. Examination of the honey-comb breccia from the Ablun fault-line proved slight gold mineralization—an assay of a grab sample revealed the presence of 1 dwt. of gold per ton.

The extent of the Derkali granites is not known and, except at Goljo, its contacts have not been mapped. It is possible that further west and south-west it may be covered by younger sediments or lavas. If, however, the contacts could be established an examination of the areas around them might prove profitable.

3. Water-supplies

In comparison with the vast stretches of the Northern Province further south, the area is well supplied with water. The Daua Parma river, which drains a portion of the Ethiopian

highlands, flows for a considerable period of the year and when flow ceases, water is always readily obtainable by digging in the sandy river-bed. The water-holes or "pans" of the Tertiary sediments in the Banissa area are a source of water for up to three months after the rainy seasons. In addition the construction of concrete dams to collect water from granite faces at El Roba (allotted to Ethiopia by the joint Boundary Commission) and Kiliwe Hiri, have proved highly successful. The shallow wells at Sank Kurari (now in Ethiopia) provide a fairly good supply of water for a few months after the rainy seasons.

To increase water-supplies the "pans" of the Banissa area could be excavated, although care would have to be taken not to penetrate the foundation of impervious clays. Most of them could be excavated for a depth of about twenty feet below the present levels. Increased use could be made of the catchment areas of granite faces by the construction of small dams. The dams should preferably be deep, offering a proportionately small surface area to evaporation. Furthermore, care should be taken to seal off any open joints. It is possible that occasional faces of inclined limestone might be utilized in a similar way in the waterless area south-east of Banissa. In general, it is considered unlikely that bore-holes would meet with much success, either in the pre-Jurassic or the limestone areas. Wells sunk in the limestones, just above the junction with the older rocks as at Sank Kurari, might meet with local success.

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