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COLONY AND PROTECTORATE OF KENYA

MINISTRY OF COMMERCE AND INDUSTRY
GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
EL WAK-AUS MANDULA AREA

DEGREE SHEETS 23, N.E. and S.E. QUARTERS
(with three coloured geological maps)

by

B. H. BAKER, B.Sc., F.G.S., and
E. P. SAGGERSON, B.Sc., Ph.D., F.G.S.
Geologists

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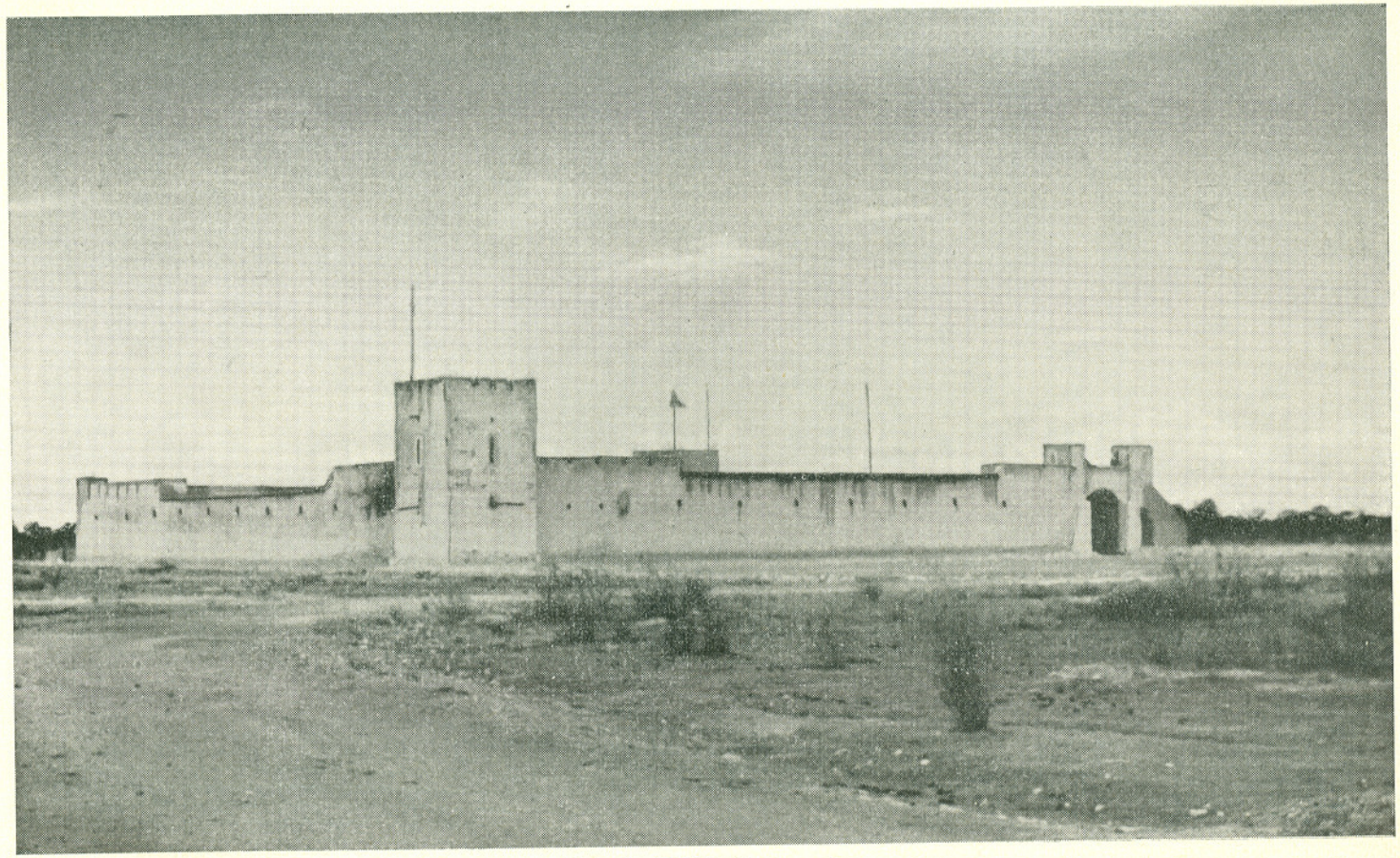


Plate I.—El Wak Police-post

FOREWORD

The publication of the report on the geology of the El Wak-Aus Mandula area makes available an account of an area half-a-degree square in size covering most of the south-east part of the Mesozoic basin of north-east Kenya. Descriptions of the ground north of the third parallel have already been published as reports Nos. 40 and 43 on the Takabba–Wergudud and Derkali–Melka Murri areas respectively, and an account on the south-western part of the basin, the Bur Mayo–Tarbaj area, is awaiting printing.

The mapping carried out by Mr. Baker and Dr. Saggerson has revealed the presence of geological structures at Bur Wein that are unique for this part of Kenya. The rocks at that locality are members of the Cretaceous Marehan sandstones and over a considerable area they have been silicified. They are thrown into a series of folds, of which the most prominent is the Bur Wein dome. The dome is asymmetrical and has a flexed axial plane. No certain explanation has been found for the structures, but as they occur in a part of the basin where the Marehan standstones are about 2,000 ft. in thickness, i.e. about five times their usual thickness, and where Jurassic beds younger than Oxfordian have been overlapped by the Cretaceous, they are of interest in connexion with the possibility of the occurrence of oil at depth. To examine the structures further and what lies below them will require the use of core-drilling, though whether the folds are underlain by a high in the basement rocks below the Mesozoic sediments could probably be determined by geophysical tests.

The most valuable mineral at present in the area mapped is water, and the authors point out that it is in short supply. They hold out little hope that the quantity available can be improved by tapping subterranean supplies, but believe that much could be done by the construction of "tanks". Numerous suggestions are given on localities where tanks could be excavated. In addition it is suggested that new buildings should be constructed so that rainfall can be caught on them and stored. This is perhaps of particular importance at places like El Wak where, although underground water can be readily obtained from wells, it has an unpleasantly saline character.

El Wak occurs in a basin in which sulphates in the form of gypsum have been deposited. The authors estimate that there are probably 2,000,000,000 tons available down to a depth of 50 ft., but in view of the remotness of the locality, it is unlikely that the mineral will become of commercial interest in the foreseeable future.

Nairobi,
21st June, 1956.

WILLIAM PULFREY,
Chief Geologist.

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MAPS

Geological map of the El Wak Area (Degree sheet 23, north-east quarter)—Scale 1:125,000	At end
Geological map of the Aus Mandula area (Degree sheet 23, south-east quarter)—Scale 1:125,000	At end
Geological map of the Bur Wein hills—Scale 1:50,000	At end

ABSTRACT

The report describes an area of approximately 2,400 square miles, extending between 30 and 120 miles north-east of Wajir, in the Northern Province of Kenya Colony and bounded by latitudes 2° 00′ and 3° 00′ N. and by longitudes 40° 30′ and 41° 00′ E. The 41st meridian nearly coincides with the Kenya–Somalia border, along the eastern margin of the area to as far north as the latitude of El Wak. The area has been bevelled by five peneplains of which the lowest, the end-Tertiary surface, comprises the largest proportion of the area, from which rise the central hill masses upon which remnants of the other peneplains are preserved.

The rocks exposed in the area consist of limestones, siltstones and sandstones of Middle Jurassic to Cretaceous age, and Tertiary to Recent claystones, kunkar, gypsum and residual (red, grey and black) soils. Subsequent to the deposition of the Mesozoic sediments the area has been gently tilted and folded, the sediments now dipping generally to the north-east. At Bur Wein, a dome-like structure within the sediments is a feature uncommon in the Mesozoic sediments of north-east Kenya.

Deposits of potential economic value are described and the possibility of finding oil is discussed. Consideration is given to the improvement of the water-supplies in the area.

GEOLOGY OF THE EL WAK-AUS MANDULA AREA

I—INTRODUCTION

The El Wak-Aus Mandula area as defined for the purpose of this report is the north-east and south-east quarters of degree sheet 23 (Kenya), bounded by latitudes 2° and 3° N. and by longitudes 40° 30′ and 41° E., and is some 2,400 square miles in extent. The area is covered by sheets No. 49 and 61 of the Colonial Survey directorate. It includes parts of Mandera and Wajir Administrative Districts, the boundary between them being along the Lugh Suri. The international boundary between Kenya and Somalia runs parallel to and just inside the eastern margin of the area. For convenience the area is treated as a whole in the report, but two maps covering it are provided, one for the El Wak area and the second for the Aus Mandula area.

The greater part of the area is a flat plain covered by moderately thick bush consisting of stunted thorn trees. A discontinuous range of low hills rising to heights of between 700 and 1,000 ft. above plain level traverses the northern half of the area from north-west to south-east. The hillsides are somewhat dissected by valleys and gullies, but the stream-courses terminate abruptly on reaching the open plains. A river, the Lugh Suri, crosses the area from north-west to south-east but contains short-lived pools only in the rainy season. The dark soil along water-courses and around El Wak, Konton, Korof Harrar, Katulo and on the Guchi plain supports a fair growth of grass, but elsewhere grass occurs only as scattered patches among the thorn trees.

The indigenous people of the area are nomads of the Gurreh and Dugudia clans of the Somali tribe, who graze their camels, cattle, sheep and goats wherever water can be found. In the dry season most of the population is concentrated within reach of the group of wells at El Wak, but during the rainy seasons and shortly afterwards, when water is found in the water-holes throughout the area, they roam the country seeking pasture for their stock.

Owing to the low rainfall (12.54 in. in 1953, the average over three years being 10.93 in. as recorded at El Wak) and the low-lying nature of the country, the climate is semi-arid and maximum daily temperatures occasionally rise above 100° F.

El Wak, with its numbers of wells, is the most important centre in the area and has the only perennial water between Mandera and Wajir, a distance of over 200 miles. There is a native shop, a few huts and a police fort (*see* frontispiece). There are also three small shops and several shallow wells at Korof Harrar, in the southern part of the area. The Wajir–El Wak–Mandera road passes through the area from south-west to north-east and a branch road connects El Wak with Wergudud, Danissa and Rahmu in the area to the north. A rough motor-track leaves the El Wak–Wajir road about one mile south of Aus Mandula and travels eastwards to Korof Harrar and thence south-eastwards to Konton. Motor-tracks lead southwards from Korof Harrar and Konton to join the Wajir–Bardera road at Wajir Bor.

The international boundary between Kenya and Italian Somaliland is marked by a straight line cut through the bush from boundary pillar No. 8 east of El Wak due south to the southern boundary of the area. This cut line is motorable with difficulty throughout its length, the most difficult parts being the diversions around the hills at Sululuti and Wabli. A few of the camel-paths, particularly those near El Wak, are motorable with difficulty in small vehicles. The principal camel-path leading westwards from El Wak was opened up during the survey so as to render it motorable as far as a point five miles short of the Aradi hills in the north-west corner of the area. A branch from this track was cut as far as the north front of the Garse hills. A further rough track was cut from a point on the El Wak–Wajir road half-a-mile south of Dimo water-holes eastwards past the west face of Bur Wein to a point one-and-a-half miles north of Lolkurte hill.

There are two small emergency landing grounds in the area, one five miles south of El Wak and the other at Aus Mandula. Both are suitable for the use of light aircraft during dry weather.

The geological maps (at end) were constructed from air photographs based on the astronomically fixed point at Aus Mandula and on the Boundary Commission pillars numbers 8, 9, 11 and 12 on the international boundary.

The international boundary was defined (Anonymous, 1934, p. 3*) as running from the centre of the pool at Damassa, which is north-east of El Wak, south-westwards towards the centre of the well El Khala until the line intersects the meridian 40° 59′ 44.34″ E. From that intersection, at the locality of boundary pillar No. 8, the boundary runs due south along the meridian 40° 59′ 44.34″ E. The boundary pillars were erected on this meridian at its intersections with various parallels as follows:—

B.P. 8	N. 2° 49′ 19.20″
B.P. 9	N. 2° 47′ 35.06″
B.P. 10	N. 2° 31′ 15.07″
B.P. 11	N. 2° 14′ 55.09″

The positions of the boundary pillars were fixed by astronomical means and the survey of the boundary included a strip of country about four or five kilometres on either side. Altitudes were determined by the barometric method and are generally approximately 100 ft. lower than those measured during the present survey.

Owing to the lack of inter-visible fixed points no comprehensive plane-table work was undertaken during the present survey, but sufficient data were obtained to check the positions of Dabasiti, Bur Wein and Jabich hills. The form-lines drawn on the maps are approximate and are based on altitudes determined by aneroid barometer. Readings were based on the altitude of Wajir, which has recently been redetermined as 867 ft. above sea-level. In general the spot heights shown on the map are accurate to within ± 20 ft.

The survey was carried out between October, 1954, and January, 1955. Geological information was plotted directly on to air photographs (scale c. 1:30,000) or on field maps (scale 1:83,333) and the final map was compiled subsequently with the aid of an eidograph.

II—PREVIOUS GEOLOGICAL WORK

Lt. L. Aylmer (1911) visited El Wak in the course of travels between the Somaliland coast and the Juba country. He estimated that there were over 100 wells there and recognized the limestone and gypsum in the neighbourhood. He commented that the El Wak well water ". . . has the most violent effects on those unaccustomed to it, causing both head and stomach aches . . .".

J. Parkinson visited the area in 1914–15 while gathering information for a geological and geographical report to the Colonial Office. He referred to ferruginous sandstones at Lakka Dima (Daka Dima) and to the El Wak Limestones (Parkinson, 1920, p. 12) which he considered to be lagoonal deposits.

V. Glenday, who was for a considerable period the Administrative Officer in charge of the Northern Province, gave a general account (Glenday, 1923) of the sedimentary rocks he had seen during his travels. He mentioned the gypsum and limestone beds at El Wak and gave a general account of the Marehan sandstones and of the limestone series, suggesting that it was Jurassic in age. Glenday was apparently the first to point out that oil might be found in the sedimentary rocks.

Glenday's information is summarized in a monograph by Weir (Weir *et al.*, 1929, pp. 9–13). In this publication it is made clear that Glenday had recognized that the Marehan sandstone overlies the Jurassic (Daua) limestones. Many fossils from the Jurassic beds along the Daua and Juba rivers and in British Somaliland are described in the monograph. During late 1925 and early 1926 the Jubaland Boundary Commission passed through the area while surveying and cutting the

* References are quoted on pp. 46–48.

international boundary. Clifford (1928, pp. 435–436) mentions the El Wak wells and thought that hills south of the wells were composed of "laterite".

During 1937 two geologists of the D'Arcy Exploration Co. and the Anglo-Saxon Petroleum Co., H. G. Busk and J. P. de Verteuil, carried out a reconnaissance survey which covered the present area. The results of their work are recorded in an unpublished confidential report, but some of the information gained during the survey was published by Busk in 1939. Busk concluded that some of the escarpments of Marehan sandstone south-west of El Wak are due to faulting and that the sandstones had formed islands in the Jurassic sea. He, therefore, considered the Marehan sandstones as older than the Jurassic (Daua) limestones and correlated them with part of the Karroo of Tanganyika, the Duruma sandstones of the Kenya Coast, and the Nubian Sandstone. He also considered that the El Wak gypsum was a part of the Jurassic succession.

As a result of a brief survey in 1943, Dr. F. Dixey (1948, p. 34) divided the Mesozoic sediments of north-east Kenya into three major groups:—

3. Marehan Sandstone.
2. Limestone Series.
1. Mandera Series.

He considered the El Wak gypsum beds to be Tertiary in age.

F. M. Ayers, an E.C.A. petroleum geologist seconded to Kenya, with the assistance of A. O. Thompson of the Geological Survey of Kenya, carried out a reconnaissance of the whole area of Mesozoic sedimentary rocks in north-east Kenya during 1950–51 (Ayers, 1952). He referred to limestones outcropping on the Wajir–El Wak road as belonging to the lower part of the (Daua) Limestone Series. He mentioned fossiliferous sandstones and siltstones on the Muguda hills and considered that they formed part of the base of the Marehan sandstone. Ayers' succession is as follows:—

5. Marehan Sandstone—Mandera Series unconformity
4. Limestone Series
3. Didimtu Beds
2. Mansa Guda Formation unconformity
1. Basement System

Temperley (1952, pp. 202–205) summarized Ayers' work on the Mesozoic rocks of north-east Kenya.

Recent work by members of the Geological Survey of Kenya in adjacent areas (Saggerson and Miller, 1957; Thompson and Dodson, at the press; Joubert, at the press) has shown that the succession is:—

5. Marehan Series	Cretaceous
—unconformity—	
4. Mandera Series	Jurassic
3. Daua Limestone Series	Jurassic
2. Mansa Guda Formation	Trias (?)
—unconformity—	
1. Basement System	Precambrian

During 1950, a short geophysical survey was made of part of north-east Kenya by Geophysical Surveys (Pty) Ltd., South Africa. One traverse from Takabba (in the area to the north-west of El Wak) to El Wak was made as part of the work, which was carried out on behalf of the Mines and Geological Department, Nairobi. An unpublished report on the work (Paver, 1951) was submitted to the Department.

In 1950 W. G. Serra submitted to the Commissioner of Mines and Geology, an unpublished copy of his *Observations Géologique dans la Northern Frontier Province du Kenya,* a result of his travels whilst in the Colony prior to the second World War.

