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GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
WAJIR-WAJIR BOR AREA
(with two coloured geological maps)

DEGREE SHEET 31, N.E. and N.W. QUARTERS

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FOREWORD

The publication of the report on the Wajir-Wajir Bor area completes the first reasonably detailed exposition of the geology of the visible Mesozoic basin of north-east Kenya. The basin lies east of the 40th meridian and north of the $1^{\circ} 30' N.$ parallel; previous reports numbered 40, 43, 44, 47 and 48 have dealt with other sections.

The Mesozoic rocks are exposed to only a small extent north-east of Wajir in the area now described, the rest of the area being covered by much younger rocks. The geology is difficult to unravel in such featureless country, but Mr. Joubert has succeeded in deciphering an intelligible succession. He shows that what have been considered previously as Tertiary sediments are in fact Quaternary, though he appreciates that Tertiary rocks may well exist, at depth. Facts are put forward that show that in the southern part of the area the depth of Quaternary sediments is considerable, and suggest that still further south the continuations of the Mesozoic rocks may be buried at great depths below younger rocks.

Water-supply is an important consideration in such an area, and some attention is given to it in the report. Mr. Joubert discounts a suggestion that has been made previously that the water-table is dropping at a rapid rate, pointing out that the wells there have not been deepened by the present inhabitants who began to live in the country some 50 years ago, and yet they still contain several feet of water.

Nairobi,
21st January, 1959.

WILLIAM PULFREY,
Ag. Commissioner (Mines and Geology).

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MAPS

Geological map of the Wajir area (degree sheet 31, N.W.)—Scale 1:125,000 ..	At end
Geological map of the Wajir Bor area (degree sheet 31, N.E.)—Scale 1:125,000 ..	At end

ABSTRACT

The area described in the report covers approximately 2,400 square miles of the district of Wajir, in the Northern Province of Kenya Colony, and is bounded by latitudes $1^{\circ} 30'$ and $2^{\circ} 00' N.$, longitude $40^{\circ} 00' E.$, and the Kenya-Somalia border.

The oldest rocks exposed are of Jurassic age and consist of limestones deposited in a neritic marine environment, and bevelled by two surfaces of Tertiary age. The remainder of the area is occupied by limestones, gypsum, sandstones and clay-bound sands deposited in lacustrine and valley-flat environments during Pleistocene times.

Deposits that may become of economic value when the area is developed or oil is discovered (a possibility which is also discussed), are described. Consideration is given to the improvement of present water-supplies.

I—INTRODUCTION

1. General Information

The area to be described in this report is bounded by the Kenya-Somalia border on the east, and lies between latitudes $1^{\circ} 30' \text{ N.}$ and 2° N. , extending as far as longitude 40° E. on the west. It comprises the north-east and north-west quarters of degree sheet 31 (Kenya) (Sheets 72 and 73 of the Directorate of Overseas Surveys). The area, which is part of the Wajir administrative district of the Northern Province, is a closed district under the Outlying Districts Ordinance (Proclamation No. 89 of 1925).

The area is mainly inhabited by Somali tribesmen of the Degodia and Ogaden sections, between whom the wells and grazing rights are divided. For most part of the year the population is centred on the wells of Wajir, but during and after the rainy seasons the inhabitants, who are nomadic, are sparsely scattered over the whole area.

Wajir is considered to be the main administration centre of north-eastern Kenya and is connected to Isiolo, Moyale, El Wak, Melka Murri and Bardera (in Somalia) by roads which are reasonably good in parts. Several of the larger camel tracks, of which many cross the area, were most useful in traversing and mapping. There is a motorable track from Wajir Bor to Riba and Balbala, which carries on to the north-eastern corner of the area and eventually links up with the border-cut to the north of the area, which can also be used by smaller vehicles. The old road from Wajir through El Tuli joins the road to Bardera at Khorof Atat. Another motorable track from Wajir, passing through Uhia and Berrer Bahar, eventually joins up with the track from El Tuli through Khorof Sharif and Gembis. The old road from El Tuli to Dif is also motorable for a long distance to the south, but is now in disuse.

Wajir is in communication with Isiolo and Nairobi by radio, the Administration using the service supplied by the Posts and Telegraphs Department, while the Police keep in touch with their outposts by the same means. The medical officer for the whole of the Northern Frontier District is stationed at Wajir.

MAPS

For convenience the results of the mapping of the area are presented as two geological maps—the Wajir sheet and the Wajir Bor sheet. In the account that follows the area covered by the two quarter-degree sheets is treated as a whole. The geological maps are based on aerial photographs, the scale of which is approximately 1 : 30,000. Ground control was provided by data from geological maps of the areas to the north, five astronomically determined points, two of which are just south of the area, and a survey of the main roads. The form-lines are based on barometer readings and are therefore approximate only.

CLIMATE AND VEGETATION

Rainfall over the area is low, as shown by the following rainfall figures for Wajir:—

Year	..	..	1950	1951	1952	1953	1954	1955
Inches	..	..	6.97	20.23	9.44	14.02	7.87	4.43

The average rainfall recorded over 29 years is 8.75 in. The maximum rainfall occurs during April and May, the heavy rains sometimes starting as early as mid-March, while localized showers fall during the months of October and November. During the rains no vehicular traffic is allowed through the area in order to protect the surfaces of the roads.

Limestones in the area are usually covered by dense low thorny scrub, while red sands are usually covered by dry open bush with clumps of larger trees and bushes in depressions. Grey soils carry a similar vegetation to the limestones, but where black soils occur trees and scrub are often absent and the only vegetation is tufts of rough grass. On the grey soils the bush often opens and surrounds circular glades for no apparent reason. Thicker thorn scrub and low trees usually follow the dry water courses.

2. Previous Geological Work

In a description of the country between the Juba river and Lake Rudolf, Lt. L. Aylmer *(1911, pp. 293-294), described the area known as Wajir (Wajeir) as having numerous wells cut straight down in solid rock and deduced correctly that a more industrious tribe than the present inhabitants was responsible for the digging of the wells. He recorded that the mouths of the wells were 36 to 40 in. across and that the water was 22 to 28 ft. below the surface. He considered the water from the wells "very wholesome as a blood purifier and febrifuge" with only the slightest chemical taste. He erroneously assumed that the piles of rock occurring in the neighbourhood were of igneous origin.

During July and August, 1912, C. W. Haywood (1913), marched from Kismayo to Meru in an effort to discover whether the Uaso Nyiro flows out of the Lorian Swamp. He passed through El Tuli (Eil Tuli, *op. cit.*, p. 466) and described the wells there as being only about 6 ft. deep, and dug in "a kind of grey sandstone", the water being strongly impregnated with sulphur. Twenty miles from El Tuli, at Siddeh Dima, a Government post had been opened and Haywood (*op. cit.*, p. 466) recorded that a large number of wells had been dug to a depth of 20 ft. or so in "a soft kind of gypsum rock" overlain by 2 ft. or more of a reddish sand. He also mentioned the cairns of rocks described by Aylmer as of igneous origin and correctly assumed them to be graves of the people who originally dug the wells of Wajir.

J. Parkinson (1920) travelled through the Northern Frontier District and Jubaland in 1914 examining the geology. He devoted much space to the palaeontology and geology of the El Wak and Wajir (Wajhir) Beds. In a later paper (Parkinson, 1922), he again mentioned the wells of Wajir as situated on the site of an old lake.

H. G. Busk and J. P. de Verteuil (1938) visited the north-eastern part of Kenya on behalf of the D'Arcy Exploration Co. Ltd. and Anglo-Saxon Petroleum Co. and carried out a rapid reconnaissance. They erroneously considered Cretaceous sandstones as horsts of pre-Jurassic rocks that stood as islands in the Jurassic sea, and assumed that the Wajir Beds were intercalated with the Jurassic limestones (Busk, 1939, pp. 220-221).

F. Dixey (1948, pp. 9-12) in a description of the geology and morphology of northern Kenya, devoted a chapter to the post-Jurassic sediments of the Northern Frontier District and came to the conclusion that the bulk of the sediments belong to the Tertiary. F. M. Ayers (1952, pp. 15-16), in agreement with Dixey, tentatively ascribed a Tertiary age to the Wajir and El Wak Beds in his description of the geology of the Wajir-Mandera District.

Since 1953 the north-eastern part of Kenya has been re-mapped in detail by geologists of the Geological Survey of Kenya (Saggerson and Miller, 1957; Thompson and Dodson, 1958; Baker and Saggerson, 1958; Thompson and Dodson, 1960; Joubert, 1960) and the present report concludes the work on the exposed Mesozoic sediments of that part of the country.

*References are quoted on p. 33.

II—PHYSIOGRAPHY

The Wajir area can be divided into two physiographic regions: (1) The north-central portion underlain by limestones of Jurassic age, where remnants of surfaces representing stable periods during Tertiary times are found and (ii) the remainder of the area, which is a wide undulating plain of Pleistocene sediments.

When the physiographic maps of the Bur Mayo-Tarbaj (Thompson and Dodson, 1960, fig. 2) and the El Wak-Aus Mandula (Baker and Saggerson, 1958, fig. 1) areas are studied, it is seen that the equivalent Erib and Muguda surfaces extend into the north-central part of the present area. Furthermore, Thompson and Dodson (*op. cit.*, p. 4) state that the surface slopes down to a level of 1,200 ft. where it enters the present area, and therefore the tops of the two hills at Gajaja represent remnants of this bevel. The high ground to the east of Gajaja would then also form a somewhat denuded part of the same bevel, which is taken to represent the maturation of an erosional phase between those that culminated with the formation of end-Tertiary and sub-Miocene surfaces.

From these northern elevations the surface on the Jurassic limestones slopes down to the east to meet the end-Tertiary peneplain, which bevels the southern part of the limestone outcrop. The slope of this surface of 10 ft. per mile to the south-south-east as described by Baker and Saggerson (1958, p. 5) for the area to the north, is also adhered to on the Jurassic limestones here. The end-Tertiary peneplain can be recognized by the presence of numerous ferruginous pellets strewn on the surface, as is the case in the Manderia area (Joubert, 1960, p. 6). The ferruginous pellets are also found on the tops of the mounds of material derived from wells piercing the Pleistocene deposits at Riba, where they are known to be at least 40 ft. thick, indicating the depth below surface of the end-Tertiary surface at this locality. On the western flank of the outcrop of the Jurassic limestones the end-Tertiary peneplain was only encountered at Forogorgor where it conforms with the general slope of the bevel.

Along the western side of the Jurassic limestones, however, three well-marked terraces were found above the end-Tertiary peneplain. The two lower terraces, the lowest of which occurs 25 ft. above the end-Tertiary surface at Forogorgor and 20 ft. below the middle terrace, are marked by surface limestone cappings, but the upper, 30 ft. higher than the middle terrace, has numerous waterworn pebbles on its surface. The pebbles of this upper terrace in the Gajaja area have been derived from Basement System and Jurassic rocks, but further south only limestones pebbles are encountered. These terraces are thought to have been formed during stable phases in Tertiary times when a deep valley was formed to the west and south-west of the Mesozoic sediments.

Dixey (1948, fig. 1.) shows the surface at Wajir as part of the end-Tertiary peneplain, a view that Thompson and Dodson (1960, p. 6) confirmed. During the present survey, however, it was found that the sediments at Wajir are of Pleistocene age and therefore that the surface is younger than at first supposed. The plain of Wajir slopes evenly at 14 ft. per mile to the south-south-east and is only slightly undulating, with wide shallow drainage valleys hardly noticeable when traversed. All the drainage channels of the area lead south to Lugh Bor which cuts across the south-western corner of the area and it is only along the southern border of the area that recent dissection of the Pleistocene deposits occurs. Ridges of limestone forming undulations in the Wajir Beds rise slightly above the general level of the plain, while shallow braided channels, hardly noticeable on the ground, are seen on the aerial photographs.

III—SUMMARY OF GEOLOGY

The rocks of the Wajir area are all of sedimentary origin and range in age from Triassic to Recent. Three divisions can be recognized:—

- (3) Quaternary sediments
- (2) Daua Limestone Series
- (1) Mansa Guda Formation.

The Mansa Guda Formation is not, in fact, exposed in the area, but quartzitic boulders and pebbles derived from its conglomerates indicate the position of the southerly extension from the area further north of these arenaceous sediments under the soil cover.

The Daa Limestone Series in this area consists of a lower fossiliferous limestone succession of Toarcian age which is an extension of the Didimtu Beds of the area further north, overlain conformably by a series of brown and grey fragmental argillaceous or finely recrystallized limestones of Bathonian-Callovian age, which are equivalent to the Bur Mayo limestones of the Bur Mayo-Tarbaj area (Thompson and Dodson, 1960, p. 24). The series was deposited in a shallow marine environment and was faulted along north-easterly striking zones and slightly folded along the strike during the Cretaceous period.

