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MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

MINES AND GEOLOGICAL DEPARTMENT

GEOLOGY

OF THE

WAJIR-MANDERA DISTRICT

N.E KENYA

PARTS OF DEGREE SHEET 7, 8, 15, 16, 23, 24 AND 31
(With Five Geological Maps)

by

F.M. AYERS, B.S., F.G.S.,
Senior Geologist, E.C.A.)

With appendices on fossils collected in the area

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FOREWORD

The report on the geology of the Wajir-Mandera district of north-east Kenya is the result of approximately two years' work by Mr. F. M. Ayers, who was seconded to Kenya as Senior Geologist under the Economic Co-operation Administration Scheme. Identifications and datings of some of the fossils that he collected during his survey arrived on the eve of his departure from Kenya, too late for him to incorporate them in the body of the report. They have accordingly been written up and added as an appendix. Other information on fossils collected in the area was received later as the report was being sent to Press, and has been incorporated as a second appendix.

NAIROBI.

26th March, 1952.

WILLIAM PULFREY,

Chief Geologist.

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ABSTRACT

The report describes the geology of an area of some 17,400 square miles extent in the north-east corner of Kenya, bounded by the Ethiopian and Somalia borders and generally by the fortieth meridian and by the parallel 2° 30' N. The area is mostly flat and low-lying, and consists largely of the remains of the sub-Miocene peneplain, lapped on the south and the east by the end-Tertiary peneplain. There are numerous residual flat-topped hills in the central part.

The western part of the area is occupied by Basement System gneisses, schists, quartzite and marbles. The remainder is occupied by sediments, ranging in age from lower Jurassic to lower Cretaceous (?), comprising: (1) the Mansa Guda formation of clastic sediments of unknown age; (2) a thick limestone series of middle to upper Jurassic age with two notable shale intercalations; and (3) the Mandera Series, and its facies variation the Marchan Sandstone, of uppermost Jurassic to lower Cretaceous (?) age.

The Mesozoic sediments form the western half of a large structural basin that is completed in Somalia. Folds and faults were mapped in the basin, and attention is given to important facies changes.

An opinion is given on the possibility of the occurrence of oil-bearing horizons in the basin.

I—INTRODUCTION

The area investigated is the north-eastern corner of Kenya and lies between latitude $2^{\circ} 15'$ and $4^{\circ} 15'$ north, and between longitudes 40° and 42° east. It comprises 17,400 square miles within its bounds.

A geological party sent to Kenya by the Economic Co-operation Administration Mission in co-operation with the British Colonial Geological Survey began field work in April, 1950. Two petroleum geologists were made available under this programme, but the junior member of the team was on hand only for a three months' field assignment. The data embodied within this report represents the results of approximately a year of field mapping by the writer. Mr. A. O. Thompson, a Mines and Geological Department geologist, ably assisted in the final stages of field mapping during a period of three months.

Aerial photos taken by the R.A.F. in 1947 on a scale of approximately 1: 30,000 were available for the border sectors in the extreme northern part of the region. Since no preliminary plots from the photos were securable by April, 1950, a base map was produced from the photos for field use until the preliminary plots arrived in June. Three army maps (E.A.F. No. NA 373, 1940; NA 376, 1941; and NB 376, 1940) on the scale of 1: 500,000 were the only other maps available. Consequently for geological mapping it was necessary to carry survey lines where possible, over much of the region. The reliability diagram on map 2 shows the area covered by cyclometer and plane-table traverses. Topographically prominent land forms were resected for location where not too distant from the plane-table road traverses.

The entire area covered by sediments was photographed by the R.A.F. during early January, 1952, when the writer had completed the field work it was possible to carry out during his tour in Kenya. Preliminary prints were loaned to the department on the 1st of February and an attempt has been made to check field data over structures, questionable faults, and contact boundaries. Beyond this, lack of time has not permitted further photo-control.

Several geologists have previously visited the area covered by Jurassic and Cretaceous (?) sediments in the Northern Province of Kenya. J. Parkinson visited the region in 1914–15 and in 1938. V. Glenday in 1923, H. G. Busk and J. P. de Verteuil in 1937 and Dr. F. Dixey in 1943.*

Between April and October, 1937, the whole of the area formed part of an oil exploration licence area held by the D'Arcy Exploration Co., Ltd., and the Anglo-Saxon Petroleum Co., Ltd., whose geologists (Busk and de Verteuil) carried out a rapid reconnaissance survey. No detailed work was done. In February, 1938, an oil exploration licence was granted to the Kenya Oil Exploration Co., Ltd., over an area of 312.5 square miles, north-west of Wajir and south of the Wadridima Plains, and in October of the same year a supplemental licence was granted to the company over an area of 3,065 square miles covering the Asharbit-Wergudud-El Wak-Bur Gawse area. The company employed Dr. J. Parkinson to investigate the areas geologically and, after an examination, he made various recommendations for drilling. Owing to the war, investigations did not proceed beyond the preliminary stage, and the licences were allowed to lapse in 1940. The department had long felt, however, that the area merited closer examination with a view to the discovery of oil deposits, and in 1949, when E.C.A. assistance became available, the help of geologists experienced in oil-field

* References are quoted on page 21.

geology was sought to complete the first stage of a more detailed survey. During the work preliminary geophysical investigations were carried out on contract by Geophysical Surveys (Pty.), Ltd., of Johannesburg.

There are usually two distinct rainy seasons in north-eastern Kenya. The short season is from about the middle of October to the middle of December. The longer period of rains starts in March, sometime after the middle of the month, and generally ends in May but sometimes extends into June. The average annual rainfall at Wajir for a ten-year period prior to 1950, as given by the District Commissioner, was near ten inches. During 1951 an average of about 16 inches of rain throughout the area was unusual.

The vegetation is mostly low thorn bush, and on limestone and sandstone outcrops is dense. At many localities it is difficult to penetrate the bush cover with the Land-Rover type of vehicle. Flat-topped acacias, dom palms and other larger trees grow along the water-courses and the lower reaches of gullies. The fruit of the tall dom palms which line the banks of the Daua River furnish in part food for Somali tribesmen and are eaten by baboon. During the rainy season grass grows luxuriantly and supports thousands of camels, goats, fat-tailed sheep, and some cattle besides numerous species of wild game. The Semitic peoples who migrated to the Northern Frontier district from the countries to the north dwell as nomads grazing their stock wherever water and food are available.

II—PHYSIOGRAPHY

The physiography of north-east Kenya is comparable in many respects to parts of Texas, Arizona or New Mexico in North America. When motoring from Wajir towards Takabba the monotony of the plains country is broken by Tarbaj Hill situated 32 miles north of Wajir. This feature rises about 300 feet out of the thornbush-covered plain, and is an outlier of the Mansa Guda conglomerate formation. Proceeding northwards from Tarbaj towards Takabba the plain extends for 18 miles before outcrops of sandstone are reached. The low sandstone and conglomerate hills extend northwards for 35 miles after which limestones control the topography. At Takabba the jagged surface of granite hills rises 300 feet or more above the surrounding terrain. North and north-east of Takabba the topography is low and gently rolling but three miles east several neighbouring limestone hills rise to heights equal to that of the granite ridges. Twenty miles east of Takabba the Marehan sandstone forms abrupt red hills at least 200 feet above the surrounding low limestone hummocks. The relative flat surface east and north-east of Derkali is congruous with the almost horizontal bedding of the outcrops.

In the vicinity of Melka Murri, tributaries of the Daua River have deeply dissected the horizontal sediments, exposing 1,500 feet of eroded limestone. About midway between Melka Murri and Rahmu a series of north-south aligned hills is a prominent physiographic feature. They stand out against the skyline 25 miles west of Rahmu and mark the position of the Dedacha Arch. Three miles east of Rahmu NE.-SW. trending hills formed by a series of limestone beds, which attain heights of 500 feet above the Daua Valley floor, are of no less interest.

The most prominent topographic features within the area are formed by the Marehan sandstone. The massive and indurated sandstone produces a series of strike ridges which from north to south are known as the Raiya, Willeh, Babo, Garri and Danissa Hills. They have west-facing scarps that rise six to seven hundred feet above the low limestone hills which form the surrounding country. Sandstone hills are prominent north-west of Danissa where the Ogar Wein Hills, due to a structural trend, have east-west strike. After the westward swing of the Ogar Wein Hills the rim of the sandstone-

filled basin continues as a high feature southward but the scarp decreases in prominence except at Bur Wein south of El Wak. Here a thousand feet of sandstone occur in a hill overlooking the El Wak plain to the north. Erosion of the sandstone hills has lowered the east-dipping slopes formed by the Marehan sandstone which gradually fade into the plains eastwards along the border between El Wak and Hafura. The Hegalu Hills along the border just east of Hafura, and passing in o Italian Somaliland, are sandstone hills aligned NE.-SW. which form an outstanding topographical feature due to structural uplift.

Drainage in the northern part of the region is to a large extent into the Dawa River. The stream-courses are parallel with the general strike of the formations and all the drainage is northwards for a distance of 50 miles to the south of Rahmu. From Wajir, in the southern part of the area for more than 50 miles to the north there is a gradual rise of nearly a thousand feet and most of the rainfall draining off the ridge formed by the Mansa Guda formation probably eventually trends towards Wajir. Rainfall on the low limestone hills overlying the Mansa Guda formation drains eastwards mostly into Lak Katulo and flows south-eastwards out of the mapped area. In the Derkali sector, west of the surficial deposits of young clay and gravels, the drainage is westwards. All streams are intermittent excepting the Dawa River, which rises in the Ethiopian highlands. It flows continuously nine months of the year but during the dry months its waters descend into the porous sand over part of its course along the Kenya-Ethiopia border.

A marked change in the type of drainage is discernible 20 miles west of Rahmu where the insequent type of drainage changes to a radial type. The present stream-courses of this radial drainage are incised into old meanders now as a result of uplift. The radial type of drainage is probably due to a renewed cycle of erosion as a result of the Dedacha uplift.

III—SUMMARY OF GEOLOGY

Bordering the basal Mesozoic sediments on the west are metamorphic rocks and granites of the Basement System. Because of strong deformation no petroleum reservoirs could exist in them.

The succession of post-Archean sediments has a basal conglomerate formation with grits and sandstones, which is mappable in the south-western part of the area (maps 1 and 2). It has been named the Mansa Guda formation and was seen no farther north than Didimtu Hill where the last vestige of the formation underlies shaly limestones of the Upper Lias.

Unconformably overlying the Mansa Guda beds there is a sequence of algal and oolitic, thick-bedded limestones containing numerous fossils. They grade upwards into an argillaceous limestone, with locally developed shales just east of the Dedacha Arch. South of Rahmu a younger fossiliferous shale horizon with thin argillaceous limestone beds outcrops in a deep gully. Succeeding limestones, where seen at the best exposures east of Rahmu, are mostly argillaceous limestones with shale partings, though thin, brown, sandy limestones occur and there are minor foraminiferal brown-green shales. Fossil zones are common throughout but are more prolific in the upper part of the succession. A variety of fossils such as brachiopods, gastropods, corals, cephalopods (ammonites and belemnites) and lamellibranchs, are found in the fossil-rich zones. Sandstone horizons have been observed near the top of the limestone succession before the overlying beds of the Manderia sandstone take up the higher part of the sequence. North-west of Derkali the Limestone Series overlies metamorphic rocks, east of Takabba it is in juxtaposition to granite, and in the Mansa Guda sector rests on the conglomerates and sandstone.