III—PHYSIOGRAPHY

A line of hills forming a broad arc extending from the north-west corner of the area to the central part of the eastern border divides the area into three parts,

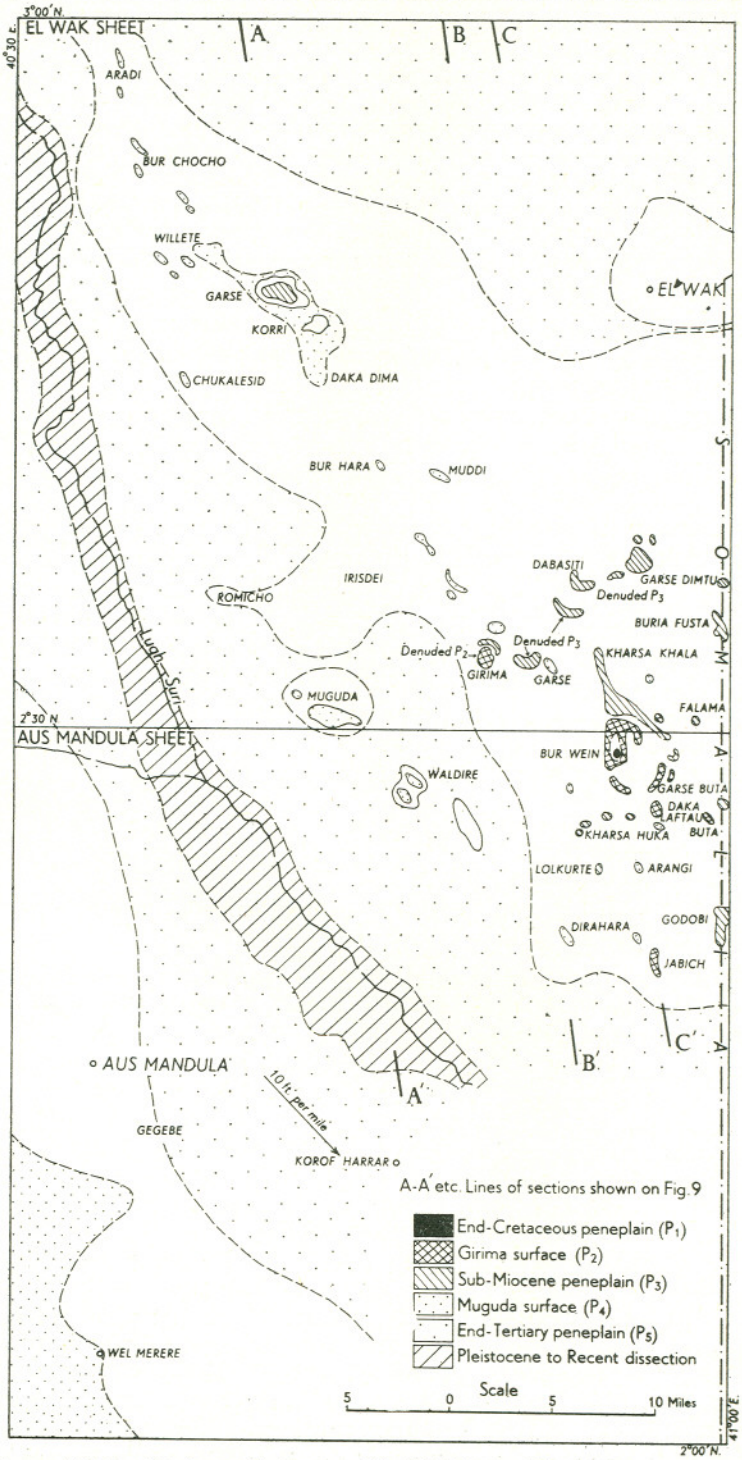


Fig. 1.—Physiographical map of the El Wak-Aus Mandula area.

a north-eastern plain round El Wak, the hill region and the more extensive plain of the Aus Mandula area (Fig. 1). The Lugh Suri is the only stream-course of any size, and it crosses the southern plain approximately parallel to the hill range. It is shallow and contains water only after exceptionally heavy rainfall, which is now rare in north-east Kenya. Other water-courses are present in and around the hills where steep-sided V-shaped valleys, particularly noticeable round the Bur Wein and Girima hills, run southwards towards the Lugh Suri. These stream-beds quickly die out on arriving at the plains, where they are represented for short distances by lines of small bushes and trees. Small impersistent streams flow to the north-east down the dip slope of the hills, quickly disappearing in the sandy plain round El Wak.

Dixey (1948, p. 16) considers that the great plain of the Northern Province is of end-Tertiary age and his diagram (*op. cit.*, Fig. 1) shows the extension of this surface into the present area, but only as far north as the southern end of the hills, and further north penetrating little west of El Wak. The sections given in Fig. 9 indicate that the peneplain in fact includes a large part of the southern plain as well as a large area surrounding El Wak, whence it continues northwards and has been recognized in the Takabba–Wergudud area (Saggerson and Miller, 1957, p. 6). The main peneplain of the area is, therefore, the end-Tertiary surface, which slopes to the south-east at approximately 10 ft. per mile.

Rising from the plain is the hill chain consisting of the Aradi, Bur Chocho, Garse, Muddi, Muguda and Bur Wein hills. All but the Bur Wein group are small isolated groups of hills, generally flat-topped and bevelled by two older peneplains. The sections shown in Fig. 9 indicate, however, that on Bur Wein the remnants of four older surfaces can be recognized. The lowest of the older surfaces, the Muguda surface, is the most extensive and is preserved upon most of the hill summits, particularly at Bur Wein where numerous small hills surround the mountain. The next higher surface is seen to bevel the Garse, Girima, Lolkurte and a shoulder of the Bur Wein hills and also isolated groups of hills along the eastern border. The summits of Korri and Dabasiti hills represent degraded remnants of this surface. Two hundred feet above this surface lies another—the Girima surface—which is preserved on Bur Wein and forms a marked but interrupted platform round the peak. Bur Wein rises to a height of 2,400 ft. above sea-level and its summit level probably represents a remnant of the oldest surface. These four older surfaces bevel the Jurassic and Cretaceous sediments and, therefore, were eroded between lower Cretaceous times and the end of the Tertiary era.

In the Takabba–Wergudud area, Saggerson and Miller (1957, p. 6) have shown that three older peneplains, the intermediate, the sub-Miocene and the end-Cretaceous, are preserved above and parallel to the end-Tertiary surface, and 200, 500 and 1,100 ft. higher respectively. In the present area the surface that bevels Garse, Lolkurte, the shoulder of Bur Wein and the north flank of Girima, etc., and which is 450–500 ft. above the end-Tertiary peneplain of the Takabba–Wergudud area, is considered to be the sub-Miocene peneplain, while the summit of Bur Wein which is 1,100 ft. above the end-Tertiary surface is likely to represent the end-Cretaceous bevel. The Girima surface, which has not been recognized in the neighbouring areas but may bevel the Warido hills in the Wergudud area, is probably of early Tertiary age.

That pediplanation (King, 1948, p. 441) has played a part in the erosion of the hills and is taking place to-day is undoubtedly true—the hills upon which remnants of earlier cycles of erosion are preserved are becoming smaller by a process of deepening and widening of valleys, and scarp retreat. The process is well seen at Wel Merere where an edge of the Muguda surface is being eroded.

Pleistocene to Recent degradation of the end-Tertiary peneplain is represented in the southern part of the area by the valley of the Lugh Suri which lies some 60 ft. below the general level of the surrounding plain. The results of erosion ascribed to the same period can be seen at El Wak which lies in a closed depression nearly

six miles in diameter and less than 50 ft. below the level of the end-Tertiary plain. Present-day conditions may be a clue to the formation of the depression. Strong winds blow across the area from time to time and remove quantities of sand, indicating that active erosion is taking place by means of deflation. The poor soil cover unprotected by good vegetation, large diurnal changes in temperature, and the soft gypsiferous nature of the beds of the depression are aids to rapid erosion. The solution of sub-surface gypsum also will tend to cause subsidence and so play an important part in the lowering of the surface. The depression is roughly equidistant from the surrounding hills and is unprotected by them and, hence, is in the most favourable position for wind erosion to have its greatest effect. That wind erosion plays a considerable part in the denudation of the area is shown by the castellated and pitted surfaces of the sandstones in the neighbouring hills. The depression lies along the axis of the El Wak syncline, a N.W.–S.E. structure, the topography being controlled by the gentle dips of the sandstones forming the surrounding hills towards the centre of the basin. It is likely that rivers originally played a part in the formation of the depression. An origin by deflation has been postulated by Mitwally (1953, pp. 158–163) for the Egyptian oases of the Libyan Desert where, however, it is unlikely that rivers played any part in their formation and where there has been a larger measure of control by geological structures than is apparent in the El Wak area.

Kunkar limestone is widespread on the southern plain generally east of Aus Mandula and round the El Wak gypsum deposit, suggesting that it has formed on the end-Tertiary peneplain. It is possible that kunkar formation is being continued at the present day, although only in basins of shallow ground-water. Dixey (1948, p. 41) has suggested that widespread silicification occurred at a former erosion bevel, comparing silicified surface layers with surface silcretes of post-Tertiary age of Northern Rhodesia. In his description he refers to the silicification of the Marehan sandstone four miles north of Girima. The pale grey quartzites he refers to occur along joints (*see* p. 30) and bear no relation to silicification on a peneplained surface. Silicification of upper surfaces of the Marehan sandstones to a thickness of a few centimetres has undoubtedly taken place but is of more recent origin. Where massive quartzites occur associated with the sandstones they are more resistant to weathering than the sandstones, which are rarely seen, so that it is possible to gain a misleading impression of surface silicification.

IV—SUMMARY OF GEOLOGY

The geological succession in the area mapped is as follows:—

			Feet
Recent	Soils and clays		—
Quaternary	El Wak Beds		72+
—unconformity—			
Tertiary (?)	Claystones		10–20
—unconformity—			
Cretaceous	Marehan Sandstones Danissa Beds	Marehan Series	2,200+
—unconformity—			
Jurassic	Golberobe Beds —disconformity— Daua Limestones	Daua Limestone Series	100+ 3,500+

The lowest horizons exposed in the area mapped are middle to upper Jurassic oolitic and shelly limestones near Aus Mandula. These poorly exposed rocks dip gently to the north-east and are overlain by sandy and shelly "Oxfordian" limestones exposed a few miles west of the Marehan sandstone hills. The limestones are dis-

swings to a more northerly direction near Aradi and more easterly south of Bur Wein. This strike of the limestones south of Bur Wein is controlled by the El Wak syncline

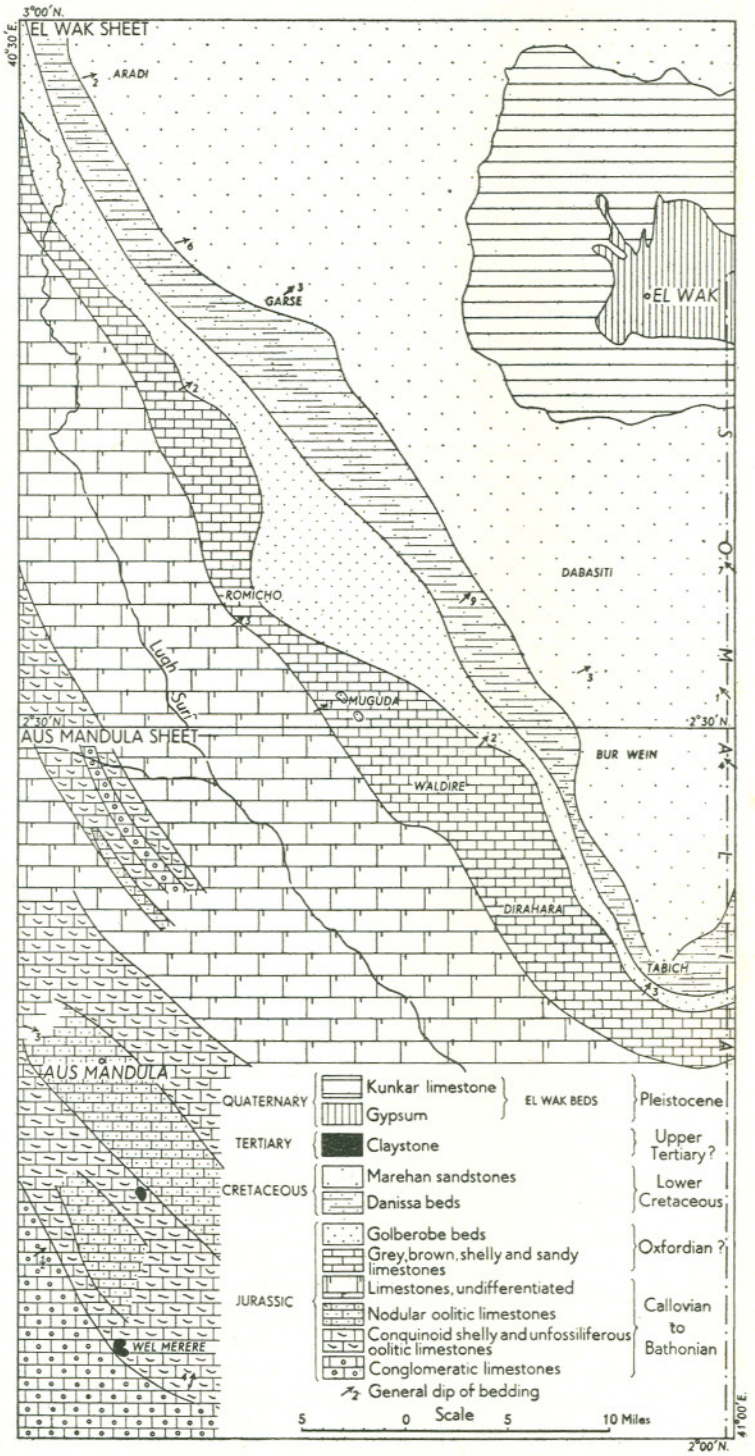


Fig. 2.—The solid geology of the El Wak-Aus Mandula area.
(For Tabich read Jabich)

				India (Himalayas) (Wadia, 1953)	Northern Nubia and A (Chardin *et al.*, 19 Arkell *et al.*, 1952
Cretaceous	Upper	Senonian		Flysch	Chalk and limestones
		Turonian			Limestones and sandstor
		Cenomanian		Chikkim series	Limestones and marls
	Lower	Albian			Nubian Sandstones
		Aptian			
		Barremian	Wealdan	Giumal sandstone	Taouilah and Marbat Sa
		Neocomian			
Jurassic	Upper	Purbeckian	Tithonian	Spiti shales	Riyadh Group includi Anhydrite
		Portlandian			
		Kimmeridgian			Jubaila Limestone
		Argovian			
		Oxfordian		Kioto limestone	Hanifa Formation (li and marls)
		Callovian			Tuwaiq Mountain Lime
	Middle	Bathonian			Dhruma Formation (lim marls and shales)
		Bajocian			
	Lower	Lias			Marrat Formation (lim
Trias	Upper			Monotis shale Limestones	Minjur Sandstone
	Lower			Limestones and shales	Upper Jilh (sandstone shales and limestones)
					Lower Jilh (limestone stones, marls and shal

TABLE I.—CORRELATION OF MESOZOIC SEDIMENTS IN INDIA, ARABIA, EASTERN AFRICA AND MADAGASCA

British Somaliland (Somaliland Oil Exploration Co. Ltd., 1954, Stefanini, 1922, 1930)			North-east Kenya (Ayers, Saggerson and Miller, Thompson and Dodson, Joubert, 1952–1958)	
(North-east)	(North-central)	(South-west)		
Limestones and sandstones	Red-brown sandstones with grits and conglomerates	Siltstones and clays, sandstones and conglomerates	Marehan Sandstones	
	Silty sandstones	(Rests on Basement system rocks)	Danissa Beds	
	Gawan limestone		Mandera Series	
	Daghani shales Wanderer limestone		Limestones and gypsiferous shales	Daua Limestone Series
	Gahodleh shales			
	Bihen limestone		Golberobe beds	
Variegated sandstones, limestones and intercalated lavas, and conglomerates near the base (Serie di Lugh of Italian Somaliland), grits and conglomerates in S.W. British Somaliland			Limestones and gypsiferous shales	
			Didimtu beds (limestones)	
			Mansa Guda formation (grits and conglomerates)	

Dotted lines denote unconformities

Present Report	Coastal Kenya (Caswell, 1956)	Tanganyika (Wade, 1937; King, 1954; Aitken, 1956)	Madagascar (North and West) (Besairie, 1946 and 1956)
			Limestones and chalk Calcareous sandstones and sandstones
			Sandstones and calcareous sandstones
		Pugu sandstones	Marls and clays
			Sandstones with marls
Marehan sandstones			Sandstones
Danissa Beds		*Trigonia schwarzi* beds	Glauconitic sandstones
	Freretown limestone		Glauconitic sandstones and limestones with shale and marls (variable in different localities)
Not exposed		Upper Reptile bed *Trigonia smeei* bed	Glauconitic sandstones and limestones with shales and marls
	Changamwe shales with lenticular limestone bands	Middle Reptile bed	Limestones and marls
Golberobe beds		*Nerinea* bed Lower Reptile bed	Limestones and marls
Sandy limestones	Rabai shales		
Oolitic and shelly limestones (base not exposed)	Miritini shales	Callovian zone *Ostrea* zone Light clay zone } U Mibande rock Nerinean limestone	Gypsiferous marls
	Kibiongoni beds / Kambe limestone	Kidugallo zone L	Limestones and shales Isalo III
	Mazeras sandstone		Isalo II Isalo I
	Mariakani sandstones Maji-ya-Chumvi beds (in part)		Sakamena beds (in part)

(Fig. 8) which is discussed in the chapter on structure (p. 36). It is not easy to arrive at an estimate of the thickness of the series as exposed in this area. In the Melka Murri area, Thompson and Dodson (1958) estimated that there are approximately 1,500 ft. of limestone exposed along the Daua river, and in the central part of the Takabba area Saggerson and Miller (1957, p. 12) showed that a total thickness of 3,500 ft. of the Daua Limestone Series is represented. In the El Wak–Aus Mandula area, however, the lack of any structural features and the paucity of dip readings make a sound estimate of the total thickness of the limestones impossible, though it is probable that a thickness in excess of 3,500 ft. is present.

The mapping of the limestones indicates a succession which is diagrammatically represented in Fig. 2 and consists of:—

7. Light brown, coquinoid limestones with shelly beds near the top. 6. Grey, sandy limestones with barren calcite mudstone bands and shelly beds.	"Oxfordian" limestones
5. Undifferentiated limestones (not exposed).	
4. Coquinoid and oolitic limestones with shelly and unfossiliferous beds and rare nodular and conglomeratic limestones. 3. Nodular limestones with thick oolite bands. 2. Organic fragmental limestones with oolitic, shelly and unfossiliferous beds and lenticular nodular limestones. 1. Conglomeratic limestones.	Main Oolite limestones

The Main Oolite limestones are poorly exposed in the south-western corner of the area near Aus Mandula and Wel Merere. Here limestone boulders litter the surface in the form of small "fields", individual boulders having random orientation, and the steep apparent dips of some of the blocks were probably caused by solution of sub-surface limestone and the falling of overlying blocks into the solution cavities. Occasionally the blocks are extremely large, occurring close together, and in these it is possible to trace the same calcite vein or joint from one block to the next. Such blocks are considered to have weathered *in situ* without disturbance and dip readings taken on such blocks are fairly reliable.

No stream or gully sections were seen during the survey and where the ground rises towards the top of the low escarpment south of Wel Merere the only significant change to be seen in the limestone outcrop is an increase in the number of limestone boulders. Eastwards from Wel Merere, near Korof Harrar and Gorojub, numerous kunkar limestone sheets overlying limestone occur in the sandy soil, while near the Kenya border there is little kunkar and the limestone series is covered by red-brown sandy soil or by the grey soils of the Lugh Suri. While walking over the limestone country, often where no limestone boulders are exposed, it is noticeable that the footsteps have a characteristic hollow sound over areas of a few square yards and different from the sound over surrounding areas. This is probably due to solution of sub-surface limestone along bedding or flat joints which has formed narrow flat cavities within the underlying rock.

