



COLONY AND PROTECTORATE OF KENYA

GEOLOGICAL SURVEY OF KENYA

GEOLOGY
OF THE
TAKABBA-WERGUDUD AREA,
MANDERA DISTRICT

DEGREE SHEET 15, S.W. and S.E. QUARTERS

(with two coloured geological maps)

by

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and

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Geologists

With an appendix on fossils collected in the area.

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FOREWORD

The report on the Takabba-Wergudud area is a revision of about one-sixth of an area in the north-east corner of Kenya that was mapped in reconnaissance style with E.C.A. aid a few years ago. The work then accomplished was, by force of circumstances, not of the standard normally attained by the Geological Survey of Kenya, and insufficient in detail to provide adequate information for the appraisal of the possibility of finding oil within the Mesozoic sediments that occupy that part of the Colony. Revision mapping has now been carried out over almost the whole of the area, and the present report is the first of a series that will give a more detailed and more accurate account of its geology. A final evaluation of the possibility of the occurrence of oil deposits cannot, however, be made until the reports on the various sections of the whole of the area are available. Should a possibility become apparent, its translation into more practical affairs would undoubtedly require much further work, particularly geophysical investigation and shallow, or even deep, drilling to determine successions and structures.

The mapping in the Takabba-Wergudud area has led to the unravelling of a geological puzzle that has misled all previous investigators. Since Glenday first made a rough map of the area in the 1920's, it has been known that there is a series of Jurassic sediments, including much limestone, and an overlying series with massive sandstone bands. That apparently simple succession has been read in various ways, even to the extent of supposing that the apparently overlying sandstones were in fact older than the limestone series. The present work has shown that the sandstones with an underlying mainly silty set of beds are of Cretaceous age and overlie and transgress the limestone series, which is proved by fossils to be of Jurassic age. At the western limit of transgression as now seen by accident of erosion, some sandy beds intercalated in the limestones underlie the silty beds associated with the sandstones, and bear some general resemblance to them, so that errors of mapping in reconnaissance are understandable. Contained fossils, however, prove that the sandy beds are Jurassic, while the silts above them are Cretaceous. Search has revealed that at other localities the sandy beds can be found intercalated in the limestones.

Nairobi,
5th April, 1955.

WILLIAM PULFREY,
Chief Geologist.

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MAPS

Geological map of the Takabba area (Degree sheet 15, south-west quarter) Scale 1:125,000	at end
Geological map of the Wergudud area (Degree sheet 15, south-east quarter) Scale 1:125,000	at end

ABSTRACT

The report describes an area of approximately 2,400 square miles extent north-west of El Wak in the Northern Province of Kenya, bounded by latitudes 3° 00' and 3° 30' N. and by the 40th and 41st meridians east of Greenwich. The surface of the area consists largely of the end-Tertiary peneplain from which rise several hill masses and isolated hills on which can be seen the remains of bevels of three earlier peneplains, the highest being tentatively correlated with the end-Cretaceous surface of Central Kenya.

In the west, Basement System gneisses and "granites" outcrop and to the east are unconformably overlain by limestones, siltstones and sandstones of Jurassic to Cretaceous age, representing depositional environments transitional from shallow-water marine to fresh-water terrestrial. Subsequent to the deposition of the Mesozoic sediments the area was gently folded and block-faulted.

The possibility of finding oil is discussed.

GEOLOGY OF THE TAKABBA-WERGUDUD AREA, MANDERA DISTRICT

I—INTRODUCTION

The area described in this report is the south-west and south-east quarters of degree sheet 15 (Kenya Colony) bounded by latitudes $3^{\circ} 00'$ and $3^{\circ} 30'$ N. and longitudes $40^{\circ} 00'$ and $41^{\circ} 00'$ E., having an area of approximately 2,400 square miles. This sparsely populated portion of the Northern Province of Kenya falls in the Mandera administrative district.

The geological survey was carried out between the months of January and July, 1953, with the object of providing more detailed information concerning the rock formations and their structure with regard to the possibility of finding oil. The work is an extension of that done by American (E.C.A.) geologists whilst attached to the Mines and Geological Department, whose findings were published in Geological Survey Report No. 22 (Ayers, 1952).*

Maps.—Mapping was based on aerial photographs on a scale of approximately 1:30,000, being controlled by a plane-table survey based on three astronomical points whose co-ordinates were supplied by the Survey Department of Kenya. The existing topographical maps of the area—the El Wak Sheet, NA373 (1:500,000), published by the East African Army Survey Group in 1940, and its reprints—are only approximate in detail and could not be used in the production of the geological map. Geological data were plotted on kodatrace overlays of the aerial photographs, final reduction to a scale suitable for printing being made by eidograph. Form-lines are based on numerous barometer readings and, therefore, are approximate only.

Owing to lack of suitable ground control some distortion of the maps along their margins has resulted and it has not been possible to adjust the errors in order that topographical and geological detail should correspond with that of more recently prepared geological maps of the areas to the south.

Communications.—The north-south Wajir-Derkali road passes through the western half of the area and is intersected at Takabba by the Buna-Takabba-Wergudud road. At Wergudud the latter joins the north-south El Wak-Rahmu road which skirts the foot of the Danissa and Garri hills. At Gamul a track, now being rapidly overgrown, branches off to Danissa. These roads have been cut through the bush and are little better than motorable tracks which become impassable during heavy rains. The lack of development in the area has not warranted any great expense being outlaid in the past for the upkeep of such communications. In the west near Takabba the roads cross red and grey soils of which the latter provide the worst foundation and quickly form pot-holes nearly two feet deep. Experience has shown that, where possible, roads should be built on the red sandy soils, when much faster communication would be provided than exists at the present time. Small towed graders could be usefully employed for the maintenance of the roads, at probably less cost than would normally be the case if gangs of Africans were used for such purposes.

Camel tracks are numerous throughout the area but particularly so in the eastern part of it, where the more hilly regions provide good grazing for camels and goats during and after the rainy periods of the year. Most of these tracks cannot be used by motor vehicles although during the present mapping it was found possible to drive a Land-Rover along the larger ones thus saving the cutting of miles of track. A motorable track had to be cut, however, through the bush to the southern Danissa hills, from the Wergudud-El Wak road. Foot *safaris*

*References are quoted on p. 40.

using camel transport are considered less suitable than track-cutting for motor vehicles, as to travel away from base camps for an extended period would require large quantities of water and numerous camels to carry it, the latter never being available when required.

Climate and Vegetation.—Rainfall occurs mainly in the periods April–May and October–November, corresponding to the change in the monsoons. Occasional showers are experienced in the period between May and September as occurred in 1953, the showers being generally light and of short duration. No meteorological records have been kept in the area but the following table gives temperature and rainfall statistics for stations nearby.

RAINFALL STATISTICS OF NORTH-EAST KENYA FROM THE ANNUAL REPORT OF THE
EAST AFRICAN METEOROLOGICAL DEPARTMENT

Station	Altitude (feet)	Years Re- corded	Mean Max. Temp.	Mean Min. Temp.	Total Rainfall in 1952	No. of Rainy days	Average Total for Period	Heaviest Single Rainfall
Wajir	800	26	92.3	71.7	9.44	16	8.58	3.15
El Wak	1,200	1	—	—	13.21	—	—	—
Mandera	1,085	11	93.1	75.5	3.92	15	8.60	1.23
Melka Murri	3,300	1	—	—	5.21	—	—	—
Moyale	3,650	33	80.8	63.2	23.62	77	26.20	2.65

The Takabba–Wergudud area lies approximately in the centre of the group of stations quoted, but the figure for rainfall at El Wak probably most closely approximates that for the area.

During the hot season, January–March, mid-day shade temperatures above 100° C. have been reported although the mean maximum temperature is a little below that. In the period June–July much lower temperatures are experienced, the cloud-cover being as much as 75 per cent for days on end, causing greatly reduced temperatures during the day and correspondingly lower night temperatures.

The vegetation is mostly thick low thorn scrub with little open grassland except near dry river-courses and at the foot of hills, where occasional large trees grow, as at Danissa. Vegetation on the hills is noticeably less dense and traversing is consequently easier than on the plains, where a compass must be used to avoid excessive wandering as the surrounding bush hides the hills. During the rainy season grass covers most of the eastern part of the area, which is then used for grazing by the local population.

Population.—The area supports a sparse population which centres itself on the El Wak wells, south of the area, and on the water-holes at Takabba. In the hot season a few people use the scanty water supplies at the latter place, the others congregating at El Wak. During and after the rainy seasons the nomadic population spreads northwards into the hilly region where rock pools and new grass are sufficient to support the people and their herds of camels, cows and goats for a few months.

The indigenous population belongs to the Gurreh tribe, which has half Somali and half Boran blood and now speaks Ki-Boran. The tribe has been diluted by generations of Shegats, i.e. people from other tribes (Boran, ex-Arab slaves, etc.), who were originally assimilated into it in order to fight its battles. Originally the Boran spread as far east as Mandera but gradually they have been pushed westwards, the Gurreh taking over their grazing lands in this part of north-east Kenya. In recent years the Gurreh themselves have found it necessary to move further westwards as the Somalis to the east have been infiltrating into their country. The Administration has been forced, therefore, to demarcate a line, Derkali–Takabba–Beloble–Wajir–Garissa, west of which the Somalis are not permitted to penetrate.

The country around El Wak and Mandera, including the present area, has always been subject to raids by tribes from north of the Kenya border, as it is on the direct route from Ethiopia to Somalia where camels and goats are bought and sold.