The Mandera Series overlies the limestone with a marked unconformity. The lack of parallelism of the beds on opposite sides of the junction is apparent south of the Daua River, and the sandstones overlap progressively on to older limestone beds from the Daua southwards. The Mandera Series is mostly composed of sandstone but there are numerous beds of non-fossiliferous limestone, marls, non-fossiliferous variegated shales and gypsum. This association is interpreted as a lagoonal facies of the Marehan sandstone formation which comprises a higher proportion of sandstone and of which the beds are more massive. The Marehan sandstone overlies the Limestone Series in the central and southern part of the area.

A suggested correlation between the Kenya succession and that in British Somaliland is given in the table on page 5. This correlation is considered to be highly speculative but should stimulate thought towards a possible long-distance relationship. Only a cursory examination of the fossil fauna of the rocks of north-east Kenya was possible as reference facilities are inadequate in Kenya. Fossil specimens have been sent to the British Museum for classification. The fossils collected by Glenday (Weir *et al.*, 1929) from the limestones and shales along the Daua River, as shown by faunal analysis, indicate deposits ranging in age from Bajocian-Bathonian to Tithonian of the highest part of the Jurassic. Species which are not new or peculiar to East Africa are identical with, or have their nearest affinities to, species of West Europe. No forms with affinities to Indian species have been recorded in the Corallian-Tithonian deposits along the Daua River.

IV—DESCRIPTIVE GEOLOGY

A composite columnar geological section (Fig. 3) of the rocks of the area has been drawn to give the reader a better impression of the complete sequence. Little attention was paid to the underlying Basement System rocks as they are of no interest from the point of view of occurrence of oil.

1. Pre-Jurassic (Basement System)

(1) METAMORPHIC ROCKS

The low-lying hills situated about 35 miles north-west of Wajir and south of Ali Gollo are known to be metamorphosed limestones. Several of the major hills between Buna and Takabba, i.e. west of Takabba, were examined and found to be quartzites. A small outcrop of gneiss, quartzite, and schist forms a very low hill near Didimtu Hill. Farther north and to the north-west of Derkali vertical quartzite beds, schist and gneiss outcrop to the west of the limestone hills. At Kubi Hill ten miles south of Takabba fine-grained gneiss forms boulders and rounded masses of dark-grey to black rock.

(2) IGNEOUS ROCKS

Boulder-like masses of a pink granitic rock which weathers in a manner typical of the exfoliation of granites, stand abruptly from the plain surface at Takabba (Plate I, 2). Owing to lack of exposures on the plains the contact between the granite and the metamorphic rocks, such as the crystalline limestone which is exposed a few miles east of Takabba, cannot be examined. Granites similar to the Takabba type also outcrop near the El Robo police post north-west of Derkali and in low hills to the west of the metamorphic rock in that section. Along the road towards Wajir, 15 miles south of Takabba, several large pink granite boulders outcrop in the road. About 19 miles north of Mansa Guda Hill and along the road several large boulders of granite are again exposed. From these exposures it is not possible to state categorically whether the granites invaded the metamorphic rocks or whether they are the remains of an ancient batholith of earlier age, though their outcrop pattern suggests that they were injected into the Basement System.

	BRITISH SOMALILAND W. A. Macfadyen (1933, p. 28)	N. E. KENYA
Lower Cretaceous? to Upper Jurassic. Unconformity.	Nubian Sandstone.	Marehan Sandstone-Mandera Series.
Upper and Middle Jurassic.	Upper Kimmeridgian .. Gawan Limestone. Middle Kimmeridgian .. Daghani Shales. Lower Kimmeridgian .. Wanderer Lst. Lower Kimmeridgian to } Argovian? .. } Gahodleh Shales. Divesian? to Callovian .. Bihen Lst.	Upper Limestones .. Upper Shales .. Middle Limestones .. Middle Shales .. Lower Limestones .. Didimtu Beds.
Lower Jurassic. Unconformity.	Upper Lias.	
Age Unknown (Mesozoic?).	—	Mansa Guda Formation.

The succession quoted for north-east Kenya is that worked out by the present writer. As divergent opinions have been expressed by earlier geologists, a comparison of their results with the newly established sequence is given in the table below.

	PRESENT REPORT	DIXEY, 1948	BUSK, 1939	WEIR ET AL., 1939 (AFTER GLENDAY)
Lower Cretaceous, Upper Jurassic.	Marehan sandstones, and Mandera Series.	—	—	—
Upper and Middle Jurassic.	(Unconformity) Limestone Series.	Marehan Sandstones, Limestone Series.	Limestone Series.	Sandstones. Limestones.
Lower Jurassic.	Didimtu beds. (Unconformity)	Mandera Series.		Shales.
Trias or earlier.	Mansa Guda formation.	—	Marehan Sandstones.	—

Busk (1939, p. 219) explained the anomalous topographical position of the Marehan sandstones with respect to the Limestone Series by postulating that they were raised up in horsts and were in existence before the limestones were deposited. Dixey (1948, p. 39) controverted Busk's hypothesis and gave a description of passage beds passing upwards from the Limestone Series to the Marehan sandstones. In the present report evidence is adduced to show that the Marehan sandstones rest unconformably on the Limestone Series.

2. Lower Jurassic (Upper Lias?)

The lowermost non-metamorphic sedimentary unit exposed in the area is a basal sandstone-conglomerate formation, of which the outcrop extends continuously over a distance of more than 40 miles along the south-western periphery of the basin. A prominent outlier from the main formation occurs at Tarbaj Hill. Several small outcrops of the conglomerate and sandstone were also observed in the Wajir sector, one 14 miles north-east of Wajir on the road to El Wak and the other 23.6 miles east of Wajir on the road to Bardera. The width of outcrop of the formation does not exceed five miles as its thickness is not great.

The best-exposed section is at Mansa Guda Hill where 300 feet of vertical outcrop forms a promontory from which to view the surrounding country. The hill is built up of sandstone and conglomerate. The sand grains are coarse and subangular, well cemented by granular quartz and chalcedonic silica in some beds, though other layers are loosely cemented, probably by decomposition products of feldspars. The pebbles are subangular quartzite fragments. The whole section is of poorly sorted material, suggesting short transportation, perhaps by streams from the nearby Basement System hills to the west.

The Tarbaj Hill section, which closely resembles the Mansa Guda exposure, consists of 250 feet of cross-bedded sandstone and conglomerates. Indurated beds form steep-faced banks along the flanks of the hill. Quartzite pebbles of various size not only help to make up the basal part but are scattered throughout to the top of the hill. Several thin, white chert zones near the top are the source of detrital cherts seen along the hill-slope.

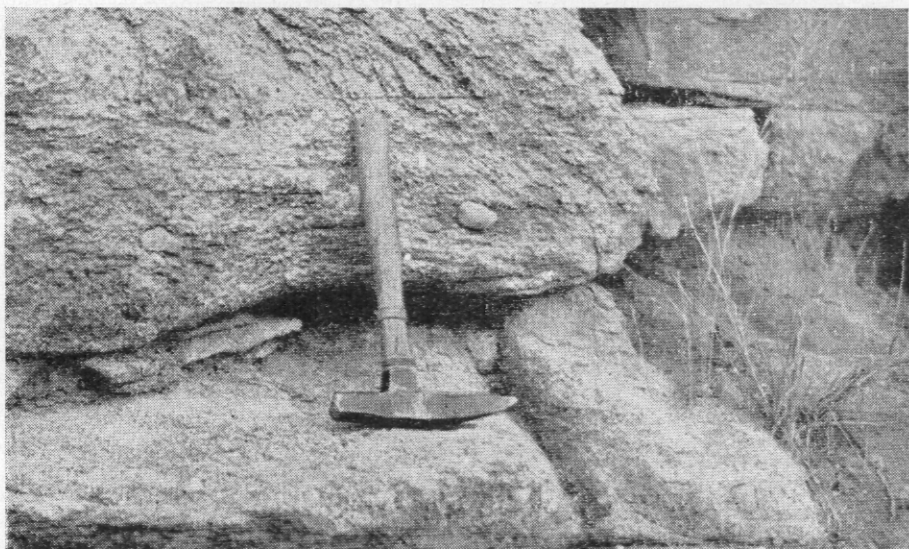
The relationship of this formation with the underlying rocks is unknown as a clear-cut junction was not visible. The metamorphic rocks exposed close to Didimtu Hill are probably of the type that can be expected below the basal sedimentary section.

The geological sequence from the Mansa Guda formation to the Marehan sandstone is shown in Fig. 1. Since nowhere has a basal conglomerate of the Marehan sandstone been observed it might be suggested that the Mansa Guda conglomerates are a shore facies of the Marehan beds. Due to the erosion of the Mansa Guda outcrop down dip to plains level, a vertical outcrop at the junction with the Limestone Series is a rarity. The best locality to observe a junction is, however, at Didimtu Hill where the limestone above the scattered conglomerate pebbles is sandy at the contact. It is concluded that the Mansa Guda beds are the oldest in the sequence, and are separated from the Marehan sandstone by the Limestone Series. No doubt with additional detailed work, with the assistance of aerial photographs on the ground, a knife-edge junction could be found along some valley. Since a tentative age determination of beds just above the conglomerate at Didimtu Hill points to Upper Lias, the Mansa Guda section must be Lower Jurassic or older.

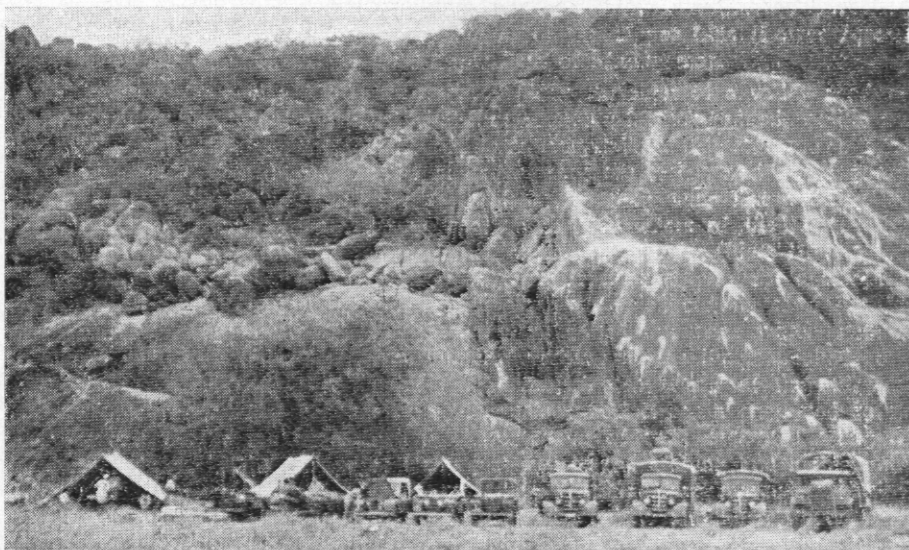
3. Lower to Upper Jurassic Limestone Series

The Limestone Series is a term given by Dr. F. Dixey (1948, p. 34; *see also Weir et al.*, 1929, pp. 9, 11, who used the term "Daua limestone") to the thick limestone succession that is of wide occurrence in the area. The series is best exposed along the south bank of the Daua River and in the hills adjoining it. The first outcrops occur about 25 miles west of Mandera and are present onwards to Melka Murri where erosion has deeply dissected the lower part of the succession. The southernmost outcrops are 35 miles north of Wajir from which they extend along the strike for 170 miles before the border is reached, where the limestones continue into Ethiopia. The width of outcrop varies from 15 to 80 miles, depending on the amount of erosion of the limestone and the extent of overlap of the Marehan sandstone. The total thickness of the Series as exposed near the Daua River, based on an average dip of one degree and without considering any duplication by unknown faults, would measure about 3,800 feet.