Main Oolite Limestones.—The rocks in the south-western part of the area are oolite limestone with conglomeratic, shelly and nodular varieties. In some layers the oolites are so uniform in size and so evenly spaced that the sorting coefficient must have been close to unity, and even in the more ill-sorted oolite beds there is little detrital material of mudstone grade in the matrix. Iron-staining is rare except where the oolites are stained internally. Throughout the Main Oolites there are local

concentrations of organic debris, usually as layers of shell fragments in which there are poorly sorted assemblages of oolites and clastic mineral fragments. Evidently currents were sufficiently persistent to winnow away the fine-grained detritus leaving the organic material.

Conglomeratic limestones are the oldest rocks present in the area and are to be seen near Wel Merere. They are very variable and contain pale-coloured oolitic, coquinoid, shelly and grey unfossiliferous bands. One specimen of the conglomerate, 23/296* (Fig. 3a and Plate IIIa), from one mile south of Wel Merere, is an orange-brown rock in which buff-coloured rounded or sub-rounded pieces of calcite mudstone

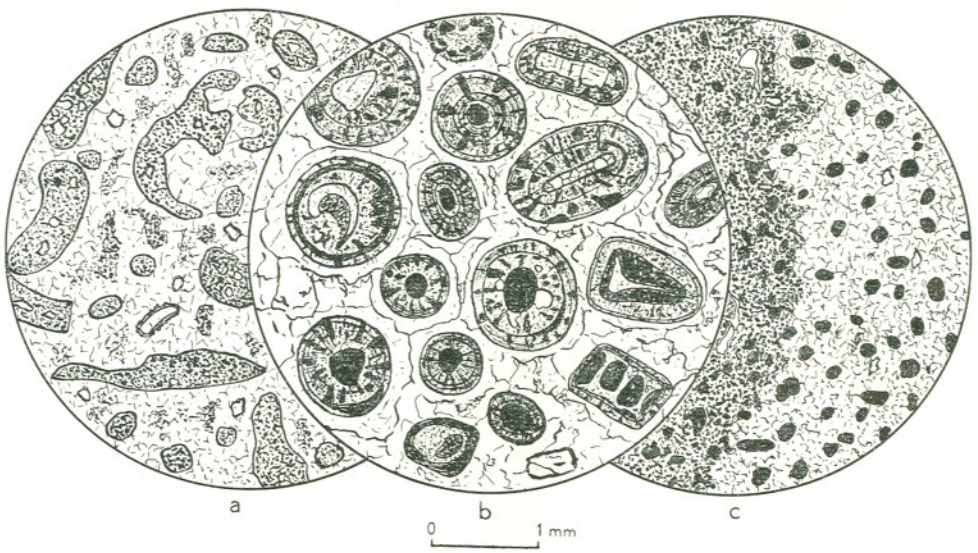


Fig. 3.—Microscopic drawings of thin sections of limestones from the Aus Mandula area.
(a) Conglomeratic limestone. Specimen 23/296, from one mile south of Wel Merere.
(b) Oolitic limestone. Specimen 23/306, from Aus Mandula.
(c) Calcite mudstone with pellets. Specimen 23/290, from Gegebe.

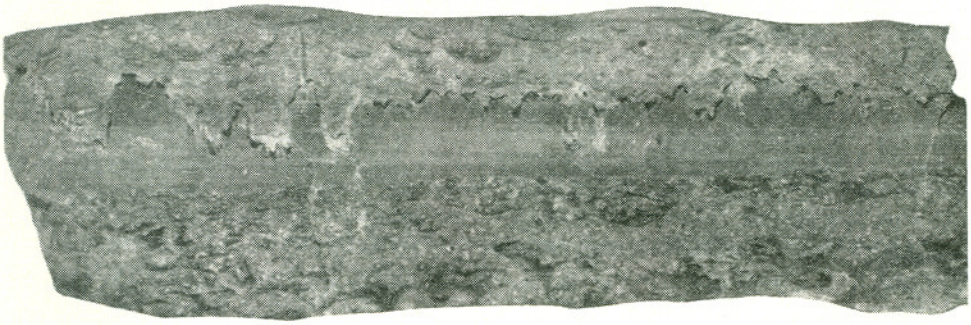
are set in a fine-grained calcite matrix. The included fragments vary from 0.1 in. to 1.5 in. in diameter. In thin section the rock is seen to contain occasional ooliths and also limestone pellets, the latter probably being material worked over by mud-feeding organisms. The presence of rare ooliths and the breccia-like character of the rocks suggest that they have been formed from pre-existing oolitic and calcite-mudstone limestones, and that they record times when currents were abnormally strong. The presence of conglomeratic limestones probably indicates a period during which slumping in water-logged sediments took place. The rocks are usually poor in fossil remains but bands containing shell fragments do occur, particularly in the limestone blocks exposed on the track from Korof Harrar where it crosses the southern border of the area.

Fragmental limestones containing shell debris comprise by far the greater proportion of the oolitic limestones seen in the area between Aus Mandula and Wel Merere. Here the rocks consist of pale brown and buff oolitic limestones with prominent bands of fragmental material of organic origin. The bands are most noticeable on weathered surfaces from which larger shell fragments and even complete fossils protrude. The banding in some cases is accentuated by selective iron-staining

* Numbers prefixed by 23/ refer to specimens in the collections of the Mines and Geological Department, Nairobi.

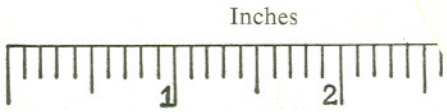
during weathering. When blocks of the limestone are broken the presence of organic fragmental bands and unfossiliferous fine-grained brown and grey calcite mudstones within the predominantly oolitic bands is revealed. A single specimen may show every variation from a fine-grained calcite mudstone to an organic fragmental limestone

Plate II



(a) Stylolite in banded limestone. Specimen 23/293, from eight miles south of Aus Mandula.



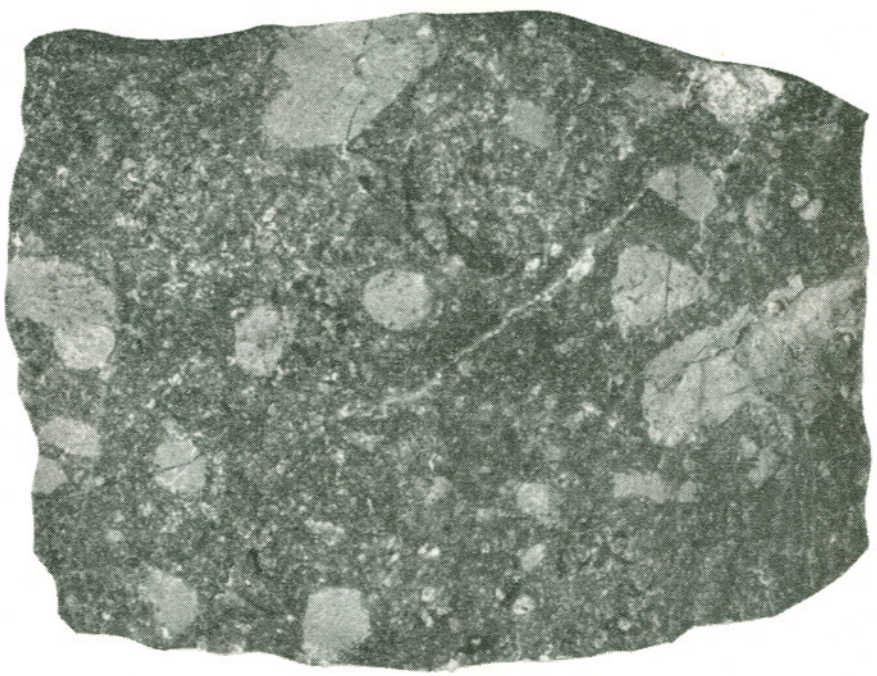


(b) Stylolite in oolitic limestone. Specimen 23/325, from eight miles

or shelly limestone. Specimen 23/300 from seven miles south of Gegebe is such a rock, the darker bands corresponding with the more fragmental horizons. A typical oolitic rock, 23/298 from the same area, is a pale buff, well-sorted rock. The ooliths are well formed, have large or small cores of shell fragments, siltstone and calcite mudstone particles, or limestone pellets, and exhibit concentric and radial structures. The matrix and ooliths are formed of tiny crystals of calcite that render the rocks semi-opaque in thin section. Iron-stained impurities between the concentric layers of the ooliths have imparted to them a pale-brown or even a red colour (e.g. specimen 23/304A) a feature that is most noticeable in the hand-specimen. The matrix, however, is usually free from impurities. In poorly sorted oolitic limestones the ooliths vary in shape from near perfect spheres to elongated varieties. In many of these rocks, as in specimen 23/301 from six miles south of Gegebe, their character has been partly obscured by recrystallization, though dolomitization is not apparent. The shelly bands consist of shell fragments, often iron-stained along their margins, set in a recrystallized groundmass of calcite. Occasionally the rocks are traversed by thin calcite veins, although this feature is usually confined to the interbanded calcite mudstones, which are fine-grained dark grey rocks with uneven conchoidal fracture.

Stylolites are frequently seen in the shelly and oolitic limestones and Plate II illustrates two specimens from the Aus Mandula area. Shrock (1948, pp. 240–241) in describing stylolites, considers that they have doubtful value as "top and bottom" criteria but that they should be critically investigated in order to determine whether

Plate III



(a) Conglomeratic limestone. Specimen 23/296, from two miles south of Wel Merere.

or not they can be used to decide whether beds are in normal succession or inverted. Specimen 23/293 (Plate II (a)), which was not found *in situ*, is a limestone in which two shelly fragmental bands are separated by calcite mudstone half-an-inch thick. Stylolites have developed along the bedding planes that separate the three bands. On close examination of the hand-specimen it is seen that the sediments could only have been deposited in such a manner that the better developed stylolite appears uppermost in the sequence. It is not the stylolite in this case, however, which determines top and bottom of the specimen but the limestone block as a whole.

Numerous theories have been advanced to account for the formation of stylolites, and some have invoked the work of organisms, crystallization, pressure, gas, erosion and solution (Gordon, 1918, pp. 564–567). Stockdale (1922) proposed that they are formed by differential solution of hard rocks (the solution-pressure theory), whilst more recently, Shaub (1939, 1949) has concluded that they form in unconsolidated sediments.

In specimen 23/293 a well-developed stylolite separates an upper shelly band from underlying calcite mudstone, while a lower stylolite with small amplitude separates the mudstone from a lower shelly band. The larger stylolite exhibits typical zig-zag structure (*see* Fig. 4 (a)), and the accumulation of clay on the summits of the

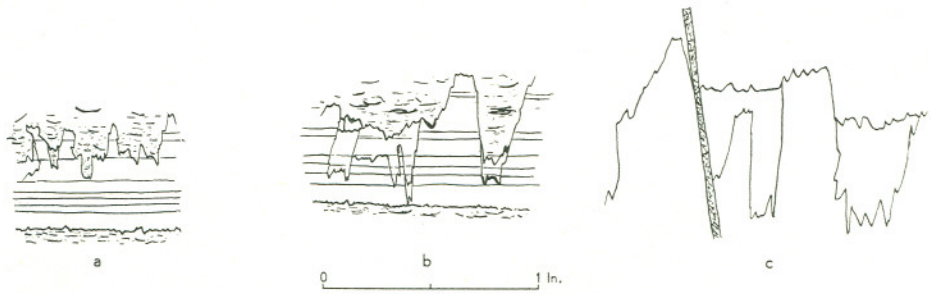


Fig. 4.—Stylolites in limestones.

(a) Stylolite in banded limestone. Specimen 23/293, from eight miles south of Aus Mandula.

(b) Stylolite in banded limestone showing development of secondary columns. Specimen 23/293 from eight miles south of Aus Mandula.

(c) Stylolite in oolitic limestone showing division of the stylolitic seam. The stylolite is seen to cross the calcite vein in the rock. Specimen 23/325, from eight miles west of Romicho.

columns and in the bases of the hollows between them (*see* Plate II (a)). The calcite mudstone shows no bending, dislocation or brecciation of its bands against, above or beneath the stylolite columns. That the banding may be colour banding of later origin than the stylolites, as suggested by Shaub (1949, p. 28), can be discounted. At various parts along the stylolite secondary "sutures" have developed below the troughs between some of the columns (*see* Fig. 4 (b)). These occur in the banded calcite mudstone without disturbance of the bands, though there appears to be some alteration of the mudstone, probably by solution. The upper shelly band has not penetrated downwards between the columns of the secondary stylolites, as it has done in the case of the primary stylolites.

Specimen 23/325, from eight miles west of Romicho, shows a stylolite developed in an unbanded oolitic limestone (*see* Plate II (b)). There is no difference between the limestones on either side of the stylolite, which in thin section is seen to cut across the ooliths. Traversing the rock nearly at right-angles to the stylolite are small calcite veins, 1 mm. in width. The veins are crossed by the stylolite in most instances and occasionally the stylolite follows the vein for a short distance. The primary stylolite occasionally branches to form secondary stylolites and then rejoins to form a single seam (see Fig. 4 (c)).

In both these examples the stylolites are considered to have been formed by the action of solutions on consolidated rocks under pressure. In the first case the stylolites developed along bedding planes in the rock due to localization of the solutions at the changes of facies. Solution has continued in some cases beneath the hollows between the original stylolite columns, thus forming the secondary stylolites between which the banded calcite-mudstone although undisturbed has been slightly altered. In this instance the stylolites enable the determination of the attitude of the rocks. In specimen 23/325 shrinkage cracks now filled by calcite developed on consolidation of the limestone, and were later intersected by a stylolite (which branches in parts) developed as a result of solution and pressure. The lower stylolites in this case may not be secondary and, therefore, cannot be used to determine whether the beds are in normal succession or inverted.

Nodular Limestones.—Siliceous nodules measuring as much as six inches in length are characteristic of the rocks in the Aus Mandula–Gegebe area. The limestones containing them are similar to the other members of the Main Oolite limestones, and also contain fragmental and shelly bands. The nodules are best seen on weathered boulders which, as a result of their presence, have knobby surfaces. They are commonly elongated, and nodules in the same block of limestone are usually elongated parallel to one another. This suggests that they have been flattened parallel to the bedding surfaces in the limestone by pressure, although this could not be proved in the field because of the poor exposures. The weathered surfaces of the nodules are orange in colour due to recent iron-staining but in cross-section they exhibit brown to buff concentric colour banding. Rarely, foraminifera are preserved in the nodules. In specimen 23/289 from Aus Mandula well-rounded ooliths are present in a very fine-grained siliceous matrix whilst silica has also penetrated and replaced the centres of the ooliths, thus partly masking the character of the nuclei which consist of shell fragments, silt grains and limestone pellets.

Although the rocks of this group occasionally contain original silica in their matrices the silification is generally confined to the nodules. It seems probable that the silica that formed the nodules was intimately precipitated with the carbonate of the rock and later redistributed and reprecipitated around centres, displacing calcium carbonate and eventually forming nodules. The scattered nature of the nodules throughout the limestones and the lack of chert bands, suggests that the amount of silica available was limited. Subsequent to the formation of the nodules partial induration of the sediments and compression due to the weight of overlying sediments have been responsible for the lenticular and ovoid shapes of the nodules as seen at the present time. In some rocks, for example specimen 23/291, the presence of chalcedonic silica in the matrix of unsilicified oolitic limestones suggests that silica was present in the water from which the limestones were deposited, although the quantity was insufficient to permit of its migration and the formation of nodules. Although boulders of nodular limestone are found scattered over a wide area, it is likely that the nodules are confined to thin bands within the oolite beds from which the boulders were derived. Such nodular bands are probably lenticular and there is some suggestion of this, as shown on Fig. 2, particularly as the main outcrop has not been traced in the adjacent area to the west of Aus Mandula.

Associated with the nodular limestones are fragmental limestones and fine-grained calcite mudstones. The calcite mudstones, of which specimen 23/290 from Gegebe (Fig. 3 (c)) is an example, consist of fine-grained calcite associated with clay and silt impurities together with small ovoid pellets which in some cases have acted as nuclei for the formation of ooliths. The pellets are considered to be of faecal origin.

Undifferentiated Limestones.—Limestones are presumed to underlie the soils in and near the Lugh Suri but the lack of any exposures prevents any speculation on their lithology.

"Oxfordian" Limestones.—Limestones form a number of low hills that lie in a zone approximately five miles to the west of the main line of hills of Marehan sandstone (*see* Fig. 2). The limestones are characteristically different from those seen

further south, being generally dark variable rocks, rarely oolitic and with shelly bands near the top. Sections can be seen at Muguda and Romicho, where approximately 200 ft. of limestone are exposed, and are generalized in the following table:—

Golberobe beds.
Kunkar (sheet) limestone.

7. Weathered pale yellow friable limestone with well preserved fossils.
6. Shelly limestones with chert nodules.
5. Coquinoid limestones with oolite bands and siliceous nodules, and intercalated siltstones and sandstones.
4. Dark grey calcite mudstones.
3. Pale brown shelly limestones.
2. Dark grey, unfossiliferous calcite mudstones.
1. Light grey sandy limestones with thin shelly bands.

Beds typical of the lower part of the succession are to be seen at Waldire where thin shelly bands are found in a grey sandy limestone which on weathered surfaces has a banded appearance. These limestones are similar in appearance to those lying immediately below the Golberobe beds at Golberobe and Ogar Wein in the Takabba–Wergudud area (Saggerson and Miller, 1957, p. 11). In a thin section of specimen 23/254 from Waldire (*see* Fig. 5 (c)), which is a calcite mudstone, typical angular or sub-rounded allogenic quartz, plagioclase and iron ore grains can be seen, contained in a matrix of calcite in which there are pellets of mudstone. Some

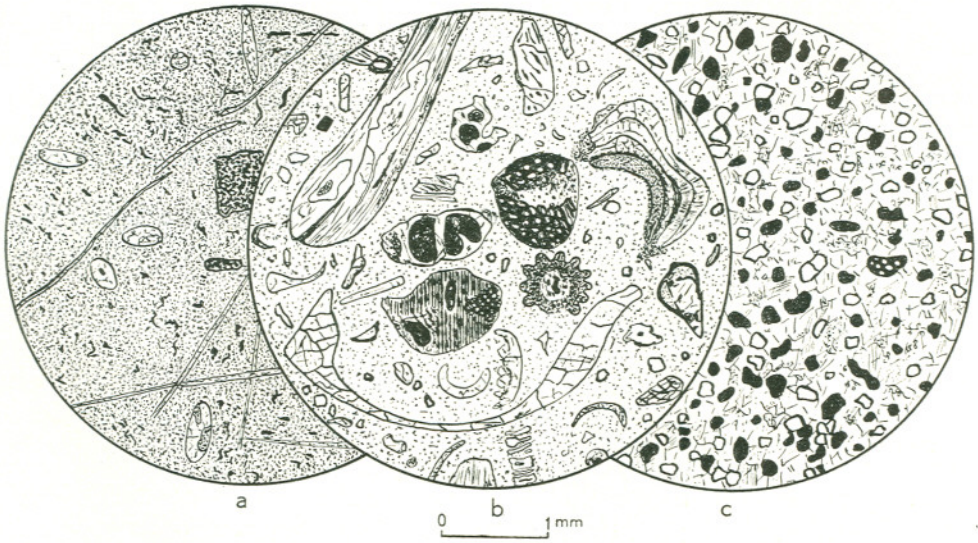


Fig. 5.—Microscope drawings of thin sections of limestone from the El Wak-Aus Mandula area.
(a) Calcite mudstone. Specimen 23/242 from Muguda.
(b) Coquinoid limestone. Specimen 23/227 from Muguda.
(c) Sandy limestone. Specimen 23/254 from Waldire.

of the pellets are aggregates of fine-grained clastic material but others consist of very fine-grained sub-opaque, structureless mud and are probably of faecal origin. These dark brown pellets are often surrounded by thin calcite shells indicating that the pellets acted as nuclei round which the calcium carbonate was deposited from solution.