Extensive continental erosion during the Tertiary era gave rise to the formation of a wide deep valley west and south of the area occupied by the Mesozoic sediments, but the valley was filled up during the Pleistocene by limestones and gypsum of lacustrine origin and by clay-bound sands and sandstone of fluvial origin. These Pleistocene deposits are representatives of the pluvial phases of the period while the widespread red sandy soil of Wajir has been derived from red ferruginous sandstones indicative of an interpluvial stage.

Fig. 1 demarcates the distribution of the sediments in the Wajir area. Table 1 summarizes the stratigraphical succession and indicates the major events contributing towards the deposition of the sediments.

IV—DETAILS OF GEOLOGY

1. Mansa Guda Formation

Ayers (1952, p. 6) first described the Mansa Guda Formation, defining it as sandstone-conglomerate beds at the base of the Jurassic limestones and came to the conclusion that it is of Lower Jurassic age or older. Thompson and Dodson (1960, p. 15) compared the Mansa Guda Formation with the Adigrat Sandstones of Ethiopia (Dacqué and Krenkel, 1909, p. 152) and with the Lugh Group in Somalia (Stefanini, 1925, p. 1,061) which are of Triassic age. When the stratigraphic position of the Mansa Guda Formation is considered, the Triassic age suggested by Thompson and Dodson is the most reasonable.

As the Mansa Guda Formation does not crop out in the Wajir area, the reader is referred to Thompson and Dodson (*op. cit.*, p. 15) for a description of its disposition, succession and petrography. Although not exposed south of latitude 2° N., the existence of the formation under the soil cover is proved by a distinct ridge where its southerly extension would be expected and by the presence of numerous quartzite pebbles, derived from the conglomerates, along channels draining the ridge. The pebbles have also been cemented in a ferruginous sand of Pleistocene age, forming a conglomeratic sandstone, which Ayers (1952, maps Nos. 1 and 2) mapped as outcrops of the Mansa Guda Formation. Since Middle Pleistocene times re-distribution of the pebbles derived from these rocks has been taking place and they are therefore widespread downstream from the presumed position of the Mansa Guda Formation. Immediately east of the line Abagaranso-Saturwario-Libiduli, the presence of the formation under the soil cover is also confirmed by large angular boulders and blocks of quartzite probably derived from the quartzites in the succession (Thompson and Dodson, *op. cit.*, p. 16).

2. Daa Limestone Series

The Daa Limestone Series (a term used by Saggerson and Miller (1957, p. 10) to replace the name "Daa Limestone", first used by Weir (1929, pp. 9-11) to describe the Jurassic limestones and shales outcropping in north-eastern Kenya) terminates in an ill-exposed broad swing in the Wajir area. It occupies the north-central part of the

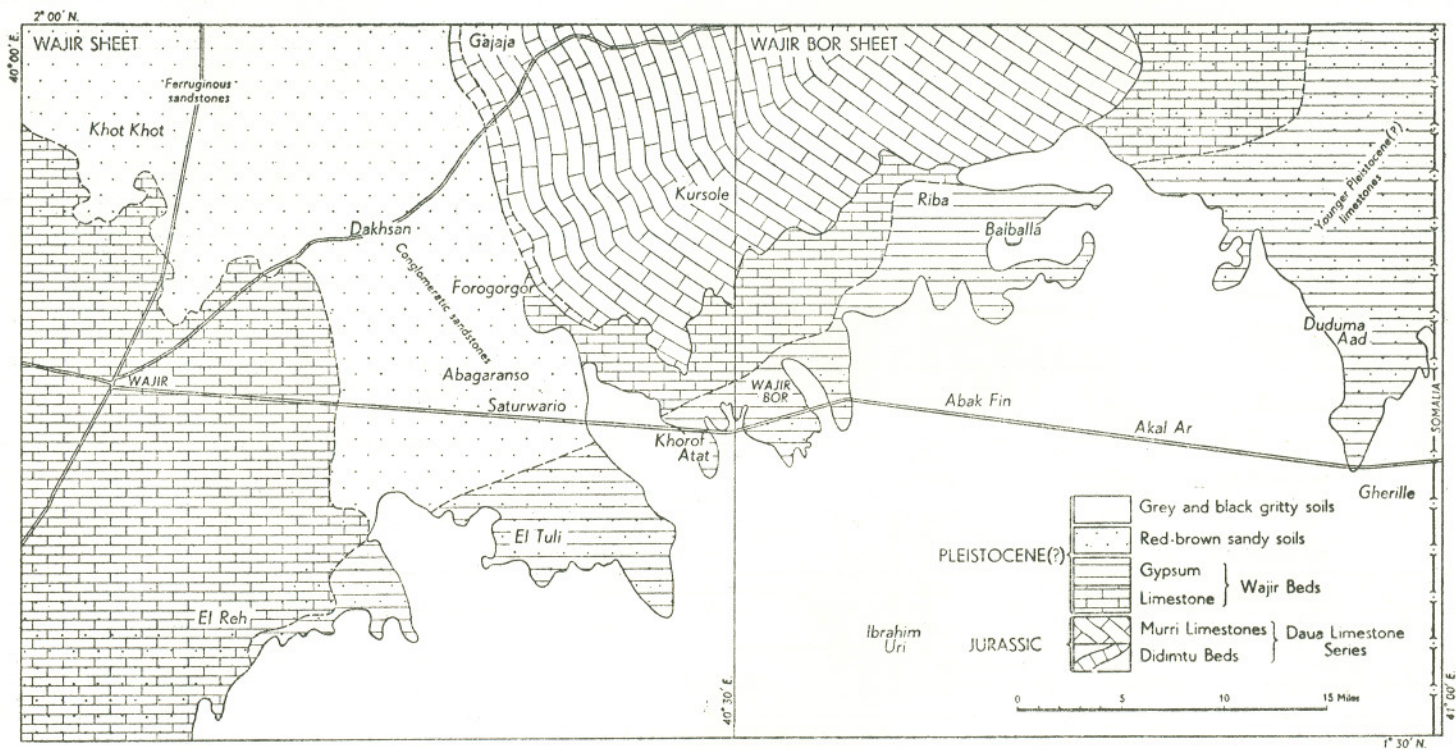


Fig. 1—Sketch map illustrating the distribution of the sediments of the Wajir-Wajir Bor area

TABLE I
Stratigraphical Succession in the Wajir Area

Eras	Periods		Local representative	Lithology	Environment of deposition	Climate	Palaeogeographic events
Quaternary	Recent			Valley soils	Terrestrial	Dry	
	Pleistocene	U		Red and brown clays	Terrestrial	Dry	Erosion
		M	(unconformity)	Grey gritty soils Laminated limestones Ferruginous sandstones and conglomerate Gypsum Impure limestones	Flood-valley Lacustrine Terrestrial	Wet Dry	Deposition
			Wajir Beds		Paludal Lacustrine	Wet	Deposition
		L (?)	(unconformity)	Sandstones Clays and sands	Flood-valley	Dry Wet	Deposition
Tertiary	Pliocene						Peneplanation Erosion
	Miocene		?	?			Deposition
	Oligocene						Extensive continental erosion
	Eocene						
Mesozoic	Cretaceous						Faulting
	Jurassic		Bur Mayo Limestones Didimtu Beds (unconformity)	Grey and brown limestones Mainly fossiliferous limestones	Marine	Warm	Extension of the gulf to the north Renewal of down-warping
	Triassic (?)		Mansa Guda Formation	Conglomerates and quartzites			Marine invasion Down-warping

area and disappears towards the east underneath a blanket of Pleistocene deposits. There are outcrops but, over most of the area occupied by the Jurassic limestones, resistant beds are seen only as strings of loose boulders along the strike, separated by tracts of red soil with little float. This feature is distinct on the aerial photographs and assisted greatly in mapping areas where buckling of the sediments gave rise to anomalous strike and dip readings at the widely separated outcrops. At Gajaja in the north-west, the Jurassic limestones dip 2° due east, the strike gradually swinging to the east further south and eventually, north-east of Riba, the strike is nearly due east with the sediments dipping to the north. Taking an average dip of 2° , it can be calculated that the lowest 4,000 ft. of the Dava Limestone Series occur in the Wajir area.

The base of the Dava Limestone Series was not observed in the Wajir area, but further north Thompson and Dodson (1960, p. 20) found the Jurassic sediments overlapping the Mansa Guda Formation. Because of the paucity of exposure, there is no proof around Wajir of a break in the sedimentation of the Dava Limestone Series, but according to Thompson and Dodson (*op. cit.*, p. 20) the series can be divided into two parts on account of a postulated overlap of beds of Bathonian-Callovian age onto the Didimtu Beds north of Didimtu. In dating the Jurassic limestones of the Wajir area, the palaeontological evidence of Ayers (1952, pp. 26-27) and Thompson and Dodson (*op. cit.*, pp. 22-24 and pp. 32-33) had to be relied on, as the fossiliferous horizons found did not yield well-preserved fossils for identification.

In the course of the survey of the Jurassic sediments of north-eastern Kenya, the field parties assigned several new names to the members of the succession and in some cases, different names referring to rocks of the same age. In Table II an attempt is made to correlate corresponding horizons.

(a) DIDIMTU BEDS

The sequence in the Didimtu Beds can only be determined from occasional cobbles on the surface in the lower part and from narrow outcrops or flags in the upper part, so that no thicknesses of the various members could be determined, though it can be calculated that the beds as a whole attain a thickness of 120 ft. in the area. The most complete sequence was obtained halfway between Gajaja and Forogor viz.:—

6. Thin brown to grey fossiliferous to coquinoid limestones
5. Cobbles of dense grey argillaceous limestone with yellow mottling
4. Flags of yellowish brown fossiliferous limestones
3. Dense grey argillaceous limestone cobbles with red mottling; occasional hard grey or brown finely recrystallized limestone cobbles
2. Small cobbles of yellow-brown oolitic limestone with larger grey mottled argillaceous limestone cobbles
1. Boulders of dense brownish grey argillaceous limestones with few fossil fragments and yellow mottling

Specimen 31/1* from the El Wak road is an example of the basal member of the Didimtu Beds and consists of a finely recrystallized grey matrix enclosing numerous minute grey pellets and a few larger, partly recrystallized argillaceous pellets. In thin section this fragmental limestone is seen to consist of numerous shell fragments and some rounded dense pellets in a recrystallized matrix of clear interlocking anhedral calcite with a little dolomite. Nearly all the shell fragments have a high degree of rounding, but are usually elongate or ovoid in shape, with random orientation. Recrystallization is encroaching on some of the shell fragments, and others of the organic remains, such as crinoid ossicles and possibly bryozoan tests, are partly absorbed.

* Numbers 31/1, etc., refer to specimens in the regional collection of the Geological Survey, Kenya.

TABLE II

The Correlation of the Jurassic Limestones of north-eastern Kenya

Stages of the Jurassic	Entire Area (Ayers, 1952)		Mandera–Damassa area (Joubert, 1960)	Derkali–Melka Murri area (Thompson and Dodson, 1958)	Takabba–Wergudud area (Saggerson and Miller, 1957)	El Wak–Aus Mandula area (Baker and Saggerson, 1958)	Bur Mayo–Tarbaj area (Thompson and Dodson, 1960)	Present Report
Tithonian	Mandera Series		Mandera Series		(Not exposed)	(Not exposed)	(Not exposed)	(Not exposed)
Kimmeridgian	Daa Limestone Series	Upper Limestones	Dakacha Limestones		“Upper” Daa Limestones	“Oxfordian” Limestones		
		Upper Shales	Hereri shales					
Oxfordian		Middle Limestones	Seir Limestones		Golberobe Beds	Golberobe Beds		
		Middle Shales	Rahmu Shales		“Lower” Daa Limestones	Main Oolite Limestones		
		Lower Limestones	Muddo Erri Limestones					
Rukesa Shales			Asaharbita Beds					
Callovian	Daa Limestone Series	Lower Limestones	Murri Limestones	Murri Limestones	(Not exposed)	(Not exposed)	Bur Mayo Limestones Marl Horizon	Bur Mayo Limestones
Bathonian Bajocian			Murri Limestones					
Lias		Didimtu Beds	(Not exposed)	(Not exposed)	(Not exposed)	(Not exposed)	Didimtu Beds	Didimtu Beds

Specimen 31/38, a banded dolomitic limestone collected at Forogorgor, occurs slightly higher in the Didimtu Beds succession and consists of dark grey, finely recrystallized limestone with irregular dense red material, the latter also occurring as thin lines and small spots. Under the microscope the clear recrystallized matrix is seen to contain numerous elongated dense tubular or ovoid bodies, shell fragments in a somewhat linear arrangement, and some oolites. The oolites, generally perfectly round and about 0.3 mm. across, show concentric and radial structures and enclose cores of calcite crystals, ferruginous material and commonly organic remains. The radial structures have formed at the expense of concentricity in the oolites as a result of alteration. Dense red irregular patches occur in parts of the section and are seen to consist of small globules of hematite scattered throughout a fine carbonate matrix, while in some parts, hematite and limonite are so abundant as to exclude all carbonate. Wherever fossil fragments occur within the ferruginous patches, they are separated from the iron oxides by clear crystalline carbonate rims. Dolomite is seen as aggregates of euhedra replacing the calcite, while secondary quartz is encountered in the dense rounded pellets. Thin cracks filled with clear calcite traverse the thin section.