PLATE I

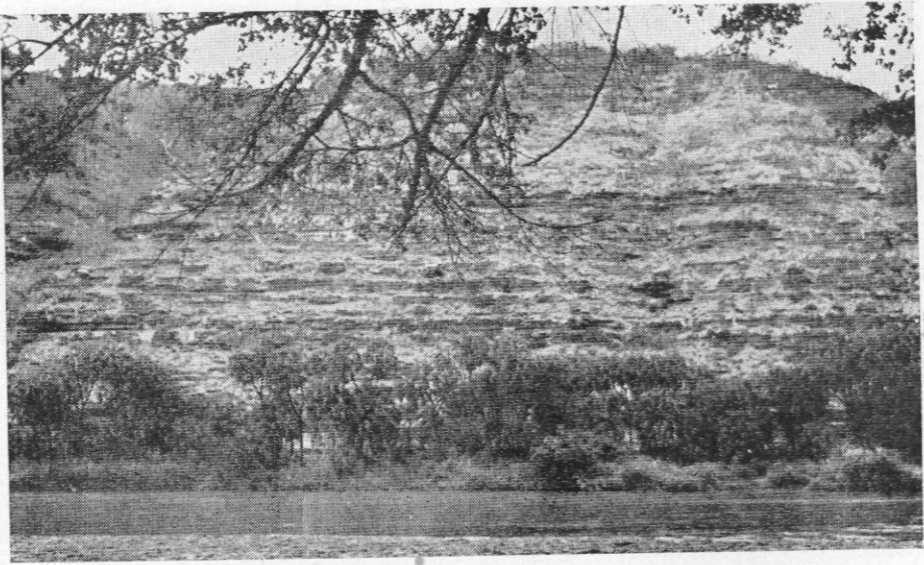


1. Mansa Guda conglomerate, Mansa Guda, about 60 miles from Wajir on the road to Takabba.

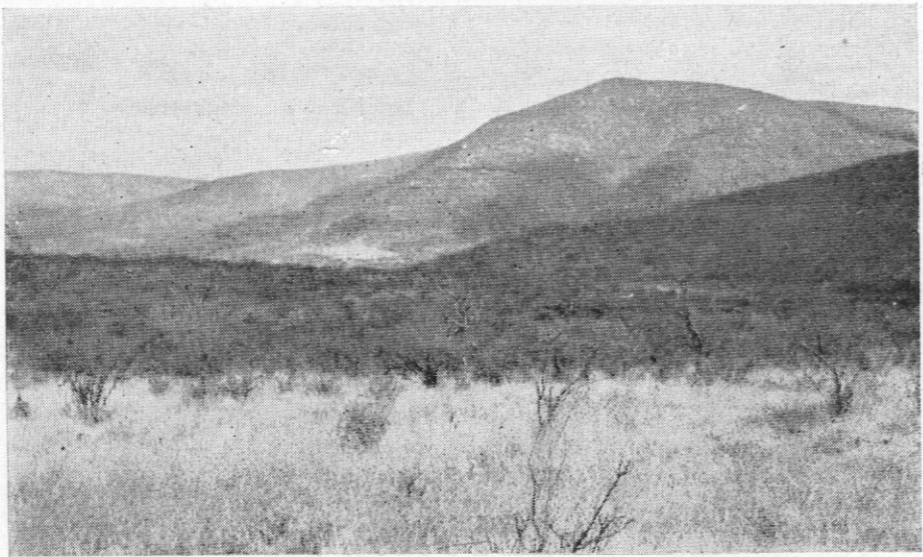


2. Granite hills, near the intersection of the Takabba-Wajir road with the Takabba-El Wak Road.

PLATE II



1. The lower part of the "Limestone Series" exposed in the Daua Valley, Melka Murri area,



2. Well-bedded limestones in the lower part of the "Limestone Series", in Ethiopia, across the Daua River, near Melka Murri.

(a) Lower Limestone

South of the Daua River and along its tributaries excellent exposures are to be found in stream-cuts and on the hill scarps which rise to 500 feet above the Daua Valley plain. The best outcrops distant from the Daua River drainage system are those at Bur Mayo, 31 miles south of Takabba near the Takabba-Wajir road. At Bur Mayo Hill 200 feet of well-bedded, cream or light-grey to buff, oolitic and algal limestone forms the lowermost beds exposed in this locality. At Didimtu, five miles south of Bur Mayo, limestone is in contact with the Mansa Guda conglomerates. The limestone-conglomerate junction at Didimtu Hill is at a higher elevation than the limestone at Bur Mayo, which may suggest lateral variation of conglomerates to limestone, along the strike. At the hills six miles east of Takabba the section can be correlated with that at Bur Mayo. The limestone beds are oolitic and algal, thick-bedded, and form steep-sided hillocks. A few fossils belonging to the genus *Rhynchonella* were gathered at these outcrops. On the road 20 miles east of Takabba the limestone is brown, slightly sandy, and fossiliferous in the lower beds, with oolitic beds in the upper part of the 50-foot section below the Marehan sandstone. Three miles west of Derkali the lowermost part of the Limestone Series (Weir *et al.*, 1929, pp. 11, 14) was studied near the junction with the metamorphic rocks, but due to the lack of suitable exposures the exact contact was not visible.

The junction of the basal limestone beds with the underlying rocks is an unconformable surface. The limestone has been deposited upon the metamorphic rocks, upon the Mansa Guda conglomerates, and rests on granite east of Takabba. Several miles north-west of Derkali the unconformable junction of the underlying metamorphic rocks with the limestone is evidenced by the presence of irregular pebbles and poorly rounded cobbles of the basement material within the limestone.

An excellent fossil assemblage was secured within a marly shale and brown limestone, about 75 feet in thickness, near the base of the Limestone Series at Didimtu Hill. The age determination of the various forms should be an index to the magnitude of the unconformity, if a stratigraphical comparison is possible between this section and that exposed at Melka Murri or Derkali. Information received in a letter from Dr. P. E. Kent of the D'Arcy Exploration Company, who delivered plaster casts of several ammonite specimens from Didimtu to Dr. W. J. Arkell at Cambridge University, indicates that they may be *Bouleiceras arabicum* of the Upper Lias (Lower Jurassic age), suggesting correlation with the *Bouleiceras* Beds of Madagascar.

The limestones at Melka Murri are exposed along the sides of a valley produced by a tributary to the Daua, where a 1,500-foot section of thick-bedded, oolitic and algal limestone is well seen. Part of the beds are recrystallized (dolomitized?). These exposures are not so fossiliferous as the higher part of the series, and no diagnostic fossils were secured which could serve as an index to their age. The bedding was considered to be horizontal from the police post to the waters of the Daua where the limestone forms sheer walls of rock rising from the water's edge (Plate II, 1). Along the affluents to the Daua River east of Melka Murri there are excellent outcrops of well-bedded, grey to brown, oolitic limestones, some of which contain algæ but few other fossils. Some exposures are of massive non-bedded limestone which strongly suggests reef-building within the series. The low arching of the limestone beds over the Dedacha Arch could in part be due to differential compaction of the sediments over a reef bioherm.* The presence of a sub-surface reef is again suggested in the steeper dip east of the arching, which is characteristic of beds deposited along the seaward side of a reef. The change of facies just east of the arching and a thickening of the section substantiates the premise regarding a sub-surface massive limestone. Eastwards from the approximate axis of the arch the oolitic and algal upper layers of the lower limestones become more argillaceous and shale members are locally

* *Bioherm*.—An American term for a dome-like, mound-like, lens-like or otherwise circumscribed limestone mass built exclusively or mainly by sedentary organisms, and enclosed in normal rock of different lithological character.

developed. Some of the beds are of detrital limestone containing fragments of corals, brachiopods (*Rhynchonella* and *Terebratula*), lamellibranchs, and other fossils (cf. Weir *et al.*, 1929, p. 14). Brown, slightly sandy, flaggy, fossiliferous limestone outcrops a few miles north-west of Rahmu near the Rahmu-Melka Murri road. In résumé; the lower limestone division of the Limestone Series as exposed along and south of the Daua River consists of 1,500 feet of nearly pure limestones and 800 feet of argillaceous limestones with oolitic and algal beds, detrital limestone and a few locally developed shales and a few brown, sandy limestone beds at the top.

Most of the limestone that is poorly exposed along the Wajir-El Wak road probably belongs to the lower part of the limestone succession. The outcrops are oolitic and algal, dark-grey to buff fossiliferous limestone with some beds of porcelaneous limestone with siliceous nodules weathering in relief.

(b) Middle Shales

Four miles south of Rahmu, in a steep-sided water-course just to the west of the Rahmu-Moyale road, are exposed 75 feet of dark-grey shales with their base obscured. Towards the top of the section the shales become interbedded with thin argillaceous limestones. The upper part of the outcrop is packed with *Terebratulids* and *Rhynchonellids*. Oyster beds appear near the top of the steep bank, while small lamellibranchs and ostracods occur in the lowermost shales and *Nautilus* was found in the stream-bed. This rich fossil zone must be several hundred feet thick, as more or less along the strike a hill, located 14 miles south of Rahmu and east of the Rahmu-El Wak road, exposes 50 feet of dark-grey, gypsiferous shale and 40 feet of thin, very fossiliferous, argillaceous limestones, with brown fossil limestones overlying them and forming the top of the low hill. Ammonites, belemnites, gastropods, *Pecten*, oysters and other fossils were found weathered freely from the formation. This shale horizon is overlain by a Pleistocene (?) siliceous limestone except in ravines and on hills over which limestone was not deposited, thus the total thickness is unknown for certain. The shales exposed in the water-course dip eastwards and it is possible there may be 300 feet of shales with thin limestone beds under the younger limestone cover, before the hills east of Rahmu are reached.

(c) Middle Limestones

The ridge-forming limestone group east of Rahmu is varied in character, a large portion consisting of argillaceous beds. The base of the westernmost hills a few miles east of Rahmu is composed of brown, flaggy, sandy, fossiliferous limestones and there are two brown, sandy zones about 80 feet apart which are easily recognizable on and along the road between Rahmu and Mandera. Above the brown basal beds there are cobbly, dense, dark-grey limestones with several fossil horizons. Near the rim of the hills a five-foot-thick limestone is grey to brown in colour, oolitic and fossiliferous, and makes an excellent marker horizon. Above this bed the limestones are brown to cream coloured, sandy, and usually with fossil gastropods and corals weathered in relief on the surface. This succession of mostly argillaceous limestone with thin shale partings comprises 700 feet of hill-forming limestone.

(d) Upper Shales

Overlying the upper brown, fossiliferous limestone beds of the middle limestones are brownish-green to grey, foraminiferal, gypsiferous shales, exposed in a stream-course and hillside just south of the road 15 miles east of Rahmu. At this locality 60 feet of foraminiferal shales outcrop without the underlying rocks being exposed. Thin 1-mm. ribbons of selenite, nodules of lime, and many small lamellibranchs within the shales are visible in the water-course and along its bank. Ammonites have also been collected at this locality in the stream-bed. Above the shales along the bank of the stream there is a ten-foot bed crowded with small lamellibranchs, while above this there are 20 to 30 feet of poorly exposed green fossiliferous shales. Five feet of sandstone and ten feet of sandy, oolitic limestone overlie the fossiliferous shales. The shales

also outcrop west of a fault at Survey Station No. 61. The beds here are similar to the above but a five-foot colonial coral bed above the stream-course is probably lower in the sequence. The total thickness of the upper shale zone is not known since the base is not visible.