Lying above the sandy limestones at Muguda is a thick band of unfossiliferous dark grey calcite mudstone that gradually passes upwards into coquinoid and shelly banded limestones, which form the top of the limestone series there. The calcite mudstones are porcellanous in part and break with a smooth conchoidal fracture. They are generally featureless, except for fine calcite-filled veins which are shrinkage

cracks formed during consolidation of the muds. A thin section of specimen 23/242 from Muguda (Fig. 5 (a)) shows that the veinlets are less than 0.1 mm. wide, and that the rock is composed of minute crystals of calcite, but is so fine-grained that it is semi-opaque.

The upper limestones of this group are coquinoid limestones with rich shelly bands developed locally. At Muguda they are interbedded with red-brown sandstones and variegated siltstones, indicating the onset of littoral conditions. The limestones are typically light brown rocks but are occasionally purplish and contain lighter-coloured calcite mudstone and chert lenses. The shell debris, which forms a large proportion of the rocks, has been washed into a fairly pure calcite mudstone that forms a fine-grained matrix (23/221 from Muguda). In thin-sections (e.g. Fig. 5 (b)) it is seen that the fragments, which are marginally iron-stained, include large and small shell fragments, often crushed, and also bryozoa and crinoid ossicles. Quartz grains are also present.

At Romicho the top of the limestones consists of highly weathered, friable, pale yellow to buff limestone, containing complete shells in a fairly good state of preservation.

Palaeontology of the Daua Limestones.—The general absence of thoroughly weathered limestones which would have enabled identifiable fossils to be obtained, made fossil collecting in the area extremely difficult. Fossils are frequently found on the limestone surfaces but their state of preservation makes specific identification in most cases impossible. At present, the age of the shelly and oolitic limestones near Aus Mandula and Wel Merere can only be decided by tentative correlation with the rocks of the neighbouring area to the west. The lowest limestones of that area, which are represented in the escarpment from the latitude of Tarbaj to Bur Mayo, can be dated as Toarcian, while somewhat higher beds have yielded middle Jurassic *Eudesia* cf. *cardium* (Ayers, 1952, p. 27). These horizons are not represented near Wel Merere but may outcrop about 20 miles north-east of Wajir and, therefore, presumably underlie the lowest limestone horizons of the area mapped.

At Romicho some well-preserved fossils were collected from the weathered limestones immediately underlying the Golberobe beds. These have been identified by Dr. Cox at the British Museum as belonging to the following genera :—

Gervillella sp.
Cucullaea (*Megacucullaea*) sp.
Ostrea sp.
Mytilus sp.

Dr. Cox remarks that "The *Cucullaea* is very imperfect but bears a distinct resemblance to *Cucullaea* (*Megacucullaea*) *kraussi* of the Neocomian of South and East Africa. The *Mytilus* sp. is a large form exceeding 10 cm. from umbo to postero-ventral corner and is larger than *Mytilus jurensis* Roemer of the Upper Jurassic". In spite of the *Cucullaea* it is considered that the fossils represent an Upper Jurassic fauna possibly of Oxfordian age, for the beds in which they are contained are overlain by the Golberobe Beds of the same age.

Other fossils collected from the shelly and sandy limestones at Muguda and Waldire include :—

Echinoid spines.
Crinoid ossicles and brachia.
Protocardia sp.
Meleagrinella sp.
Lopha sp.
Lima (*Plagiostoma*) sp.
Ostrea sp.
Chlamys sp.
Entolium sp.
Grammatodon (*Indogrammatodon*) cf. *irritans* (Hennig).
Belemnopsis cf. *tanganensis* Futt.

As these upper limestone horizons are possibly of Oxfordian age and are overlain by Golberobe beds of the same age, it is likely that the lower limestones near Aus Mandula and Wel Merere are Bathonian to Callovian in age.

(2) Golberobe Beds

Overlying the limestones a few miles west of the foot of the escarpment formed by the Marehan Series are the Golberobe Beds which, in the Takabba–Wergudud area (Saggerson and Miller, 1957, p. 13), are considered to be intercalated in the limestone series. The beds are exposed in such hills as Chukalesid, Romicho, Muguda and and Dirahara where they are seen to dip gently to the north-east. At Muguda the beds, which cap small hills, are nearly horizontal and represent outliers of the main band. The unusual width of outcrop here and at Romicho is due to small flexures and not to any appreciable thickening of the beds. In the present area it is considered that the Golberobe Beds overlie the limestones unconformably, though the time interval represented by the break in deposition was probably not great. Evidence for this unconformity is to be seen at Romicho, where weathered limestone is overlain by a sheet of kunkar a few inches thick, which appears to pass beneath the overlying Golberobe beds. Kunkar was also seen near the junction of the same beds, on the hills three miles south-east of Waldire. It is considered that these exposure are indicative of an old land-surface beneath the Golberobe Beds. Still further evidence can be seen at Dirahara where horizontal, massive-bedded, shelly limestones outcrop within 50 yards of overlying Golberobe beds that dip 3° to the north-east. Unfortunately the junction is concealed by sandy soils and the nature of the unconformity cannot be seen.

Although about 105 ft. of Golberobe beds are exposed at Chukalesid and similar thicknesses are seen in the hills elsewhere along the strike, no safe estimation of total thickness can be given as the top was nowhere seen. There is a wide belt of ground between the highest exposed beds and the base of the overlying Marehan series, but no evidence of Jurassic rocks overlying the Golberobe beds was found. The sections on the geological maps accordingly suggest a thickness for the Golberobe beds greatly in excess of 200 ft.

The Golberobe beds are fossiliferous pale reddish brown sandstones with thin intercalations of buff to light brown siltstones. In thin section, as exemplified by specimen 23/263, from the north-western extremity of Mirril, the sandstones are seen to be moderately well-sorted rocks in which angular quartz fragments are closely packed. Cementation by the deposition of secondary silica in crystalline continuity with the detrital quartz has taken place and new crystal faces have developed round the original crystal boundaries. Argillaceous material is present in the form of thin screens between the quartz grains. The siltstones, of which specimen 23/238 from Muguda is an example, are not such closely packed rocks, the larger grains being separated by fine-grained silt material. This argillaceous detritus formed the original cement which was later replaced by silica as a result of cementation by enlargement of the detrital quartz grains.

The exposures of Golberobe beds are widely scattered and usually concealed by thick screes which make measurements of detailed sections impossible. Sufficient evidence was gathered, however, to establish generalized successions in the various hills and these have been tabulated for the sake of clarity (*see* Table II).

The basal beds are typically well-jointed yellow siltstones that weather into small blocks characterized by the presence of worm borings. Marly and calcareous bands are common in these lower siltstones and at one hill (Mirril) south-west of Bur Wein, a thin, silicified, oolitic limestone band (23/287) occurs immediately beneath the overlying sandstones. The overlying sandstones are everywhere characterized by the lamellibranch *Meleagrinella* which occurs approximately 40 to 60 ft. above the base of the beds. The *Meleagrinella* band consists of laminated and flaggy fine-grained sandstones in which small current-bedded units are prominent. These flags in turn

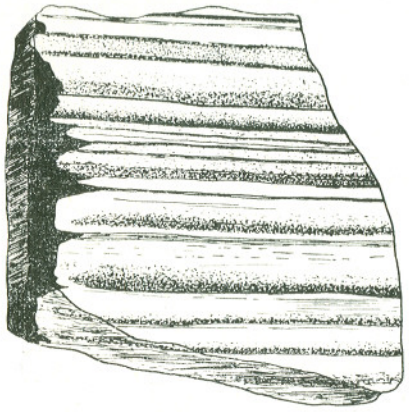
TABLE II.—SEQUENCE OF GOLBEROBE BEDS IN THE EL WAK–AUS MANDULA AREA

(*Approximate thicknesses are given where they can be estimated*)

Chukalesid	Romicho	West Muguda	Central Muguda	East Muguda
	Buff and pale yellow, slabby, medium to fine-grained sandstones. 30 ft.	Brown, laminated, cross-bedded, fine-grained sandstones with yellow fissile siltstones. 5 ft.		Pale brown, laminated, cross-bedded, medium-grained sandstones. 30 ft.
Pale, fissile siltstones with mauve staining.	Brown, cross-bedded, medium-grained sandstones. Yellow, flaggy, fine-grained sandstones. 30 ft.	Pale buff, hard siltstone with ripple-marked bedding surfaces. 30 ft.		Yellow, grey and white, fissile siltstones, stained mauve in part with sandy and marly bands. 10 ft.
Buff, brown and yellow, friable, current-bedded sandstones containing *Meleagrinella*. (*c.* 105 ft.)	Pale brown, flaggy, fine- to medium-grained sandstones with thin laminated sandstones near the base, all containing *Meleagrinella*.	Brown, flaggy, fine-grained sandstones with interbanded pale-buff siltstones, all containing *Meleagrinella*. 15 ft.	Pale brown, fissile sandstones with interbanded pale siltstones, all containing *Meleagrinella*.	Yellow and pale-brown, flaggy fine-grained sandstones with interbanded fissile siltstones, all containing *Meleagrinella*. 5 ft.
	Yellow fine-grained sandstones with worm-borings. 20 ft.	Brown and yellow, finely laminated siltstones with worm-borings. 15 ft.	Light brown, fossiliferous siltstones. Yellow-brown siltstones and calcareous siltstones with slump-bedding and worm-borings.	Pale yellow, laminated siltstones with buff and brown streaks. 55 ft.

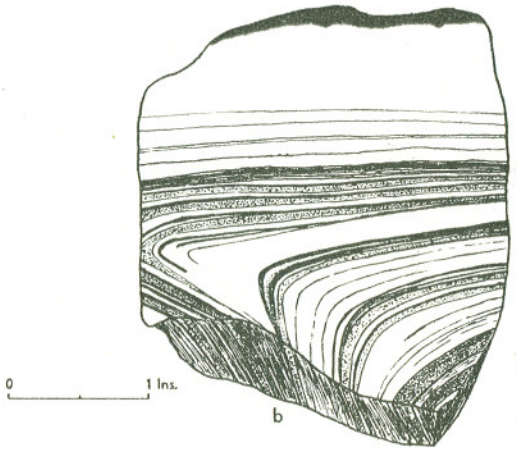
North-west Mirril	East Waldire	Central Mirril	Dirahara	Jabich
Pale yellow, brown and buff silicified sandstones.		Brown, laminated, cross-bedded sandstones.		
Yellow, brown and reddish grey, flaggy or faintly laminated, cross-bedded, medium-grained sandstones.		Brown, slabby, fine-grained sandstones with blotchy, red, brown and purplish staining. White spotted (unstained) in part. Yellow, marly siltstone. 20 ft.	Yellow, maroon- to mauve-stained banded siltstone with interbanded brown sandstones.	Pale yellow, hard, faintly-bedded, fine-grained sandstone with secondary iron-staining.
Pale to red-brown laminated thin-bedded, medium to fine-grained sandstones with *Meleagrinella*. (73 ft.)	Thin, laminated, medium-grained sandstones with *Meleagrinella*. 5 ft.	Yellow, calcareous and marly siltstones with *Meleagrinella* confined to thin bands. Thin yellow sandstone. 6 ft.	Brown, laminated sandstones with *Meleagrinella* and mussels. Calcareous sandstone with *Meleagrinella*. (90 ft.)	Thin, laminated sandstones with *Trigonia*. Pale yellow, white-spotted, clayey siltstones. (56 ft.)
Yellow, fine-grained sandstone, fossiliferous near the top.	Yellow, fissile, fossiliferous fine-grained sandstones with interbanded blocky calcareous siltstones near the base. 20 ft.	Shelly, calcareous sandstone, one inch in thickness. Thin, orange-brown, silicified, oolitic limestone. 20 ft. Yellow-brown, earthy siltstones with worm-borings.	Yellow, well-jointed, blocky siltstones.	Yellow, well-jointed, blocky siltstones.

Fig. 6.—Three examples of rhythmic colour-banding due to iron-staining in sandstones from the Golberobe beds at Jabich.



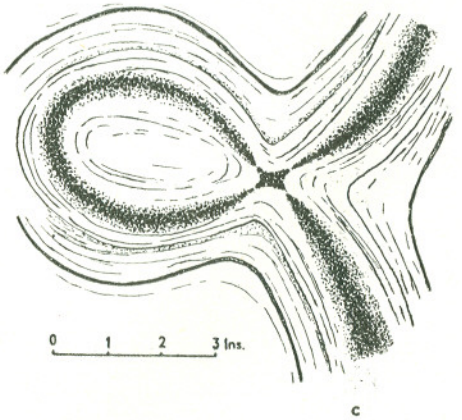
a

(a) Sandstone rhythmically colour-banded parallel to bedding planes. Specimen 23/319.



b

(b) Concentric colour bands, rythmically spaced round a heavily iron-stained centre. Specimen 23/321.



c

(c) Colour bands forming a loop in sandstone.

grade upwards into more coarsely-grained and strongly current-bedded, unfossiliferous sandstones. All the sandstones contain intercalations of yellow siltstone which are locally calcareous and ripple marked.

The sandstones and siltstones immediately overlying the *Meleagrinella* band are invariably irregularly iron-stained in brown, red and mauve colours. At Jabich, however, the iron-staining is much more regular and unusual in character. Here the Golberobe beds consist of hard, pale yellowish buff, fine-grained sandstones that are nearly structureless. The iron-staining has imparted a rhythmic colour-banding to the sandstone (*see* Fig. 6 (a)), the bands being approximately 8 mm. in width and exhibiting the following colour pattern: pale brown, yellow, pale brown, red-brown (2½ mm.), maroon (4 mm.). Other banding varies from yellow to blue to deep red. Usually the colour-banding is most prominent near the weathered rock surfaces and joint planes indicating that it is a post-depositional feature and probably due to weathering. Any large slab of sandstone shows that the banding is more intensely coloured near the weathered surfaces and that the centre of the rock is comparatively unstained. The banding in such rocks parallels the bedding planes which themselves parallel the upper and lower weathered surfaces but, near the steeply dipping or vertical joints, the iron-staining spreads and forms a zone parallel to such surfaces. Colour-bands that are not parallel to the faces of the blocks probably indicate that the blocks have been recently broken, the bands then indicating the direction of the original rock surfaces. Occasionally the colour banding occurs as concentric rings round a centre of intensely iron-stained sandstone, the bands being spaced closely near the centre where the colours are strongest and progressively wider and less strongly coloured towards the outside. In such instances the banding is again rhythmical, the strongest colour in each band occurring farthest from the centre. In one instance, as seen on a weathered nearly horizontal surface, the banding forms a complete loop, and in others sub-parallel banding diverges suddenly so that it lies at an angle to bedding, weathering surfaces and joint planes. Stansfield (1917, p. 14) cites examples of spiral forms. Three types of colour banding are diagrammatically represented in Fig. 6, all of which occurred within a few feet of one another. Thin sections of such banded rocks (23/320) indicate that the iron-stained banding does not result from differential staining of graded bedding, as the rocks have an even grained texture. The colour bands are considered to be Liesegang rings.

Iron-impregnation of the sandstones of the Golberobe Beds has produced hard iron-rich crusts (0.1 in. thick) on joint surfaces and on weathered and bedding surfaces. The crusts are deep brown and characteristically different from the lighter mauve staining of the bands. This recent deposition has penetrated the rocks to a limited extent, and on joint surfaces the iron oxides have been introduced along the less heavily iron-stained bands (Fig. 6 (a)). Botryoidal iron ore (23/226) was seen in patches, as a crust on the sandstone surface at Muguda but is of only local occurrence.

Palaeontology of the Golberobe Beds.—The Golberobe beds are characterized by a fossil band containing abundant *Meleagrinella* which was seen at all the outcrops along the strike. Unfortunately, the species of *Meleagrinella* found in north-east Kenya cannot be identified with certainty and hence the dating of the beds in which they occur must rest on the faunal assemblage. Fossils from equivalent beds in the Takabba–Wergudud area (Saggerson and Miller, 1957, pp. 13–23, 42) confirmed the Jurassic age of the beds but it was not possible to define their exact stage within the Jurassic. In their concluding remarks, however, the authors tentatively consider the beds as of "Oxfordian" age (*loc. cit.*, p. 23). The fossils from the present area occur in the sandstones and siltstones and are not well preserved. They are similar to those seen in the Takabba–Wergudud area, and specimens including *Meleagrinella* sp., *Ostrea* sp., *Modiolus* sp., *Lopha* sp. and *Eopecten* sp., were sent to the British Museum for confirmatory identification. At Dirahara the *Meleagrinella* band was found to be richer in mussels than at other localities, whilst at Jabich a small *Trigonia* is characteristic. The siltstones intercalated in the band at Muguda contain numerous

Plate IV



(a) Elliptical structure, possibly the axial part of a small basin-shaped fold. Dimo water-hole.



(b) Iron-staining on weathered surface of Marehan sandstone, Lolkurte.

worm-borings, possibly of *Serpula*, and a poorly preserved star-fish and part of the leg of a crustacean were also found. Apart from these non-molluscan fossils which have not been discovered elsewhere, there did not appear to be any new species associated with *Meleagrinella* that were not seen in other areas. The Golberobe beds are, therefore, considered to be of probable "Oxfordian" age.

2. Cretaceous System—Marehan Series

The Marehan Series is divisible into two groups of rocks: the lower the Danissa beds consisting of "siltstones" and flaggy, fine-grained sandstones, and the upper the *Marehan Sandstones*, a thick formation of cross-bedded, unfossiliferous sandstones. The maximum thickness of the series—at Bur Wein—is approximately 2,200 ft., a thickness very much greater than that found elsewhere in north-east Kenya—in the Takabba–Wergudud area for example (Saggerson and Miller, 1957, pp. 26, 27) the series is only about 400 to 600 ft. in thickness. The base of the series is not exposed in the present area but its position can be inferred with reasonable accuracy, particularly in the south-eastern part of the outcrop. The Danissa beds rest on the Golberobe beds with unconformity, as they do in the Takabba–Wergudud area (*op. cit.*, p. 27). No identifiable fossils have been discovered in the Marehan Series, but poorly preserved plant stems have been seen in the Danissa beds in the Garse hills, west of Bur Wein, and at Garse water-hole. A Wealdan plant, *Weichselia reticulata*, was, however, discovered in the Danissa beds of the Takabba–Wergudud area (*op. cit.*, p. 27) and its occurrence suggests a Lower Cretaceous age for the lower members of the Series.