Rock Exposures.—Almost all the rock exposures in the area have positive topographic expression and only a single stream section was seen during the whole survey. The area west of the limestone escarpment consists of a sandy plain interrupted by a few isolated hills of Basement System rocks, while the younger sedimentary succession to the east is poorly exposed and only seen in four ranges of hills, viz. Owork-Dukdera, Golberobe-Warido, Ogar Wein-Sagari and Danissa-Garri.

Acknowledgments.—The assistance given by various members of the Administration at Isiolo, Wajir and Mandera is gratefully acknowledged.

Invaluable assistance has been provided by Mr. W. N. Edwards, Keeper of Geology at the British Museum (Natural History) and by Dr. L. R. Cox, Mr. L. Bairstow, Dr. H. Dighton Thomas and Mr. S. E. Ellis of his department, in the examination, identification and dating of the fossils collected during the survey. The writers express their gratitude for the help given.

II—PREVIOUS GEOLOGICAL WORK

Although travellers entered the Northern Province before the beginning of the twentieth century, the first published reference to El Wak, which lies close to the southern border of the present area, was made by Lieutenant L. Aylmer (1911, p. 293). He mentions the barren country west of the Juba river and refers to the rocky hills northwards towards the Abyssinian border. No actual reference is made to localities in this area, but as Takabba is marked on his map it is not unlikely that he visited the wells there to replenish his water supplies.

A few years later, in 1914–15, J. Parkinson visited the Northern Province whilst conducting a water supply survey for the Government of Kenya, and showed on the evidence of ammonites collected at Kukatta on the Juba river* that some of the sediments are of Upper Oxfordian age. His results were published in 1917 and 1920.

In 1923 V. G. Glenday published a short account of part of the Northern Province in which he mentioned the gneiss monadnocks and described the sediments as a south-easterly dipping sequence of limestones and sandstones. He suggested that oil investigations should be carried out between Buna and the Juba river.

H. G. Busk and J. P. de Verteuil, when carrying out a reconnaissance oil survey of the Colony, made a rapid examination of north-east Kenya in 1937, paying particular attention to the Mesozoic sediments. They considered the limestones to be younger than the sandstones, the latter having been islands in the Jurassic sea in which the limestones were formed. The sandstones, they thought, were equivalent to the Duruma sandstone of the Kenya coastal succession. The escarpments in the Wergudud area were believed to be due to Rift faulting and a diagram subsequently published in a paper by Busk (1939, p. 218) shows a "Rift Valley" passing just east of the present area, the Wergudud escarpments being associated with faulting on the western flank of the southern end of the rift.

In 1943, F. Dixey carried out a hydrographical survey of Turkana and the Northern Province, the geological results of which were published in Report No. 15 of the Mines and Geological Department. He made traverses along all the then existing roads in the present area and suggested a succession, which is given in the table below.

During 1950 and 1951 F. Ayers, an E.C.A. geologist with the assistance for about three months in each case of R. G. Murchison, also an E.C.A. geologist, and A. O. Thompson

*The Juba river was at that time the eastern boundary of Kenya.

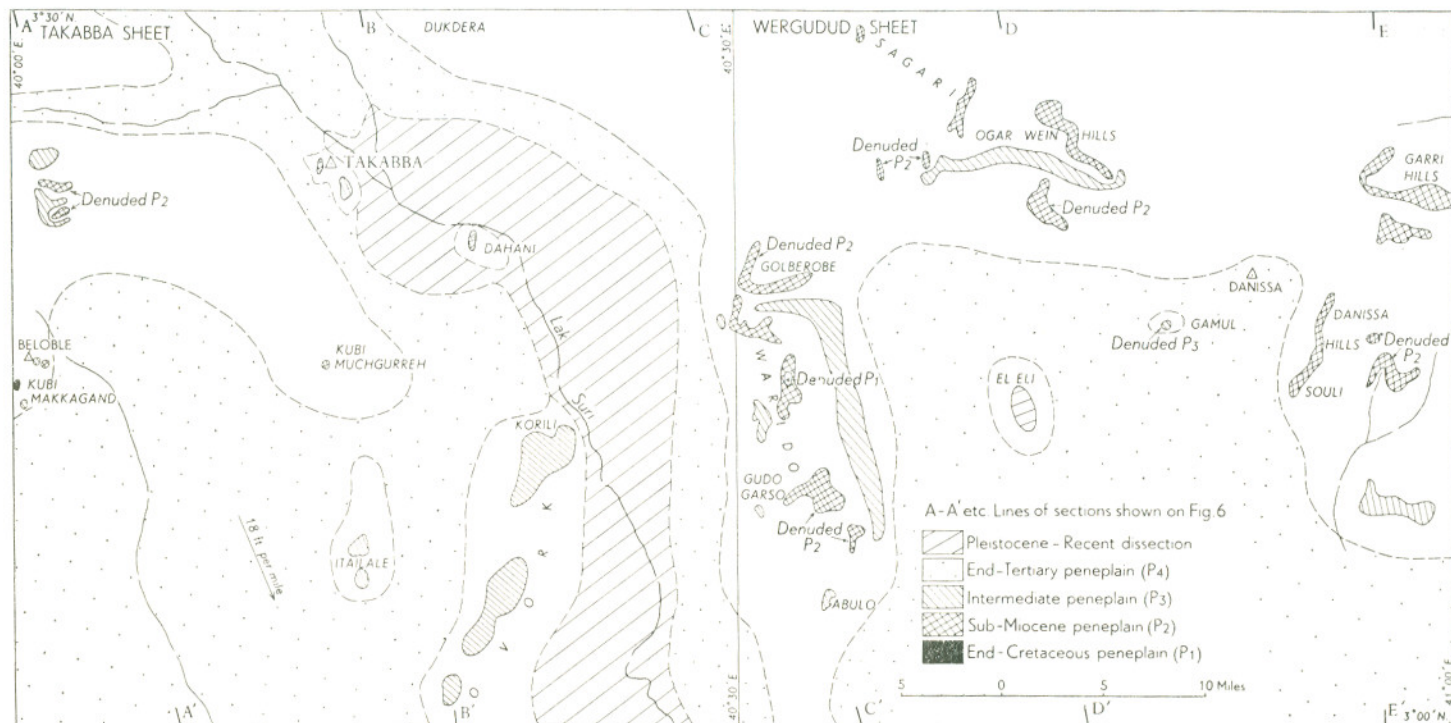


Fig. 1.—Physiographical map of the Takabba-Wergudud area.

The topography has reached the "old age" stage in the semi-arid erosion cycle, the peneplained area now far exceeding the area of the hill masses. The peneplain slopes to the south-south-east at 18 feet per mile, suggesting that it may have been gently tilted in that direction. Dixey (1948, p. 16) considers that the great plain of the Northern Province is a peneplain of end-Tertiary age. He believes, however, that the part of the present area underlain by Jurassic sediments is bevelled by an earlier mid-Tertiary surface. The sections given in Fig. 6 (at end) conclusively prove that the same surface bevels both the Basement System and the younger sedimentary rocks and, as this surface is continuous with that traversed from the Nyambeni hills to Wajir, it is probable that it is of end-Tertiary age.

Standing above the end-Tertiary peneplain are many flat-topped hills and ridges with even crest-lines (*see* Plates I and II (b)). As indicated in Figs. 1 and 6 the summits of these hills appear to be remnants of three older peneplains which are parallel to the end-Tertiary surface and 200, 500 and 1,100 feet higher respectively. The lowest of these older surfaces is well-developed on the eastern hill of Takabba (*see* Plate I (a)), Itailale, Owork, on the limestone and siltstone hills in the vicinity of the Ogar Wein and Sagari hills and on the Warido and Danissa hills. The next higher surface bevels the Sagari, Garri (*see* Plates I (b) and II (b)), Danissa, Golberobe, Takabba, Dahani, Kubi Muchgerreh, Warido and Ogar Wein hills.

The south-eastern hill of Ogar Wein, Uwa and Gudo Garso represent degraded remnants of this surface. In the extreme west of the area near Beloble, Kubi Makkagand, a hill over 3,100 feet in height, is probably bevelled by the highest surface, of which the summit of Warido is believed to be a degraded remnant. Thus it is seen that all four peneplains cut across both Basement System and Jurassic-Cretaceous rocks. The three higher surfaces were, therefore, eroded between Cretaceous times and the end of the Tertiary era.

Dixey (1948, p. 15) states that the southern Abyssinian plateau is separated from the end-Tertiary peneplain by an erosional escarpment which falls in height from 1,000 feet at Mega in the west to 800 feet at Gurar in the east. Assuming that the decrease in vertical interval between the two erosional surfaces continues uniformly eastwards, the separation at the Danissa hills would be between 500 and 600 feet which is, in fact, the case (*see* Fig. 6). The southern Abyssinian plateau is considered by Dixey (*op. cit.*, p. 16) to be the equivalent of the mid-Tertiary surface of Uganda. In North Nyanza (Shackleton, 1951, p. 378) and around the Cherangani hills (Miller, 1956, p. 7) the sub-Miocene surface lies between 300 and 700 feet higher than the end-Tertiary peneplain. Shackleton (1951, p. 380) correlates the sub-Miocene surface of Kavirondo with the mid-Tertiary Buganda peneplain. It is considered therefore that the higher surface which bevels the Danissa hills is probably of sub-Miocene age. The intermediate surface may be of Miocene or Pliocene age and the highest surface which bevels Kubi Makkagand is possibly of end-Cretaceous age.