The upper part of the Didimtu Beds is best exposed in the Gajaja area where thin flaggy pavements of yellow-brown fossiliferous and dark grey coquinoïd limestones alternate with bands in which occasional dense mottled argillaceous limestone cobbles are encountered. The lowest horizon of the fossiliferous limestones (specimen 31/7) is a fawn-coloured yellow-weathering, finely recrystallized limestone. Normally such a rock would be massive, but because of the thinness of the bedding and resistance to erosion, it occurs as a series of flags strung out along the strike. Black shell fragments are all arranged parallel to the bedding. In thin section numerous oolites, and very often elongated lenticular fossil fragments in linear arrangement, occur scattered throughout an even-grained mosaic of yellow-stained calcite. Where the matrix is clear, small globules of limonite occur interstitially. The oolites have sometimes formed around single crystals of calcite, but mainly around pellets composed of finely divided calcareous matter. Composite oolites are rare, while occasional foraminiferal tests are encountered in the matrix or enclosed by oolite rims.

The fossil content of the Didimtu Beds at Gajaja sometimes increases to such an extent that the limestones become coquinoïd with the black shell fragments, all roughly arranged parallel to the bedding, imbedded in a yellowish brown calcareous matrix and imparting a general dark grey colour to the rock. Under the microscope specimen 31/8 from Gajaja is seen to consist of an equigranular iron-stained calcite mosaic containing many shell fragments. The iron-staining is usually most prominent around shell fragments and is of a patchy nature. Occasional large clear patches of interlocking anhedra of calcite have formed in the spaces between the shells, the shell fragments being themselves sometimes recrystallized. The shell fragments are often rimmed by dense black material, probably manganiferous, which imparts the black colour to the shells in hand-specimen. Limonite globules occur scattered throughout the matrix or as small aggregates, while occasional angular detrital quartz grains occur within the calcite matrix.

Fossils occur in profusion in some of the limestones of the Didimtu Beds in the Wajir area, but no fossils suitable for identification were collected as they resist removal without fracture from the enclosing rock. There is, however, no doubt as to the age of these beds as a significant fauna has been yielded by the argillaceous beds at Didimtu and north-east of Tarbaj hill, north of the present area (Ayers, 1952, pp. 9 and 26-27; Thompson and Dodson, 1960, pp. 22-24). The fossils of consequence are *Pecten (Weyla) ambongoensis* Thevenin, a species described from the Upper Lias of Madagascar; a spiriferina like *S. rostrata* var. *madagascarensis*, a genus which became extinct in the Lias; *Bouluceras nitescens* Thevenin, which is characteristic of the Toarcian; and *Paracenoceras anomphalum* (Pia), mainly a Toarcian species. The fossils not only establish the age of the Didimtu Beds but also indicate a marine link with the Kenya coast and Madagascar during those times, a link that was severed during the mid-Upper Jurassic period.

(b) BUR MAYO LIMESTONES

In a discussion on the age of the Bur Mayo Limestones, Thompson and Dodson (1960, p. 33) mention that the Aalenian and Bajocian appear to be missing as no fossils indicating these stages have been found, and that the limestones can be dated as Bathonian-Callovian.

The sequence in the Bur Mayo Limestones was determined largely from boulders along the strikes of the various resistant horizons, which are separated by tracts of soil containing float of the underlying sediments. Outcrops do occur in the Gajaja area, which gave most of the evidence for the subdivision of the lower part of the succession and in the north-central parts where the middle sequence of the succession was obtained. Further east no outcrops were encountered so that only scanty information exists on the upper Bur Mayo Limestones.

The sequence as mapped is as follows:—

	<i>Approximate thickness feet</i>
8. Mainly brown to buff oolitic and grey argillaceous limestones	1,750
7. Mainly non-oolitic brown banded and dense grey limestones	900
6. Oolitic brown and grey banded limestones.	140
5. Non-oolitic brown banded and grey argillaceous limestones	470
4. Thin-bedded hard finely recrystallized or dense brownish grey limestones, sometimes banded	110
3. Thin brown flags and occasional grey argillaceous limestone cobbles ..	170
2. Thin brown banded and dense grey argillaceous limestones	110
1. Dense grey argillaceous limestones with prominent yellow and red mottling	160
Total	3,810

The base of the Bur Mayo Limestones (1) is best exposed along the hill front at Gajaja and consists of dense grey argillaceous limestones (calcite mudstones) with distinctive red and yellow mottling. Within the stained patches, the limestones sometimes contain clear acicular crystals and only rarely, solution cavities. South of Gajaja these limestones form the edge of the higher ground built of the Jurassic sediments, but the relief is much less prominent here than at Gajaja hill. Occasionally single fossils are found imbedded in the argillaceous limestones, but two softer unexposed horizons forming grooves on the hill front may be fossiliferous. These beds, covered by talus and not exposed further south, divide the basal beds at Gajaja into three thick-bedded bands.

In thin section specimen 31/6 from Gajaja, one of the calcite mudstones, is seen to consist of finely divided calcareous matter, densely strewn with small globules of limonite which sometimes aggregate to form dark brown patches. Occasional small clear patches of finely recrystallized calcite occur and where these are lenticular and curved, they are thought to replace shell fragments. Minute angular grains of detrital quartz are scattered thinly but evenly throughout the matrix.

The succeeding limestones (2) consist of thin yellowish brown beds alternating with grey argillaceous limestones with yellow mottling, fossiliferous in the lower part and laminated in the higher. The first-mentioned rock type is prominent in the lower parts, where numerous flags and slabs of red-weathering limestones occur strewn on the surface, while occasional cobbles of grey argillaceous limestone indicate that this type

forms a minor component of the sequence. Higher in the succession the mottled argillaceous limestones become prominent, with a darkening in the colour of the thin banded limestones from yellow to red to dark purplish grey. The sequence is terminated by a greyish brown finely banded limestone.

The lowest bed is distinctive in being banded in red, brown and grey, and recrystallized along bands. Specimen 31/37, collected east of Forogorgor, has a rough finely pitted surface, which reflects the oolitic nature of the rock. The freshly fractured surface is grey with large irregular yellow and red patches and numerous small dark structureless spherules. In thin section it is revealed as micro-coquinoid with numerous fossil fragments, foraminifera, crinoid ossicles and clay pellets, nearly all with an oolitic rim, emplaced in a finely recrystallized calcite matrix. Brown ferruginous patches are seen, with higher magnification, to consist of mosaics of dolomite euhedra with interstitial and intergrown globules of limonite. The clay pellets are usually dense, but sometimes have recrystallized cores, and normally contain a few clastic grains of quartz. In the hand-specimen 31/5, collected in the Gajaja area, is a dense greyish brown limestone joined at a sharp contact with a red recrystallized limestone with numerous red spherules. Under the microscope 31/5 resembles 31/37, but it is bioclastic with advanced recrystallization of the dolomitic calcite matrix, and with many of the rounded detrital pellets containing a large amount of limonite globules.

Slightly higher in the succession at Gajaja, specimen 31/10 was collected. It is a red-weathering, flaggy, yellow, recrystallized limestone and occurs within the fossiliferous zone as it contains numerous shell fragments, partly destroyed by recrystallization. The thin section is that of a coquinoid calcarenite containing large and small shell fragments, numerous dense pellets averaging 0.15 mm. across, probably of faecal origin, and partly destroyed ooliths as well as occasional crinoid ossicles in a recrystallized calcite matrix. All these dense pellets tend to become partly absorbed by the recrystallized matrix, which also contains some detrital quartz grains.

The succeeding beds (3) of the Bur Mayo Limestones are distinguished by their lack of exposure and it is assumed that they consist mainly of argillaceous rocks. Thin brown laminated flags outcrop, however, and their silty nature is reflected by fine cross-bedding on weathered surfaces. The siltstones are presumed to alternate with brownish grey dense argillaceous, banded and porcellaneous limestones which occasionally appear as cobbles on the surface. The beds form a hollow along the strike between two ridges formed by the resistant limestone beds below and above them.

In contrast to the underlying beds, the rocks of group (4) consist of hard recrystallized grey limestones, which form a curved ridge along the strike. Specimen 31/28, collected near the top of this sequence, five miles south-east of Gajaja, is a dense brownish grey limestone with occasional patches of recrystallized calcite and faint banding. In thin section numerous dense pellets, usually 0.2 mm. across but which may be as large as 0.4 mm. occur in profusion in a matrix that is only slightly less dense than the pellets. Many detrital grains or aggregates of calcite crystals, usually rounded and iron-stained, are clearer than the matrix and are enclosed by rims of dense calcareous matter, and it is thought that they may have arisen by recrystallization of the dense pellets. Angular quartz grains are commonly found in the dense pellets, and ovoid pellets are arranged with their longer axes parallel to the bedding. The pseudo-oolitic nature of this rock is of primary sedimentary origin as vague sorting of the pellets is noticeable.

The lower part of the succeeding beds (5) is again poorly exposed, dark dense argillaceous limestone cobbles indicating that this type forms the major part of the sequence. In the better exposed higher part brown colours become more abundant in resistant horizons, dense rocks being brownish grey with some thin finely recrystallized brown limestone horizons. Near the top yellowish brown recrystallized, sometimes banded, limestones and buff porcellaneous limestones break the monotony of the

succession, the upper limit of the beds being marked by thin poorly fossiliferous horizons, sometimes somewhat oolitic, which form the base of the overlying oolitic rocks.

Rocks of oolitic nature are common in the Bur Mayo Limestones, but oolites are especially abundant in the upper part (6), forming a zone approximately 140 ft. thick and about 1,000 ft. above the base of the formation. The lowest bed of this zone is unmistakable as it includes large chert nodules containing numerous ooliths, elongated and strung out along the bedding, and forming prominent whitish protruding knobs on finely pitted red weathered surfaces. Often small shell fragments, all arranged parallel to the bedding, occur in bands in this horizon. In thin section, specimen 31/11 from 29 miles north-east of Wajir on the El Wak road, is found to contain numerous ferruginous ooliths, partly altered to dense structureless pellets, and averaging 0.6 mm. across, in a finely divided carbonate matrix. In the matrix lenticular shell fragments composed of large clear calcite anhedral or partly or entirely replaced by chalcedonic silica indicate vague bedding. Occasional ooliths are ovoid, but the majority are perfectly round while composite ooliths are rare. Chalcedony also forms patches in the matrix, showing fine aggregate structure under crossed nicols, and replaces some oolith cores. Cross-cutting veins of chalcedony and calcite are common while clastic quartz grains sometimes form cores to ooliths.

Banded limestones are common in this part of the sequence, usually being banded in brown and grey. Specimen 31/12 was collected from beds overlying the oolites represented by specimen 31/11. It has a light brownish grey matrix with numerous light yellow ooliths which are evenly distributed, but with a slight preference for certain zones, imparting a faint banded appearance to the rock. Under the microscope the rock is seen to consist of ooliths, nearly all of which are slightly flattened or broken up by the recrystallization of the enclosing coarsely crystalline dolomitic calcite matrix. The ooliths are large, often about 0.9 mm. across, their concentric structure being partly destroyed by the formation of a more pronounced radial structure. Dense rounded pellets are also present and are smaller than the ooliths and usually contain crystals and grains of secondary quartz. Banding is again evident in specimen 31/13 from the same locality, and it has thin bands of chert in which ooliths are almost as abundant as in the surrounding rock. In thin section it can be seen that the chalcedony of the chert has replaced the calcareous matrix, and frequently the cores of ooliths. Sometimes concentric zones of the ooliths are also replaced by chalcedony. Composite ooliths are still very few, but they occur more frequently in this thin section than in any of the others.

Porcellanite nodules elongated parallel to the bedding, occur in specimen 31/27, collected seven miles south of the El Wak road in the oolitic zone. In the thin section the host-rock is seen to be a calcarenite and sorting of the dense calcareous pellets in it has produced indistinct fine-grained bands alternating with coarser bands. Shell fragments are also arranged parallel to the bedding thereby enhancing the banded effect. Recrystallization of the finely divided matrix occurs in patches and irregular veins or in intragranular spaces. Clastic grains of quartz are common while one grain of rutile was seen. Specimen 31/23 collected in the same zone, one mile south of the El Wak road, shows fine light and darker grey laminations which are prominent on the weathered surface. Under the microscope the laminations are seen as concentrations of angular clastic grains of quartz, plagioclase and potash feldspar. These silty bands alternate with bands of finely recrystallized mosaics of carbonate with numerous dense pellets and some shell detritus. Secondary quartz occurs as small patches, while a few flakes of biotite as well as rare grains of zircon are encountered in the sandy layers.