(e) *Upper Limestones*

Overlying the upper shale succession, along the south bank of the Daua River and the low hills adjoining it, there is a limestone succession which probably represents a neritic phase of deposition. Argillaceous limestones with thin grey to green shale beds are predominant in this group. The limestone beds carry fossils throughout the succession but the highest part of the section is more prolific in fossil remains. The uppermost beds are easily accessible for examination on the south bank of the Daua River at the first major limestone outcrop descending to the river on the road to Rahmu, 25 miles west of Mandera. The junction between the sandstone of the Mandera Series and the underlying limestone occurs on the road at the top of the hill before descending to the river and cannot be missed. At the base of the limestone hill and on the south bank of the Daua River the following section can be observed between the water's edge and the top of the hill:—

	<i>Feet</i>
(4) Cobbly limestone—buff to brown, very fossiliferous with gastropods, corals and lamellibranchs	35
(3) Oolitic limestone—brown weathering	3
(2) Sandstone—fine grained, cross-bedded, and brown weathering ..	40
(1) Argillaceous limestone—grey, dense, fossiliferous, and weathering with bouldery outcrops	20

The upper portion of the Limestone Series taken as a group is more fossiliferous than any equal proportion of the series. The 40-foot sandstone horizon intercalated with limestone beds suggests rhythmic deposition of shallow-water sediments. The measured section through the Upper Limestone group is 520 feet in thickness.

Dark-grey, dense, oolitic algal and fossiliferous limestones outcrop along the crest of the Hafura structure south of Mandera along the boundary between Kenya and Italian Somaliland, and can possibly be correlated with the upper part of the Limestone Series. Age determinations of the fossils indicates that they are of Upper Jurassic or even Lower Cretaceous age (*see* page 31). Approximately 200 feet of limestone outcrops in the Hafura sector.

4. Uppermost Jurassic-Lower Cretaceous (?)

(1) MANDERA SERIES

The term "Mandera Series" was adopted by Dr. F. Dixey (1948, p. 34) for a group of sediments that outcrop west and south-west of Mandera and which he considered to be older than the Limestone Series. From the present work the writer agrees with Dr. Dixey's description and areal mapping of the series but would not place it in the same position in the geological sequence. Throughout the Mandera Series and the Limestone Series, where they are best exposed in Kenya (*i.e.* along the Daua River), the regional dip was found to be gentle towards the east (map 4). The dip west of Mandera, measured by plane-table and alidade, was 108 feet per mile to the south-east, *i.e.* a little over one degree, which would necessarily place the Mandera Series above the Limestone Series in the geological column.

The most accessible point to see the junction of the limestone and sandstone series is some 25 miles west of Mandera, along the road to Rahmu. The junction strikes the eye where the brown, weathered sands meet cobbly, grey limestone at a wide curve in the road two miles before it reaches the river bank. The actual junction is seen a mile south of the road at the base of two small sandstone hills. The succession seen is:—

	<i>Feet</i>
(5) Buff- to ochre-coloured marlstone	8
(4) Fine-grained, friable sandstone	6
(3) Sandy shale	7
(2) Brown, sandy marl	2
(1) Green shales (dark-grey, fossiliferous limestones of the Limestone Series)	10

The overlying sediments as exposed in the hills along the road to Mandera from these basal outcrops are massive, cross-bedded and friable sandstones, thin beds of marly, gypsiferous shale varying in colour from green to purple and rose; thin, dolomitic limestone beds which are often associated with the marlstones; and a few thin, sandy, glauconitic limestone beds. Ripple-marks and leaf imprints are common within the cross-bedded sandstones while gypsum is a common constituent of the variegated shales, and beds of gypsum outcrop just west of Mandera.

One of the best exposures to be found is situated 17.3 miles west of Mandera near the road where a west-facing scarp yields 200 feet of section as follows:—

	<i>Feet</i>
(11) Pleistocene (?) limestone (top of scarp)	20
(10) Thinly bedded, lithographic limestone	5
(9) Fine-grained, brown, weathered sandstone	10
(8) Sepia- to rose-coloured marlstone	1
(7) Brown, crystalline, dolomitic limestone	3
(6) White, fine-grained, laminated sandstone	31
(5) Brown, argillaceous limestone	$\frac{1}{2}$
(4) Fine-grained, bedded sandstone	55
(3) Green and purple, gypsiferous shales	27
(2) Buff to brown, sandy limestones	18
(1) Purple shales (base of escarpment)	30

Nine miles west of Mandera on the road to Rahmu, and several hundred yards to the south of the road, a low hill reveals massive sandstone. The exposure consists of 40 feet of red, weathered, highly fractured, well-cemented and well-sorted sandstone. This type of massive sandstone extends in a NE.-SW. aligned outcrop for about five miles. The massive outcrops of sandstone form stacks and chimneys along the strike of the formation and in that respect it resembles the Marehan sandstone of which, indeed, it is regarded as a facies. The overlying beds of platy limestones, inter-bedded sandstones, and gypsiferous shales to the east of the massive sandstone outcrop in a valley located between exposures Nos. 5 and 6 (map 4) and have dips that suggest compaction over a massive, lenticular component.

Four miles south of Mandera, just east of the old road and near the border, a red-weathered, massive sandstone forms a bluff 120 feet above the surrounding plain. It is highly cross-bedded, iron-stained, fractured and with almost no normal bedding. A petrified tree trunk found on top of the hill suggests that it is a terrestrial deposit or at least a near-shore deposit. No doubt these exposures of massive sandstone represent original coastal sand-dunes. The character of the deposits of the Mandera Series as a whole suggests the site of deposition was lagoonal.

At Bur Gawse Hill, which is on the international boundary south of Mandera, there are exposures of gypsiferous, green and purple shales at the border line. Cross-bedded sandstones overlie the shales and a ten-foot bed of algal, dolomitic (?) limestone caps the hill. About half-way up the hill a bed five feet in thickness of reddish, marly shale yielded poorly preserved *Trigonia* and fish remains. It is doubtful whether these poorly preserved fossils, when classified, will be diagnostic for age determination of these beds.

PLATE III

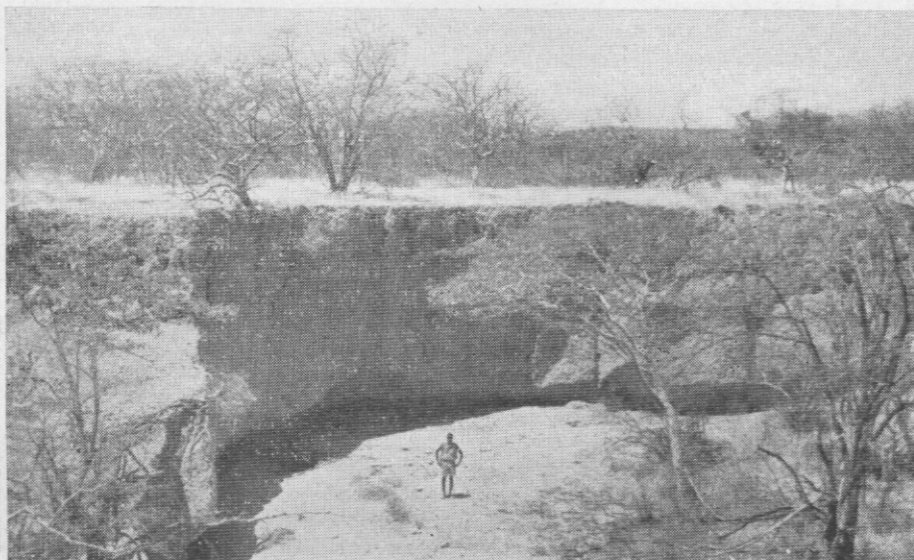


1. Unconformable contact between the Marehan sandstone and the underlying Limestone Series. Hamassa Hills, between Takabba and Wergudud.



2. The Marehan sandstone escarpment, north-east of Survey Station 200, north of Danissa, in the Koblolu area

PLATE IV



1. Gully erosion in fine-grained red sandy soils at the base of the Hamassa Hills, between Takabba and Wergudud.



2. Peneplain surfaces, 19 miles SW. of Mandera, on the El Wak road to Mandera.

The very gentle eastward dip of the Mandera Series over an outcrop-width of 25 miles exposes 2,200 feet of sediments west and south of Mandera. Only 300 feet of deposits typical of the Mandera Series outcrop at the most north-easterly extension of the Raiya Hills below the massive, pinnacled Marehan sandstone. The remaining 1,900 feet of the Mandera Series thins southwards and passes laterally into the massive Marehan sandstones with minor shale and marlstones intercalations. Typical Mandera Series beds can be identified as far south as the Danissa Hills.

(2) MAREHAN SANDSTONE

The Marehan sandstone, which fills the centre of a sedimentary basin lying in both Kenya and Italian Somaliland, has an outcrop 100 miles across (map 1). The most prominent topographical features such as the Raiya, Babo, Garri, Danissa and Bur Wein Hills (map 4) form a pattern of NE.-SW.-trending escarpments rising some 500 feet above the lower undulating limestone hills. North and west of El Wak the dip is gently eastwards and as a result of erosion of the overlying beds, surface elevations decline towards the east. Between Mandera and the Damassa water-pan very low hills form the bedrock of the country except at the Hegalu Hills where a structural uplift has brought the sandstone to a high elevation. At Wergudud the massive sandstones are low in elevation and continue as low hills eastward for some distance until they grade into the plain. South of El Wak and near the border the resistant Marehan sandstone forms hills at Bur Wein, 1,100 feet in height above the surface of the El Wak plain. The Marehan red sandstones are in part of marine origin as is indicated by the fossils found in the basal beds at some localities. These fossil beds may be examined in the northern outcrops of the Ogar Wein Hills and at the small outliers 25 miles as the crow flies south-west of El Wak. They are very fossiliferous with a *Pecten*-like form occurring at both localities. The sands are remarkably fine-grained at the base but are coarser higher in the group. Mica is a common constituent. Near the junction with the Mandera Series the beds are usually thin and flaggy and weather a purplish colour. All through the group a white, powdery, ash-like material forms beds and blotches of white within the red sands. The sandstones generally were water-lain and the red colour is probably due to ferruginous material derived from the ancient residual soils of a semi-arid region. Convergency of beds and lensing of horizons were observed along the northern front of the Raiya Hills.

V—TERTIARY (?) DEPOSITS

Limestones in the El Wak and Wajir areas have been given a Tertiary age by Dr. F. Dixey (1948, p. 9). He states "Beyond the fact that they are post-Jurassic and considerably older than the later lower Pleistocene lake beds of Chelbi desert there is no definite information available in the Northern Frontier District as to the age of these beds. . . .". They consist of white, porous kunkar limestone and occur for about a radius of ten miles from El Wak in all directions. The sink-holes within the white gypsiferous limestone around El Wak are solution cavities where about 20 feet of deposits may be examined. The material from the El Wak wells which were dug to 80 feet depth includes dark-grey gypsite and selenite as well as limestone. No log was kept, however, of the exact footage of limestone and gypsum passed through. The gypsum weathers with a chalky whiteness in outcrops and the gypsum terrain is distinguishable from the limestone by the absence of sharp-edged, irregular boulders. Building material for the construction of the El Wak police fort was secured from these beds.

At Ndegas Nest south of Wajir, i.e. west of the aerodrome, a borehole was sunk to 351 feet. This is probably the deepest hole drilled to date and it was bottomed in sandstone. Unfortunately no samples are at hand for study of the precise succession in the Wajir wells. Several hand-specimens were handed to the writer, however, by a member of the hydrographic survey from depths around 30 feet and they were found

to be compact, non-calcareous sandstone. In contrast to the Wajir wells, the Wajir Bor wells some 36 miles east of Wajir passed through gypsum from top to bottom. A well near the highway from Wajir to Bardera exposes 30 feet of gypsum.

No information is available as to the type of rocks which underlie the Tertiary (?) rocks of the Wajir area as no wells have been drilled deep enough to penetrate older formations.