Takabba (2,550 feet) and Dahani (2,450 feet) both have flat tops which are 500 and 450 feet respectively higher than the surrounding plain, and would thus appear to be bevelled by the sub-Miocene surface. As can be seen from Fig. 6, however, the plain here is about 100 feet lower than it is to both east and west. This degradation is ascribed to erosion by the Lak Suri. The gap in the limestone feature between Dahani and Dukdera was cut by the Lak Suri since Tertiary times. It seems possible that the lak was initiated on the raised sub-Miocene surface and degraded it by the same amount that it lowered the end-Tertiary surface.

IV—SUMMARY OF GEOLOGY

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

Recent	Soils and alluvium	
Cretaceous	Marehan Sandstones	} Marehan Series
	Danissa Beds	
	—unconformity—	
Jurassic	"Upper" Daua Limestones	} Daua Limestone Series
	Golberobe beds	
	"Lower" Daua Limestones	
	—unconformity—	
Pre-Cambrian (?)	Granitic and basic intrusive rocks	
Archaean	Metamorphosed sediments of the Basement System	

The Basement System gneisses and granitic intrusions are confined to the western portion of the Takabba sheet. They form isolated hills and monadnocks, the gneisses near Kubi Muchgurreh being folded into a small syncline trending N.N.W.-S.S.E. The System includes semi-pelitic and psammitic sediments which have been metamorphosed and invaded by granitic bodies and a dyke now converted to an amphibolite.

East of the north-south road passing through Takabba are the Jurassic sediments. The lowest horizon present is a poorly fossiliferous, middle Jurassic, oolitic limestone, which forms a westerly-facing escarpment and dips very gently to the east. Coquinoid limestones higher in the Jurassic sequence outcrop at Warido and Golberobe where they underlie an escarpment formed by Golberobe Beds, Danissa Beds and Marehan Sandstones. Here the limestones are richly fossiliferous and have yielded species not previously discovered in north-east Kenya. The Danissa Beds and Marehan Sandstones also form the principal outcrops in the Ogar Wein-Sagari-Danissa-Wergudud area. They occur in low-lying flat-topped hills which stand up above the end-Tertiary peneplain. It is considered that deposition throughout took place in relatively shallow water, the environment changing from marine to estuarine between the Jurassic and Cretaceous periods. Folding and faulting have affected the rocks of all the pre-Recent periods, the greatest effects being seen in the Mesozoic sediments.

The fossil record is by no means complete but those collected and forwarded to the British Museum have been identified and from comparison with neighbouring areas and Somaliland it has been possible to date the sediments tentatively.

The area is extensively covered by thick superficial deposits comprising red sandy soils, grey soils, black alluvial soils and kunkar.

V—DETAILS OF GEOLOGY

1. The Basement System

For descriptive purposes the Basement System rocks will be dealt with under the following genetic classification:—

- (1) Metamorphosed semi-pelitic sediments
 - (a) Biotite gneisses
- (2) Metamorphosed psammitic sediments
 - (a) Quartz-felspar gneisses and granulites
 - (b) Granitoid gneisses
- (3) Intrusive rocks
 - (a) Acid
 - (i) Granodiorites
 - (ii) Granites
 - (iii) Porphyry dykes
 - (b) Intermediate
 - (i) Altered tonalites
 - (c) Basic
 - (i) Amphibolites

(1) METAMORPHOSED SEMI-PELITIC SEDIMENTS

(a) Biotite Gneisses

One mile east of Kubi Muchgurreh there is a small outcrop of well-foliated gneiss (15/141)* containing much biotite and pink felspar. A thin section shows that it is composed of quartz, orthoclase, oligoclase, biotite and epidote. The felspars measure up to

*Numbers prefixed by 15/ refer to specimens in the collections of the Mines and Geological Department, Nairobi.

5 mm. in length and are highly sericitized, strained anhedral quartz of 1 mm. average diameter forming a mosaic between the larger crystals. Biotite, which is pleochroic from dark to light green, occurs with epidote in clusters. The micas frequently contain several strings of sphene crystals, sometimes arranged parallel diagonally across the flakes. The pale greenish epidote which is fractured irregularly sometimes reaches 0.5 mm. in length, but usually occurs as minute aggregates associated with biotite which appear to be replacing the feldspars. Leucoxenized ilmenite is often associated with the larger biotite-epidote clusters.

(2) METAMORPHOSED PSAMMITIC SEDIMENTS

(a) *Quartz-Feldspar Gneisses and Granulites*

Two outcrops of this rock-type occur, one being two miles east of Kubi Muchgurreh while the other forms the three hills of Uwa. At the former locality a sugary-textured quartz-feldspar rock (15/139) represents an original quartz-microcline-oligoclase granulite which has been partly replaced by a fine-grained aggregate of quartz, albite, and epidote, in places with microcline, white mica and chlorite. It is suggested that this aggregate is due to shearing movements which occurred in the gneiss subsequent to its main metamorphism but while the temperature was still high, the anorthite molecule in the plagioclase breaking down and yielding epidote and albite.

(b) *Granitoid Gneisses*

Three miles east and four miles south of Kubi Muchgurreh are outcrops of granular-weathering pink and grey acid gneisses. A slide of specimen 15/140 shows large porphyroblasts of microcline up to 3 mm. in length which have grown in a mosaic of quartz and oligoclase composed of grains of average diameter 0.3 mm. The gneiss has been considerably crushed and biotite-epidote aggregates have developed along the resulting cracks in the feldspars. Similar gneisses form the small isolated hill of Kublishen lying between Takabba and Uwa. Strained quartz, which forms 35 per cent of a thin section of the rock (15/144), and oligoclase make up an equigranular mosaic in which are microcline-perthite porphyroblasts up to 6 mm. long, containing many inclusions of the surrounding minerals. Sphene is present in long, irregular crystals. The gneiss has been sheared with the production of biotite and epidote along the planes of movement. The granitoid gneisses are considered to have developed as the result of feldspathization of psammitic granulites.

(3) INTRUSIVE ROCKS

(a) *Acid Intrusions*

(i) *Granodiorites*.—The hills of Beloble and Kubi Makkagand are composed of unfoliated tor-forming granodiorite containing visible pink feldspars and quartz with subordinate biotite. Under the microscope the Beloble granodiorite (15/146) is seen to have the following estimated modal composition*:

	Per cent
Quartz	20
Microcline	10
Oligoclase	65
Biotite	4
Iron Ore	1

The granodiorite possesses an equigranular allotriomorphic texture, individual crystals being about 2 mm. in diameter. The feldspars are slightly sericitized and the ferromagnesian minerals occur in small clusters, the biotite being a green variety.

*The modes quoted in this section are volumetric.

Many mylonite veins, about 0.5 inch in width, are associated with a shear-zone about ten feet wide which traverses the granodiorite on the south-western side of Beloble. A thin section (15/147) shows one of these veins to be composed of angular broken fragments of granodiorite from 0.1 mm. to 4 mm. in diameter contained in a groundmass of microcrystalline quartz, feldspar and rock powder. Silicification of the shear-zone is shown by invasive quartz in the slide which has a flamboyant and feathered structure.

In an outcrop of granodiorite on the road one mile from Beloble towards Takabba are lentils of fine-grained melanocratic rock containing inclusions of granodiorite. Microscope examination of these lentils (15/148) reveals that they are composed of euhedral crystals of epidote up to 1 mm. in length set in a finely crystalline groundmass of prisms of oligoclase and hornblende and granular epidote together with pools of quartz and alkali feldspar. These lentils are considered to be xenoliths although their origin is unknown.

(ii) *Granites*.—Pink felsic rocks of granitic appearance, characterized by complete absence of foliation, form the two hills of Takabba (*see* Plate I (a)). Transecting the hills are sets of vertical, inclined and horizontal joints which have allowed the formation of "tors". An estimated mode of a thin section of specimen 15/143, from Takabba, is quoted below:—

	Per cent
Quartz	30
Orthoclase	18
Microcline-perthite ..	40
Oligoclase	10
Biotite	1
Sphene	+
Magnetite	1

Texturally the granite is allotriomorphic, individual crystals ranging from 0.2 mm. to 4 mm. in length. The quartz is strained and the feldspars cloudy in patches. Green biotite flakes are sparsely distributed through the rock together with subhedral sphene. A few magnetite octahedra are present but the ore generally occurs as irregular masses up to 0.8 mm. in length.

(iii) *Porphyry dykes*.—Cutting tonalites on Kubi Muchgurreh hill are two sheets of grey, fine-grained quartzose rock containing visible crystals of pyrite, chalcopyrite and feldspar. One sheet lies in the plane of the schistosity whilst the other is vertical. The microscope (15/150 and 152) reveals biotite-epidote aggregates, sometimes around pyrite, and variably sericitized untwinned feldspar phenocrysts in a fine-grained matrix of quartz and feldspar. Their field relations suggest that they are porphyry dykes, possibly representing a late stage in the intrusion of the tonalitic mass.

(b) *Intermediate Intrusions*

(i) *Altered tonalites*.—These form the bulk of Kubi Muchgurreh and also underlie the terrain lying immediately to the east and north of the hill. The rocks range in appearance from melanocratic, unfoliated, biotite-hornblende-rich types with subordinate quartz and plagioclase to felsic varieties in which quartz and feldspar comprise 80 per cent of the rocks. A thin section of specimen 15/151 shows an equigranular assemblage of quartz, oligoclase, hornblende and biotite, the felsic minerals constituting 50 per cent of the rock although the hand-specimen appears melanocratic. The quartz exhibits undulose extinction and the feldspars are cloudy. The hornblende is pleochroic from green to brown, and is in all stages of alteration to blue-green amphibole with fibrous habit. The alteration generally begins at the margin of the hornblendes and then progressively replaces the hornblende by acicular crystals of amphibole with their long axes orientated parallel to the prismatic cleavage. Biotite was the last-formed mineral, occurring as large unaltered plates containing strings of small sphene crystals. The biotite encloses and replaces all the other minerals present, also being developed along cracks and cleavage planes within those minerals. There is a minor development of epidote associated with the biotite.