A spotted argillaceous limestone (specimen 31/24) was found interbedded with the oolites two miles south of the El Wak road. The yellow ferruginous spots are seen under the microscope as small patches and veins of dolomite euhedra, usually rimmed by globules of limonite or iron-stained in patches when fine-grained. About five miles

south of the El Wak road large and small irregular angular dense argillaceous blobs and pellets occur within recrystallized limestones. As this type of "brecciated" limestone is not confined to the oolitic zone and is not constant along the strike, it is probable that later deformation, possibly as a result of faulting, caused partial recrystallization, leaving angular blocks and blobs of the original rock floating in the finely recrystallized parts.

Towards the south along the strike of this zone, oolites become less prominent but their appearance interbedded with grey and brown limestones still serves to separate the zone as a distinctive unit.

Overlying the oolitic zone are limestones (7) of the same types as those described above but, because oolites are not so obvious as before, the beds serve to separate the oolitic zone from the upper part of the Bur Mayo Limestones where ooliths are common in nearly all the outcrops and groups of boulders. Most limestones of this part of the sequence are dense and argillaceous and, under the microscope, are seen to consist of finely divided carbonate with minor detrital quartz. Specimen 31/15, collected 30 miles from Wajir on the El Wak road, is a yellowish brown porcellaneous limestone which under the microscope, displays numerous indistinct dense pellets in a finely divided carbonate matrix. The pellets average 0.1 mm. across and are often iron-stained, in which case they are more distinct. In specimen 31/16 from the same locality, a dark grey limestone, the pellets are much larger and although they vary in size, are generally 0.4 to 0.5 mm. across. Perfectly round pellets are scarce and often show a vague concentric structure. The pellets are closely packed in parts of the thin section and tend to shape to the available space and therefore must have been relatively plastic to yield to pressure during compaction. In contrast to specimen 31/15, the matrix here consists of clear anhedral crystals of calcite.

Specimen 31/17, an example of the few oolites that occur in these beds, was also collected on the El Wak road, 31 miles from Wajir. It is a perfect example of a rock derived by the erosion and redeposition of an already deposited calcareous layer. The weathered surface is banded by thin inconsistent resistant lines displaying current bedding and reflecting the silty nature of some of the bedding planes. Under the microscope numerous ooliths, pellets and allogenic grains are seen, enclosed by an equigranular recrystallized dolomitic matrix, with the angular clastic grains of quartz and plagioclase more concentrated in zones parallel to the bedding. Pellets and ooliths are usually elongated parallel to the bedding planes, but are evenly distributed. Allogenic calcite clusters, usually iron-stained, as well as some of the clastic grains collected a dense calcareous rim in the process of transportation before final deposition. Dense pellets are sometimes enclosed by concentric oolitic rims which have often been broken in the process of deposition and recrystallization of the groundmass. Leaf-shaped pellets, arranged with longer axes parallel to the bedding planes, are thought to have been derived by the rolling of the pellets in one plane only, and point to strong and consistent currents in one direction. Occasional small angular fragments of large shells in the matrix also point to powerful currents. A few foraminifera are present.

Fossiliferous zones are nearly always found associated with the oolites and it is therefore consistent that a few fossiliferous horizons have been found in these beds. Specimen 31/18 is an example of such a rock, consisting of shell fragments, arranged roughly parallel to the bedding planes, many dense pellets and a few poorly preserved ooliths in a coarsely recrystallized clear calcite matrix.

Specimen 31/19, collected 31 miles from Wajir on the El Wak road, is a clastic limestone consisting of small lenticular dense grains in a fine equigranular groundmass. Occasional larger round dense pellets occur but are indistinct, as by recrystallization they have come almost to resemble the groundmass. The lenticular pellets are all arranged parallel to the bedding planes, and a vague sorting is noticeable in the thin

section, while in the hand-specimen banding is seen as fine current bedding. A few quartz grains and small shell fragments complete the composition of this rock. Specimen 31/20, a calcarenite from the same locality, is a pink fine-grained limestone, the colour being due to even iron-staining with occasional aggregates of limonite. In thin section it is seen to consist of well-rounded aggregates or iron-stained calcite, often showing vague oolitic concentricity, contained in a finely recrystallized clear matrix, which also has a few clastic grains of quartz.

An intra-formational conglomerate (specimen 31/59) was found three miles south-west of Shandermot where a fine-grained grey limestone with numerous small red dots contains large elongated to sub-rounded pieces of dense mottled limestone up to 5 cms. in length. The rough surfaces of the pellets in this rock form a relief on its grey weathered surface. A crude orientation of the pebbles is hardly noticeable in the hand-specimen, but is obvious in thin section where it can be seen that their orientation coincides with that of the elongated dense pellets, shell fragments and stringers of the partly recrystallized matrix. The pebbles are dense to finely recrystallized and often have rectangular clear areas of fine calcite which may have replaced columns of aragonite. The matrix, which is dolomitic in parts, contains limonite as small pellets or as aggregates of globules and encloses numerous detrital grains of quartz, some plagioclase and altered ooliths.

Ooliths again become evident in hand-specimens from above 2,000 ft. from the base of the Jurassic limestones (group 8). Because of paucity of exposure in the upper part of the Bur Mayo Limestones, subdivision was impossible as resistant horizons, usually exposed as bands of boulders, are separated from one another by tracts of soil, sometimes quite wide, with no indication of the buried rock underneath. Most of the visible succession consists of a rather monotonous repetition of similar beds, a set commencing with banded limestone, very often oolitic and/or fossiliferous, giving way to dense light brown porcellaneous and mottled limestone which is in turn succeeded by dark grey argillaceous limestone. Within these sets of beds innumerable varieties of limestones occur which are thin and not consistent along the strike and therefore valueless as marker horizons.

Specimen 31/56, collected eight miles north-west of Riba, on weathered surfaces displays fine current bedding which is hardly noticeable on the greyish brown freshly fractured surface, where iron-staining in bands show no concurrence with the bedding. In thin section it can be seen that fine recrystallization has encroached on pellets and left only curved elongated dense bodies arranged parallel to the bedding. Dense bands have also been broken by recrystallization to leave dense blobs strung out along the bedding as insets in a finely crystalline calcite matrix. Clastic quartz grains occur throughout the rock but are prevalent in the finely recrystallized layers where they are concentrated in zones parallel to the bedding. Small rounded blobs, coloured brown by the inclusion of numerous globules of limonite, may have been derived from ooliths or ferruginous limestone pellets and occur throughout the thin section. Specimen 31/57, collected at the same locality and with the same mineral composition as 31/56, is dark grey with red mottling and no sign of banding. The red mottling is seen under the microscope as concentrations of the ferruginous blobs, like those described above, and therefore a secondary feature.

The first exposure of Jurassic limestones north of Riba is a splintery yellowish brown calcarenite (specimen 31/41) with numerous yellow and some larger buff pellets distinguishable on close examination. Under the microscope the pellets are seen as indistinct, iron-stained and finely equigranular insets about 0.5 mm. across, in a clotted matrix. A few of the pellets show organic or oolitic structures and are thought to have been derived from a previously deposited sediment. Some larger clear shell fragments as well as coarsely crystalline calcite veins are also present.

Pink, finely recrystallized limestones are often encountered in this part of the succession. Specimen 31/42, an example of such a rock, collected four miles north of Riba, shows under the microscope that the colour is derived from patchy distribution of ferruginous globules and specks, which, in this case, are distributed in an equigranular mosaic of recrystallized calcite and dolomite.

Five miles north of Riba a calcirudite was collected which, in the hand-specimen, is a light grey dense rock containing darker pellets and elongated blobs. The weathered surface is even more distinctive as the grey pellets, which are elongated parallel to the bedding, form a relief on a dead white background. Under the microscope the rock is seen to consist of a dense matrix containing small quartz grains and somewhat clearer rounded or elongated patches with small dense pellets. These patches have been derived from another sediment before consolidation and are themselves calcarenitic.

Slightly higher in the succession, about six miles north of Riba, the only porous limestone found in the Jurassic limestones was collected (specimen 31/45). It is light pink in colour with indistinct greyish white recrystallized layers imparting a vague banding to the hand-specimen. Numerous pin-sized holes dot the weathered as well as the freshly fractured surface. The thin section shows a microcoquinoid calcarenite with the shell fragments all arranged parallel to the bedding and with dense and finely recrystallized pellets in an equigranular mosaic of calcite and dolomite. The cavities in the section are nearly all lined by slightly coarser carbonate crystals and are nearly always elongated across the strike of the bedding. This secondary porosity no doubt developed during diagenesis. The discovery of a porous rock of this nature in the Jurassic limestones has not been described before, but the discovery of one such horizon, although thin, points to the possibility of more such horizons in poorly exposed parts of the succession, and is important when considering the possibility of the occurrence of oil in north-east Kenya.

The great majority of the rocks collected in the upper part of the Bur Mayo Limestones, although it is not always obvious in the hand-specimen, are found to contain pellets when examined microscopically. This also applies to fossiliferous horizons such as are represented by specimen 31/48, collected seven miles north of Riba, in which numerous fossils and shell fragments are cemented in finely recrystallized carbonate also containing some coarser crystalline calcite and small dense pellets. Even oolites contain structureless pellets, as in specimen 31/49 from the same locality as 31/48. This oolitic limestone, apart from having numerous partly altered and sometimes flattened ooliths, has many smaller sub-rounded dense pellets and small shell fragments, sometimes with oolithic rims, enclosed in a recrystallized calcite groundmass. In the hand-specimen flattened argillaceous limestone pebbles occur along zones parallel to the vague bedding of the rock. Such pebbles were also seen in the rocks eight miles north of Riba, where specimen 31/50 was collected. This fossiliferous calcarenite has patches of recrystallized carbonate containing small globules of hematite that impart a distinctive spotted appearance to the rock.

In comparison with the underlying Jurassic sediments, it can be noted that porcelaneous and microcoquinoid limestones are much more abundant in the upper part of the Bur Mayo Limestones and that the typical grey argillaceous limestones, so prominent in the lower parts, are virtually absent above 2,500 ft. from the base.

The Jurassic limestones of the Wajir area do not reach so far to the north-east as to include the "Oxfordian" Limestones of Saggerson and Baker (1958, pp. 16-18).

(c) STRUCTURES IN THE JURASSIC LIMESTONES

In an area where outcrops are rarely encountered, such as at Wajir, it is only to be expected that zones of structural weakness would not be exposed. Several structural features, however, were recognized on aerial photographs and subsequently substantiated

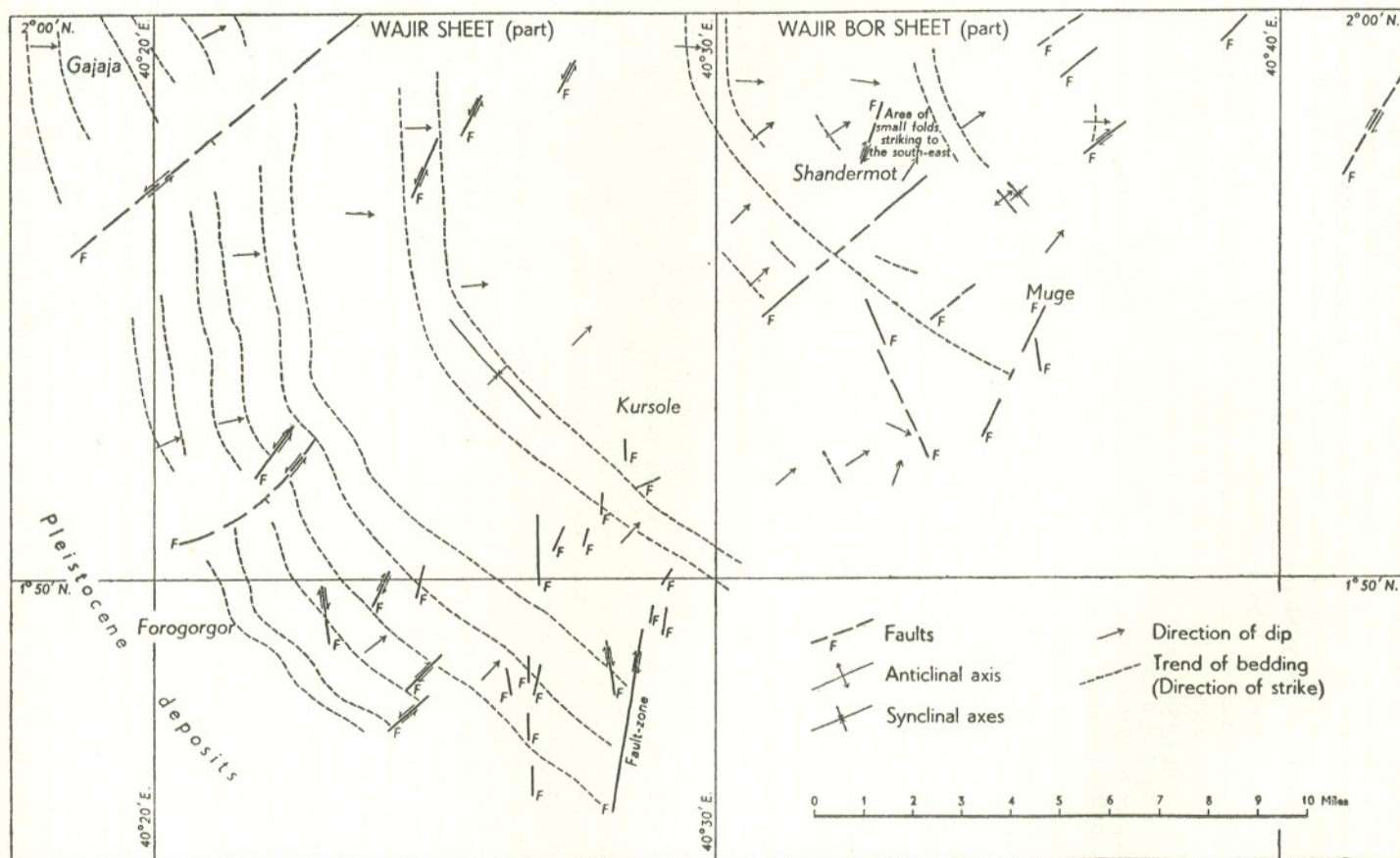


Fig. 2—Structural map of the Jurassic limestones, Wajir area

in the field and are shown in Fig. 2. Apart from being evident on the aerial photographs, the strike of the Daua Limestone Series is reflected in the trend of ridges formed by resistant horizons and by the scattered dip measurements. The beds are seen to form a broad arcuation with easterly dips in the north with a gradual swing round to north-east dips further south.