The land surface north, west and south of El Wak rises gently and the Tertiary (?) deposits fade into a red sand which is derived from the weathering of the Marehan sandstone.

VI—QUATERNARY

1. Pleistocene (?)

A few miles south-west of Rahmu large boulders up to ten feet in thickness, composed of white porcellaneous limestone with nodules of chalcedony, cap the hills. One of the best exposures to be observed is along the bank of a gully four miles south of Rahmu to the west of the Rahmu-El Wak road. At this locality 30 feet of white limestone abuts against the Jurassic black shales, with some beds about ten feet in thickness passing over the top of the shales, thus displaying an overlap on to the Jurassic section. In the dry stream-course there are large boulders of siliceous, algal limestone with some boulders riddled by *Teredo* worm-borings. This young formation is very irregular in outcrop pattern. It is to be found in patches in valleys some 15 miles west of Rahmu where the camel trail from Rahmu meets the Derkali road. It forms a deposit of 30 feet or more in thickness in the gully, extending for six miles north of the intersection of the Derkali-Rahmu road and camel trail south-west of Rahmu. Several outcrops of soft, marly limestone are visible along the road in the direction of Derkali. Several fossils were secured from the formation; one of a coral and others of small lamellibranchs, none of which has yet been identified. Remnants of this very siliceous limestone cap several Jurassic limestone hills some 12 to 15 miles north-east of Asharbit. About 20 miles north of Asharbit and south of the Derkali-Rahmu road is another isolated outcrop of siliceous limestone which is several miles in extent and 15 to 20 feet thick. About 12 miles east of Melka Murri and two miles north of the Melka Murri-Rahmu road a low hill stands above the plain surface and consists of siliceous limestones similar to that of localities mentioned above. This outcrop is not shown on the maps as it is of small extent.

This formation must have been fairly widespread as its remnants are miles apart, and it is also believed that other remains of the cherty limestone have been left as chalcedony fragments on many of the Marehan sandstone plateaux, on the hills of the Mandera Series and on hill-tops of the Limestone Series east and south of Rahmu. Dr. F. Dixey (1948, p. 41) has considered, however, that the silicification is due to surface alteration rather than the presence at the surface of intrinsically siliceous sediments.

North-east of Derkali in the Banissa area, deposits of conglomerate and claystone 50 to 75 feet thick are spread over a restricted area. The conglomerates, which directly cover brown Jurassic limestones, contain water-worn pebbles of metamorphic rocks. Brown to yellowish sandy claystone outcrops along the road from Derkali to Banissa and from Banissa to Lulis. A mile or so east of Banissa, Jurassic limestone again outcrops and no evidence of the overlying deposits was seen again in that direction. This local formation is interpreted as a fluvial deposit. The stream-borne materials were derived from the highlands to the west and deposited as an alluvial fan upon the plains surface. The sediments cannot be correlated with the Pleistocene (?) siliceous limestones on lithological grounds but their position in the stratigraphical sequence and their position on the highest plateaux of the region, suggests that they are of equivalent age.

2. Recent

Deposits, no doubt of Recent age, are found at several localities along the Dawa River. Gypsiferous, coarse sandstone exposed just south of the store at Rahmu forms low hills bordering the Dawa River and is similar to a poorly consolidated, gypsiferous, pebble sandstone near the Dawa in the Mandera sector. Along the road from Rahmu to Melka Murri, a few miles west of Rahmu, poorly consolidated sands are also considered to be of Recent age. Limestone exposures between Mandera and Hafura, along the road and to the west of it, are no doubt of lacustrine origin and of relatively recent age.

Recent alluvium covers the Jurassic sediments in flats along the Dawa River between Mandera and Rahmu. Other Recent deposits are represented by soils. Much of the area between the rock outcrops is covered by thick, red, sandy soil which has been exposed by gully erosion to depths of 30 feet or more (Plate IV, 1).

VII—STRUCTURES

Regionally, the mapped area forms the west flank of a sedimentary and structural basin which is completed in Italian Somaliland (map 1). The general dip of the sediments in Kenya is between one and three degrees eastwards. The presence of younger deposits in the El Wak and Wajir districts and the presence of permanent water supplies there suggest proximity to the axis of the basin.

Until further information is obtained it must remain hypothetical whether north-eastern Kenya was the southern extension of an arm of the Tethys Sea during Jurassic time, with waters invading from the north. The evidence available at this stage does point to a great similarity between the fossil fauna of British Somaliland and that of the north-east Kenya Jurassic rocks. Preliminary work on the fossil fauna of the Northern Province shows that it has affinities with that of British Somaliland but little with that of coastal Kenya (Weir *et al.*, 1929). This faunal difference may not be so wide as has been thought once good collections have been made throughout the successions and all the fossils have been classified.

On the theory of sea invasion from the north it would be expected that the thickest section of rocks would be found in the northern part of the area. This may be the case but the geology of the entire region must be studied in more detail before a definite conclusion can be drawn. Any structures near the centre of the basin would be the most likely prospects for petroleum as the geological section should there be at its thickest. Additional information that may be secured from more detailed mapping of the surface and geophysical work will no doubt produce results which may be an aid in establishing the configuration of the Basement System floor underlying the Jurassic sediments.

1. Hafura Structure

The most interesting structure within the region lies near the international border and crosses into Italian Somaliland north-east of Hafura, which is 45 miles south of Mandera. Although no field mapping was possible in Italian Somaliland, evidence of folding in the Marehan sandstone was observed on aerial photographs for six miles across the border. The crest of the feature, shown by the Limestone Series outcrops, lies mostly in Kenya where the limestone was traced along the axis for a distance of six miles. The limestone outcrop over the crest has been exposed by erosion of the Marehan sandstone for a width of more than a mile but the wave-length of the fold from syncline to syncline, or to where the dip flattens in Italian Somaliland, is four miles.

The sandstone-limestone contact was examined on the Kenya side but due to detrital material no exact junction could be fixed. Some evidence exists for faulting along the flanks but is difficult to prove. Accurate elevations, determined by plane-table and telescopic alidade, on the limestone at the crest compared with those on the lowermost sandstone outcrops along the flanks, would check the presence or absence of a fault. Judging from aerial photographs dips steepen rapidly east of the almost horizontal beds on the eastern flank of the fold. This suggests further faulting. A southward plunge of the fold is indicated by the presence of Marehan sandstone beds, east of the road, seven miles south of Hafura.

A conservative cross-section (Fig. 5) has been attempted starting from the limestone-sandstone junction at the base of the Raiya Hills. Projected into the sub-surface at an angle of one degree, the junction of the Marehan sandstone and the Limestone Series is brought 1,000 feet below the surface in the syncline east of Hafura. The outcropping Limestone Series at the crest of the fold would have to assume a dip of ten degrees to reach the 1,000-foot mark in the syncline, without fault displacement. The section has been constructed to show an uplift with faults on two sides—a horst structure—with a displacement of nearly 1,000 feet on either side.

2. Dedacha Arch

A structural anomaly is represented by a topographical feature 25 miles west of Rahmu. A very low arching of the oolitic limestones has produced a west dip on its west flank, northern closure, and north-east dip steeper than the regional dip of the area on its east flank (map 3). It is a broad, gentle uplift which in part may be due to a massive reef limestone in the sub-surface. Some biostrome* outcrops, north and east of Melka Murri, suggests evidence of reef building in this sector. The limestone near the axis is very cavernous and highly undulating throughout the outcrops. The southern extension of the arch is unknown but the hills decrease in elevation several miles south of the Rahmu-Derkali road, south of Dedacha, and it is thought that this may represent a plunge to the south.

The alignment of the axis of the feature is NNE.-SSW., approximately parallel to the regional grain of the rocks. The fold is best expressed in the outcrops of the northern part between the Rahmu-Melka Murri and the Rahmu-Derkali roads. Detailed mapping using the aerial photographs now available may produce added pertinent information regarding this feature.

3. Gamul Structure

The Gamul structure (map 5) is a fold aligned in a nearly east-west direction and almost at right-angles to other trends of the region. It is probably a reflection of the basement structure and may suggest an older line of folding as compared with the NE.-SW. trends. If it is an older trend of folding it did not reach its culmination until after the deposits of the Marehan sandstone had also been folded. The Mandera Series cannot be identified beyond this line of folding and the writer considers that this area must have been above sea-level, or at least a sub-sea barrier preventing the southward extension of the deposits of that Series. The position of the axis of the fold is indicated by dips to almost due north and by several to slightly west of south over a linear distance of 20 miles. The north-east flank has a breadth of at least six miles but the south-west flank is not over four and a half miles in width. This trend is one of major proportions, larger than any other yet mapped within the area. Structural closure will be difficult to measure due to lack of outcrops at the east near Wergudud and to the west where the plunge is probably into the low limestone hills.

* *Biostrome*—An American term for fossiliferous bedded limestones consisting of and mainly built by sedentary organisms, and not swelling into mound- or lens-like forms.

4. Faults Associated with Folding

A fault within the argillaceous limestones of the Jurassic was mapped 15 miles east of Rahmu (map 4). It is considered to be a normal fault with upthrow on the west side, and a vertical displacement of not over 100 feet. The fault is easily discernible on the aerial photographs, about three miles south of the road between Rahmu and Mandera, 15 miles east of Rahmu, and can be traced on them for 15 miles from the north tip of the Raiya Hills to Ethiopia. The shale and limestone beds flatten east of the fault-line before continuing their eastward dip. There is some semblance of closure within the limestone beds east of the fault. A small amount of reversal of dip was observed west of the fault in the thick, oolitic limestone beds south of the road. The fold associated with the faulting is not a closed structure but a terrace structure, i.e. the beds flatten with only a slight amount of reversal west of the fault, before continuing their dip eastwards into the regional trend. Geophysical methods may be useful to ascertain the importance of this feature.

A fault is postulated east of Danissa and Wergudud, extending as far north as Asharbit. It has been drawn on the maps because of a great divergence in the strike and dip of the sediments in the Danissa Hills and those to the north, as compared with the strike and dip of the sediments in the Ogar Wein Hills. The two sets of strikes are approximately at right-angles to each other as the beds dip to the east in the Danissa Hills, but to the north in the Ogar Wein Hills. Field evidence of the fault is practically lacking as there is no surface expression of it in the eluvium-covered area it traverses, except at Asharbit where the younger limestones could have been disturbed by it as shown by variable dips and strikes.

VIII—GEOLOGICAL HISTORY

The post-Archæan sedimentary record points to the presence of a land mass north-west of Wajir in pre-Jurassic times. The highlands of this land were the source of the material that gave rise to the deposits of the basal sedimentary series. After the deposition of the basal clastic sediments the area was down-warped, allowing the invasion of the sea and, with gradual subsidence, the deposition of a thick series of limestones and shales. The basin of deposition was probably never very deep as corals are present throughout the section at various horizons and shallow-water oyster beds are very common. During the deposition of the upper beds of the lower limestones a shore-line lay to the east of Rahmu as there is evidence for this part of the section grading into argillaceous limestone eastwards. During Upper Jurassic times there were minor fluctuations in sea-level which produced sandstones interbedded with the limestones. Many fossils have been found complete with both valves in place, suggesting that they were buried in quiet waters. After the deposition of the thick Limestone Series there was uplift of the borderland areas leading to rejuvenation of the rivers and increased erosion. During the interval, after the deposition of the Limestone Series and before the Marehan sandstone was laid down, there was considerable denudation which produced a very irregular limestone surface on which the sandstone was deposited. There is a marked unconformity within the region and this no doubt marks a time gap of considerable duration. After the formation of the Marehan sandstone-Mandera Series there was a regression of the sea, the area became land, and there was a long period of continental erosion. Evidence points to the regression of the sea northwards, as the massive Marehan sandstones of the southern part of the area grade northwards into thick gypsum beds, fine-grained sandstones, red and green shales and non-fossiliferous limestones. This represents an evaporite series in the final stage of deposition of an enclosed basin.