The Cretaceous beds of British Somaliland, which locally overlie Jurassic limestones and older rocks with unconformity (Somaliland Oil Exploration Co. Ltd., 1954, pp. 15–16) can be correlated with the Marehan Series. They range from Barremian to Senonian in age, and consist of alternating limestone and sandstone beds varying from 600 to over 3,000 ft. in thickness, becoming predominantly sandy towards the west, and are interpreted as shallow-water marine deposits (*op. cit.*, p. 15). The Cretaceous of the Guban of north-central British Somaliland is very similar to the Marehan Sandstones, the beds being cross-bedded, locally stained by iron oxide, sometimes friable, at other times quartzitic. Locally the sandstones in British Somaliland become silty at the base, suggesting correlation with the Danissa beds (*op. cit.*, p. 17).

The change from the marine limestone and shale deposition characteristic of the Jurassic to the deposition of shallow-water marine or estuarine sandstones in the Cretaceous is found in numerous localities in India, in the Somalia peninsula and its hinterland, and elsewhere. In the trans-Indus ranges of India, Neocomian white sandstones rest unconformably on upper Jurassic limestones and shales (Wadia, 1953, p. 258). A Cretaceous marine transgression beginning with estuarine-fluvial sedimentation is suggested by the rocks of the Coromandal coast, the Madhya Pradesh and the Deccan. Similar conditions on the south-east coast of the peninsula are indicated by the succession there, which begins with the Utatur Stage, consisting of silts, clays and gritty sandstones overlain, unconformably, by cross-bedded grits and sands of the Trichinopoly and Ariyalin Stages (*op. cit.*, pp. 282–3). In Kashmir the Cretaceous Giumal sandstone rests on Jurassic limestones and shales, and in Idar State of Western India massive red and brown sandstones and shales with *Weichselia reticulata* are found (*op. cit.*, pp. 289–90).

Weichselia reticulata, a plant that has till recently been considered to be characteristically Wealdan in age, has been found in the middle and upper Jurassic beds of North Africa, and de Lapparent (1952, p. 119) considers that the *Weichselia-Brachyoxylon-Dadoxylon* flora, commonly found in terrestrial deposits of North and Central Africa, is not necessarily proof of lower Cretaceous age. Nevertheless, *Weichselia reticulata* has been found associated with a vertebrate fauna of undoubted lower Cretaceous age in south Tunisia and at Baharija Oasis in Egypt (*op. cit.*, p. 120).

Taylor (1948, p. 1357) in a summary of the succession in the Somali–Ethiopia area mentions a thick non-fossiliferous sandstone of possible Turonian age overlying a gypsiferous series of Portlandian to Barremian age (= Mandera Series).

Chardin *et al.* (1930, pp. 66–67; *see* also Arkell *et al.*, 1952), correlating the Mesozoic deposits of north-east Africa and Arabia, show that the Cretaceous in the Hadramaut has a generally similar succession to that in British Somaliland, the Marbat sandstones of the lower Cretaceous being overlain by the unfossiliferous Djebel Semhan limestone. In the Yemen the Cretaceous is represented by the Taouilah Series which is composed of sandstones and is overlain by Tertiary basalts of Deccan type. The equivalent of the Taouilah Series west of the Red Sea is the Daoenleh sandstone of the Abyssinian plateau. In the Hedjaz (the Sinai peninsula) and the Arabian desert, limestones, sandstones, shales and quartzites form a succession from the upper Cenomanian upwards while the lower Cretaceous is represented by the Nubian sandstone (*continental intercalaire* of French authors, e.g. de Lapparent, 1954, p. 123).

The Cretaceous of the Kenya coast consists only of the Freretown Limestown, a faulted remnant of Neocomian age which, though there is no field evidence to allow a decision, it has been suggested may rest conformably on Jurassic rocks (Caswell, 1953, p. 52).

In Tanganyika red sandstones with conglomerates and mudstones rest unconformably on Karroo beds in the Rukwa trough (Spence, 1954, p. 17–18) and are correlated with the Dinosaur beds of Nyasaland, which have been dated as Cretaceous in age. Cretaceous sandstones occur also in the hinterland of Lindi and Dar es Salaam. The Pugu sandstones and the Newala sandstones (Wade, 1951, pp. 9, 40, 46) are considered to be Cenomanian or Turonian in age, while recent work (Aitken, 1956, p. 2) has indicated that the Tendaguru beds are of Aptian to Oxfordian age. The *Trigonia smeei* beds of the upper part of the Tendaguru beds are Tithonian, and the Upper Reptile (Saurian) bed is placed in the uppermost Jurassic. Aitken (*op. cit.*, p. 2) has also found structural evidence of an unconformity between the *Trigonia schwarzi* beds and the underlying Jurassic rocks. Most of the deposits of Cretaceous age in Tanganyika are arenaceous and were deposited under estuarine, fluvial or sub-aerial conditions; marine beds are found only near the coast.

The foregoing summary of the Cretaceous in East and north-east Africa, Arabia and India which is summarized in Table I (p. 9) indicates that our knowledge is still fragmentary. The general picture suggests that at the end of the Jurassic period a general regression of the sea occurred, allowing some erosion of Jurassic rocks and that a subsequent transgression during the Wealdan gave rise to marine deposits near the coasts and fluvial/estuarine or terrestrial deposits further inland. A second regression and transgression appears to have occurred during the Cenomanian when marine beds were more widespread in India and parts of Arabia.

Since sedimentation of limestones of the Jurassic facies appears to have continued into the Neocomian in Somalia (Stefanini, 1922, p. 1062), and since Taylor (1953, p. 1357) described gypsiferous beds probably equivalent to the Mandera Series as Portlandian to Barremian in age, it seems that Cretaceous arenaceous sedimentation may have begun in the Barremian or Aptian in the Somalia–Ethiopia area. In view of the discovery of the Wealdan plant *Weichselia reticulata* in the Danissa beds (*see* p. 24), the base of the Marehan Sandstones is here drawn at the top of the Wealdan.

(1) Danissa Beds

The base of the Danissa beds is not seen in the present area, due to lack of exposures. The upper boundary of the beds is, however, drawn at the base of the lowermost massive sandstone bed of the Marehan sandstones. Since the massive sandstones frequently form hills and as the dip is to the north-east, the upper boundary of the Danissa beds is usually found low on the south-western slopes of the hills. The exposures are too scattered to allow the measurement of detailed sections,

but generalized sequences were established and are given in Table III. There are numerous gaps in the succession representing unexposed beds, but only the largest of them are shown in the table. It will be seen that there is lateral variation; the place in the sequence of the coloured "siltstones"* which figure prominently in the Bur Chocho, Willete and Garse hills is taken to the south-east by pale brown, flaggy sandstones.

The Danissa beds are distinguished from the Marehan sandstones by the presence of numerous coloured siltstones, by the absence of thick, cross-bedded sandstone beds, and by their general lighter colour. Such sandstones as occur in them are generally flaggy, often ripple-marked, and where current bedding is present, which is rare, the beds are not more than a foot or two thick. Poorly preserved fossil plant fragments have been found in the Danissa beds, but are indeterminate.

Typical of the streaky siltstones is specimen 23/214, from Dimo water-hole. The rock is roughly banded with irregular mauve, buff and yellow-brown bands which coincide with the bedding. Under the microscope the banding is seen to be due to the presence of iron oxide in the clay matrix between the angular, poorly-sorted quartz grains. No difference in grain size between the heavily and less heavily iron-stained parts of the rock can be discovered. A similar rock is a flaggy micaceous siltstone (23/210) from the south Willete hills. It has irregular colour zones in reddish brown and buff, and although the zones are commonly elongated parallel to the prominent bedding parting of the rock, they frequently cross the bedding at right-angles. Features such as these, indicating that the colour-zoning of the rocks is not a depositional feature, are widespread throughout the Marehan Series and, to a lesser extent, the Golberobe beds. This feature is discussed on later pages (pp. 29–30). A brown siltstone with narrow, buff streaks is represented by specimen 23/208, from the south Willete hills. The rock is compact and the irregular parallel buff streaks appear to outline small-scale current bedding. Such small-scale current bedding is common in these brown siltstones, particularly in the Danissa beds on the south slope of Jabich hill. The current bedding is usually picked out by diffuse dark bands, and is characterized by frequent changes in direction of the fore-set beds. The structure is probably due to deposition from shallow water under deltaic conditions.

Some of the siltstones and fine-grained sandstones are finely colour-laminated with mauve, buff and brown bands. Specimen 23/235, from the eastern Garse hills, is typical of these rather rare rocks. Under the microscope the rock is seen to be micaceous; the quartz grains are mainly angular and the rock has much variably iron-stained clay in the intergranular spaces. A rather different laminated siltstone is represented by specimen 23/216, from the north side of Girima hill. It is a pale grey rock with numerous grey and dirty white laminations. The laminations are irregular as if due to contemporaneous "scour and fill" on a small scale. A worm-boring, one and a half inches long, penetrates the specimen and is infilled by sand. One of the siltstones in the western Garse hills shows several bedding planes with reticular drying cracks and others with worm-casts.

Ripple marking is very much rarer in the Danissa beds than in the overlying Marehan sandstones, but the nature of the Danissa beds suggests that they were laid down in shallow water, possibly under deltaic conditions. A quiet mode of deposition without torrential episodes is suggested by the lack of pebbles or coarse grades in the rocks and it can be inferred that the land mass from which the sediments were derived must have had low topography and that the prevailing climate was equable.

The Danissa beds reach a maximum thickness of about 400 ft. in the Willete hills and a minimum of about 300 ft. in Jabich hill. The thickness agrees well with that of their equivalents in the Danissa, Babo and Raiya hills.

* Most of the rocks called siltstones in the present area are, in fact, fine-grained sandstones. Siltstones are accepted by most authors as having grains of 0.1 mm. or less, but the term is used in this report for arenaceous rocks of grain size less than 0.15 mm. to distinguish the finest sandstones from the coarser types.

TABLE III.—THE SEQUENCE OF THE DANISSA BEDS EXPOSED IN THE EL WAK–AUS MANDULA AREA

(Owing to poor exposures the thickness of most beds cannot be given)

	Bur Chocho	Willete	W. Garse	W. of Girima
MAREHAN SANDSTONES	Cross-bedded, massive sandstone *c.* 100 ft. Red-brown sandstone *c.* 50 ft.	— —	— Red-brown friable sandstone.	— Red-brown sandstones.
DANISSA BEDS	Streaky, white-mauve siltstone 15 ft. Cross-bedded, flaggy yellow sandstone 20 ft. Flaggy, white and yellow siltstone.	Streaky, mauve-yellow-white sandstone. Sandstone with coloured siltstones. Mauve-white siltstone. Sandstone. Grey siltstone 1 ft. Hard, yellow siltstone 20 ft. Pale red-brown sandstone. Yellow-white siltstones with ripple marks. Pale red-brown sandstone. Mauve-buff, micaceous siltstone. Grey-buff sandstone. Sandstone with plant fragments. *c.* 350 ft.	Mauve-grey streaky siltstone 7 ft. Buff siltstone 6 ft. (gap in exposure) White-yellow siltstone 20 ft. Red-brown-buff sandstones 30 ft. Red-brown sandstone 76 ft.	Yellow-grey siltstone *c.* 50 ft. Massive sandstones 80-125 ft. Yellow-buff siltstone 5–10 ft. Buff, cross-bedded sandstone.

TABLE III.—(*Contd.*)

	Girima	E. Garse	Mirril-Lolkurte	Jabich
MAREHAN SANDSTONES	Cross-bedded red-brown sandstones.	Gritty cross-bedded sandstone.	Coarse cross-bedded sandstones.	Red-brown sandstones. Buff sandstones.
DANISSA BEDS	Nodular weathering mauve-buff siltstone. Red-brown sandstone. Light grey, laminated siltstone. Buff-yellow, cross-bedded sandstone. Mauve-buff siltstone 3 ft. Brown, flaggy sandstones with pale brown, interbedded siltstones.	Lilac siltstone. Sandstone. Flaggy sandstone. Yellow-grey siltstone. — Pale, flaggy sandstones. Yellow-brown, fine-grained sandstones with plant fragments.	Flaggy sandstones. Yellowish brown, fine grained sandstones. Pale brown siltstone 10 ft. Yellow-brown, fine-grained sandstones.	Pale brown, flaggy siltstones. Pale red-brown, fine-grained sandstones. Flaggy, pale brown, fine-grained sandstones.

(2) The Marehan Sandstones

The Marehan Sandstones consist of approximately 2,000 ft. of massive cross-bedded rocks with intercalated flaggy sandstones and siltstones. Poorly preserved plant remains are occasionally found in the rocks which are otherwise unfossiliferous. Quartzites predominate in the Bur Wein hills where they were formed as a result of silicification of sandstones. Throughout their outcrop the beds are variably stained and cemented by iron oxide, giving rise to variations in colour from pale yellow-brown to yellow, brown or deep reddish brown. The more massive sandstones outcrop in low escarpments while lesser beds form features on hillsides. The outcrops are generally scattered, and although it is possible to follow resistant beds for distances of up to several hundred yards along the strike, it is impossible to measure detailed sections. Moreover, the rapid lateral changes in lithology and colour and the lack of marker beds militate against the establishment of a stratigraphic succession.

Ripple-marked horizons are common in the upper parts of the massive, cross-bedded sandstones, and testify to the shallowness of the water during sedimentation. The ripple-marked horizons are often heavily coated with iron oxides, and stand out as prominent pavements in rocks otherwise devoid of bedding, and as a result dip and strike were usually measured on such surfaces.

The sandstone formation contains no grit beds or conglomerates and few rocks of argillaceous grade. Grey fissile shales and brick-red clay fragments were obtained from the spoil of an old well on the east slope of Aradi hill, and locally zones of small white clay galls were seen on the eroded upper surfaces of current beds. Gritty layers were seen at the base of the current-bedded sandstones in the uppermost sandstone in the Garse hills. The current bedding is usually emphasized by a faint colour lamination, the slightly coarser beds being invariably darker than the finer ones. The style of the current bedding is tabular (Shrock, 1948, p. 245), or rarely a combination of tabular and lenticular. The angle of the fore-set beds to the bedding is remarkably constant at 18° to 20°, which is considerably lower than the maximum angle of repose of sand in water. The direction of dip of the fore-set beds in the Marehan Series is fairly constant to the north-east. Isolated dip recordings on fore-set beds were made throughout the area on most exposures and all correspond generally with 50 readings taken in a single cliff exposure at Garse, west of El Wak, suggesting that the shore-line was situated somewhere to the south-west of the area. Rarely were opposing dips recorded. Top-set laminae are characteristically absent and the fore-set laminae are usually bevelled so that only the lower parts of the fore-set beds remain. Frequently the junction between two tabular cross-bedded sandstone beds is marked by ripples, which are asymmetrical in outline and have a wave-length of 2 to 2.8 in. The ripple marking is most often seen in cross-bedded sandstones and not in flaggy homogeneous rocks. Small-scale cross-lamination is common in some of the finer-grained sandstones and intercalated siltstones, and laminations are sometimes emphasized by diffuse narrow streaks of buff-coloured clay. The cross-bedded banks range throughout the rocks from small units of an inch or two in the fine sandstones and silts to units four or six feet thick in the coarser rocks.

Rain-pitting superimposed on ripple-marks was observed on the south slope of Bur Wein hill and a worm-bored sandstone was seen on Godobi hill. Coloured siltstones containing worm-borings were also observed in the Garse, Girima and Kharsakhala hills. At the base of the worm-bored siltstone near Kharsakhala the rock (specimen 23/232) was seen to be finely interbedded with lenses and fingers of buff clay. Many of the clay laminae exhibit reticular drying cracks.

The rocks of the Bur Wein, Kharsakhala and the Dabasiti hills are predominantly quartzites, which, although they differ from the sandstones in colour, hardness and style, show the same textural features and are clearly equivalent to the sandstones stratigraphically. The disposition of the quartzites appears to have been controlled by the Bur Wein structures and by the prominent joints north of Bur Wein. The area of quartzites at Bur Wein is shown on the 1:50,000 map at the end of this report.

Under the microscope the sandstones are seen to be composed of sub-rounded to sub-angular quartz grains, but in some of them twinned plagioclase and microcline crystals are also present. The cross-bedded sandstones are of grain size up to 0.3 mm., but many others are poorly sorted and the grains range from 0.05 to 0.25 mm. in size. Patches, lenses and spots of clay are common in the rocks, specimen 23/201, from the western end of the western Garse hills, being an example with such inclusions. The clay streaks are in the form of irregular discs; many are curved and contain scattered angular quartz grains. The clay-bodies are outlined by narrow zones of iron-staining, while a little iron oxide staining occurs in the intergranular films of clay in the sandstone. The clay bodies are probably thin skins of dried clay broken up and washed down during floods, to be redeposited among sands. Another sandstone containing clay bodies is specimen 23/212, from the south Willete hills. This rock is a hard, buff-spotted, brown, faintly laminated quartzite. The quartz grains, of 0.2 mm. average size, are closely packed and are cemented by intergranular films of pale reddish brown flamboyant chalcedony. Chalcedony also occurs coating the sides of small solution channels $\frac{1}{2}$ to 1 mm. in diameter. The buff spots are slightly flattened pellets of clay containing small scattered angular quartz grains.

Iron-staining of one form or another is seen in almost every sandstone exposure (*see* Plate IV (b)), and occurs as coatings on joints and weathered surfaces, as sinuous, cylindrical and annular zones and more rarely as narrow vein-like bodies. The colour variations in the sandstones and siltstones are almost entirely due to variations in the amount of iron oxide introduced into them. The variability of iron-staining is not a depositional feature, except in the case of the slight colour lamination apparent in the cross-bedded sandstones, for the zones of deep reddish brown iron-staining do not bear any regular relationship to the sedimentary fabric of the rocks, though it is a common feature that they are elongated parallel to the bedding surfaces, and this is considered to be due to the effect of bedding partings rather than to the influence of rock fabric.