Faults.—The base of the limestones is nearly 1,100 ft. above sea-level at Gajaja and less than 900 ft. south-east of Forogorgor, and consideration of the topography and the dip and strike of the limestones indicate that there must be dip-faults between those two localities. Two faults striking to the north-east are postulated to explain the structure, one running along the valley south of Gajaja hill and the other north of Forogorgor where they are presumably responsible for the off-setting and strike variations mapped. In the areas where these faults occur, exposures are non-existent but, apart from the change in direction of strike of the limestones, they also have topographic expression in the elevated areas to the north of the faults. It is considered that horizontal movement was responsible for the curvature of the beds as indicated on Fig. 2. The fault near Forogorgor has greatest displacement in the south-west and gradually disappears towards the north-east. The downward movement on the south-east side of this fault is also expressed in a widening of the outcrop width of the beds east of Forogorgor, which is thought to be due to a decrease in the angle of dip of the limestone beds in that area. Other faults indicated on Fig. 2, were taken from aerial photographs on which they appear as straight lines across the strike, and usually show slight horizontal displacement. They are generally of small magnitude and lose themselves in minor deflections of the bedding trend of the limestones along the strike.

In the field, faulting is recognized by cross-cutting zones of recrystallized limestone, irregular lumps of clear calcite crystals in limestone, or by sudden deviations of the strike. Coarsely recrystallized yellowish and pinkish brown limestones occur along cross-cutting zones as smooth brown boulders which display their coarsely crystalline nature only on fracturing. Under the microscope these rocks (specimens 31/21, 13/25 and 31/58) exhibit large replacive pools of carbonate usually dense with evenly scattered grains of limonite. In specimen 31/25, collected 30 miles N.N.E. of Wajir, the matrix also encloses detrital grains of quartz and calcite which were not affected by the recrystallization.

Specimen 31/26 was collected 30 miles N.N.E. of Wajir, and contains large and small angular blocks of dense dark grey limestone scattered in a large brownish grey recrystallized matrix. The dense angular fragments are distinct on weathered surfaces and give the rocks the appearance of a breccia with widely spaced fragments. These rocks do not form a continuous horizon along the strike and as other indications of faulting are evident in the area, it is thought that partial recrystallization resulted on fracturing.

A common feature of the Jurassic limestones, especially in the eastern parts, is thin clear calcite veins traversing the limestone boulders. The veins are nearly always perpendicular to the bedding of the boulders, which indicates that they are vertical or nearly vertical, and in outcrops or boulders found *in situ*, the veins strike north-easterly which is the main strike direction of the faulting. In rocks where chalcidonic nodules occur, chalcidony is sometimes found within the veins with the calcite.

Clear crystalline calcite sometimes occurs as lumps and stringers in the limestones along faults. About one mile north-east of Shandermot where small shears occur along the edge of an unexposed fault-zone, such a crystalline calcite mass can be seen on a fault-plane as shown on Fig. 3 (a). The strike of the fault-zone is 20° N.E. and the strike direction of the small shears make an angle of about 50° with the strike direction of the main fault which passes to the west of the faults shown on the plan. Horizontal displacement along the shears is very small. The angle of dip of the beds increase towards the west as the main fault-zone is neared.

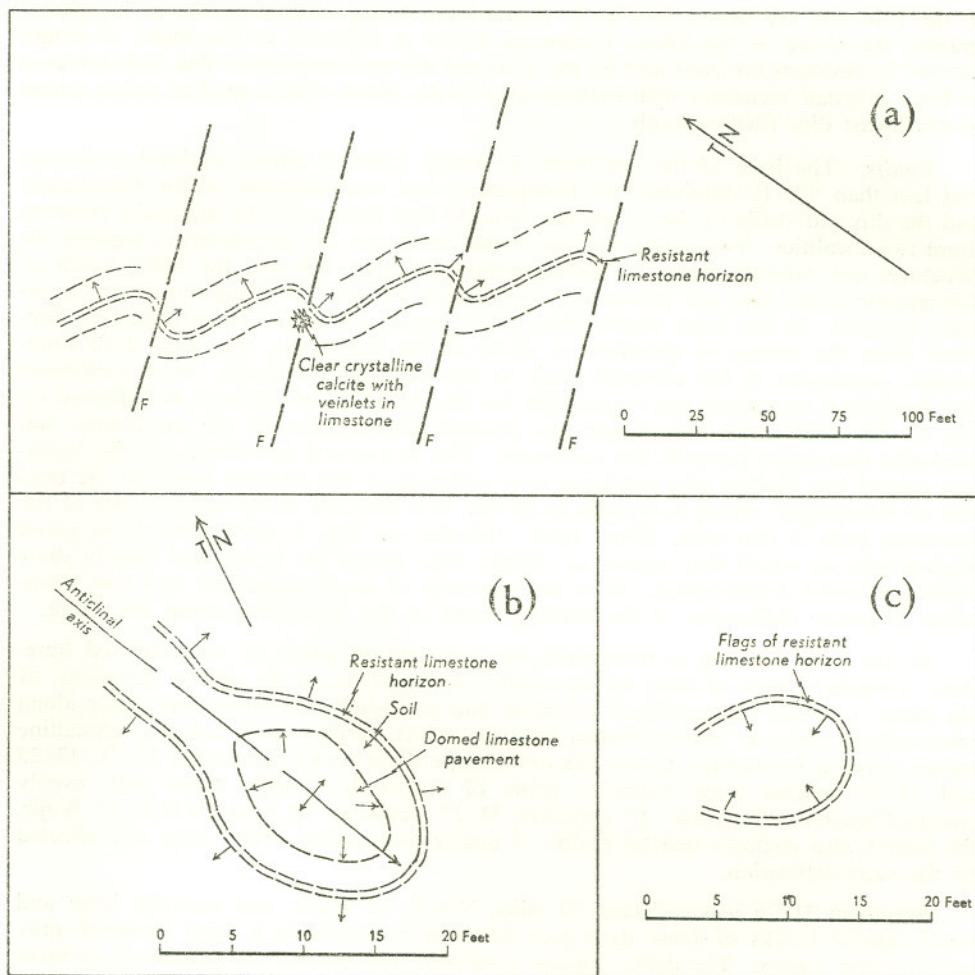


Fig. 3—Sketch plans of structures in the Jurassic limestones

Folds.—Small folds of any consequence do not exist in the Jurassic limestones, but that minor plication did take place can be deduced from increases in the angle of dip and from occasional south-westerly dips. An increase in the angle of dip is obvious west of Kursole and locates a south-east-north-west synclinal axis in that area (Fig. 2), but the paucity of exposures to the north and south of the syncline prevents the location of adjoining anticlines. The folding in this area is probably the reason for the widening of the outcrop width of the oolitic zone there, while the cause for folding must be sought in the situation in the wedge between the fault north of Forogorgor and the fault-zone north of Khorof Atat.

Steep dips were recorded in the area north-east of Shandermot where low southerly dips are also encountered. The dome shown in Fig. 3 (b) occurs about two miles north-east of Shandermot and explains the contrary dips by mild buckling of the limestones in small domes and saucer structures.

Saucer structures as shown in Fig. 3 (c) are quite common in the limestones and are usually formed by flaggy limestone boulders in the soil, all dipping inwards at varying angles. In the vicinity of Shandermot where the dips are normally low, they are presumed to occur as the counterpart of the domes as shown in Fig. 3 (b), but in other areas where their components usually dip steeply they are thought to have resulted by the collapse of subterranean channels in the limestones.

Synthesis.—The conclusion is reached that the fault pattern of the Jurassic limestones of the Wajir area is the expression on the surface of deep-seated wrench faults, and that the shears and small folds are manifestations of the re-orientation of stress or differential movement along the fault-planes.

3. Quaternary Sediments

Sediments of Quaternary age occupy the major part of the area, excluding only the north-central sector which is occupied by the Daua Limestone Series. The dating of the deposits depends on correlation with similar beds in the Daua valley to the north and the stratigraphical position occupied in relation to the end-Tertiary peneplain. The classification adopted in this report is as follows:—

Recent	River Soils	
	Upper	Red and brown clayey soils with calcareous nodules
Pleistocene	Middle	Grey and black soils Thin laminated limestone Ferruginous sandstones and conglomerates Gypsite and gypsum Impure limestones
	Lower (?)	Sandstones Clays and sands
		} Wajir Beds

(a) WAJIR BEDS

Encircling the sediments of Jurassic age are the Wajir Beds (Parkinson, 1920, *Wajir Beds*, p. 11 *et seq.*), which consist mainly of white to grey laminated impure limestones and gypsiferous beds, the presence of the former being indicated by kunkar limestone outcropping in the red sandy soil, while gypsum is indicated by light or dark grey soil containing numerous calcareous nodules. Yellowish to light grey loams forming part of the Wajir Beds are sometimes seen in circular depressions in the vicinity of Wajir, while quartzitic or felspathic sandstone cobbles and pebbles in the Saturwarior-Libiduli area indicate the presence of sandy horizons in the sequence. To the north of Wajir the Wajir Beds are overlain by partly indurated ferruginous sandstones, sometimes containing pebbles derived from the Mansa Guda Formation. Patches of the conglomeratic ferruginous sandstones appear on the Wajir Beds further south, east of Wajir, and finally disappear under the grey soils in the southern part of the area. The easterly extension of the Wajir Beds forms a ribbon between the Jurassic limestones to the north and the grey soils to the south.

Because of the prevalent red soil cover and the presence of kunkar limestone, the true nature of the Wajir Beds cannot be determined on the surface, but excavations, and quarries as well as the numerous wells in the Wajir area, provided information on

the upper parts of the beds. During 1952-53 Bestow (1953), while conducting an intensive study of the geological conditions controlling the ground-water distribution in the area, came to the conclusion that, although the Wajir beds vary greatly in thickness and lithology both laterally and vertically, a fairly uniform succession exists within the well area at Wajir as follows:—

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

The logs of the bore-holes drilled at Wajir during the war do not appear to be reliable, but indicate that unconsolidated arenaceous clays underlie the above succession to a depth of 150 ft. On the Tarbaj road, 16 miles north of Wajir a test hole disclosed the following succession (Bestow, *op. cit.*, appendix K):—

	feet
5. Surface sand	0-5
4. Red friable sandstones	5-9
3. Highly arenaceous white limestones	9-50
2. Calcareous and gypsiferous loams	50-80
1. Highly calcareous white sandstones with yellow mottling ..	80-85

Further to the north, outside the area under discussion, another test-hole in the vicinity of Tarbaj gave the following succession (Bestow, *op. cit.*, appendix K):—

	feet
7. Surface sand	0-6
6. Red ferricrete	6-20
5. Red sandstones	20-25
4. Pink fine-grained non-calcareous sandstones with white mottling	25-71
3. Yellow calcareous loams with pebbles of loams like those of Wajir	71-80
2. Damp yellow sands with loamy bands	80-97
1. Damp sandy clays, pebbly in parts	97

A pilot well at Waghalla, 8 to 9 miles west of Wajir, disclosed the following sequence (Bestow, *op. cit.*, appendix K):—

	feet
8. Surface limestone	0-6
7. Reddish sandstones	6-22
6. Calcareous loams becoming less calcareous downwards	22-42
5. Grey sands with calcareous nodules	42-52
4. Grey calcareous loams with calcareous nodules	52-62
3. Clays	62-91
2. Clayey sands	91-92
1. Sand	92-93½

At Ganuri, 12 to 13 miles W.S.W. of Wajir and nearly 10 miles outside the present area, the following succession was obtained (Bestow, *op. cit.*, appendix K):—

	feet
7. Sand	0-4
6. Gritty limestones	4-41
5. Grey clays	41-45
4. White friable sandy limestones	45-54
3. Clays	54-70
2. Argillaceous greyish-yellow sands	70-78
1. Pink sandstones	78-83

Bestow (his appendix H) also gives the analysis of the argillaceous sand occurring at a depth of 52 ft. in Well No. 1 at Ganuri, where it is the aquifer:—

	%
SiO ₂	74.57
Al ₂ O ₃ and TiO ₂	8.82
Fe ₂ O ₃	3.47
MgO	2.19
CaO	0.58
Moisture at 110° C.	7.57
Loss on Ignition at 900° C.	3.46
Cl	0.08
SO ₃	0.23
	100.97

Anal: Industrial Research Board, Nairobi.