A large portion of the mapped area in the northern part, i.e. as far south as Asharbit, was later covered by still younger deposits of which remnants can still be found in certain localities. Fossil remains secured from the younger beds at Asharbit

and 13 miles south-west of Rahmu at Observation Station No. 87 is evidence of a marine environment, and no doubt represents the final stage of deposition before the region became entirely land.

IX—OIL AND GAS POSSIBILITIES

No seepages of oil or gas are known in the area mapped. It is, however, not highly folded or faulted, facts which would reduce the expectancy of gas or oil seepages emanating from the sediments. A residue of hydrocarbons is often present in regions of strong uplift where faulting has allowed the escape of seepage material such as along the front of mountain chains. Although petroleum is produced from many areas in the world where there have been no surface evidences of petroleum, the presence of liquid or gaseous hydrocarbons at the surface does enhance the possibilities of any region, as it is then known to be petroliferous.

The evaluation of facies changes are important in outlining favourable petroliferous areas, as also are the structures developed within basins. The facies factor is as important as are structural conditions or perhaps even more so, in controlling oil and gas accumulations. Variations in porosity and permeability are commonly the result of lateral variation changes.

Among the source-rocks of the present area are considered to be the black shales and fossiliferous limestones about 1,800 feet below the Marehan sandstone-Limestone Series junction. The oolitic and algal limestones of the lower part of the Limestone Series may also possibly be source-rocks. The upper fossiliferous, gypsiferous shales that contain foraminifera are considered good source material especially if they thicken towards the centre of the basin.

Towards the centre of the basin the Mansa Guda formation may possibly grade into sandstones and shales underlying the Limestone Series unconformably (Fig. 1). The surface of the unconformity could be an oil reservoir under proper conditions, provided the source beds had not been removed during denudation. Exploration for the concealed equivalents of the Mansa Guda formation would entail more risk than searching for oil in the higher formations as there is no surface evidence of their existence.

The sub-surface conditions in such a basin cannot be known without drilling, but the knowledge that there are lateral variations in facies on the surface leads to the supposition that such changes would be as great or even greater in the sub-surface, as the centre of the basin is reached.

Reservoir rocks can be anticipated in the Limestone Series where pore space might be associated with dolomitization. Fractures in the limestone or intraformational erosion surfaces would create porosity as well as solution cavities. The sandy limestones about 1,200 feet below the Limestone Series-Mandera Series junction may possibly grade into sand zones towards the centre of the basin, where any anomaly would be a good reservoir for oil or gas generated from the source shales.

Trap conditions under which oil may be preserved in rocks arise in several circumstances. Igneous intrusion into a sedimentary succession may, for example, create permeable pockets within the host-rock. Progressive overlap over an igneous high or against an impervious high may produce a favourable stratigraphical trap. A combination of stratigraphical and structural conditions may account for the accumulation of oil, such as in sand lenses along the flank of an uplift. Even a structural terrace effect within a sand horizon, such as the faulted feature 15 miles east of Rahmu, may be sufficient to lead to the accumulation of petroleum.

Recommendations and Conclusions

Now that the area described in this report has been completely photographed from the air no doubt considerably more detailed data will be gathered by use of the photographs in the field. The better localities for more detailed study of the stratigraphical section and for additional fossil collecting may be deduced from the photographs, where they indicate that the strata are best exposed. A careful examination of the photographs may lead to the discovery of additional sectors where there are structural features.

Added information may be secured by digging pits in certain localities to establish the character and attitude of the rocks where there are no exposures, for example between El Wak and Wajir within the Limestone Series the soil cover at certain intervals along the road is suggestive of shale horizons just below the surface. Boring with augers and subsequent punch-coring within the shale horizons over blind sectors may be profitable, providing the soil cover is not too thick.

It may be possible after palaeontologists have had time to examine the fossil fauna of the region to make definite statements regarding unconformities at the base of the Limestone Series as well as at its top. It is not possible to distinguish the limestone beds on lithology alone, and it is highly speculative to state that the basal limestone beds in the southern part of the region are higher or lower in the geological sequence as compared with the lowermost beds in the northern part of the region. Detailed fossil collections may aid in the correlation of all the series within the basin.

If, after detailed mapping, the apparent local horizons extend for any appreciable distance, they should be given formational or member status in the nomenclature of the region. It is advisable to map such horizons, where not exposed, by pitting or core-drilling so as to bring out their pattern in an attempt to interpret the geological history more clearly.

As the next step in the evaluation of the resources of the north-eastern part of the Northern Province it may be advisable to initiate a drilling programme, along with added geophysical work and detailed mapping of the surface geology. Four locations suggested for drill-hole sites have been plotted on the most promising structures of the region (maps 3, 4 and 5). The number given to each location is in direct relation to the importance of the structure on which it is sited. The advantages of test-drilling at widespread localities are: (a) penetration of the section at each location will be instrumental in the evaluation of sub-surface conditions of sedimentation and the character of the sediments; (b) the cores will be an aid to future gravimetric work in providing material for specific gravity determinations; (c) correlation of the sub-surface section may be possible; (d) facies and lateral variation changes, which may lead to the proper understanding of the potentiality of the area, will be determinable. The depth to which each drill-hole should be taken would have to be decided by geologists on the site. As nothing is known of the sub-surface in this region a wealth of information could be secured from such drill-holes on the known structures. An important prerequisite to the discovery of petroleum in this area is the establishment of the presence of a thick series of sediments. Equipment for drilling the tests should be of the type that would make a hole $5\frac{1}{8}$ inches to 6 inches in diameter to a depth of 5,000 feet.

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APPENDIX I

Report on Fossils Collected During the Survey of the Wajir-Mandera District

During his survey Mr. Ayers and his assistants collected numerous fossils, but owing to the lack of adequate palaeontological literature and material for comparison in East Africa it was not possible to identify most of them, or to ascribe to them any but the broadest age. Accordingly specimens were submitted in 1951 and early 1952 to the British Museum (Natural History). A report on the first batch of macro-fossils sent was received from Mr. W. N. Edwards, the keeper of geology at the Museum, in March, 1952, and is incorporated in the following pages. The report consisted of several sections, the lamellibranchs and gastropods being dealt with by Dr. L. R. Cox, the brachiopods by Dr. H. M. Muir-Wood, the corals by Dr. H. Dighton Thomas, the ammonites by Dr. L. F. Spath, and the belemnites and echinoderms by Mr. L. Bairstow. The assistance of the specialists at the British Museum in identifying and dating fossils is most gratefully acknowledged.

All the fossils submitted for examination were obtained from the Limestone Series, and came mostly from an area within a 20-mile radius of Rahmu, though a few were obtained from localities as far south-west as the Gamul structure. The variation of age of the specimens is from Bathonian or possibly Bajocian to Upper Jurassic or possibly Cretaceous, most falling within the Bathonian-Kimmeridgian range. Insufficient determinations have been made to allow the construction of a zonal map, but it appears as if in general the beds young towards the Daua Valley. The systematic distribution of the fossils according to the determinations made is as follows:—

Upper Jurassic 16/29c (coral)
 Kimmeridgian 16/31, 16/55, 16/64 (?), 16/66 (?; or Corallian)
 Oxfordian to Kimmeridgian 16/64 (ammonite)
 Argovian 8/5, 16/24, 16/41 (?), 16/52 (?), 16/66, 16/67
 Callovian to Argovian 16/57
 Callovian 16/17 (?), 16/29c (?), 16/31 (?), 16/56 (?)
 Bathonian 15/28a, b, c, 16/38a (or Callovian), 16/41 (or Callovian).

The fossils from locality 15/28, which is eight miles north-west of the Babo Hills, comprise casts in pink or yellow limestone of—

Palaeoneilo sp.,
Nuculana sp.,
Grammatodon cf. *bathonicus* Cox & Arkell,
Trigonia stefaninii Venzo,

Astarte sp.,
Eomiodon angulatus (Morris & Lycett),
Platymya sp.,
Sphaeriola oolithica Ro'lier,
Corbula cf. *lulliana* Morris.

Dr. Cox points out that conclusive evidence of age is lacking, but that it can be suggested that the assemblage is of Bathonian age and contemporaneous with the Bathonian *Trigonia* beds of northern Oltreguiba and SE. Borano, the fauna of which was described by Venzo (*Pal. Hist.*, 1949, Vol. 45).

A grey limestone, weathering reddish-brown, from locality 15/38a, near survey point 193 (map 5), 15 miles north-west of the Ogar Wein Hills, is full of the lamelli-branch *Meleagrinea* cf. *echinata* (W. Smith). Dr. Cox comments that the beds are probably Bathonian or Callovian, those being the stages in which *M. echinata* commonly occurs, but they could conceivably be Bajocian.

Fossils collected from locality 16/41, 12½ miles WSW. of Rahmu, include brachiopods and casts of lamellibranchs—

Somalirhynchia tumida Muir-Wood (?) (fragmentary),
 Rhynchonellid,
Lima (*Plagiostoma*) *subcardiiformis* Weir (non Greppin),
Eligmus polytypus Eudes-Deslongchamps,
Ceratomya wimmisensis (Gilliéron),
Mactromya cf. *aequalis* Agassiz,
Homomya or *Phacaclomya* sp.

Miss Muir-Wood considers that the doubtful brachiopod probably indicates an Argovian age, but in view of the presence of *Eligmus* and *C. wimmisensis* Dr. Cox considers that the age is Bathonian or Callovian, to which *Eligmus* is restricted. Dr. Cox points out the *Lima* was considered by Weir to be upper Bajocian.

Specimens from locality 16/17, 14 miles NNE. of the Raiya Hills, included—

Bihenithyris barringtoni Muir-Wood,
Bihenithyris weiri Muir-Wood,
Terebratula cf. *zieteni* de Loriol,
Ornithella sp.,
Eupecten aubreyi (Douvill ),
Ostrea sp.

Dr. Muir-Wood considers that the brachiopods probably indicate a Callovian age, and Dr. Cox dates the lamellibranchs as Middle or Upper Jurassic. The *Ornithella* is stated to be the same as that in specimen 16/56.

Locality 16/29c, 15¼ miles NNW. of the Raiya Hills, yielded—

Dermosmilia sp. cf. *corymbosa* Koby,
Ornithella sp. (?),
Lima (*Plagiostoma*) sp.

Dr. Dighton Thomas states that the coral (a compound dendroid form) is known only from the Upper Jurassic, *D. corymbosa* Koby itself being derived from the Astartien of Switzerland. The *Ornithella* has prominent growth lines and slight uniplication, together with much incurved umbo, and Dr. Muir-Wood thinks it might be the same species as that from localities 16/17 and 16/56. If so, she states, it may possibly be of Callovian age. Dr. Cox states that the *Lima* is not obviously identical with any representatives of the genus previously described from East Africa, and considers its age indeterminate.

Fossils collected from locality 16/31, from an outcrop south of the Rahmu-Mandera road, 19 miles east of Rahmu, comprise—

"Cidaris" sp.,
Bihenithyris barringtoni Muir-Wood (?),
 Terebratulids,
 Gastropods.

Mr. Bairstow states that the "Cidaris" might have any age between Trias and Recent, but Dr. Muir-Wood considers that the brachiopods might indicate a Callovian age. The gastropods consist of internal casts of a winged form belonging to some genus of the Aporrhaidæ, and Dr. Cox compares them with casts that have been determined as *Harpagodes oceani* (Brongniart), a Kimmeridgian species. Similar specimens are represented in the collection from locality 16/55, 10½ miles SW. of the Raiya Hills.