The iron oxide occurs in two forms—as minute granules concentrated mainly in the clay matrix of poorly sorted sandstones, or as amorphous deep brown patches infilling the intergranular spaces. The latter type is well seen in specimen 23/202, a pale reddish brown sandstone traversed by a deep red-brown zone one inch wide. The dark zone has a marginal zone 5 to 9 mm. wide which grades into practically unstained sandstone. The quartz grains of the iron-rich zone appear to be smaller and more angular than those outside the zone, and the grains are often irregular in shape, as if they had been partly digested by the iron-oxide matrix. Analysis of the dark iron-rich zone showed that it contains 17.66 per cent Fe_2O_3, while the iron-poor zone, consisting of pale yellow-brown sandstone such as is commonly seen in the series, contains 1.03 per cent Fe_2O_3. A typical pale reddish brown sandstone (specimen 23/206, from the western Garse hills), such as commonly forms the more massive portions of the sandstone succession, contains 0.58 per cent Fe_2O_3. The iron staining is concentrated along joint surfaces and in the western Garse hills and on Korri and Dabasiti hills, vein-like ironstone bodies completely fill joint fractures. As seen at Dabasiti and on a small hill west of Kharsakhala, the introduction of the iron and the silicification are closely associated. Near the summit of Dabasiti hill there is a fracture, possibly a small fault, cutting the sandstone. Up to 14 in. on either side of the fracture the sandstones are silicified to a buff, spotted quartzite. Outside the zone of silicification there is a zone of iron-staining which decreases as one goes outwards from the fracture. The contact between the quartzite and the iron-stained parts of the rock is diffuse and irregular, there being patches of dark rock in the quartzite and tongues and zones of light quartzite penetrating into the iron-stained rock. The exposures suggest that iron-staining first took place along the fracture and in the rocks adjacent to it, and that this was followed by silicification along the same fracture, with the result that the siliceous solutions dissolved the iron oxide and redeposited it along the margin of the zone of silicification.

The small hill west of Kharsakhala is composed entirely of mixed quartzitic and iron-stained rocks, the exposures again being suggestive of the presence of a fracture.

The variable iron-staining of the rocks may be regarded as being due principally to the redistribution of iron of detrital origin by circulating ground-water. As a general rule the coarser-grained rocks are more stained than the fine-grained ones, and this suggests that porosity played an important part. The degree of sorting also influences the degree of iron-staining, for most of the iron oxides are found in the clay matrix of less well sorted sandstones. In the quartzites and other partly silicified rocks it is clear that the greater part of the iron has been removed and redeposited elsewhere. But the silicification is confined to the neighbourhood of Bur Wein, while the iron-staining is seen throughout the sandstones, and occurs in so many forms unrelated to the rock fabric that it is difficult to decide the factors controlling its formation.

The quartzites are generally pale brownish grey to buff, hard rocks which outcrop conspicuously on steep hillsides. They frequently show ripple-marks and faint colour lamination indicative of cross-bedding, and have variations in grain size comparable with those of the sandstones. Near the margin of the quartzite outcrop some variations in the degree of silicification are notable. On the southern slopes of Bur Wein some beds are more quartzitic than others, and locally beds become bouldery in outcrop, the harder silicified parts of the rocks standing out as large rounded blocks while the softer rocks have been weathered down.

The quartzites are frequently spotted with yellowish brown limonitic marks, but they are so similar from place to place that it is exceedingly difficult to distinguish one bed from another, and to make correlations over long distances.

Typical of the Bur Wein quartzites is specimen 23/266, from the southern part of Bur Wein. It is a hard, homogeneous, pale grey-brown rather fine-grained quartzite. In thin-section it is seen to be composed of interlocking quartz grains showing no obvious overgrowths. Intergranular material is confined to small patches of pale red-brown aggregates of chalcedony. Specimen 23/285, also from Bur Wein, is a rather coarser rock showing faint colour laminations due to cross-bedding. The thin section shows it to consist of interlocking quartz grains without intergranular material.

East of Kharsakhala and north-east of Dabasiti are several low hills consisting of pale quartzites with a yellowish brown sandstone at the base. The extension of silicification so far north of Bur Wein compared with the limited extent southwards is considered to be due to the prominent north-north-west-trending joints which cut the rocks north of Bur Wein. These are regarded as having acted as planes along which siliceous waters travelled more easily than through the comparatively unfractured rocks to the east, south and west of Bur Wein.

Narrow veins of quartzite are commonly seen in the north Mirril, Lolkurte, Jabich and Godobi hills south of Bur Wein. The veins are due to the silicification of sandstone along zones 2 or 3 mm. wide, are generally vertical, and form anastomosing networks striking in every case towards the centre of the Bur Wein dome structure. The localization of the general silicification in the vicinity of the Bur Wein structure and the evidence of the quartzite veins strongly suggests that the silicification is connected in some way with the folding at Bur Wein. If, as is suggested on p. 38, the Bur Wein structure were due to shearing movements in the crystalline Basement System rocks below the sediments, then it would be possible that siliceous hydrothermal waters could have been active during the movements, and have caused the silicification.

The Marehan sequence as a whole exhibits many of the features of cyclic deposition. In most cases each thick sandstone is cross-bedded only in its upper parts, where also there are numerous ripple-marked horizons. Below the cross-bedded sandstones are buff, or yellowish brown friable massive sandstones which are usually partly exposed and which grade upwards into more massive beds culminating in the cross-bedded sandstones. Above the cross-bedded sandstones the beds are usually flaggy and show little cross-lamination, and often have intercalations of thin hard buff or iron-stained siltstones.

Features such as worm-borings, ripple marks, cross-bedding and the occurrences of clay galls are indicative of sedimentation in shallow water, and cyclic deposition is often explained by assuming a steady rate of subsidence which is less than the rate of sedimentation. By this means the sediments are repeatedly built up nearly to water-level, where they are exposed to current action with the result that small-scale cross-lamination and current ripples are formed. The "swash" marks that are often seen associated with ripple-marked beds are due to wave action on the beaches, and indicate the temporary emergence of the sediments above water-level. The small-scale cross-lamination of siltstones has been attributed to "scour and fill" action (Shrock, 1948, p. 250). No undoubted terrestrial deposits have been observed in the Marehan sandstones but the rarity of argillaceous rocks and the absence of pebbles, conglomerates or breccias suggests that the detritus was obtained mainly from erosion of terrestrial sands.

3. History of Sedimentation During Mesozoic Times

The first sediments to be laid down in north-east Kenya were the Mansa Guda conglomerates, grits and sandstones which outcrop in the area to the west of the El Wak–Aus Mandula area. Subsidence during Toarcian times led to a marine incursion followed by the deposition of marine limestones. Shallow-water conditions prevailed during deposition and are indicated by the preponderance of shelly and oolitic bands in the Daua Limestone Series. Modern marine oolites are forming in shallow water, where vigorous movement of the water by tidal currents and waves keeps the nuclei in a constant state of agitation, and where strong evaporation is responsible for the concentration of dissolved salts. Some of the oolitic bands present in the Aus Mandula area show a remarkable degree of sorting, indicating prolonged agitation of the waters in which the oolites were forming. Associated with these oolitic bands are siliceous nodules. The presence of such nodules in the limestone lends support to the shallow-water origin of these sediments. Tarr, as quoted by Twenhofel (1939, p. 374), considers that the silica accumulates in shallow epicontinental seas in which, at the same time, calcium and magnesium carbonates are being deposited. The lack of intercalated sandstones or siltstones in the middle Jurassic limestones of this part of north-east Kenya would suggest that the sediments were formed in shallow seas of epicontinental character rather than close to shore-lines where sand bars and banks are often formed. A feature of the "lower" limestones of the area is the presence of intra-formational conglomerates which have been derived from lime-muds under subaqueous conditions, or even perhaps as a result of erosion of the muds after desiccation and induration. The debris is of local origin and has suffered little from transportation, and no evidence of brecciation due to slumping was traced. The presence of such conglomerates represents only minor breaks in deposition that mainly occurred soon after the transgression by the Jurassic sea. Only minor developments of intra-formational conglomerates were noticed in the higher part of the sequence.

A change in sedimentation from shallow-water marine to estuarine conditions is first indicated by the sandy limestones and interbedded siltstones and sandstones with numerous worm-borings of the Golberobe beds of Oxfordian times. A break in sedimentation was followed by the deposition of the beds on a gently sloping floor on which local slumping of siltstones took place. The sandstones represent sand-banks formed in shallow water. On such sand-banks supplies of oxygen and sunlight would be unlimited and permit such molluscs as the pecten *Meleagrinella* and mussels to flourish. The remains of a star-fish and a crustacean discovered in the same deposits point to the shallow state of the water at that time. The lower sediments in the Golberobe beds contain chert nodules and thin chert bands associated with calcareous sandstones. These siliceous beds were probably formed where fresh and salt water mingled (Twenhofel, 1939, p. 374) and are a further indication of the estuarine conditions prevailing at the time. It is estimated that nearly 200 ft. of Golberobe beds exist in the present area, which represents a much thicker sequence

than was seen in the area to the north, and it is apparent that the sandy beds thicken southwards, suggesting the presence of a shore-line not far south or south-west of the present area in Oxfordian times.

The unconformable relationship between the Golberobe beds and the Danissa beds has already been mentioned (p. 24). The base of the Danissa beds is tentatively placed in the Barremian stage, and there are thought to be no exposed deposits in the area representing Kimmeridgian to Neocomian times. In the area to the north-east, however, deposition of the Daua Limestone Series continued to the end of Kimmeridgian times and sedimentation continued without a break into the uppermost part of the Jurassic (Tithonian) with the deposition of the Mandera Series (Joubert, at the press). It is possible, therefore, that a full Jurassic succession was deposited in the present area also, but that it was eroded during a part of the lower Cretaceous, though members in the sequence higher than the Golberobe beds can be expected beneath the Cretaceous sediments. The Danissa beds overstep the upper members of the Daua Limestone Series in a south-westerly direction, but the angle of unconformity is probably less than one degree.

The Danissa beds have no conspicuous basal members in the present area, and they consist of thin siltstones and sandstones characteristic of deltaic sedimentation, and are generally similar to the Golberobe beds. Since no significant folding or faulting appears to have taken place during the period of erosion prior to the deposition of the Danissa beds, the topography was probably of low relief when they were laid down. The siltstones and sandstones were, therefore, probably derived partly from the erosion of sands washed from the area of Basement System uplands to the west and other pre-existing formations. The conditions of sedimentation were probably estuarine or locally fluvial, and the proximity of a land mass is suggested by the presence of plant remains in the rocks.

With the deposition of the more massive and coarser cross-bedded Marehan sandstones a change in the type of sedimentation is indicated. Uplift of the adjacent land mass may well have rejuvenated the drainage to a small extent, and tilting towards the east may have caused a complementary subsidence of the area of deposition. The result of such movements would be to increase the rate of sedimentation and the grade of the detritus being deposited. The presence of ripple-marked beds, worm-bored siltstones and ubiquitous cross-bedding suggests, however, that the sea remained shallow and that there were frequent emergences of the deposits above water-level. The type of sedimentation is also deltaic, though many of the sandstones lacking cross-bedding are probably littoral. The lenticular nature of the beds, and their lithological homogeneity suggest that they were deposited along a shifting shore-line which was backed by a hinterland of low relief, possibly covered by sand deposits and, nearer the shore, by sand dunes. Deposition was probably brought to an end by recession of the sea.

4. Tertiary

At Wel Merere and ten miles north of this water-hole on the Wajir–El Wak road the limestones are covered by a thin bed of unfossiliferous claystone which is considered to be of upper Tertiary age. The larger outcrop at Wel Merere, where there is a thickness of about 10 to 20 ft. of claystone, is exposed along the sides of a shallow water-course. The deposit is limited in extent and could not be traced for more than a few tens of yards on either side of the road, and is locally overlain by Recent kunkar limestone and soil. The more northerly of the two outcrops is also exposed on the road and in a shallow gully, but it cannot be more than a few feet thick. Bedding is absent in both deposits but a crude lamination is apparent at Wel Merere. The claystone which contains infrequent, small, sub-rounded particles of quartz and limonite measuring up to 0.25 mm. in diameter, has a characteristic deep yellow colour suggesting incipient oxidation of iron compounds (Milner, 1952, p. 376). A thin section of the claystone (23/292) shows that the rock is extremely fine-grained, and much of the material must have been in colloidal form at the time

of deposition. Allogenic sub-angular quartz grains, some turbid with argillaceous material, iron ore and/or carbonaceous material are set in a limonitic matrix, which under high powers of magnification is seen to have a crystalline structure.

The deposits are considered to have been laid down in hollows upon the Muguda surface (*see* Fig. 1) and were probably derived partly from higher ground to the north-west of the present area and deposited under fluviatile conditions (cf. Ayers, 1952, p. 16) and partly from the residuum after solution of limestones. The lack of grits and conglomerates associated with these claystones, both of which are found with comparable beds (the Banissa beds) in the Melka Murri area (Thompson and Dodson, 1958) suggests quiescent deposition. Pettijohn (1949, p. 16) in his discussion on the origin of transported clays considers that under conditions of peneplanation little other than ionic or colloidal solutions should reach the basin of deposition. It is likely that conditions approaching peneplanation existed during the formation of the clay in this area when iron hydroxides, produced by the weathering of iron-bearing minerals, and small particles were washed into the basins where precipitation of colloidal hydrated aluminous silicates and limonite was taking place.

The claystone deposits were probably originally of greater areal extent, but subsequent to deposition and induration have been eroded to something like their present size, and in recent times partly obscured by kunkar and soil deposits.

5. Pleistocene

(1) El Wak Beds

The central part of the El Wak basin is occupied by limestones and gypsite, the latter occurring in the centre of the basin in the vicinity of El Wak and extending eastwards into Somalia, and the former outcropping as a roughly annular zone of variable breadth about the gypsite. Parkinson (1920, pp. 12–14) refers to these beds as the El Wak limestones. In view of the presence of gypsite beds and the possibility of other, as yet unexposed, sediments, they are renamed the El Wak Beds.

The gypsite outcrops conspicuously as white powdery rocks which are overlain by thin light or dark superficial clays. Up to 68 ft. of gypsiferous rocks are exposed in the various wells of the El Wak basin and in no case have any interbedded sediments been observed. The surface outcrops are generally soft and porous and have a thin coating of microcrystalline gypsum. The matrix of one of the surface rocks, specimen 23/278B from beside El Koseye well, contains a high proportion of calcium carbonate traversed by narrow sub-parallel brown zones of gypsum crystals. The rocks from various depths in the well at this locality show a remarkable uniformity, and are composed of pale green microcrystalline gypsum mixed with small amounts of calcareous clay, and contain scattered, clear selenite crystals up to one inch in length. A similar rock, specimen 23/279, was collected from 60 ft. down in an old well at El Khalla. It is a pale greenish grey rock consisting of microcrystalline gypsum and is traversed by a band of coarsely crystalline, interlocking selenite crystals, some of which are up to two inches long. In small sink-holes on the gypsite the surface rocks appear light grey or buff with irregular sub-horizontal brown zones of microcrystalline gypsum. The upper parts of the gypsum deposit have the appearance of having been subjected to leaching with the result that they are poor in gypsum.

At the margin of the gypsite outcrop south and west of El Wak there is a shallow valley called Garsele, approximately 100 yards wide, with gypsum on the one side and limestone outcrops on the other. The floor of the valley or depression is occupied by soil containing numerous small limestones nodules, but no exposures of bed-rock were seen. This valley is regarded as a transitional zone between surface limestone and the upper parts of the gypsite body where the rocks are intimately mixed and probably very powdery, and being soft, are easily weathered away. Evidence for the mixture of limestone with gypsum is seen in several localities among the limestone outcrops, particularly near the margin of the gypsite. Thin irregular

vein-like bodies of brown microcrystalline gypsum traverse cracks and cavities in the limestone boulders, and on occasion form such a high proportion of the rock that the limestone occurs only as nodules in a base of gypsum.

The limestone exposures are generally scattered, the greater part of the ground marked Qc on the map being occupied by patches of reddish brown sandy soil. Numerous shallow depressions occur on the limestone surface, and are possibly sink-holes. The limestone outcrops as structureless rounded boulders with many cavities, frequently having the nodular and banded appearance characteristic of kunkar deposits. North-west of El Wak a few outcrops of flat or slightly domed limestone pavements occur. These appear at first sight to be like bedded limestones, but the undersides of the slabs are irregular and rest on loose boulders and pebbles of limestone surrounded by sand. Some of the limestones exposed south of Dila Mandera water-hole, on the Wegudud road, are pale reddish brown in colour and contain rounded fragments of buff limestone. These "nodular" limestones are uncommon in the El Wak area but are very like those seen near Korof Harrar and on the international boundary near El Alo. There can be little doubt that the El Wak limestones as exposed are kunkar deposits of superficial origin, although in some localities they can be seen to extend several feet below ground surface. There is no evidence of what lies below the surface limestones.

Dixey (1948, p. 10) regarded the El Wak gypsite as being an equivalent of the Merti beds and numerous other occurrences of sandstone and gypsiferous beds which underlie the flat plain of the eastern part of Northern Province. These beds he regarded as being of Tertiary age and as having been bevelled by the end-Tertiary erosion surface. The present writers, however, regard the El Wak gypsite as a Quaternary deposit, possibly late Pleistocene in age, for it is unlikely to have survived the climatic changes of the Pleistocene period without suffering considerable erosion. It is probable that the El Wak basin was deepened below the level of the Tertiary peneplain by river erosion during the pluvial phases of the Pleistocene and that as a drier climate supervened the south-east end of the valley, as it was then, was blocked by accumulations of sediments deposited by receding rivers. In this way a basin of internal drainage could have been formed in which lake-beds may have been deposited. As the lake dried up it is assumed that swampy conditions prevailed and were maintained over a long period by accessions of surface waters that carried in little detritus and by seepage from the water-table. Concentration of the waters by evaporation would lead to the precipitation of calcium carbonate and ultimately of gypsum with a tendency for the greater proportion of the gypsum to occur in the central part of the basin. To allow the accumulation of such thick beds of gypsum as occur at El Wak the cyclical process of precipitation and the addition of fresh supplies of water containing the sulphate radicle must have continued for a long time. The last phase, which probably took place in Recent times was the formation of kunkar limestone around the outer part of the basin of deposition. The possibility of there being Pleistocene lake beds below the gypsite cannot be ruled out, and it is possible that the water-table at El Wak is perched on an impervious bed below the gypsite.

(2) Stone Age Artefacts

During the survey a number of stone implements fashioned by Prehistoric Man were found lying on the surface at various localities, mainly in or near the hills. Those found between the hills two miles north of Muguda (23/215a-d) represent a stage of the Somaliland branch of the Stillbay culture and are, therefore, of an Upper Pleistocene age. Similar tools of this culture are commonly found in other parts of north-east Kenya. A flake, 23/318, from the Muguda area and another, 23/317, from the surface of the claystone six miles south of Aus Mandula, belong, however, to a different and earlier culture. Dr. L. S. B. Leakey of the Coryndon Museum, Nairobi, tentatively suggests that they might represent flakes of the Kenya Hope Fountain culture of Kanjeran age (*see* Leakey, 1950). Undoubtedly further

collecting will have to be carried out before the presence of this culture in this part of Kenya can be established. J. D. Clark (1954, p. 35) describes tools from Damero in north British Somaliland that bear a superficial resemblance to the Hope Fountain Culture. These tools are most interesting as they suggest a much more northerly distribution of the Hope Fountain culture than has previously been recognized in Africa.