A thin section of specimen 15/149, a leucocratic variety collected on the road north of Kubi Muchgurreh, shows a similar mineral assemblage and relationship. Here the hornblende has been almost entirely altered to aggregates of chlorite, glassy felspar and iron ore which are partly replaced by biotite. Elsewhere euhedral iron ore is found by itself and also surrounded by clusters of biotite flakes. The granular texture and probable original quartz, oligoclase and hornblende assemblage suggests that these rocks are intrusive tonalites which have been lightly metamorphosed.

(c) Basic Intrusions

(i) *Amphibolites*.—A greenish-black amphibolite, composed of short blocky ferro-magnesian crystals and trending with the strike of the Basement System gneisses, outcrops in a belt ten yards wide one mile east of Kubi Muchgurreh. Float blocks of a similar nature were picked up two miles south of Uwa. The Kubi rock (15/138) consists almost entirely of granular crystals of a green amphibole about 1 mm. in diameter with a maximum extinction angle of 30°. The amphibole is partly replaced, both marginally and internally, by blue-green chlorite. Magnetite, probably derived during the process of chloritization, occurs as strings of small grains in the chlorite between the amphibole crystals, but is also found as larger grains up to 0.3 mm. long. Although no relic structures of pyroxene now remain it is probable that the amphibolite represents a metamorphosed basic dyke.

2. Jurassic System

(1) DAUA LIMESTONE SERIES

The term "Daua Limestone" was first used by Weir (1929, pp. 9–11) in connection with the well-exposed limestone series along the Daua river, which coincides with part of the Kenya–Ethiopia border north of the present area. Dixey (1948, p. 34 *et seq*) refers to the same limestones as the Limestone Series.

During the present survey it was found that the limestones of the Golberobe and neighbouring areas pass up into a series of sandstones and siltstones, the Golberobe beds, proved by fossils to be of Jurassic age (cf. Dixey, 1948, pp. 39–40). The clastic sediments must be older than the upper part of the Daua Limestone Series as exposed in the Daua valley, and are accordingly considered as part of the Series, though so far they have not been identified north of the Wergudud area. In the Takabba–Wergudud area the Daua Limestone Series is represented by three groups of beds

3. The "Upper" Daua Limestones
2. The Golberobe Beds
1. The "Lower" Daua Limestones

The succession represents, however, little more than half of the full sequence of the Daua Limestone Series in the Daua valley, and the terms "Upper" and "Lower" attached to the limestones are used with only local significance, to distinguish the limestones lying above and below the Golberobe Beds. The two stages are considered together in the description that follows.

(a) The Daua Limestones

The lowest limestone horizon is to be seen in the low-lying hills which form a westerly-facing escarpment east of the north-south road passing through Takabba. Here the limestone is presumed to overlie unconformably the Basement System rocks which outcrop as isolated hills in the western part of the area. In no place can the limestones be seen in contact with Basement rocks, the closest outcrops being those at Takabba where granite knolls lie two and a half miles west of the limestone at Dahani. The limestones were considered by Dixey (*op. cit.*, p. 39) to rest on an uneven surface of the Basement System rocks and the findings of the present survey lend support to this idea. For example the dip of the limestones forming the outlier at Itailale, if projected eastwards, would carry the uppermost horizon well beneath the base of the limestones forming the main escarpment. The presence of Basement System hills (Kubi Muchgurreh and Takabba) near to the escarpment also suggest that the sub-Jurassic floor was not a peneplain.

On the Ovork escarpment the maximum thickness exposed is about 250 feet, the limestone dipping gently eastwards at two to five degrees, and disappearing beneath alluvium five miles east of the escarpment. At Bur Maiyo Kondi in the south and near Dahani the limestone has been eroded, little of the escarpment remaining, the presence of the limestone beds being shown by occasional limestone blocks on the soil surface. The escarpment feature is not present between Dukdera and Dahani, faulting having displaced the outcrop.

The limestones of the escarpment are usually well-bedded, cream, buff, purple or grey in colour and often cherty. Fossil remains are not abundant, but occasional specimens can be seen weathered-out on the surface. Others consist of broken remains forming thin shelly bands a few centimetres thick that contain foraminifera, as are found on Korili. At the base of Dahani there is an orange-brown band of iron-stained foraminiferal limestone crammed with foraminifera and belemnites, the former being predominant. The majority of the limestones are oolitic and in thin sections, e.g. of specimens 15/158, 15/161 and 15/165, oolites ranging in size from 0.2 mm. to 1.0 mm., occasionally iron-stained and exhibiting radial and concentric structures, are usually well-defined. Both foraminiferal and oolitic varieties are cemented by calcite. Creamy porcellaneous limestones are common near Bur Maiyo Kondi, fossils being preserved in medium-grained clear calcite contained in a fine-grained calcite mudstone.

There are no limestone outcrops between the Ovork and the Warido-Golberobe hills, though the easterly dip of the limestones on Ovork and the presence of limestone at the foot of Warido suggest that a continuous sedimentary succession underlies the ground between the hills, though no evidence has been obtained on its composition. It is to be noted, however, that there is no difference in appearance between the soils in this part of the area and those overlying the Basement System rocks to the west. At Warido the easterly-dipping limestones, which are dominantly coquinoid with oolitic bands, can be seen at the base of a second north-south escarpment and outcrop along its entire length from the Sagari hills to just north-west of Gudo Garso in the south. Good outcrops are exposed in some of the gullies at Korkai Hamassa, whilst thick-bedded cherty limestones form the majority of outcrops in these hills. The coquinoid limestones are characterized by innumerable broken shell fragments which occur in thick bands and, at a locality 400 yards north of Kailta, there is an echinoid band. The shelly bands comprise the higher part of the lower limestones and yield fossils which are remarkably similar to those found in the overlying Golberobe Beds. Silicification of the fossils causes them to stand out on weathered surfaces, whilst silica nodules are also common. Several calcareous siltstones and a yellow calcareous mudstone are interbedded with the limestones.

In the north of the area the gently folded limestones surround the Ogar Wein hills and outcrop at the foot of the Babo and Garri hills and the northern end of the Danissa hills. Dips are generally low, about two or three degrees, steep dips being associated with faulting. The dips are rarely measurable on actual rock outcrops because of the poor exposure, but features give a good indication of the direction of dip of the beds. The limestones lying immediately below the siltstones of the Golberobe Beds are oolitic and coquinoid like their stratigraphical equivalents in the Warido-Golberobe area. One specimen, 15/211 from south-east of Ogar Wein, is an iron-stained oolitic limestone in which the oolites are near-perfect spheres exhibiting concentric and radial structures. The oolites, some of which have cores of broken shell fragments or silt grains, are cemented by calcite which is partly replaced by silica, the whole rock being uniformly iron-stained. Towards the top of the upper limestone stage the limestones become sandy and actual sandstone horizons, indicating the beginnings of littoral deposition can be mapped for short distances. In thin section, as for example of 15/197 from Tifo, these sandy limestones are found to contain occasionally rounded but usually angular grains, up to 0.8 mm. in length, of quartz, microcline and plagioclase in a matrix of well-crystallized calcite, with rare loose clusters of iron ore granules and occasional silicified patches. Iron-staining along the rhombohedral cleavages of the calcite has occurred in patches.

A single boulder of shelly limestone was picked up in the bed of the valley, three and a half miles south-west of the Wergudud road junction, but although a search was made no limestone outcrops were seen. Stratigraphically it is likely that limestone exists beneath the alluvium west and south of Wergudud and that the boulder has been washed down from one of those areas.

Lack of suitable exposures in the limestone series, often due to surface kunkar, made it impossible to establish a detailed succession in the area or to measure dips accurately. Dips taken along the Ovork escarpment range from nearly horizontal at Dahani up to 5° near Korili. This latter figure is high and is probably a local dip only. The average dip of the rocks is approximately 3° , which gives a total thickness of 3,500 feet for the portion of the Daa Limestone Series represented in the central part of the area. This may be contrasted with the figure of 3,800 feet given by Ayers (1952, p. 6) for the complete succession of the Daa Limestone Series in the Daa valley, a figure that was based on an average dip of one degree neglecting folding or possible duplication by faulting. North-east of the Warido-Golberobe escarpment the limestone thickness could not be determined through lack of outcrops and the folded and faulted nature of this part of the country.

PALAEONTOLOGY OF THE DAA LIMESTONES

No identified fossils have previously been collected from the Ovork-Dukdera escarpment. During the present survey a foraminiferal limestone horizon was discovered at the foot of Dahani containing Lagenidae, Ammodiscoidae and Fusulinidae with various other multilocular, uniserial, turreted and coiled evolute types. A useful fauna was found by Ayers (1952, p. 27) in the continuation of the same escarpment at Bur Maiyo and Didimtu, respectively one and five miles south of the present area. At the latter exposure *Bouleiceras* sp. and *Pecten ambongoensis* are considered by Arkell to be of probable Toarcian age (upper part of the lower Jurassic) though they may possibly be as old as Domerian (middle lower Jurassic). Somewhat higher beds on Bur Maiyo hill yielded middle Jurassic *Eudesia* cf. *cardium* and *Rhynchonella* sp. If the limestones of Bur Maiyo and Didimtu are stratigraphically equivalent to those of Ovork and Dukdera, then the latter range in age from Toarcian to Bathonian, though there is no proof that the Didimtu beds are in fact represented in the area mapped.