From sequences given it is clear that the succession is highly variable from place to place, but this feature becomes even more marked when the sections of groups of wells around Wajir are studied. Lateral variations in the sediments are found within a single well group.

The lower parts of the Wajir Beds are not exposed, but the occasional pans in the area show yellowish and light grey dusty soils which may have been derived from the loams in the lower beds. In the Saturwario-Libiduli area several pans lined by surface limestone contain boulders and cobbles of quartzitic or felspathic sandstones. The deposition of the sandstones may date back to the Tertiary, but the stratigraphical position agrees with that of the sandstones usually underlying the limestone in the Wajir beds. The quartzite (31/32) is pink and faintly banded due to sorting of the quartz grains and contains a number of red-brown clay galls flattened parallel to the banding. Under the microscope the clastic minerals are seen as sub-angular to rounded quartz grains, feldspar, mica, hematite, limonite, chalcedony and tourmaline. The grains are usually closely packed and cemented by secondary quartz and opaline and chalcedonic silica, the latter minerals displaying a fine banding. The quartz grains are fresh and sometimes contain numerous small inclusions, while the feldspars are altered, usually to dense brown material and fine calcite. The plagioclase feldspar is oligoclase while microcline is the most abundant of the potash feldspars. Both muscovite and altered biotite are present in the finer-grained bands, where the fine dark minerals are concentrated. Individual grains in the quartzite range in size from 0.15 to 1 mm. across.

The sandstone (specimen 31/32 (a)) is also pink in colour but is mottled with light yellow, and is flaggy with a sugary texture. Sorting is also distinct and red-brown clay pellets are elongated parallel to the bedding. Surfaces along which the rock splits show numerous small flakes of mica. Microscopically this sandstone resembles the quartzite described above but is not so well cemented and the cement consists only of secondary quartz.

Dixey (1948, p. 10) found only surface limestone in the wells examined by him, but although interbedded limestone is absent in some wells at El Shelati, and in the pilot well two miles north of Wajir, the average thickness of the limestone in the Wajir Beds is about 5 ft. (Bestow, *op. cit.*, p. 10). In the quarries around Wajir and in excavations in the vicinity of Wajir, the limestone appears as a chalky white laminated rock which is fissile along the bedding planes. Sometimes it is massive as in specimen 31/35 (from Abak Halul) which is light grey in colour and contains many unsorted grains and some larger rounded quartz granules. Under the microscope the rock exhibits numerous quartz grains, all showing a certain degree of rounding and ranging in size from minute to 1 mm. across, in a dense carbonate matrix. The matrix has a clotted appearance due to the recrystallization along irregular veins, leaving rounded patches of dense carbonate. Minor clastic grains of plagioclase feldspar and rutile as well as rounded grains of detrital calcite indicate that both the Basement System and the Jurassic limestones contributed to the composition of the rock. Secondary banding consisting of successive crystalline calcite and dense argillaceous carbonate layers is noticed in the recrystallized calcite veins or lining solution cavities, while coronas of recrystallized carbonate rim the clastic grains, with the width of the corona dependent on the size of the grain.

The limestones are being altered to superficial limestone at their upper surface and nodules of kunkar are forming in the soil cover. This alteration of the limestone destroys the bedded appearance of the rock, which then becomes porous with irregular darker grey greasy-looking patches (specimen 31/62, Wajir), and at the surface becomes dense grey with irregular dark spots and lighter coloured porous patches (specimen 31/61, Wajir). In a thin section of the latter rock there are numerous sub-angular quartz grains, some feldspar fragments, and chert grains in a dense nodular calcareous matrix. Dense brown irregular nodules are probably composed of opaline silica with much iron. Vugs in the thin sections are lined by thin layers of clear calcite. The chemical analyses of these rocks show a marked increase in lime near the surface.

	31/61	31/62
	%	%
SiO ₂	23.02	46.06
Total R ₂ O ₃	1.40	1.58
MgO	1.19	2.36
CaO	39.72	25.56
Loss on ignition	34.22	24.78
Total	99.55	100.34

31/61—Kunkar limestone, Wajir township, at surface.

31/62—Kunkar limestone, Wajir township, taken seven feet below surface.

Analyst: J. Furst.

Further to the east, at Wajir Bor and Riba, the limestones rest directly on the Jurassic sediments. Isolated patches of kunkar limestones indicate the position of hollows on the end-Tertiary peneplain where the limestone accumulated during the Pleistocene period. In the Wajir Bor-Riba section the limestones of the Wajir beds are thin in places and locally the gypsum overlying them sometimes seemingly rests on the Jurassic sediments and it appears that the limestones are even absent in places. Gypsiferous deposits are found along a zone stretching from El Reh in the south-west, through Rama Agon, El Tuli, Khorof Atat, Wajir Bor, Riba, and Balballa to Duduma Aad in the east (see Fig. 1). The gypsiferous zone increases in width towards the east which is largely due to the slight unconformity between the gypsum and overlying grey soils and to a lesser extent to a thickening of the gypsum at the expense of limestone in that direction.

The gypsum rarely appears on the surface, but its presence is usually detected by light grey dusty soils containing numerous calcareous and gypsiferous nodules with some water-worn quartzitic pebbles. The lower parts of the gypsum are exposed in the wells of El Reh where it is seen as chalky gypsite, but at El Tuli, higher in the succession, it is finely banded in alternating indurated and chalky laminations, with some massive crystalline bands. Single gypsum crystals, up to one inch in length, are found scattered on the surface. A curious feature of many of the gypsiferous occurrences is the presence of the water-worn quartzitic pebbles on the surface, a feature which was also noticed at Jilello where a lens of gypsum is interbedded in the grey soils overlying the Wajir beds.

Specimen 31/3, an example of gypsite collected at El Tuli, is buff-coloured and banded with hard indurated bands alternating with powdery white layers which effervesce with dilute hydrochloric acid. The banded appearance seems to be a secondary feature with the indurated bands of gypsum forming at the expense of the soft gypsite. The thin section exhibits a fine-grained aggregate of gypsum euhedra in random orientation, together with random sub-rounded clastic grains of quartz. Banding is effected by strips of fibrous gypsum with the fibres elongated across the bands. Carbonate is present as dense fine-grained patches and the thin section contains a rounded pellet of dense brownish carbonate, 6 mm. across, which encloses rounded quartz grains and has irregular veins of clear finely crystalline calcite associated with black, probably manganiferous, material. Gypsum sometimes occurs within the veins enclosed by the calcite, while the gypsum surrounding the pellet is fibrous perpendicular to its periphery.

The crystalline rock gypsum consists of an aggregate of fine and coarse selenite, sometimes pink in colour, and with random orientation. The absence of carbonate can be detected by the lack of effervescence with dilute hydrochloric acid.

Parkinson (1920, p. 14) mentioned that Salkeld had noted in descending order gypsum, clay, black sulphurous sand, stones and hard white sand at El Tuli. The thickness of the gypsum is indicated in unsatisfactory logs of bore-holes drilled during the war at El Tuli, Wajir Bor and Riba. The probable thickness of the gypsum and underlying limestone at El Tuli is indicated as 30 ft., but it increases to 36 to 44 ft. at Wajir Bor and Riba respectively. As these bore-holes were not drilled through the full thickness of the gypsum, it is possible that it may be as much as twice as thick as the bore-holes seem to indicate.

The Wajir Beds dip to the south at an angle only slightly more than the slope of the surface of the country south of Wajir, but the indistinct bedding displayed in the gypsum of the wells at Riba often has a slight easterly dip. Irregular, usually vertical, selenite veins traverse the gypsum and usually strike N.N.E., but the selenite veins in one of the wells form a circle on the side of the well. It may be noted that the existing wells have been dug along zones of selenite veining. Undulations in the gypsum were noticed in wells at Riba, but the direction of the axes was indeterminable. Similar undulations also occur in the limestones south-east of Wajir and are reflected by low surface limestone ridges, striking north-south and rising 10 to 20 ft. above the general level of the surface. Bestow (1954, pp. 4-5 and 11-12) also postulates the existence of an anticlinal ridge striking N.W.-S.E. through El Murille with a corresponding trough on the northern side, and a sharp monocline of similar strike at Ganuri, outside the Wajir area. The gypsum at El Reh may well occur as a lens in the limestone, but it is possible that it is a pocket of gypsum preserved in a synclinal fold formed during the compaction of the Wajir Beds.

Early travellers through El Wak nearly always commented on the numerous circular depressions in the area, the largest being about a quarter of a mile across and perhaps 30 ft. deep. The depressions are usually lined by surface limestone when occurring on limestones and rarely serve as water reservoirs. The origin of the depres-

sions is obscure as they show no preference for certain types of rock, they occur singly or in groups and display no pattern in their distribution. Twenhofel (1950, p. 59) describes similar depressions formed in deserts by deflation in unexpected places, the lower limit of aeolian erosion being the level of the water-table. If the depressions in the Wajir area formed in this way, they may indicate the drop in the water-table level since the time of their formation.

The lithology and variability of the lower part of the Wajir Beds suggest valley-flat sedimentation which was succeeded by lacustrine conditions when the channels were choked, giving rise to the formation of the limestones. The limestones were formed over a widespread area to the north and west, but the thinning of the limestones south-east of Wajir and the deposition of gypsum diachronous with limestone points to a shallowing of the lake and desiccation in that direction, where swampy conditions probably existed.

The post-Cretaceous sediments overlying the Basement System has never been pierced in the present area but many of the pilot wells put down by the Public Works Department further north encountered rock belonging to the Basement System at varying depths and showing the Wajir Beds thinning out in that direction, where they were deposited on an uneven surface (Bestow, 1954). Deep bore-holes south-west of Wajir at Ndegas Nest and Muddo Gashi revealed clays and sandstones, while to the north pilot wells and bore-holes as far as Buna yielded interbedded limestones.

The Merti beds of the southern part of Northern Province as well as the Wajir Beds and the deposits at Golana Gof and Muddo Gashi were referred by Dixey (1948, p. 9) to the Tertiary, an age adhered to by Ayers (1952, p. 15). This dating followed the discovery that some of the beds are entrenched by valleys in which certain of the lower terraces yield Middle Pleistocene implements. Beds of possible Miocene age in the north Kitui district are described by Dodson (1955, p. 20) while clays and sands underlying the Lower Nyambeni basalts dated as Lower Pleistocene (Mason, 1955, p. 6) were encountered in bore-hole No. C136, situated half-way between Garba Tula and Isiolo. It is therefore assumed that beds of Miocene age may occur buried under the Wajir beds.

Dixey (1948, p. 10) also ascribed a Tertiary age to the El Wak Beds which are without doubt the northern extension of the limestones and gypsum of the Wajir Beds. Recent mapping, however, has disclosed that these beds occur in depressions in the end-Tertiary peneplain which dates them as Pleistocene and an Upper Pleistocene age was tentatively put forward (Baker and Saggerson, 1958, p. 34; Joubert, 1960, p. 48). The post-Tertiary age is substantiated in the Riba area where small ferruginous concretions, which normally typify the end-Tertiary surface, were found on top of the mounds of the material derived from wells which penetrated the gypsum of the Wajir Beds.

When the sequence of the post-Tertiary sediments of the Wajir area is compared with that of the sediments occurring along the Daua river, on the northern border of Kenya, it is reasonable to correlate the limestones and gypsum of the Wajir Beds with Shangalla Limestones and the gypsum of the Gingo area, which are dated as Kamasian (Joubert, 1960, p. 46). The logs of the pilot wells north-north-west of Wajir show that the limestones of the Wajir Beds, although variable in thickness, are almost continuous and that the lower part either contains pebbles or is at least highly arenaceous, or that the limestone is underlain by pebbly clays, sands or sandstones (Bestow, 1954, pp. 40-46). Small quartz pebbles are also recorded as occurring in a grey calcareous loam underlying the limestone at Sideh in the Wajir well area (Bestow, *op. cit.*, p. 17). Conglomerates and grits occur at the base of the Shangalla limestones, and as they were taken to represent the onset of the Kamasian Pluvial in the Mandera area, it may follow that the sandstones underlying the limestones in the Wajir well area, represent the first inter-pluvial, i.e. the upper part of the Lower Pleistocene. The sandstones are often ferruginous (Bestow, *op. cit.*, p. 11).