6. Superficial Deposits

Ironstone and Laterite.—Ironstone boulders are to be seen lying in the soil in the Gegebe area and small ironstone pellets and pebbles are commonly found on the soil in the vicinity of Olia water-hole, near Aus Mandula and in the Gegebe area. The pellets and pebbles are chocolate-brown, range from 2 to 15 mm. in diameter, and have the onion structure that often characterizes concretionary bodies. The boulders result from the cementing together of the pellets by structureless ironstone, and occasionally they are as much as 2 ft. in diameter. The ironstone pebbles are sometimes derived by the weathering and disintegration of such rock, although it is likely that in many places they were never cemented together to form blocks. Similar ironstone pebbles were seen in the bed of a river one mile south-west of Bur Wein, where they occur in lateritic red soil, and on the surface of the claystone at Wel Merere. Ironstone pebbles were also seen cemented together by secondary limestone in deep grikes in limestone blocks north-west of Aus Mandula. The ironstone boulders and pebbles are probably remnants of a widespread lateritic surface deposit which was seen in many gullies.

Kunkar Limestone.—Kunkar limestone is widespread as a surface deposit on the low hills of Jurassic limestone in the central part of the area. It is exceedingly rare, however, in the south-west corner of the area where there are large numbers of limestone blocks in the soil. To the east of the area of limestone blocks and west, south, and east of Korof Harrar, kunkar limestone pebbles different from the superficial limestone found on or near limestone exposures are often seen on the soil. The superficial limestone is usually grey and occurs as flat slabby plates enclosing pieces of sedimentary limestone, whereas the pebbles of kunkar limestone resting on the soil around Korof Harrar are similar to the El Wak limestone, being nodular and having numerous vug-like cavities. Similar pebbles and small boulders occur at Boundary Pillar No. 11, where they consist of pale grey-brown nodules in a pale reddish brown matrix. Nodules are common in the pale clays filling depressions in the plain surface such as those at El Alo, Konton, Gorojub, Korof Harrar and along the Lugh Suri.

Pebble Sheets.—Pebbles composed of rounded fragments of arenaceous rocks form superficial sheets at several localities, most often on the slopes of the low hills formed of Golberobe beds, and more rarely among Marehan sandstone outcrops. Excepting pebble sheets at Romicho and in a low col in the Girima hills, they do not appear to represent deposits on a definable erosion surface, but are little travelled rock fragments that have been rounded by being swept down hillsides during torrential rainstorms. The lowermost Golberobe beds are closely fractured soft rocks, and comprise most of these pebbles, for the flaggy sandstones and siltstones above, and the more massive rocks in the Marehan Series, do not tend to weather into small fragments.

Other pebble sheets in the Girima, Willete and Bur Wein hills are probably far travelled, and consist of well-rounded, quartzitic and iron-stained hard rocks.

Soils.—Among the Marehan Series hills and covering the pediments sloping gently away from them is an expanse of yellowish and reddish brown sandy soil. On the hillsides, which are exposed to the action of small seasonal streams, there is only sand with little soil, which supports only a very sparse growth of thorn scrub. The sandy soils of the lower flatter slopes are sometimes underlain by hard, deep red-brown lateritic beds. The sandy soils rapidly absorb rain and only rarely

does one find swampy pans surrounded by thick bush such as are characteristic of the dusty soil of the plains.

On the flat ground in the south-western part of the area there are reddish brown dusty soils. These soils support a fair growth of grass and trees and have essentially developed by the weathering of limestone under semi-arid conditions. Some varieties are little more than yellowish brown dust, which changes to a glutinous grey-brown clay during the rains. These soils grade into buff, brown, grey and dark grey clays that have formed in depressions and which occur on the open plains at Katulo and Dida Guchi. These clays, which are fine dust when thoroughly dry, support a good growth of grass but few bushes and very few trees. They occur on open plains which provide excellent grazing after the rains, and where a few Somali tribesmen have attempted, with variable success, to grow millet. Small kunkar limestone nodules are commonly found in these soils and in the shallow wells at Konton gypsum crystals occur with the kunkar. The occurrence of kunkar limestone nodules and occasioned gypsite beds is characteristic of poorly drained areas with stagnant ground-water. The soil overlying the El Wak gypsum is of the same type and the occurrence of these soils in depressions, water-holes, stream-courses and on flat ground near and along the Lugh Suri suggests that they are formed from the red soils under swampy conditions, and that they indicate the presence of ground-water not far below the surface. The dark colour of the soil is probably due to the presence of alkali-humus compounds. Dark grey soils of this type are closely similar to "black-cotton soil" and like them have characteristic contraction cracks when dry.

7. Minor Intrusives

At the roadside, one mile north-east of Wel Merere, a single rounded boulder, three and a half inches in diameter, of meta-dolerite (23/295) was found. No igneous rocks were seen *in situ* in the area mapped, and it is likely, therefore, that the rock has been transported by either stream action or by human agency to its present position. Dolerite pebbles have been collected from the area west of the present area and it is probable that these and specimen 23/295, have been derived from intrusive rocks in the Basement System rocks which are found west of the Mesozoic sediments in north-east Kenya.

The rock, which is grey in colour, exhibits an excellent ophi-mottling relationship between the felspars and the ferromagnesian minerals. When examined in thin section it is seen to be highly altered. The larger felspars have a composition close to andesine (An_{32}), and enclose small prisms of pale green epidote and needle-like actinolite. Prisms of the felspar are often partly or entirely enclosed by the ferromagnesian mineral which is an amphibole. Associated with the alteration products is piedmontite, a manganiferous epidote, which displays characteristic colours and is usually pleochroic from pale pink to reddish violet. Accessory iron ore is present. Although no pyroxene was seen in the slide it is likely that original pyroxene is represented by the amphibole.

VI—STRUCTURE

Viewing the surrounding country from the top of the tower of the police fort at El Wak it is noticeable that one is surrounded on all sides by low hills of Marehan sandstone. This is due to the existence of a broad syncline elongated in a north-north-west–south-south-east direction whose axis passes near El Wak, and which can be traced as the El Wak syncline from Godobi hill in the east central part of the area and through the hills west of Sululuti, whence it is presumed to pass north-westwards into the Takabba-Wergudud area (Saggerson and Miller, 1957, p. 33). It controls the general disposition of the Marehan sandstone outcrops over a wide area and gives rise to the gentle north-easterly regional dip which is characteristic of them, since they occupy the south-west flank of the syncline over most of the area mapped (*see* Fig. 7).

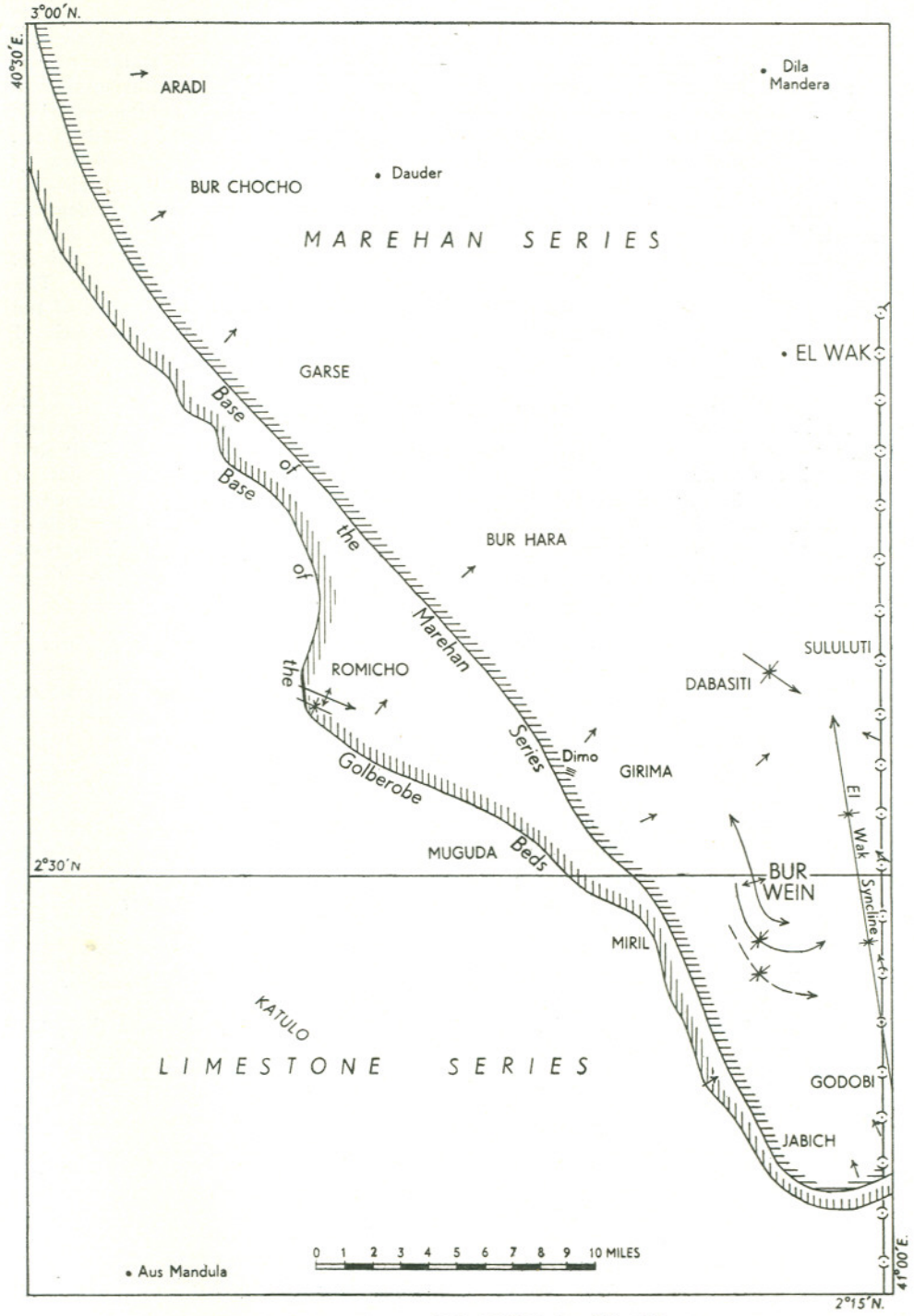


Fig. 7.—Structural map of the El Wak-Aus Mandula area.
(For Miril read Mirril)

Slight flexures of the flank of the syncline are noticeable at Aradi and Mirril, the flexures being synclinal and anticlinal respectively, with axes plunging gently to the east-north-east. Several folds of small wave-length give rise to locally high

dips, the more important being at Romicho, north-east of Dabasiti, and at Bur Wein. The Bur Wein folds comprise the most interesting structural feature of the area: the fold axes are curved, the principal structure being an elongated asymmetrical dome, the major vertical axial plane of which is situated in the Palehimemamallah erosion depression (*see* map of Bur Wein area, at end). At the northern end of the dome the axis plunges at four to nine degrees, with dips between 10 and 20 degrees in the flanks. At its south-east end the fold has an almost symmetrical closure, semi-circular in plan, the rocks dipping outwards at angles between 15 and 22 degrees. Immediately south of the dome is a complementary syncline which plunges to the south-east and, curving to the north-east, passes into a shallow monocline. This is paralleled again to the south by an indistinct synclinal-monoclinal flexure. The curvature of the fold axes is most marked and although this would be expected of the synclinal axes south of the dome, the reason for the curvature of the long axis of the dome is not known.

On the side of the road near Dimo water-hole are three small structures of an unusual kind (Plate IV (a)). They are indicated by elliptical outcrops of coloured siltstones, the long axes of the ellipses being 32 ft., 25 ft. and 12 ft. long and orientated east-south-east–west-north-west. In each case the beds dip inwards at angles between 27 and 56 degrees. The three structures are situated on a north-south line and are about 35 yards apart. Assuming the structures to be of tectonic origin—there may be some doubt in the case of one of them—they represent the culminations of three small basin-like folds. It is possible that they are due to localized intra-formational crumpling or collapse.

Jointing is common in the rocks of the area, but due to the poor exposure of the limestones most of the joint determinations were made on Marehan Series beds. The massive cross-bedded sandstones are cut by curved widely spaced joints which frequently contain coatings of iron oxide. In the fine-grained sandstones and flaggy siltstones the joints tend to be straight and closely spaced.

Many joints in the vicinity of Dabasiti and Kharsakhala hills are strongly silicified and iron-stained, while joints in the Bur Wein quartzites are clean, the iron oxides having presumably been driven out by the silicification. The orientation of the major joints in the Bur Wein area are shown on the 1:50,000 map of that area (at end) and poles to a number of joint planes measured throughout the Marehan Series outcrop are shown on Fig. 8. The figure shows that the greatest number of joints is orientated NE-SW, with minor but more diffuse concentrations about NNW-SSE and WNW-ESE. The figure does not include the large number of NNW-SSE and major joints which are plotted on the Bur Wein map. Were these joints added the ENE and WSW maxima in the diagram would probably dominate over the others. The NNW joint direction is parallel to the axis of the El Wak syncline and the joint planes are frequently silicified. The joints of the NE-SW direction are commonest in the north-western part of the area and the joint surfaces are frequently coated with iron oxide. This direction coincides with the direction of the faulting in areas further north (Joubert; Saggerson and Miller, 1957, p. 36). These joints may be interpreted as tension fractures sub-parallel to the direction of the compression that caused the folding.

Most of the structures in the area are due to post-Cretaceous folding which is thought to have been caused by the pressures directed on north-east–south-west lines. As indicated in Fig. 7 the apparent outcrop of the Golberobe beds widens and thins considerably but this may be due to original lateral variation or to the lack of discovery of overlying Jurassic beds. Previous to the deposition of the Marehan Series the Daua Limestone Series beds dipped very gently generally eastwards. The curvature of the fold axes of the Bur Wein structure may have been due to localized stresses causing movement along fractures in the comparatively rigid Basement System rocks below the sedimentary beds, or alternatively, to later compression in a different direction.

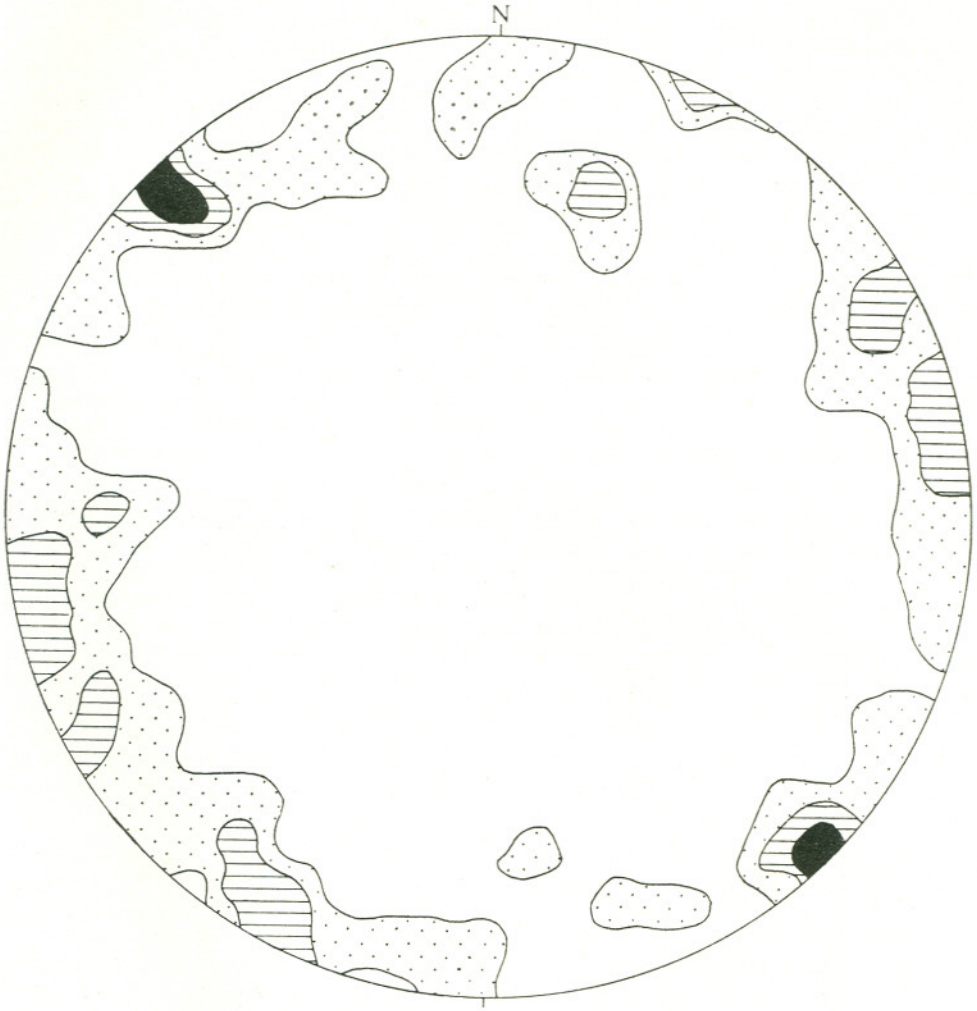


Fig. 8.—Stereogram (lower hemisphere, Schmidt net) showing poles to 133 joints, measured in the Marehan Series. Contour interval at 7, 6, 4 and 2 per cent per 1 per cent area.

VII—ECONOMIC GEOLOGY

1. Oil

The lack of indigenous fuel resources other than wood in Kenya has focused the attention of those concerned with oil exploration on the Mesozoic basin of north-east Kenya, of which the present area is a part.

The D'Arcy Exploration Co. Ltd., and the Anglo-Saxon Petroleum Co. Ltd., were granted an Oil Exploration Licence for a period of two years, with effect from 22nd February, 1937, covering an area of approximately 76,000 square miles in eastern Kenya* which included the El Wak-Aus Mandula area. The Exploration Licence was relinquished however, after rapid geological reconnaissance, with effect from 30th September, 1937,† and the area reopened to prospecting and mining with effect from 1st November, 1937.‡

The Kenya Oil Exploration Co. Ltd., who employed the services of T. Dejean, W. G. Serra and J. Parkinson, was registered as a company on 8th February, 1938, and later examined the same ground. An area of 3,065 square miles round El Wak and as far south as Bur Wein, was closed to prospecting and mining with effect from 29th July 1938,§ so that an application from the company could be considered. With effect from 18th October, 1938, an Oil Exploration Licence was granted to the company‖ for a period of two years. The licence was extended for a further period of one year from 17th February, 1940. The area was reopened to prospecting and mining in 1950.¶

No surface indications of oil were seen during the present survey, and data on sub-surface conditions are almost entirely lacking. Nevertheless, a general assessment of the oil potentialities can be made as a result of the survey, any further development being dependent on geophysical work and core-drilling.

The Jurassic limestones, which contain many beds rich in shell remains, are possible source rocks, and there may be shaly beds rich in organic remains that are unexposed at the surface. The Golberobe beds, and the dominantly arenaceous Marehan Series can, however, be ruled out as source rocks.