The limestones lying at the foot of the Golberobe-Warido hills and around the Ogar Wein-Sagari and Danissa-Garri hills cannot be precisely dated. Fossils were collected from several localities, that lying four hundred yards north of Kailta at the foot of Golberobe, where a coquina limestone contains echinoids, lamellibranchs and other molluscs (see Plate IV), being the most prolific.

The specimens collected are incomplete or poorly preserved, so that specific identification is impossible. Dr. Cox and Mr. Bairstow of the British Museum (Natural History) were able to name the following genera:—

- Ostrea* sp.
- Lopha* sp.
- Cyprina* ? sp.
- Pygurus* or *Pseudopygurus*
- Acrosalenia* ?
- Cidarid spine

The evidence of these fossils points to a middle or upper Jurassic age, despite the fact that the echinoderms are long-range forms. The lamellibranchs are distinctive and unlike those found at other localities in the area.

A few feet below this echinoid band a fossiliferous yellow calcareous mudstone yielded a useful fauna which included:—

- "*Terebratula*" *ferrandii* Stefanini
- Terebratulids
- Bihenithyris barringtoni* Muir-Wood

Dr. Muir-Wood, who identified the fossils, suggests that the age is probably Callovian. In addition the lamellibranch *Trigonia stefaninii* var. *medioumbonata* Vanzo, from the same locality, has been identified by the authors.

The specimens collected from limestones immediately underlying the Danissa beds near the Ogar Wein fault include:—

Meleagrinnella

Lopha cf. *costata* (J. de C. Sow)

Ostrea (*Catinula*) cf. *ancliffensis* Cox and Arkell

Exogyra nana (J. Sow)

The specimens named as *Lopha costata* and *Ostrea ancliffensis*, Dr. Cox states, have been given qualified identification with European Bathonian species, and he thinks that the balance of evidence favours a Bathonian age for the beds. Other fossils, collected from the limestones north of the Golberobe hills, indicate only that the beds are of Jurassic age. They comprise *Ostrea* sp. indet., *O. (Catinula)* cf. *ancliffensis* Cox and Arkell, and *Lopha* cf. *marshi* (J. Sow).

The evidence of age for the upper part of the limestones in which the Golberobe Beds are intercalated, as determined from the fossils collected, is not conclusive. On comparison with the known stratigraphy (Ayers, 1952, Fig. 2) in the area further north-east, however, it is likely that they extend up into the Oxfordian and the following age classification has been adopted for the purposes of the map:—limestones of Kaila up to the Golberobe Beds, Bathonian to Oxfordian; Golberobe Beds, Oxfordian; limestones above the Golberobe Beds, Oxfordian.

(b) Golberobe Beds

Dixey (1948, p. 39–40) considered that an unbroken sequence exists between the Daa Limestones and the Marehan Sandstones and described passage beds connecting the arenaceous and calcareous formations. Ayers, however, mapped the passage beds as the basal member of the Marehan Sandstones, and regarded them as overlying the Daa limestones unconformably (1952, p. 19). There has, however, been confusion between two sets of beds that underlie the Marehan Sandstones in different places. The stratigraphically lower set, which is dated as Jurassic by the fossils it yields, corresponds with the lower 100 feet of the passage beds described by Dixey as occurring between Takabba and the Danissa hills. These beds, which in places can be seen to be intercalated in the Daa Limestones, are now renamed the "Golberobe Beds". The upper part of Dixey's passage beds in the same area, and the whole of his passage beds in the main escarpments of Danissa and Babo are of younger age, and their base transgresses from limestones overlying the Golberobe Beds in the east to the Golberobe Beds themselves in the west. They contain remains of Cretaceous plants, and are renamed by the writers the "Danissa Beds". They form the lower part of the Marehan Series, which has as its upper member the Marehan Sandstones.

The Golberobe Beds consist mainly of fossiliferous pink and yellow sandstones with subordinate thin brown siltstones containing fucoids, and thin limestones. In the Ogar Wein and Golberobe hills the first indication of the incoming of the Golberobe Beds is the intercalation of siltstone and sandstone bands among limestones, the base of the beds being taken as the top of the main limestone in that area. On the Rahmu road, seven miles north of Danissa, where the lower part of the Golberobe Beds forms a small feature consisting of 45 feet of alternating sandstones, siltstones and thin cherty limestones with a dip at one degree to the east, they are marked by a fossiliferous horizon. The same horizon, particularly characterized by the lamellibranch *Meleagrinnella*, occurs forty feet above the base of the Golberobe Beds throughout the Ogar Wein, Sagari and Warido-Golberobe hills.

PALAEONTOLOGY OF THE GOLBEROBE BEDS

Ayers (1952, p. 15) mapped the *Meleagrinnella* band in the north Ogar Wein hills and to the west of the Garri hills. The type fossil of the band was identified by Dr. L. R. Cox as *M. echinata* (W. Smith), and dated as probably Bathonian or Callovian. In Appendix II of the report (*op. cit.*, p. 29) *Meleagrinnella ovalis* (Phil.) was recorded from a locality about four miles north-west of Koblulu and it was considered that it might be at the same horizon as the Ogar Wein band. Here, however, the age was defined as Corallian (beds between the Oxfordian and the Kimmeridgian) on the grounds of ammonites found in beds about one mile further west. *Meleagrinnella* sp. was also found in beds dated as Kimmeridgian at

a locality about 20 miles further north-east, and only a few miles from the Daua river (*op. cit.*, p. 30). It is clear, therefore, that unless the species of the *Meleagrinnella* can be identified with certainty and they are stratigraphically restricted species, they cannot be used as index fossils in north-east Kenya.

During the present survey numerous fossils were collected from the *Meleagrinnella* band in the Golberobe Beds at various localities in the Golberobe, Sagari, Ogar Wein and Garri hills. The fauna includes *Meleagrinnella*, *Mytilus*, *Lopha*, *Ostrea*, *Pygurus*, belemnites, corals and various molluscs (*see* Plate V, VI and VII). The specimens collected were identified by the British Museum (Natural History). Dr. Cox, who examined the lamelli-branches, wrote: "Unfortunately, apart from the *Meleagrinnella* and the small oysters, their general state of preservation is poor. The results confirm the Jurassic age of the beds at the localities Tifo, Korkai Hamassa, Ogar Wein, Chimpa and (probably) Golberobe". He commented, however, that it was not possible to define the exact stage of the Jurassic that is represented. He considered that there is a slight balance in favour of a middle Jurassic (approximately Bathonian) age, but that it is not impossible that the beds are upper Jurassic, though the absence of ammonites may be significant. He stated that in England, and almost everywhere else, ammonites are surprisingly rare in the Bathonian.

Discussing the *Meleagrinnella* Dr. Cox said: "*Meleagrinnella* seems to be abundant at two horizons in East Africa. The first is Bathonian or Callovian, and the species represented is known as *M. echinata* (W. Smith), the second is Kimmeridgian, the species represented being known as *M. lieberti* (G. Müller) (synonym, *M. tendagurensis* (Hennig)). *Meleagrinnella* is extremely variable, and I find myself unable to say definitely to which of these species your specimens belong . . .".

The Golberobe Beds on the road near Tifo yielded:—

Isastrea sp. indet.

Pygurus sp.

Modiolus imbricatus (J. Sow)

Brachydontes (*Arcomytilus*) *laitmairensis* (de Loriol)

Lycettia dalpiazii Venzo

Ostrea (*Catinula*) sp.

Exogyra cf. *nana* (J. Sow)

Lopha cf. *marshi* (J. Sow)

Lopha costata (J. de C. Sow)

Lopha sp. nov.

Placunopsis sp.

Trigonia sp. (small costate form)

Belemnopsis cf. *tanganensis* Fütterer

The mussel *Lycettia dalpiazii* was originally described by Venzo from supposedly Bathonian *Trigonia* beds (now regarded as probably Portlandian) at Cud Finagubi (Finaguba), near Mander, but his species of *Trigonia* is not represented in the present collection. *Modiolus imbricatus* has a long range in the Jurassic, *Brachydontes laitmairensis* ranges from Bathonian to Argovian, (i.e. upper Oxfordian) while *Lopha costata* is a widespread Bathonian species. The fauna indicates a middle or upper Jurassic age though Cox thinks there is a slight balance towards the age being Bathonian. The *Belemnopsis* suggests a possible Oxfordian flavour.

The specimens collected at Korkai Hamassa are ill-preserved, and only a few of them are identifiable specifically. Here again Cox considers that there is a slight balance in favour of a Bathonian age. The specimens obtained comprise:—

Nucula sp.

Modiolus imbricatus (J. Sow)

M. (Inoperna) plicatus J. Sow

Pteria sp. indet.

Meleagrinnella sp.

Gervillia cf. *monotis* Endes-Deslongchamps

Plate I



(a) View of Takabba from the east, showing the sub-Miocene, intermediate and end-Tertiary peneplains.



(b) Asahaba water-hole and Garri hills, with Danissa beds capped by Marehan Sandstone which is bevelled by the sub-Miocene peneplain.