During the present survey fossils were collected in the red soil and nodular kunkar on top of the Wajir Beds limestones. They were identified as the modern terrestrial gastropod *Achatina fulica hamillei* (Pet.), which is of no diagnostic value. Parkinson (1920, p. 12 and 17) recorded *Bythinia* and *Planorbis* spp. from the Wajir Beds and many other fossils collected in the Cainozoic sediments to the north-west and south-west of the present area. Mr. R. Bullen Newton, who identified these fossils, tentatively correlated the sediments with Pliocene lake beds in French Somaliland. The fossils found have an age range from Miocene to Recent, but so far as present knowledge goes, the limestone and calcareous deposits which yielded them were not deposited in pre-Pleistocene times.

(b) FERRUGINOUS SANDSTONES AND CONGLOMERATES

Overlying the limestones of the Wajir Beds north and north-east of Wajir are friable ferruginous sandstones and conglomerates, which also occur in isolated depressions east of Wajir and overlie the gypsum of the Wajir Beds in the south. The friable nature of these sediments renders them subject to easy weathering and they are therefore only exposed in depressions or encountered on digging in the omnipresent red-brown sandy soil which is the weathered product of the ferruginous sandstones. Bestow (1954, appendix K) encountered the ferruginous sandstones in the pilot wells north of Wajir, while Ayers (1952) indicated the occurrences of conglomerates of this age at Dakhsan and Saturwario on his maps numbers 1 and 2 as outcrops of the much older Mansa Guda Formation. It is remarkable that ant-hills are numerous on the ferruginous sandstones but are absent from the red soil overlying the Wajir Beds, a feature that enabled the writer to map the extent of the ferruginous sandstones from aerial photographs, on which their dotted appearance is distinctive.

The sandstones are thin in the south, where they disappear under the grey soils, but thicken to the north-east where they become conglomeratic, with the inclusion of pebbles derived from the Mansa Guda formation. In the vicinity of Wajir the sandy soil is usually from 4 to 6 feet thick but varies from 2 to 10 feet at the extremes. The pilot well 16 miles north of Wajir indicates 9 feet of soil and sandstone, which increases to 25 feet at Tarbaj, north of the present area. The pilot wells indicate a greater thickness as the hills in the east are neared, but to the west, where the area has been denuded by the Lugh Bor and its tributaries, the sandstones are absent.

The friable ferruginous sandstones north of Wajir are only evident on digging, but are exposed further east, at Dakhsan, where the sandstones contain the pebbles derived from the Mansa Guda Formation. In the shallow valleys between Hawal Badil and Saturwario, the pebbles have been redistributed and occur in pockets and patches. At Abagaranso and at Saturwario conglomeratic sandstones line the water-pans and here unsorted rounded quartz pebbles and ferruginous concretions occur in a brown gritty groundmass. The average size of the pebbles is just over 4 mm. but the largest in the hand-specimen 31/36 from Abagaranso is nearly 1.5 cm. across. About $3\frac{1}{2}$ miles west of Saturwario, the equivalent rocks become dark brown to black in colour because of the mainly ferruginous cement. Sorting is evident here and gives the hand-specimen (31/34) a stratified appearance. The rock which is a fine-grained conglomerate containing only small quartz granules and larger ferruginous concretions, is porous, with intergranular spaces more evident along certain bands, thereby enhancing the stratified appearance.

Similar partly consolidated ferruginous sands occur on the 30 m. terrace of the Daua river, where red-brown sandy soil is also widespread (Joubert, 1960, p. 47). These were taken to represent the second inter-pluvial period of the Pleistocene in the Mandera area and as they also followed on limestone and gypsum, a correlation between them and the red soils of the Wajir area seems to be reasonable, suggesting that the ferruginous sandstones and conglomerates were formed during the Kamasian-Kanjeran interpluvial.

The conglomerates are always encountered near to, or where the Mansa Guda Formation is expected and therefore it is reasonable to conclude that the Mansa Guda Formation was exposed in the area mapped up to the end of the Kamasian pluvial, after which the conglomeratic sandstone formed *in situ*, concealing the Mansa Guda Formation.

(c) THIN LAMINATED LIMESTONES

Limestones overlying the ferruginous sandstones are patchily distributed on the flanks of the low hills formed by the Jurassic limestones. It is thought that most of the surface limestone patches north of Riba occurring on the Jurassic limestones represent pockets of limestone deposited during the Kanjeran stage of the Pleistocene. Patches of such limestone still exist in the Wajir Bor, Riba and Duduma Aad areas, which suggests that deposition was widespread during this period. Two miles south of Wajir Bor on the Bardera road, military excavations in the limestone indicate a thickness of at least 6 feet, but at Riba, where these rocks have been entirely altered to surface limestone, only about 2 feet occur overlying the gypsum. There is again an increase in thickness in the Duduma Aad area, but as exposures are poor and the limestones lie directly on limestones of the Wajir beds, the exact thickness is indeterminate.

An attempt was made to map these limestones as a separate unit, but the patchy distribution and the lithological similarity to the limestones of the Wajir Beds as well as the subsequent alteration to surface limestone of both horizons made distinction in nearly all cases impossible.

Specimen 31/60, collected 2 miles north of Khorof Atat, is typical of the laminated limestones in being finely banded and fissile along the bedding planes. The microscope reveals a brownish matrix consisting of fine-grained carbonate grains containing numerous rounded to angular detrital quartz and calcite grains arranged in bands along the bedding. Some of the detrital calcite occurs as crystals showing original faces but rounded aggregates are the predominant form. The matrix is iron-stained in patches, while zircon, rutile and hematite complete the composition of the rock. At Duduma Aad the limestone contains in its upper part many water-worn pebbles derived from the Jurassic limestones, the pebbles in conjunction with the arenaceous character of the laminated limestones, showing that fluvial conditions played a major role during deposition.

The limestones overlie the gypsum of the Wajir Beds at Riba, the limestones of the Wajir Beds at Duduma Aad and the Jurassic limestones north of Khorof Atat. Thus, they overstep the ferruginous sandstones and the Wajir Beds onto the Jurassic limestones. This involved removal of at least parts of the ferruginous sandstones prior to the deposition of the laminated limestones, which are therefore unconformable on the underlying sediments.

When the age suggested for the underlying sediments is considered, it follows that the laminated limestones were probably deposited during the onset of the Kanjeran pluvial stage. The limestones may be correlated with the calcareous silts, marls and conglomerates of that age in the Daua valley, which yielded an artifact of the Kombewa technique (Joubert, 1960, p. 47).

(d) GREY AND BLACK GRITTY SOILS

South of the area occupied by the Wajir Beds, large tracts of country are covered mainly by unconsolidated clay-bound sands. The colour of these soils is generally grey, but is sometimes brownish grey and in the low-lying parts, which become water-logged in the short wet spells, the colour tends to dark grey or black.

The soils are composed of approximately 75 per cent of granules, consisting of coarse and medium quartzitic sand, with 25 per cent of grey clay which effervesces

with dilute hydrochloric acid. Greater amounts of carbonate are evident in patches where the soil becomes nearly white in colour, with a marked absence of trees. The calcareous patches are evident on the aerial photographs and show no pattern in their distribution. Gypsum occurs occasionally as nodules on the surface, usually associated with water-worn quartzite pebbles on the treeless grass-covered patches. These patches are well-known to the Somalis as the best grazing in the Wajir District, for example at Ber and Jilello. When the soils are brownish grey they are evidently less calcareous and also less gritty and support a low thorny scrub. Disintegration of the grey soils by surface wash leaves patches of pink quartzitic grit. The clay particles are washed into the low-lying black soil areas where, as at Erap, bands of soil containing lesser or greater amounts of grit are reflected in the vegetation.

The chemical composition of the clayey component (-80 mesh) of the grey soil collected at Jirtoi is as follows:—

	%
SiO ₂	58.36
R ₂ O ₃	15.46
MgO	2.87
CaO	3.56
Total Alkalis as Na ₂ O	1.39
Loss on ignition (less CO ₂)	16.11
CO ₂	1.39
SO ₃	nil
	99.14

Analyst, J. Furst.

A bore-hole at Dif, on the border 35 miles south of the present area, shows that the grey soils attain a thickness of at least 360 feet there and that the composition, except for minor variations in the amount of grit and carbonate as nodules, is fairly uniform. The underlying brown ferruginous sands, which are micaceous here, occur between 340 and 380 feet below the surface, which indicates a slope of the base of the grey soils and underlying laminated limestone coinciding with the dip of the Wajir Beds, which is 14 feet per mile to the S.S.E. Crystalline gypsum associated with water-worn quartzitic pebbles was encountered at a depth of 180 feet in the bore-hole, while the grit in the clay sometimes attains pebble size. Gritty calcareous clays encountered between 240 and 340 feet below the surface probably represent the laminated limestones.

It is thought that the grey soils were deposited in a flood plain environment during the Kanjeran pluvial stage and that the deposition followed conformably on the laminated limestones. The grey calcareous grits and gypsite in the Daua valley occurring below the 30 m. terrace (Joubert, 1960, p. 47) were probably contemporary with the grey soils of the Wajir District.

(e) RED-BROWN AND YELLOWISH BROWN CLAYS

Dixey (1948, p. 10) mentions old native-dug tanks in dark brown clay with gypsum nodules at Gherille and Dif. These clays are of great importance to the Somalis because of their impermeability to water, pans dug in the clay containing water for long periods during and even after, the rainy seasons. Such water-pans occur at Abak Fin, Akal Ar, Wel Ade and Ibrahim Uri.

At Akal Ar and Wel Ade the clays are slightly different from elsewhere in being red in colour with calcareous nodules, while at Abak Fin they also contain water-worn pebbles, originally derived from the Mansa Guda Formation. The clays are extremely

fine and become very hard when dry. From their distribution it is seen that they are associated with the drainage system and they are therefore thought to have been formed by a process of illuviation (Robinson, 1932, p. 145). At Ibrahim Uri, leaching was apparently restricted owing to excess of evaporation over rainfall which inhibited the removal of silicic acid.

The clays are usually better developed along the western sides of the drainage channels, probably indicating an easterly migration of the drainage system, elongated remnants of red-brown clays marking the position of old channels. The existence of these clays suggests a period when the rainfall exceeded present precipitation, and from their stratigraphic position it may be deduced that they are post-Middle Pleistocene in age.

(f) RED AND GREY SOILS

On the Jurassic limestones fine dusty soils occur which can be divided into red mature soils mainly occurring in the elevated areas and following the softer limestone beds, and younger grey soils occurring in the valleys and associated with surface limestone. Robinson (1932, pp. 427-429) recognizes two distinct groups of soils that form on limestones—a grey group characterized by excess of calcium carbonate and a red leached group expected in upland regions. The red soils in the Wajir area give expression to the strike of the Jurassic limestones where they follow softer horizons, or occur along lines of structural weakness while the grey soils occur along present drainage channels.

(g) VALLEY SOILS

River soils in the area are dependent on the type of soil being traversed by the drainage. Alluvial deposits are non-existent, and most of the soils have been produced by the removal of certain of the components of other soils or by illuviation. The red sandy soils either have some of the sand removed or are enriched in the clayey component and very often contain nodules of kunkar. The water-pans in such areas receive much water during the rainy season, but it is lost underground soon afterwards. Where drainage channels cross areas of grey soil, the colour of the soil becomes darker and at Ibrahim Uri many pebbles derived from the Mansa Guda Formation occur scattered, or in small sheets, along the river channel.

V—GEOLOGICAL HISTORY

The lithology, structure and stratigraphical sequence of the sediments of the Wajir area permit the following interpretation of their depositional history. Down-warping of the Kenya coast was initiated towards the close of the Palaeozoic (Caswell, 1953, p. 50; Thompson, 1956, p. 42) and it is therefore likely that the transgression of the sea into a gulf in north-eastern Kenya took place at approximately the same time. It is suggested by Thompson and Dodson (1960, p. 34) that the Mansa Guda Formation was deposited as a delta into this sea and that the material was derived from an area that was rapidly being denuded under arid conditions. Recurrence of down-warping followed in Lower Jurassic times and allowed the sea to overlap onto the Mansa Guda Formation and spread to the north, the tilting being continued up to Middle Jurassic times after which the sea gradually regressed from the Wajir area as a result of infilling by sediments. The nature of the Daua Limestone Series suggests deposition in a shallow epicontinental sea where intermittent changes of sea-level gave rise to thick-bedded grey limestones alternating with oolitic and cross-bedded silty limestones, and sometimes even intraformational conglomerates. During the deposition of the upper parts of the Bur Mayo Limestones, the oscillations were of small magnitude and currents active, giving rise to thinly bedded fragmental limestones.