The possibility of parts of the Jurassic limestones acting as oil reservoir rocks is good. Porosity is likely to be low, but the limestones may have an additional permeability due to sub-surface solution along fissures and joints. The arenaceous parts of the Golberobe beds must also be considered as possible reservoir rocks, and in this connexion the possibility of higher beds, equivalent to the limestones above the Golberobe beds in the Takabba-Wergudu area (Saggerson and Miller, 1957, p. 10), occurring beneath the Marehan Series towards the centre of the El Wak basin, cannot be overlooked. The Marehan Series rocks cannot be considered as possible reservoirs, notwithstanding the fact that they are of suitable lithology, for there is no cap rock to preserve oil in them. Oil reservoirs are possible among the weathered rocks immediately beneath the sub-Golberobe beds and sub-Marehan Series unconformities, in particular the former, where erosion is likely to have rendered the limestones cavernous and full of fissures.

The likelihood of oil having accumulated in any of these possible reservoir rocks would be enhanced by favourable structures. Suitable structures can arise at faults, but faulting has not been proved in any part of the area. The remaining possibility for the formation of structural traps is folding, which is gentle except in Bur Wein dome and its associated folds, which are promising in this connexion. The Marehan quartzite can, however, be ruled out, either as reservoir or cap rocks, and the interest lies in the possibility of there being sufficiently impervious cap rocks

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* *See* Government Notice No. 167, dated 2nd March, 1937; *Official Gazette of Kenya,* Vol. XXXIX.

† *See* General Notice No. 1352, dated 25th September, 1937; *Official Gazette of Kenya,* Vol. XXXIX.

‡ *See* Government Notice No. 797, dated 15th October, 1937; *Official Gazette of Kenya,* Vol. XXXIX.

§ *See* Government Notice No. 613, dated 29th July, 1938; *Official Gazette of Kenya,* Vol. XL.

‖ *See* Government Notice No. 795, dated 27th October, 1938; *Official Gazette of Kenya,* Vol. XL.

¶ *See* Government Notice No. 549, dated 16th May, 1950; *Official Gazette of Kenya,* Vol. LII.

in the underlying Danissa beds or the Golberobe beds. Should the solutions which brought about the silicification of the Marehan sandstone in the Bur Wein area prove to have been deep-seated in origin, the possibility of there being an impervious cap rock is much reduced. The origin of the siliceous solutions is, in fact, unknown, but the occurrence of silicification in the Bur Wein folds somewhat reduces the oil potentiality of the structure.

The oil potentiality of the El Wak area as a whole, and of the Bur Wein area in particular, cannot be ruled out, but further geological information is required to enable a more complete geological picture to be drawn, and thus to allow a more conclusive assessment of the oil possibilities. Some of the additional geological information required can only be obtained by core-drilling, which should be planned to decide the following points—

(1) the occurrence of sediments younger than the Golberobe beds below the Marehan Series in the neighbourhood of El Wak;

(2) the thickness and succession of the lower part of the Daua limestone series which is poorly exposed in the southern part of the area.

The conclusions drawn from the survey of the present area must, in any case, be considered in conjunction with the results of the mapping of the remainder of north-east Kenya (Saggerson and Miller, 1957; Thompson and Dodson, 1958; Thompson and Dodson, Bur Mayo-Tarbaj area; Joubert, Mandera area).

2. Gypsum

The gypsum deposit at El Wak occupies an area of approximately 27 square miles. The gypsum, usually in the form of pale green selenite crystals, is present in a soft, earthy, fine-grained aggregate of gypsum and clay. Many of the wells which have been sunk in the El Wak area indicate that the gypsum extends downwards to at least the water-level which at the time of survey varied in different wells between 60 ft. and 72 ft. and it is probable that the gypsum continues well below this level. The exposed gypsum in the wells is very uniform in character with no limestone impurities. Near the surface, where it has been altered by downward percolation of surface waters which have imparted a banded appearance in the upper few feet of the deposit, it is more massive and stained pale to dark brown. A chemical test made on a large block of rock taken from a depth of 60 ft. in a new well being dug five miles east of El Wak, gave:—

	%
Gypsum	74.7
Insoluble	25.3

Analyst: W. P. Horne.

This analysis is based on the presumption that the total calcium content in the rock is required to form the sulphate and not the carbonate. A second analysis of a gypsum specimen, 23/278, from El Koseye at El Wak gave:—

	%
CaO	24.36
SO_3	37.81
Acid Insoluble	1.77
Loss on Ignition	24.22

Analyst: Mrs. R. Inamdar.

The gypsum content of this specimen was determined by solubility in hot water as 78.29 per cent.

In the opinion of the writers the amount of gypsum available is approximately 2,000,000,000 short tons. For the purposes of the calculation of this figure it was

assumed that 14 cubic feet of gypsiferous rock is equivalent to one short ton (the specific gravity of the rock was determined as 2.2), that the average depth of the deposit, excluding an overburden of 3 ft., is 50 ft. and that the rock contains 75 per cent of gypsum. Further reserves probably exist in depth and also beneath the kunkar limestone which completely surrounds the deposit.

The deposit could be easily worked by open-cast mining, particularly with the use of mechanical excavators, and the overburden is easily removable and would present little difficulty. Although the deposit is situated on the main road between Mandera and Wajir the great distance to the populated centres such as Nairobi (515 miles), the presence of much more accessible deposits in both Kenya and Tanganyika, and the competitive price of imported gypsum (gypsum from Cyprus was priced at Sh. 150 per short ton c.i.f. in 1955) would prevent the economic removal of the El Wak gypsum at the present time.

Gypsum has many uses of which the most important is its action as a "retarder" in Portland cement. In addition it is used in the manufacture of fertilizers, insecticides, textiles, plaster of Paris, moulds, paints, building materials, and also in the brewing industry, as a filler for paper and as a fluxing agent. A large plant for the production of ammonium sulphate in India uses gypsum as a source of sulphate.

3. Limestone

Analyses of four limestones from the area mapped are given in the following table:—

	1	*2*	*3*	*4*
	%	%	%	%
SiO_2	3.29	1.44	2.71	3.52
R_2O_3	1.31	0.17	0.03	0.87
MgO	0.12	0.12	0.17	0.06
CaO	50.14	55.00	51.80	53.19
Loss on Ignition ..	42.07	42.65	41.00	41.70
P_2O_5	0.47	0.20	0.29	0.37
	97.40	99.58	96.00	99.71

1. Specimen 23/242, calcite mudstone, Muguda.
2. Specimen 23/294, shelly limestone, 6 miles S. of Gegebe.
3. Specimen 23/307, oolitic limestone, Aus Mandula.
4. Specimen 23/313, coquinoid limestone, Gorojub.

Analyst: Mrs. R. Inamdar.

These limestones are remarkably free from magnesium oxide while other impurities are not present in high percentages, particularly in the case of specimen 23/294. The limestones could be used in Portland cement manufacture but their location, far from the main centres of population, makes the likelihood of economic production very remote at the present time. The best places for quarrying would be the small hills near the main road, 30 miles south of El Wak and round Aus Mandula and Wel Merere. An inferior limestone is provided by the kunkar that surrounds the gypsum deposit at El Wak and which was used in conjunction with the gypsum for the construction of the El Wak police post.

4. Water

Water is the most valuable mineral to the inhabitants of the area, and is in short supply at the present time. Such wells and water-holes as there are were made many years ago by the previous inhabitants of the area—the Galla and the Boran, people who displayed considerable initiative and skill in exploiting the meagre water-resources at their disposal. The shallow wells at Konton, Korof Harrar

and Aradi, as well as the more elaborate ones at El Wak, were made by these people. They also constructed the water-holes at Dauder, Korof Gi and Bura Ela. Since the construction of these wells and pans, little has been done to improve or maintain existing water-supplies. A brief hydrographic survey was carried out in 1943, however, and some of the recommendations made as a result of that survey (Dixey, 1944) are being implemented at the present time in adjacent areas. A comprehensive hydrological survey of the Wajir wells area and the Dugudia clan area was carried out in 1952 (Bestow, 1953).

The only perennial water in the area is found in the wells at El Wak. There are in use some ten main wells (shown on the map) which are approximately 75 ft. deep, with the water-level at 60 to 72 ft. below ground-level, and numerous others that have been abandoned due to their collapse. Water is drawn from the wells by means of ropes and giraffe-hide buckets containing 1½ to 2 gallons and, when a chain of men is formed, water can be drawn at a rate of up to 1,500 gallons per hour (Dixey, 1944, p. 5). The water from the wells is slightly turbid, smells of hydrogen sulphide and has an unpleasant taste. It is essentially a solution of calcium sulphate as is indicated by the following analysis:—

	Pts. per 100,000
Alkalinity (as $CaCO_3$):	
Carbonate	nil
Bicarbonate	21.1
Ammonia:	
Saline	0.008
Albuminoid	0.032
Oxygen absorbed:	
4 hrs. at 80° F.	1.12
3 mins. at 80° F.	0.63
Cl	19.1
SO_4	178.6
NO_2	nil
NO_3	nil
Ca	66.0
Mg	8.7
Fe	0.02
SiO_2	6.8
Total hardness	200.7
Permanent hardness	179.6
Temporary hardness	21.1
Total solids	336.0
F	0.1
H_2S	2.5

Analyst: Government Chemist, 11th August, 1956.

The next most important group of wells is at Korof Harrar, where several shallow broad wells have been sunk into reddish brown clay soil. These contain water for several months a year, but are unlikely to be perennial. Similar broad wells occur at Konton and Aradi, but are partly fallen-in and do not appear to be in regular use. Water-holes of varying sizes are widespread, the main ones being at Dimo, Garse, Rahmu, Bura Ela, El Alo, Italo, Dauder, Ademeleja, Aradi, Wel Merere and Dila Mandera, but they are quickly depleted by the large herds of cattle and camels that use them. Many small natural pans are used throughout the area, where clay provides an impermeable floor. They are, therefore, rare where the soils are sandy. Water also often accumulates in small pools in rocky gullies in the Marehan sandstone hills, and provides a short-lived water-supply.

During the dry months the Somali and their stock remain near the El Wak wells, though some migrate to the wells of the Wajir group and others move to wells in the area to the west, near Tarbaj. As soon as the rains begin they move to fresh pasture far afield and obtain their water requirements from pans. Since the rainstorms are usually scattered the Somali have developed great skill in observing their courses and can often predict which pans will contain water. When, with the onset of dry weather, the pans and shallow wells are exhausted, they return again to the wells. Owing to the severe over-grazing that is characteristic of the areas around permanent water and the larger water-holes, the Somali frequently load their camels with large wooden water containers and lead small herds of stock into the bush for limited periods to find better grazing.

As summarized by Dixey (1944, pp. 6–7), the principal need in north-east Kenya is for many more scattered water-sources, so as to make use of a wider grazing area in order to reduce over-grazing. The wider provision of water-supplies would also alleviate the hardships suffered by the Somali in years of drought, when the meagre supplies fail over large areas and many cattle, sheep and goats die as a result. The shortage of water, and the associated shortage of grazing in certain areas, is also of importance in so far as clans inhabiting drought areas are forced to intrude into the territory of other clans, or even to cross into Somalia to find water, with the result that inter-clan fighting and raiding break out.

The only measures so far undertaken in attempts to improve the water-supply of the area are the drilling of three bore-holes. One, No. 160, on the road a few miles north of Wel Merere, was completed late in 1931. It was drilled to a depth of 360 ft., and water was struck at 350 ft. and rose to 260 ft., the yield being 1,920 gallons per 24 hours. Two others were drilled near the main road south-east of Muguda and at Dabasiti (No. 169 and 178). They were drilled to 195 and 350 ft. respectively and neither struck water. These facts, taken with the results of other bore-holes drilled in sediments in Northern Province indicate that the water-table is deep, and that holes must be drilled to at least 500 to 600 ft. to be conclusive (Dixey, 1944, pp. 9–10). It is the writers' opinion that drilling to such depths is likely to be unjustifiable economically, in view of the doubts concerning the availability of fresh ground-water, for, of the five deep bore-holes drilled into sediments in this part of the Colony, two have yielded saline water (Dixey, 1944, p. 10) while the majority of the shallow holes were either saline or dry.

The possibility of the construction of "tanks" or excavations for storing water below ground-level, was discussed by Dixey (1944, pp. 10–14), who concluded that tanks, if constructed in considerable numbers, could alleviate water-supply difficulties over large areas. The shallow wells at Korof Harrar and Konton could be called tanks, for they represent accumulated surface water rather than ground-water. These excavations are, however, much too small at present to yield an adequate supply and are fed by surface water from only a small area of ground. Some of the wells may be maintained by short-lived perched water-tables. Excavations of this type could be converted into tanks for the storage of rain-water by enlarging their size and by providing channels and sloping banks to drain surface water into the tanks. It is considered that this could be carried out with success on selected wells at Korof Harrar and Konton.

Improvements in existing water-holes and the construction of new ones on selected sites is another method for augmenting water-supply. The principal factors causing the early exhaustion of water-holes are the high rate of evaporation, which may reach one inch a day or more in the dry season, and the large numbers of stock which crowd into the water-holes. The first factor can be reduced by converting the water-holes to tanks with a large ratio of volume to surface area, and the second can only be alleviated by the provision of a large number of water points. In an area of sporadic and scattered rainfall tanks must be provided with an adequate catchment area. This can be provided on level ground by the use of a bulldozer to scrape out a broad shelving surround to the tank. On sloping ground the material taken from

the enlargement of the hole could be used to make an embankment on the down-slope side of the hole so as to increase its storage capacity. Perhaps the most important factor in choosing sites for "tank" construction is the nature and porosity of the soil. All the existing water-holes have a more or less effective clay seal to prevent the downward seepage of water and the best water reservoirs are found in areas of clay soil.

At present the main area of grazing during the drier months is within 15 miles of El Wak and, though this area is liable to severe over-grazing each year, fortunately the grass on the dark clays overlying the gypsum recuperates to a certain extent during the rains, when the stock is further afield. A large area of fair to good grazing which is not fully used lies along the banks of the Lugh Suri and on the Katulo and Guchi plains. Along the river the soil, which is probably of considerable depth, becomes a brown clay when wet and numerous tanks could be constructed in it with a good expectation of success. The most promising sites for tanks would be in the beds of some of the small tributaries, where a small but adequate catchment area is assured.

It is probable that an earth dam across the Lugh Suri would not be successful, for the river has not been seen to flow even after heavy rains. The back-cotton soil along the river course absorbs water to a great extent. In any case, were there any regular flow during the rainy seasons, there would be evidence of it in the form of sand washed out of the soil and of alluvial deposits in the river-bed. Nor is it likely that dams on any of the streams in the hills would be successful, for the porous sand common among the hills would not be suitable for dam construction.

The best and most economical means of improving the amount and distribution of the water-supplies of the area are to improve and extend the life of existing water-holes by excavating them and providing a larger catchment area for them and by constructing new ones in suitable places. The need for a stock route along the general line Mandera–El Wak–Wajir is becoming felt, and to enable a route to be established, water-supplies of an improved kind will have to be provided.

The water-hole at Wel Merere, situated as it is at the base of a slope of claystone, could be considerably expanded by judicious clearance of bush and by leading some of the local drainage channels into the depression. Olia water-hole is also by the main road, some five miles north of Aus Mandula, and is capable of improvement by deepening, although the presence of limestone blocks in the soil nearby may make excavation difficult.

Further north again are the open plains of Katulo, where no water-holes exist, but where one could be made in the brown clay soil. The plain is flat and any "tank" constructed on it would have to be surrounded by a wide drainage shelf. Alternative sites are on the south bank of the Lugh Suri where a gentle slope could be utilized, together with shallow drainage channels, with embankments to lead water into a tank backed by a low wall. Several such tanks could be built along the clay soil slopes of the Lugh Suri valley and these would give access to a large area of good grazing.

By the roadside north-west of Waldire and south-east of Muguda is a small swampy depression that receives run-off from the road, which slopes gently down from the north to this point. This depression holds pools of rain-water, and could be enlarged and channels cut to lead flood water from the road into it.

In the north-western part of the area the Aradi, Bura Ela and Dauder water-holes could all be developed on the lines suggested, but Ademeleja and Dila Mandera holes are not worthy of attention, for the first is on kunkar limestone and does not appear to hold water well, and the second is on sandy soil and is consequently very short-lived also. The Dimo water-holes are widely used after the rain and the water does not last long as a result. The shallow valley about half-a-mile south-east

of Dimo water-hole receives drainage from a rocky slope to the north. A tank could be constructed at a point in the lower part of the valley where the soil is suitable.

The construction of tanks is not likely to provide perennial water, however, unless they are extremely large and deep. There will be a necessity, therefore, for the provision of a permanent water-supply in the form of wells or bore-holes, in spite of the unfavourable conditions in the central and southern parts of the area. The most promising sites for bore-holes are probably along the Lugh Suri, where the underlying limestones are likely to be fissured by the movement of ground-water, and where the depth to ground-water is slightly less than elsewhere nearby.

A further area that should be considered is the dip-slope of the Daua Limestones west of Aus Mandula and Wel Merere. A marl bed in the lower part of the succession in the Tarbaj area is possibly a relatively impervious horizon and a local water-table may exist on it. The depth to the marl bed is, however, over 1,000 ft. at Aus Mandula, though a few miles west of Wel Merere its depth is much less.

Apart from the area around El Wak, where the water-table is accessible to wells, the ground-water is probably too deep for successful wells to be dug. "Perched" water may, however, be found locally and in this connexion a geophysical survey of the Korof Harrar and Konton well groups might be fruitful. It is possible that "perched" water may be found in the clays of the flat-lying Katulo plains and here again geophysical methods might be employed with profit.

It is understood that a rain-water storage tank was constructed in the police fort at El Wak, but that the tank was found to leak. Rain-water run-off from the roof of the fort would provide approximately 40,000 gallons of water in a year of average rainfall, and this is sufficient to provide three gallons per man per day for the occupants of the fort. In view of the unpleasantly saline nature of the well-water at El Wak it is suggested that the provision of a rain-water supply would be a great boon to the Police stationed there. Similar rain-water storage tanks would be advisable for any new building erected in the area.

Summarizing, it is considered that the first steps in ameliorating water-supplies in the El Wak–Aus Mandula area should be to develop existing water-holes and wells and to provide additional ones, particularly in the area Lugh Suri–Katulo–Guchi–Aus Mandula–Gorojub–Wel Merere. Since the storage of surface water is unlikely to provide reliable perennial supplies a number of bore-holes and wells will be necessary. The sites for improved or new water-supply points should be at least ten miles away from inter-clan and international boundaries, to minimize trespass of one clan into the territory of another. Where mechanical excavators and bulldozers are employed motorable tracks will be constructed to outlying water-supply points. These tracks, if maintained, would be valuable for the maintenance of the supply points and for the administration and policing of the area.

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