Grey limestones weathering pinkish-brown at locality 15/56, from a point 1¼ miles east of the Rahmu road, 14½ miles WSW. of the Raiya Hills, yielded—

Bihenithyris barringtoni Muir-Wood,
Terebratula cf. *bihinensis* Weir,
Terebratula africana Weir,
 Terebratulids indet.,
Ornithella sp. nov.

Dr. Muir-Wood considers that the brachiopods probably indicate a Callovian age. The *Ornithella* is the same species as that recorded from locality 16/17 and probably that from 16/29c.

Locality 16/57, 5 miles WSW. of Rahmu, provided—

Astrocoenia somalica Thomas,
Entolium demissum (Phillips).

Dr. Dighton Thomas points out that the coral is known only from the Bihen limestone (Callovian-Argovian) at Bihendula in British Somaliland. Dr. Cox comments that the hard, pink, highly fossiliferous limestone in which he identified the *Entolium* resembles the "calcari a *Entolium demissum*" of S. efan ni (*Pal. Ital.* 32, 1939. Surp. 4, pl. 21, fig. 3), found in southern Italian Somaliland and attributed to the "Oolitico medio", but which he considers was probably dated by its position in the stratigraphical succession, the fossil species having a long range.

The grey limestones at locality 8/5, on the Rahmu-Melka Murri road 16½ miles north-west of Rahmu, at the north-east end of the Dedacha Arch, are dated as Argovian by Dr. Muir-Wood on the evidence of brachiopods. Dr. Cox states that the lamelli-branches are ill preserved and their ages indeterminate. The faunal list is—

Somalirhynchia sp.,
Somalirhynchia tumida Muir-Wood,
Somalirhynchia somalica (Dacqué),
 Rhynconellid,
 Terebratulid,
Lopha sp.,
Protocardia sp.,
Quenstedia sp. (?),
Fimbria sp.

Light-grey limestones at locality 16/24, 1¼ miles SW. of Rahmu, are also dated by Miss Muir-Wood as Argovian. The fossils identified are—

Somalirhynchia bihendulensis Weir,
Somalirhynchia africana Weir,
Somalirhynchia africana var. *mesoloba* Muir-Wood,

Somalirhynchia smelliei Weir,
Terebratula cf. suprajurensis Thurmann,
 Belemnopsids.

The fragmentary belemnopsids are dated by Mr. Bairstow as Middle or Upper Jurassic.

Crushed and immature rhynchonellids that might be *Somalirhynchia* but which would require sectioning to confirm identification, were found in pinkish limestone at locality 16/52, 6½ miles SW. of the Raiya Hills. Dr. Muir-Wood considers that they may be of Argovian age. An ill-preserved lamellibranch of indeterminate age was tentatively identified by Dr. Cox as *Fimbria* sp.

Argovian brachiopods were identified without doubt by Dr. Muir-Wood in grey limestones from locality 15/66, 1½ miles SW. of Rahmu. Oysters also present were dated by Dr. Cox as Bathonian to Kimmeridgian, most probably Corallian or Kimmeridgian. The fauna comprised—

Somalirhynchia africana Weir,
Somalirhynchia africana var. *mesoloba* Muir-Wood,
Somalirhynchia tumida Muir-Wood,
Somalirhynchia bihendulensis Weir,
Somalirhynchia sp.,
Terebratula cf. suprajurensis Thurmann,
 cf. *Terebratula cf. longisinuata* Krumbeck,
 Terebratulid,
Lopha gregarea (J. Sow.).

Specimens labelled 16/67 were derived from the same locality and have been identified as—

Montastrea sp. aff. *lifoliana* (Michelin),
Somalirhynchia africana Weir,
Somalirhynchia bihendulensis Weir,
Somalirhynchia africana var. *mesoloba* Muir-Wood,
 Terebratulid,
 Indeterminable ammonite.

The brachiopods are dated as Argovian by Dr. Muir-Wood. The oyster *Lopha* ranges from Bathonian to Kimmeridgian. Dr. Dighton Thomas states that the coral is of the species described by J. W. Wells as occurring "about 700 feet above the base of the Jurassic section", Harrar Province, Ethiopia.

From a locality 2½ miles SW. of Rahmu (16/64) the following assemblage was obtained—

Crinoid stem fragment,
Mytilus jurensis Roemer,
Pinna (Stegoconcha) sp.,
Cam tnectes lens (J. de C. Sowerby),
Lima (Plagiostoma) sp.,
Exogyra sp. nov.,
Biplices aff. *africanus* (Daqué),
 Belemnopsid.

Dr. Smith dates the ammonites as probably uppermost Oxfordian or Kimmeridgian, and Dr. Cox points out that *Mytilus jurensis* suggests Kimmeridgian age, though the evidence of the remaining species is less definite.

A specimen was also submitted for examination from Sidimo in Italian Somaliland (41° 57' 20" E., 2° 26' 45" N.), in which Dr. Cox identified *Exogyra nana* (J. Sowerby) and cross-sections of *Trichites* sp. The age is Bathonian to Kimmeridgian, which is the range of *E. nana*.

Other fossils collected in Kenya that have proved to be of less stratigraphical value include *Eopecten* (= *Velata*) sp. from locality 16/16, 20 miles NNE. of the Raiya Hills, *Nerinea* sp. from locality 16/33 in the Daula Valley 18½ miles east of Rahmu, and three oysters—*Lopha marshi* (J. Sow.), *Lopha gregarea* (J. Sow.), and *Lopha* sp. from locality 16/44, 6½ miles SSW. of Rahmu. Crushed rhyconellids were also obtained from locality 16/55, 10½ miles SW. of the Raiya Hills, and eight coarsely costate rhyconellids that Dr. Muir-Wood considers may be a new species, and two imperfect terebratulids from locality 15/19, on the Rahmu-Dedacha road, 14 miles east of Dedacha. The oysters are dated by Dr. Cox as Bathonian to Kimmeridgian, and the *Nerinea*, which is probably a new species though not describable, as Jurassic or Cretaceous. The *Eopecten* is of no stratigraphical value.

Commenting on the fossils she examined Dr. Muir-Wood noted that no specimens of *Daghanirhynchia* occurred in any of the samples, and as that genus is characteristic of the Callovian of Somaliland its presence in northern Kenya would be expected.

Weir (1929) dated fossil assemblages from the general area from which the fossils named above were derived. He found that the beds at Dedacha Korma Adaui are probably of lower or middle Kimmeridgian age, and that beds at Muddo Erri, which corresponds approximately with locality 8/5 of the present work, range from Bajocian-Bathonian at the base of the section to Oxfordian or Corallian at the top. For the nearby Rukesa section he showed that the fossils indicated that the lower beds are Corallian, correlating them with the upper Muddo Erri beds, and that the higher beds are Kimmeridgian. The Corallian at Muddo Erri is separated by less than 40 feet of beds from the Bajocian-Bathonian horizons, and there is no appearance of any physical break between the two. From scanty evidence Weir ascribed the beds at Malka Dakka, approximately locality 16/33 of the present report, to the Kimmeridgian or possibly to the Tithonian. Fossils from Dabeir, about 31 miles north-east of Bur Mayo, and on the south flank of the Gamul structure, were dated as not older than Corallian, and probably Kimmeridgian. Specimens from Galitcha, a few miles east of Muddo Erri, it was suggested, were probably of the same age.

APPENDIX II

Report on Fossils Collected in the Mandera-Hafura-Dedacha Area

As the report was being sent to Press an account of fossils collected in the northern part of the Wajir-Mandera area was received from an oil company, which has kindly consented to its use for publication. The almost complete extract given below is quoted verbatim.

"The report which follows describes a collection of fossils made during a reconnaissance of the Jurassic outcrops in N.E. Kenya under the guidance of F. M. Ayers in June and July, 1951.

The great bulk of the fossil identifications is the work of Professor J. A. Douglas who furnished also valuable comments on nomenclature and the dating of the various assemblages. Dr. W. J. Arkell identified the ammonites, Dr. L. R. Cox examined some of the mollusca, and Dr. Muir-Wood advised on critical brachiopods.

1. BASAL JURASSIC

The Mesozoic sequence begins with an arkose series called the Mansa Guda or Tarbaj Grits by Ayers, which is an unfossiliferous series; this is directly followed by Jurassic limestones.

Significant fossils were found above it at two localities. One of these was a *Spiriferina* (5302) found in limestones which must be very close to their base N.E. of Tarbaj Hill. Although partly masked by matrix it can be matched with *Spiriferina rostrata* var. *madagascarensis* in its more elongate forms. This is the last member of the genus.

A useful fauna was found by Ayers further north 4 miles SSW. of Bur Mayo Hill (Didimtu). There several ammonites and many small Pectens were found in a shaly zone in the basal limestones, within 20 feet of the underlying arkosic grits. Arkell identifies the ammonites as *Bouleiceras* sp., closely similar to those of Madagascar and North Africa, and the Pecten as *P. ambongoensis*, known with the same ammonites in Morocco, Madagascar and Arabia. This assemblage (which includes the above-named *Spiriferina* abundantly in Madagascar) is dated as probably Toarcian, but may possibly be as old as Domerian. Somewhat higher beds on Bur Mayo Hill yielded Middle Jurassic *Eudesia* cf. *cardium*.

The occurrence of marine Liassic beds in N.F.D. was quite unexpected from regional trends, and the fauna supports other indications of a direct marine connexion with the Kenya coast and Madagascar in at least L-M Jurassic times. The presence of the typical *Spiriferina* fifty miles south of the other forms further suggests that the base of the limestone is of much the same date at different localities along the outcrop.

2. BATHONIAN-BAJOCIAN LIMESTONES (DAUA LIMESTONES)

In the Dawa Valley the Middle Jurassic is developed as a continuous limestone series, measuring something over 1,500 feet near Melka Murri (Fig. 2). The lowest beds of this series, possibly only a short distance above the basal beds mentioned previously, yielded *Bakevellia* (*Gervillella*) sp. somewhat resembling the Bathonian *B. waltoni* (Lyc.) (J.A.D.). In the main mass of limestone no fossils were found, but about 1,200 feet higher was an Upper Bathonian fauna—

Pseudomonotis aff. *braamburiensis* (Phil.),
Brachydontes (*Arcomytilus*) *bathonicus* (Mor. and Lyc.),
Anatina (*Cercomya*) *silicus* Ag.,
Trigonia pullus Sow.,
Exogyra fortaui Stef.,
 ? *Corbula* sp.

Fossiliferous beds were located in two places close to the top of the limestones in the Dedacha area—

Loc. 5326.—*Lima* (*Plagiostoma*) *subcardiiformis* Greppin, *Burmihynchia subversabilis* Weir, *Kutchirhynchia* aff. *morieri* (Dav.).

Loc. 5325.—*Pygurus* cf. *depressus* Currie, *Eligmus rollandi* Douville, *B. subversabilis* Weir, *Terebratula* indet.

Of these forms the *Burmihynchia* and the *Eligmus* become more abundant in the succeeding beds.

An entirely unexpected discovery—in the light of persistent structural trends—is the occurrence of probable Bathonian also at Manderia. Arkell called attention to a fauna figured by Venzo from hills on the border (a locality where we also collected, our specimens being thought too poorly preserved for firm dating) which includes a considerable range of lamellibranchs (with *Trigonia* spp.) ascribed to Bathonian (*Pal. Italica*, 1948). Dr. L. R. Cox at our request has reviewed the assembly, and comments that the dating is somewhat questionable, as the species are individually long-ranged or (in some cases) identifications are doubtful. Nevertheless they can hardly be as late as Kimmeridge or Lower Cretaceous (as presumed from their position), and as Venzo states that the beds are overlain by Callovian on the Italian side of the boundary the dating must presumably stand.