Plate II

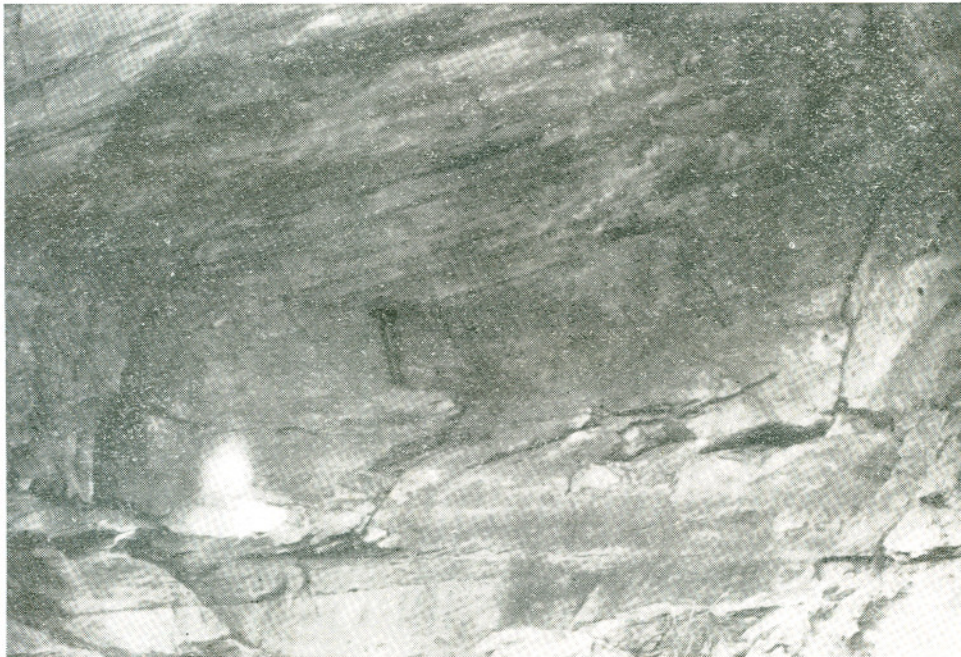


(a) Danissa beds at Gamul, dipping to the south.



(b) Tifo hill, Garri hills, from the south-west, with capping of Marchan sandstones, which are visible as crags, overlying the Danissa beds.

Plate III

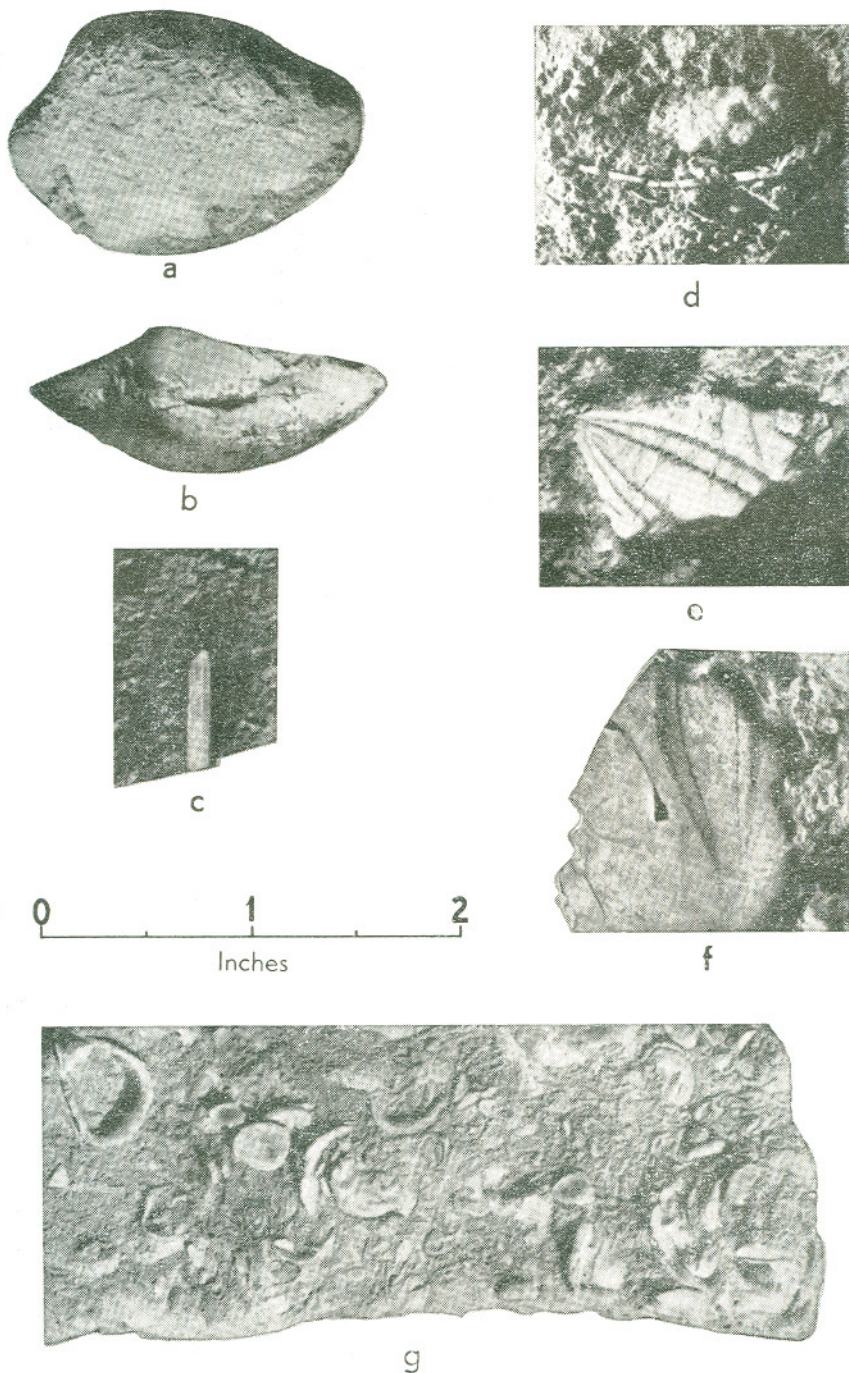


(a) Marehan Sandstone, Danissa hills, showing cross-bedding.

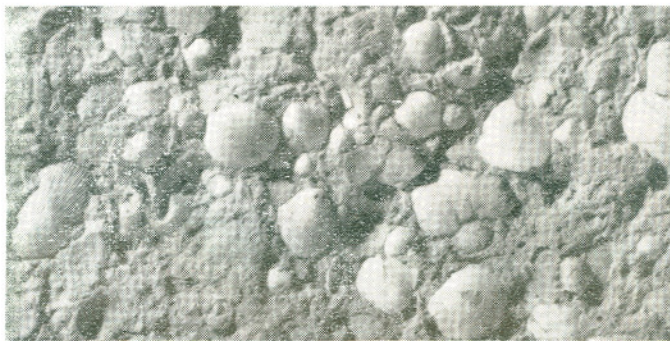
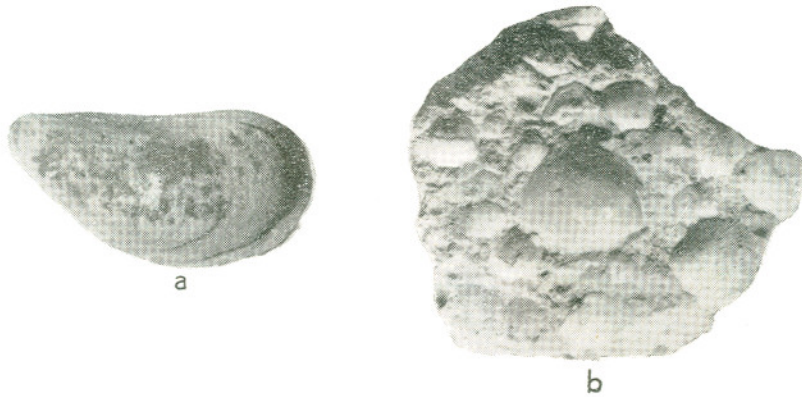


(b) Castellated weathering of Marehan Sandstone, Danissa hills.

Plate IV—Fossils from the Daa Limestone of Golberobe.