The faults that transect the Jurassic limestones are parallel to faults of Cretaceous age along the Hegalu hills in the Mandera area (Joubert, 1960, p. 51). It is likely that the faulting in the Wajir area took place during the same period. The faulting probably initiated extensive erosion which continued during the lower Tertiary times and resulted in the formation of a wide and deep valley west and south of the Mesozoic sediments. There is no evidence for a structural origin of this depression and it is therefore thought that it is the consequence of denudation and scouring of the Basement System by surface wash.

During the Miocene Kenya experienced sedimentation at many localities and it is almost certain that at that time the Wajir depression received some sediments, of which much must have been removed again during the uplift of Pliocene times (Thompson 1956, p. 45). Subsequently the end-Tertiary peneplain bevelled the sediments of Mesozoic age.

Slow entrance of sediments into the depression occurred during the first pluvial phase of the Pleistocene, when clay-bound sands with lenses of sands and pebbles were deposited along a wide valley-flat. The red sandstones of the Wajir area are taken to represent the following inter-pluvial phase, while the arenaceous and pebbly nature of the base of the limestones of the Wajir Beds may indicate the sudden onset of vigorous Kamasian pluvial conditions. During the latter period widespread shallow lakes formed, in which impure limestones were deposited. Desiccation at the close of this phase gave rise to the gypsiferous deposits to the south and east of Wajir, and eventually these conditions gave way to sub-aerial erosion on an area of low relief which resulted in the formation of the ferruginous sands. At this time the Mansa Guda Formation was still exposed or close to the surface and the deep weathering of its conglomerates released pebbles, which were then included almost *in situ* in the ferruginous sand.

Shallow sheets of water again formed over the area during the Kanjeran Pluvial phase, but their outlines did not conform to the shape of the lakes of the previous phase. This feature can be ascribed either to the preceeding erosional stage or to slight tilting prior to the deposition of the laminated limestones. After the first intense spasm, the Kanjeran pluvial phase reverted to milder valley-flat sedimentation of clay-bound sand, with lenses of limestone and gypsum forming in small pools of water. Since Middle Pleistocene times erosional forces have carved the Wajir area to its present configuration.

VI—MINERAL DEPOSITS

1. Oil

The Jurassic sediments of north-eastern Kenya constitute a small portion of a sedimentary basin of vast areal proportions, extending into Ethiopia and the Somalias. The basin as a whole must be considered in the search for oil in this part of the world, and information on the rocks of the Wajir area is of importance in completing the picture.

The palaeontology of the Didimtu Beds indicates a marine link with Madagascar during Toarcian times, a connexion which was subsequently severed if the scanty fossil data is to be relied on. As previously mentioned, the sea transgressed to the north with rise in sea-level since the Bathonian and it is therefore likely that at a certain stage in the sedimentation, the marine gulf in north-eastern Kenya was somewhat restricted and favourable conditions for the formation of oil existed.

The great thickness of marine limestones in the Jurassic succession presents no scarcity of source-rocks and suitable host-rocks exist in porous horizons such as are represented by specimen 31/45 from the present area (p. 15), or in highly jointed limestones. Effective seals would be formed by the many dense argillaceous limestone horizons.

The faulting of the Jurassic limestones may also provide structural oil-traps, as the faults probably extend much further to the north-east in an area of no exposures, where folding may also be of greater significance than in the Wajir area.

2. Building Materials

Although of an inferior quality, all material for building purposes in Wajir is at present derived from the limestones of the Wajir Beds. The softness and fissility of the limestones, which facilitate the grinding and the cutting of dimension stone, as well as the proximity to Wajir render it the cheapest source of building material. The Jurassic limestones, which can yield better quality dimension stone and crushed stone for concrete aggregates and road metal, will hardly be quarried until such time as the area is developed, when improved buildings and better roads are required.

All the components for natural and Portland cement are within easy reach of Wajir, but the remoteness of the area makes the likelihood of production improbable. Gypsum and lime, sources of which are abundant in the area, can be used for many purposes, but as they do not occur in the vicinity of developed communities, can only serve as structural materials.

3. Water

The most vital and immediate problem of the Wajir District is water-supply and therefore it has received much attention in the past. The first hydrographic survey of the Northern Province was carried out by Dixey (1944), whose recommendations are now being implemented. Since then Bestow (1953) has carried out a comprehensive hydrological survey with reference to the Wajir District in particular, and many of his findings are incorporated in this chapter.

The only permanent water in the area is found in the wells in the immediate vicinity of Wajir, where the surface has now been denuded of pasture and it has become necessary with the increase in livestock, to locate water sources in areas of good grazing. Bestow (*op. cit.*, appendix F) found 841 wells in a radius of about 9 miles around Wajir, of which 301 were in use at the time of his investigation. The wells usually vary in depth from 25 to 50 feet and are from 24 to 32 inches across, though they often bell out in depth. Bestow discovered two water-tables in the Wajir Beds, which in the pilot well 2 miles north of the township, occur at depths of 50 and 71 feet respectively. The upper aquifer, which is sometimes as thick as 25 feet, is usually a uniform light-coloured sandy clay but varies much laterally both in lithology and thickness and affects the yield of wells, as well as the quality of the water, from one well group to another and sometimes between wells of the same group.

The yield of the wells varies from negligible to in excess of 2,500 gallons per day. The water always contains a large proportion of mineral salts, as is seen in Table III.

Bestow records that the water-table is dropping from 2 to 4 inches annually and summarizes the evidence to prove this on page 33 of his report, but remarks on page 16 that wells having a high yield cannot be deepened far below the water-table. He postulates a southerly seepage to account for part of the loss of water. It is well-known that the Somalis, who entered the area around 1906, have not deepened any of the wells, and as a few of the wells have more than 5 feet of water in them, the drop in the water-table cannot be as great as calculated by Bestow, or the wells would all have failed by now. It is also true that the population and the number of livestock have increased considerably since the British occupation with a consequent higher drain on the water-supply.

Other wells in the area have been dug in the gypsiferous deposits of the Wajir Beds. Such wells are found at El Reh, Rama Agon, Khorof Sharif, El Tuli, Khorof Atat, Khorof Higlithi, Wajir Bor, Riba and Balballa. These wells are said to be perennial but during the dry season in the course of the survey it was found that they were either completely dry or had polluted water insufficient for even a small number of stock. Since the Somalis invaded the area, many of the wells have been allowed to

TABLE III
Chemical Analyses of Waters from the Wajir Wells

Number of Well ..	El Bey* No. 1	Well* "D"	Makoror* No. 46	Wichir* No. 21	Anissa* No. 53	Kumbe* No. 3	Raifeti* No. 14	El* Murille No. 2	El Nur* No. 25	Waghella* No. 1	Bangal* No. 9	School* No. 1	Wajir ?
Turbidity ..	None	None	None	None	None	None	None	None	None	None	None	None	None
Colour ..	Pale yellow	Pale yellow	Pale yellow	Pale yellow	Light brown	Pale yellow	Brownish	Pale yellow	Yellow	Yellow	Light brown	Clear	Clear
Odour ..	None	None	None	Earthy	None	None	Earthy	None	Earthy	Earthy	Earthy	None	None
Suspended matter ..	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount	Small amount	Little vegetable	Slight fibrous sediment
pH ..	7.35	7.45	7.15	7.3	7.05	8.3	7.35	8.1	8.3	6.95	7.35	7.5	7.3
Parts per 100,000													
Carbonate ..	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Bicarbonate	28.8	16.2	27.9	18.7	54.5	43.9	65.4	46.5	48.8	37.6	30.6	20.2	23.1
Chlorides ..	46.4	44.2	43.8	74.4	34.4	71.4	40.6	76.2	123.0	31.6	73.6	22.0	34.8
Sulphates ..	22.4	17.2	18.4	25.6	3.2	26.0	19.2	17.9	36.6	29.8	21.2	8.1	8.6
Nitrites ..	Nil	Nil	Heavy	Trace	Heavy	Nil	Nil	Nil	Heavy	Heavy	Trace	Nil	Heavy
Nitrates ..	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Present	Present
Calcium ..	18.5	9.5	12.8	16.3	11.9	16.9	14.5	19.7	34.2	103.0	21.3	7.5	13.0
Magnesium	9.0	5.2	6.2	10.5	6.9	12.0	10.5	12.6	16.4	29.7	11.5	5.8	6.8
Total ..	83.3	45.1	57.5	83.9	58.1	91.6	79.6	101.1	153.0	379.7	100.6	42.6	60.5

*Taken from Bestow (1953, Appendix G)

fill up with rubble and are now only marked by depressions with adjacent mounds of gypsum originally taken out of the wells. Deepening the existing wells in the gypsum will certainly increase the yield and in places like Riba, Balballa and Wajir Bor where the contact between the gypsum and the Jurassic limestones occurs at relatively shallow depths, the wells will be made permanent when deepened to this contact.

Tanks or sumps for the conservation of rain water have been excavated at Wajir Bor, Abak Fin, Akal Ar, Wel Galul, Jilello, Ibrahim Uri, Erap, Duduma Aad and Wel Geris, while small natural depressions exist at Dakhsan, Abagaranso, Saturwario, Wer Ade, and Sabanseida, as well as many depressions on limestone of the Wajir Beds, such as at Komorro, El Bey, Libiduli, etc. As surface run-off in the greater part of the district is virtually absent, the collection of water in these tanks is almost entirely dependent on rainfall which, unfortunately, is frequently very localized. The most successful tanks are those excavated on the impervious brown and yellow clays, while the depressions on the limestones of the Wajir Beds are of little use as reservoirs.

The most urgent need of the district is the decentralization of water-supplies and the position can be alleviated by increasing the size of the existing tanks and by the excavation of further tanks on the grey-brown and yellowish brown clays which are indicated on the map. In siting these tanks, attention must be paid to the topography to obtain as much of the surface run-off as possible, and to the proximity to areas of good grazing, such as at Ber. It would also be advantageous to have the tanks widely scattered to profit most from the localized storms during the short rains. The surface run-off from the Jurassic limestones is significant when compared to the other parts of the area and can be collected in dams in the shallow valleys draining the north-central part of the area where the impervious clays are absent.

Disregarding bore-holes drilled during the war, the logs of which are completely unreliable, the following information on bore-holes in the area is available in the records of the Ministry of Works and Communications:—

BORE-HOLE C367—WAJIR

<i>Depth in feet</i>	<i>Lithology</i>
0-18	Limestone
18-29	Clay
29-38	Grey marl
38-85	Clay and marls

BORE-HOLE C368—WAJIR

<i>Depth in feet</i>	<i>Lithology</i>
0-18	Limestone
18-30	Clay
30-88	Clay and marls

BORE-HOLE—RIBA

<i>Depth in feet</i>	<i>Lithology</i>
0- 2	Soil
2- 9	Limestone
9-27	Crystalline rock (Gypsum ?)
27-44	Tough clay and pebbles
44-66	Limestone

BORE-HOLE—WAJIR BOR

<i>Depth in feet</i>	<i>Lithology</i>
0-26	Kunkar
26-36	Detritus and pebbles
36-46	Limestone
46-57	Limestone
57-62	Yellow clay and boulders of limestone
62-408	Limestone

After the geological survey of the Wajir area a bore-hole was drilled at Gherille, near the Somalia border, to a depth of 450 feet without encountering any water. From the log, which follows, it seems that it pierced Pleistocene deposits only and indicates the thickness of the deposits of that age in the area.

BORE-HOLE C2644—GHERILLE

Depth in feet				Lithology
0-20	..	..	..	Red kunkar
20-100	..	..	..	Yellowish buff gritty calcareous clay with small water-worn quartzitic pebbles, and some non-calcareous greenish clay pellets
100-120	..	..	..	Coarse quartzitic sand with small kunkar chips
120-160	..	..	..	Buff-grey gritty calcareous clay
160-180	..	..	..	Coarse quartzitic sand with kunkar chips
180-200	..	..	..	Buff-grey calcareous clay with fine grit
200-260	..	..	..	Yellowish brown calcareous clay with kunkar and greenish calcareous clay pellets, and some small rounded quartz pebbles
260-280	..	..	..	Buff gritty calcareous clay
280-300	..	..	..	Coarse quartzitic sand with small lumps of kunkar limestone and large well-rounded quartz pebbles
300-320	..	..	..	Yellow calcareous clay
320-360	..	..	..	Slightly calcareous brown clay
360-400	..	..	..	Reddish brown non-calcareous clay (380-400 ft. sample—a lump of kunkar limestone)
400-450	..	..	..	Brown non-calcareous clay, red ferruginous sand and small lumps of kunkar limestone. Lower parts with small water-worn quartzitic pebbles

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