3. CALLOVIAN LIMESTONES-AND-SHALES

The shale-and-limestone alternation next higher in the series has yielded fossils at several localities. The westernmost is an outlier of shaly beds nearly midway between Rukesa and Murri.

At this locality the lower beds (5329) yielded—

Burmishynchia subversabilis Weir,
? *Cymatorhynchia quadriplicata*,
Pholadomya carinata Goldf.
Lopha solitaria (J. de C. Sow.).

Higher up the slope *Eligmus* appeared in quantity in the following assemblage—

Eligmus rollandi Douv.,
Mactromya aqualis Ag.,
B. subversabilis Weir.

Beds directly above the Bathonian Limestone on the main outcrop (loc. 5324) yielded—

Lima (Plagiostoma) harronis Dac.,
L. (Plagiostoma) subardiiiformis Greppin,
Velata abjecta Mull.,
Eligmus rollandi Douv. (abundant),
E. rollandi var. *lavis* Douv.,
B. subversabilis Weir (one only).

Rich faunas were collected at two points close to Melka Rukesa. From the lower of these, near the presumed Bathonian contact (loc. 5332), were obtained—

Lopha costata (J. de C. Sow.),
Homomya gibbosa (J. Sow.) or *crassiuscula* Lyc.,
? *Gryphea* sp.,
Coelastarte sp. (possibly *C. excavata* var. *asiatica* Douv.),
Trigonopsis cf. *viridunensis* Buv.,
Ceromyopsis sp.,
Lopha solitaria (J. de C. Sow.),
Eligmus rollandi Douv.,
Ptyctothyris quillyensis (Bayle),
Burmishynchia subversabilis (abundant).

Some of these forms have a Bathonian aspect and the fauna may be transitional, or the lithological change lies a little below the Callovian base. Somewhat higher beds down dip (loc. 5331) yielded—

Mactromya aff. *impressa* Mor. and Lyc.,
Ceratomya wimmisensis (Gill.),
Corbis aff. *lajoyei*, d'Arch.,
Lucina cf. *lirata* Phil.,
Astarte ? sp.,
Globularia sp.,
Lopha solitaria (J. de C. Sow.),
B. subversabilis Weir,
Pseudoglossothyris sulcata Muir-Wood (common).

Above this level are the Muddo Erri beds from which Weir collected; it seems likely that his sections extended into Oxfordian, for *Somalirhynchia* is recorded as well as Callovian forms. (Weir regarded this genus as Corallian, but as shown below, it occurs with Oxfordian ammonites.) The Callovian must consequently be quite thin.

The "Rukesa" specimens on which Weir reported were presumably from a little further east, as they form a different assemblage of Corallian-Kimmeridgian aspect.

4. OXFORDIAN SHALY BEDS

South-west of Kalicha and Rahmu is a belt of ground without exposures, and the next beds seen are shales with subordinate limestones near the Rahmu-Wergudud

road (locality 5322). Here a large ammonite found loose (5321) proves to be an *Aspidoceras* of Lower Oxfordian aspect. Several loose *Nautilus* were also seen. The fauna found *in situ* is listed as follows—

Peltoceratoides cf. *constantii* (d'Orb.)—Lower Oxfordian,
Belemnopsis tanganensis (Futt.),
Lopha solitaria (J. de C. Sow.),
Brachydontes (*Arcomytilus*) *laitmairensis* de Lor.,
 "Terebratula" *beirutiana* Krum. (abundant),
Somalirhynchia africana Weir and varieties,
S. smellei Weir (abundant).

The lack of exposures suggests that the soft beds of this group are fairly thick, but as the only section is a strike stream nothing is known of the remainder of the faunal sequence.

5. CORALLIAN SHALES-AND-LIMESTONES

A short sequence is available in the earlier Corallian beds about 12 miles south of Kalicha. Three samples were collected in a single exposure; the lowest five feet were shaly and yielded—

Pleuromya aff. *solodurinensis* de Lor.,
Thracia depressa J. de C. Sow.,
Parallelodon egertonianus (Stol.) var. *crericostatus* (Stef.).

The next beds (5319) consisted of a shale-and-limestone alternation about 20 feet thick with—

Lopha gregarea (J. de C. Sow.),
Liostrea sp.,
Belemnopsis tanganensis (abundant),
Exogyra vinassai.

Capping these beds were thicker limestones, of which tumbled blocks yielded a good fauna (5318)—

Macrocephalitid ammonite—? *Dhosaites* comparable with "*Macrocephalites*" *rabai* Dacqué,
Perisphinctes of the *plicatilis* group (common) ("almost any one of which might have been collected from the Corallian of Oxford"—Douglas),
Nautilus sp.,
Bourguetia striata Sow.,
Gervillia (*Gervillia*) aff. *aviculoides* Sow.,
Pinna stoliczkaia Cox,
Pseudomelania sp.?,
 ? *Myopholas acuticostata* (J. de C. Sow.),
Parallelodon egertonianus (Stol.),
Exogyra nana (J. Sow.),
Lopha gregarea (J. de C. Sow.),
Ceromyopsis sp. cf. *C. somaliensis* Weir.

Probably some 50 feet higher in the succession another locality (5339) yielded—

Milleporidium somaliense,
Meleagrinnella aff. *ovalis* (Phil.).

Ayers has followed a "*Pecten*" —(strictly *Meleagrinnella*)—horizon for a number of miles southwards, probably at this horizon.

At about the same level, east of Rahmu, a smaller assemblage was collected (5340)—

Ammonite, probably *Mayaites* sp.,
Belemnopsis tanganensis Futt.

To the east of the other Corallian occurrences and 12 miles E. of Rahmu *Meleagrinnella* spp. cf. *ovalis* and cf. *maltonensis* again suggest beds of this date (5342). The limestones thereabouts are undulating gently and Corallian may be brought in as shown on the map (Fig. 2).

The southernmost indication of this fauna is in the Willeh Hills, near Asharbit (loc. 5317). There the Marehan sandstone is separated by soft beds (yellowish marls with sandstone and sandy limestone) from a 4-foot quartz grit/pebbly limestone containing abundant *Belemnites* of *tanganensis* aspect. This with the general thinness and absence of typical Kimmeridge faunas indicates that the Marehan sandstone is transgressing on to Jurassic horizons at least as low as middle Kimmeridge, most probably Corallian.

6. KIMMERIDGIAN AND "TITHONIAN" LIMESTONES AND SHALES

This uppermost Jurassic stage is represented by well-bedded limestones with a medium belt of gypsiferous shales. The limestones below the shale break were investigated in several places—

Loc. 5336.—*Pholadomya ragazzi* Pant.

Loc. 5337.—? *Ctenostreon* (spines), *Nerinea* sp., *Ostrea* cf. *costata*, Hydrozoan indet.

Loc. 5335.—*Ceratomya concentrica* (J. de C. Sow.), *Entolium* sp. ?cf. *solidum*, *Mytilus alatus* Krum., ? *Trichites suprajurensis* Krum. (cast), *Pinna stoliczkaia*.

Loc. 5343.—*Entolium* sp., *Belemnopsis tanganensis* Futt.

The gypsiferous shales yielded a rich fauna—

Loc. 5345.—*Radulopecten* cf. *erlangeri* Dacqué, *Ceratomya excentrica* (Roemer), *Ceromyopsis* cast., *Brachydontes (Arcomytilus) subpectinatus* d'Orb., *Modiolus (Inoperna) perplicata* (Etallon), *Modiolus* cf. *ungulatus* Young and Bird, *Mytilus alatus* Krumbeck. = *M. tigrinus* Bland., = *M. jurensis* Roemer, *Parallelodon egertonianus* (Stol.), *Oxytoma* aff. *expansa* Phill., *Astarte ovata* W. Smith, *Cypricardia (Pseudotrapezium)* aff. *cardiformis* Desh., *Lucina rugosa* Roemer, *Nucula* sp., *Ampullella* cast., *Harpagodes (Pterocera)* aff. *polypoda* Buvignier and *Harpagodes* cf. *thirria*, *Nerinea somaliensis* Weir ? cast., *Pinna* sp. poor., *Ostrea (Gryphaea) balli* (Stefanini)? poor., *Apiocrinus* aff. *roissyanus* d'Orb. columnals, *Terebratula (Lophrothyris?) subsella* (Leym.) = *suprajurensis* Thurm.

Prof. Douglas comments that considerable variation is shown by the figures of the last named species given by different authors. The larger forms which occur at this level have been figured as *T. subsella* by Dacqué, and in 1925 by Weir, who later figures the same specimen as *suprajurensis*.

A few feet lower in the section (loc. 5344) a large ammonite was collected *in situ*; this is compared with *Perisphinctes achilles* d'Orb. and is possibly the *Lithacoceras kenyaense* described by Spath (1930). This specimen was associated with—

Brachydontes (Arcomytilus) subpectinatus d'Orb.,
Mytilus alatus Krum.

At much the same level another locality (5349) yielded—

Lima (Plagiostoma) ? astartina Thurm.,
Apiocrinus aff. *roissyanus* d'Orb.,
Berenicea somalica Dacqué,
? *Thamnoseris gibberosa* Greg.,
Ornithella sp. cf. *humeralis* Roem.,

and nearby (loc. 5348) also—

Modiolus perplicata (Etal.),
Meleagrinnella sp.

The limestones above the gypsiferous shale are interbedded with thick sandstones, a foretaste of the oncoming of Marehan conditions. Two localities yielded collections, and these may be at equivalent horizons. The westernmost (5346) yielded—

Camptonectes cf. *viridunensis* (Buv.),
Astarte ovata W. Smith,
Gryphea sp.,
Ceromya excentrica (Roem.),
Modiolus subangustissimus Dacq.,
Ampulella sp., *Harpagodes* sp.

In addition there were several brachiopods including a new *Terebratula* (see below), not yet investigated. The beds directly beneath the presumed Marehan sandstone equivalent (5347) provided—

Anomia sp.,
Brachydontes subpectinatus d'Orb.,
Modiolus (Inoperna) perplicata (Etal.),
 ? *Opis michelinea* Buv.,
Terebratula (Lophrothyris) subsella Leym.

An inlier of beds of similar date occurs 70 miles to the SSE. at Hafura in the Hegala Hills, on the Somaliland frontier (localities 5351, 5352 and 5353). This yielded a few molluscs (*Plagiosoma* cf. *sublæviuscula* and *Pholadomya*), Ornithellids of Upper Jurassic/Lower Cretaceous aspect, and a number of specimens of a new *Terebratula* characterized by coarse punctation and very marked growth-halt stages. Professor Douglas comments as follows:—

'So far I have found nothing like it in the Jurassic except *Cheniothyris* of Buckman from the Lower Oolites (Pal. Indica, New Ser. Vol. III, Mem 2. Brachiopods of the Namyau Beds, Burma. Pl. XXI, Figs. 23–26). There is however a variety of *Terebratula carteroni* d'Orb figured by Pictet from the Valanginian to which it bears a striking resemblance. (See Pal. Suisse, Fossiles du Terrain Cretace des Environs de Sainte-Croix. Pl. CCI, Fig. 4anc). In addition to these stepped forms are a number of others which at first I referred to *T. subsella* (see note on 5345) but they agree equally well with figures of *T. carteroni*. They are all much smaller than the specimens of *T. subsella* from the Kimmeridge.'

There is thus a possibility that these highest beds are post-Kimmeridge, and they might be as late as Lower Cretaceous."