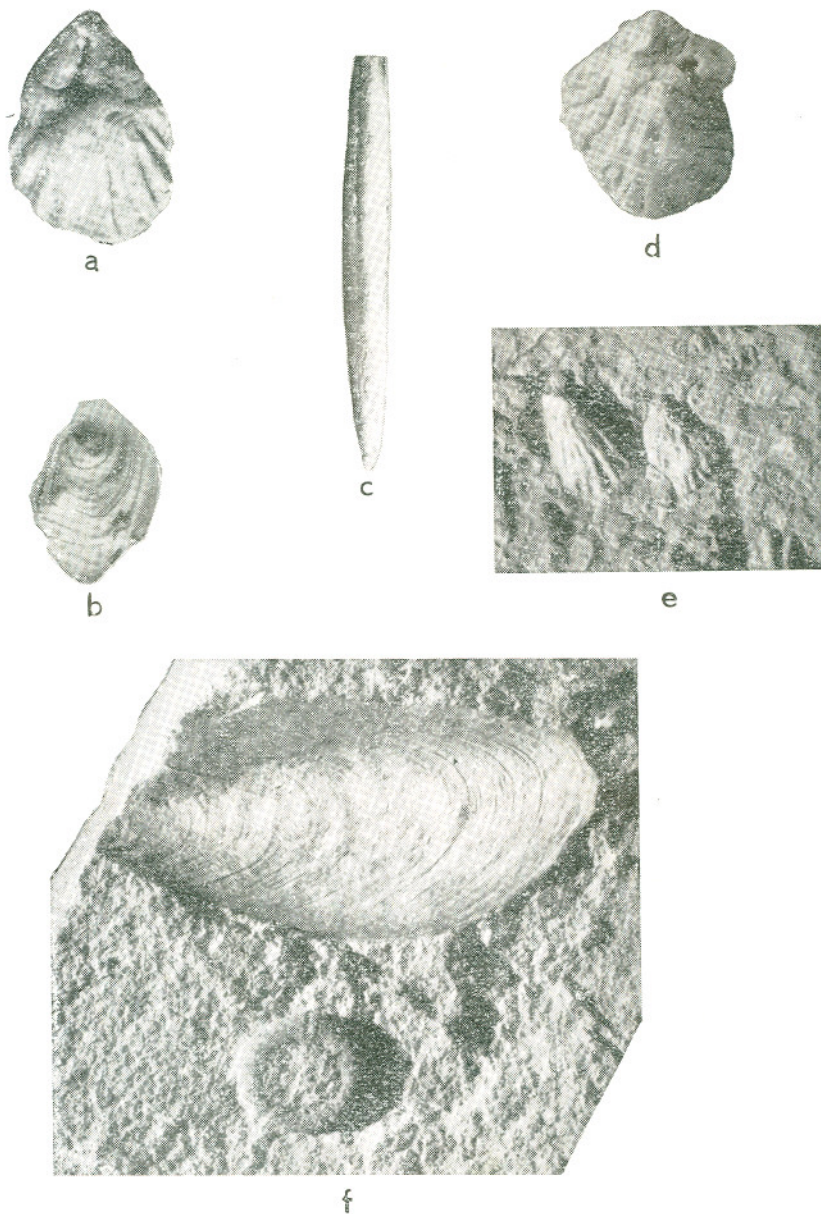


- (a) and (b) Left valve and dorsal view of the lamellibranch *Cyprina* sp. ?
 (c) Cidarid spine.
 (d) Broken portion of an echinoderm test, *Acrosalenia* sp. ?
 (e) and (f) Broken portions of tests of *Pygurus* sp.
 (g) Shelly limestone with numerous mollusca.

Plate V—Fossils from the *Meleagrinnella* band, Golberobe Beds.

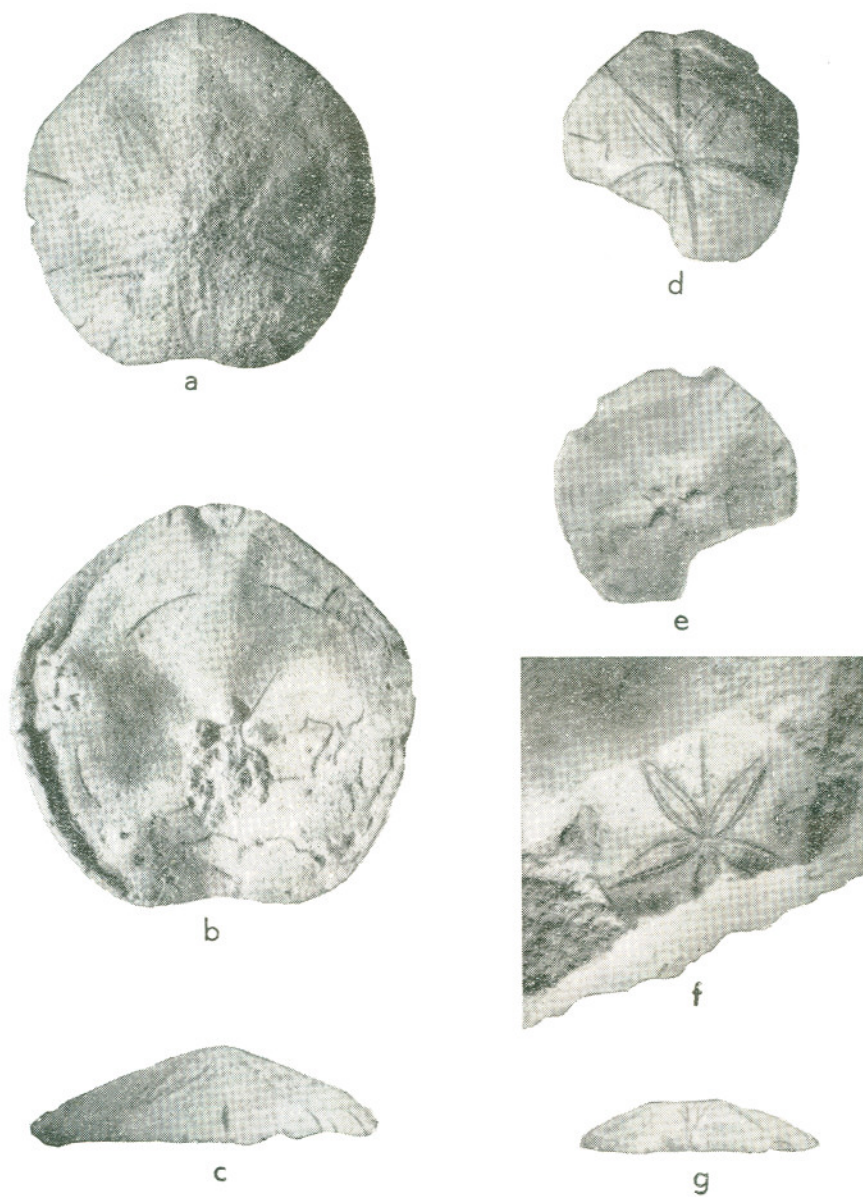
- (a) Left valve of *Modiolus* sp. ? from the Ogar Wein hills.
 (b) and (c) Shelly sandstone containing *Meleagrinnella*, from the Ogar Wein hills.
 (d) Shelly sandstone containing *Meleagrinnella* from Golberobe.

Plate VI—Fossils from the Golberobe Beds around the Garri hills.



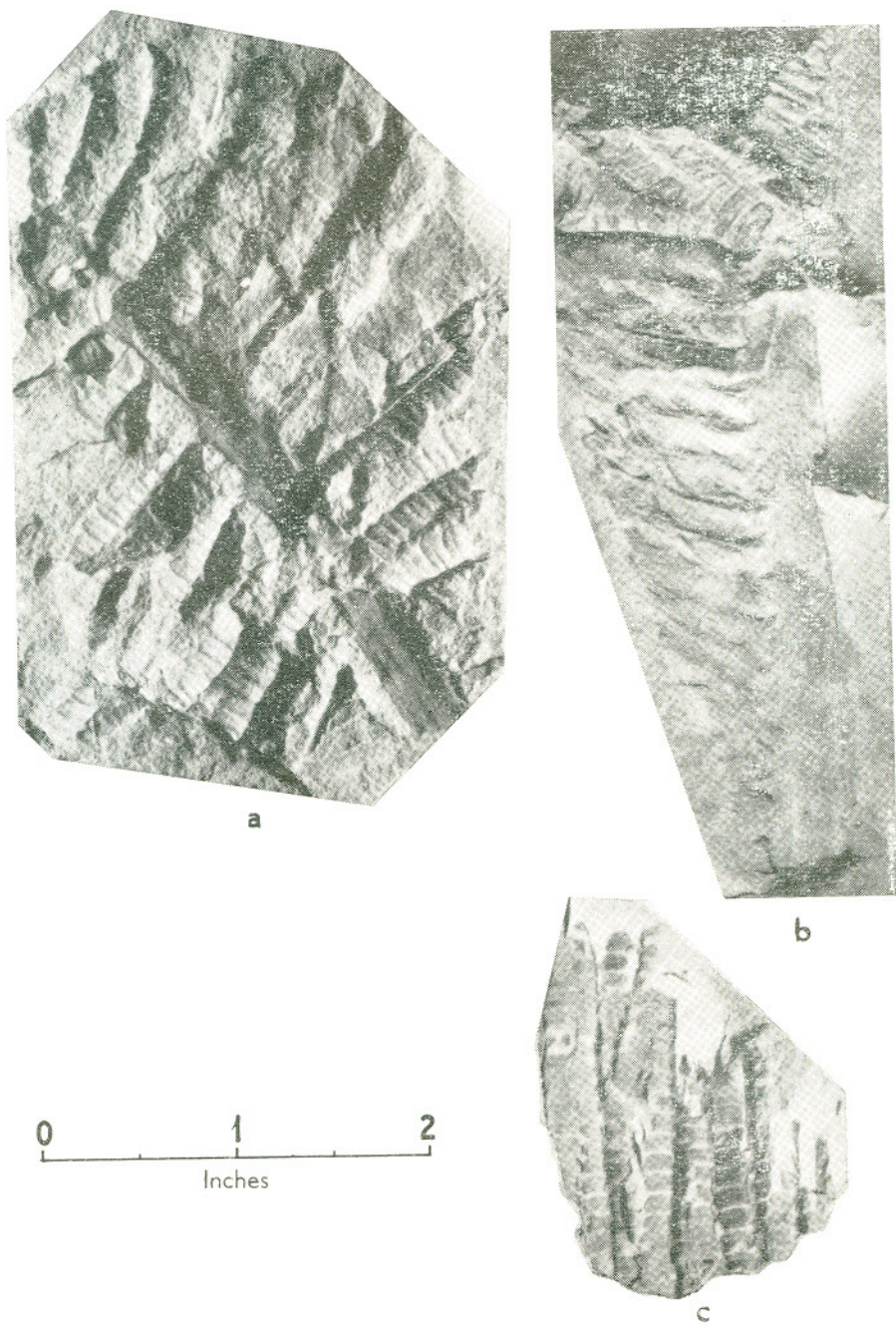
- (a) *Lopha costata* (J. de C. Sow).
 (b) *Exogyra* cf. *nana* (J. Sow).
 (c) *Belemnopsis* cf. *tanganensis*.
 (d) and (e) *Lopha* sp.
 (f) Cast of right valve of a lamellibranch and a regular echinoderm.

Plate VII—Fossil echinoderms from the Golberobe Beds of the Garri hills.



(a), (b) and (c) Aboral, oral and side views of *Pygurus* (?), (d), (e), (f) and (g) Aboral, oral, impression of aboral, and side views of *Pygurus* (?).

Plate VIII—Impressions of the plant *Weichselia reticulata* in Danissa Beds siltstones from Kailta hill, Golberobe.



(a) and (b) Stems bearing leaves.
(c) Leaves.

Lopha costata (J. de C. Sow)
Lopha sp. nov.
Trigonia sp. (small costate form)
Astarte sp.
Tancredia ? sp.
Quenstedtia ? sp.
Sphaera sp.
Mactromya sp.
Isocyprina sp.
Protocardia ? sp.
Ceromya ? sp.

The *Meleagrinnella* sandstone exposed on the northern side of the North Ogar Wein fault yielded the following species:—

Cucullea sp. indet.
Lycettia dalpiazzi Venzo
Meleagrinnella sp.
Gervillia sp.
Ostrea cf. *acuminiata* J. Sow
Lopha sp.
Tancredia cf. *angulata* Lycett
Quenstedtia sp.

Here again the fauna might be of middle or upper Jurassic age, though Cox considers that the balance of evidence favours a Bathonian age. The specimens named as *Ostrea acuminiata* and *Tancredia* cf. *angulata* were given qualified identifications with European Bathonian species.

At Chimpa and Asahaba a few fossils were collected from the lower part of the Golberobe Beds, but they throw no additional light on the age of the beds. The faunas comprise:—

CHIMPA	ASAHABA
<i>Nuculana</i> sp.	<i>Lopha</i> sp. indet.
<i>Meleagrinnella</i> sp.	<i>Lopha</i> sp. indet. (small forms)
<i>Lopha</i> sp. (small forms)	<i>Inoceramus</i> ? sp.

As in the case of the adjacent limestones, the fossil evidence is not conclusive in deciding the age of the Golberobe Beds. In view of the stratigraphy of the area further north-east, they are tentatively considered as of Oxfordian age.

3. Cretaceous System—Marehan Series

The Cretaceous System is represented in the Takabba–Wergudud area by the Marehan Series which has the following succession:—

2. Marehan Sandstones
1. Danissa Beds

The series forms the Garri and Danissa hills, part of the Ogar Wein hills, and the greater proportion of the Golberobe–Warido range, and is presumed to underlie a large part of the Wergudud area where a thick covering of residual sandy soil hides the underlying rocks.

The Marehan Series overlies the Daua Limestone Series unconformably although the junction was not found exposed in the field. At Golberobe the Danissa Beds are seen to overlie the Golberobe Beds directly, but at Tifo the latter are interbedded in the Daua Limestones (Fig. 2). In addition, a limestone block was found in bedded sandstone in the Danissa beds near Asahaba water-hole. These facts indicate a period of erosion prior to the deposition of the Danissa Beds, which overlap the Limestone Series westwards.

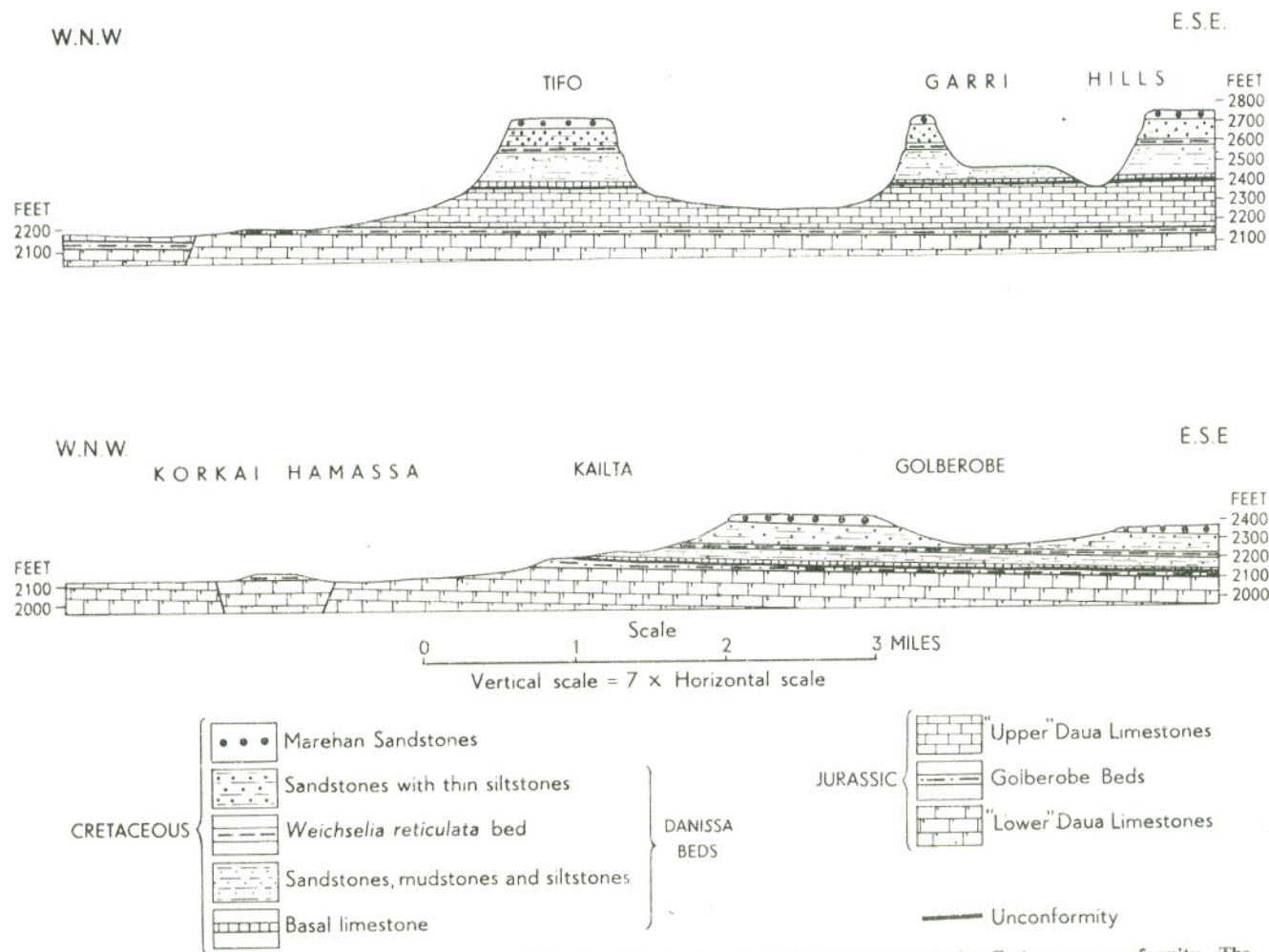


Fig. 2.—Geological cross-sections of the Garri and Golberobe hills showing the position of the Jurassic-Cretaceous unconformity. The cross-section through the Garri hills is on the same line as part of the section B-C on the coloured Wergudud map.

(1) DANISSA BEDS

Ayers (1952, p. 15 and map No. 5) mapped what are now known as the Danissa Beds in the Danissa-Babo hills area as the Mander Series, which he considered passed laterally into the Marehan Sandstones. He also stated that the Marehan Sandstones have basal marine beds (his *Pecten* band), e.g. in the Ogar Wein hills. There was some confusion in mapping, however, for on the road west of Tifo, Ayers mapped the *Pecten* band (now part of the Golberobe Beds) as lying within the Daua limestones, whilst further west the same bed was taken as a horizon near the base of the Marehan Sandstones. The base of the Marehan Sandstones, in this report, is considered to be the base of the first thick sandstone band, which can be seen clearly in the escarpments at Danissa, Tifo and Garri. Above this, siltstones are only locally developed and do not form major bands within the sandstones. The main difference between the Marehan Sandstones and the Danissa Beds is essentially that the former are a sandstone facies and the latter a predominantly siltstone-mudstone sequence.

The Danissa Beds are well-exposed in the Warido-Golberobe, Danissa and Garri escarpments and form nearly the whole of the Ogar Wein and Sagari hills. The beds consist of alternating sandstones, variegated siltstones, marlstones and porcellaneous limestone, being well-bedded and distinctively coloured white, pink, buff, brown, yellow, green, grey and purple. Slump bedding can be seen in most exposures and indicates pene-contemporaneous movement which probably did not originate as a result of tectonic movement, but rather with sliding on a gently sloping floor on which the beds were being deposited.

Most of the hill slopes are covered by rock debris which conceals the sequence but the following sections have been measured and give some idea of the alternating nature of these beds:—

GOLBEROBE						Ft.
Lilac and banded siltstones and pink sandstones					}	175
Pink sandstones with banded siltstones						
Orange, yellow and grey siltstones with <i>plant</i> remains					..	10
Red and purple iron-stained sandstones	..	..	..	..	..	10
Yellow and pink sandstones	..	..	..	..	..	50
Banded variegated siltstones	..	..	..	..	..	20
						265
DANISSA						Ft.
Flaggy light-pink sandstone	..	..	..	..	..	35
Banded variegated siltstones	..	..	..	..	..	10
Ripple-marked flaggy light-pink sandstone (Band 2)	..	..	..	..	..	30
Grey-green calcareous mudstone	..	..	..	..	..	30
Orange-red mudstone	..	..	..	..	..	1
Nodular marly limestone	..	..	..	..	..	1
Grey-green calcareous mudstone with <i>fucoïds</i>	..	..	..	..	..	20
Pink sandstone (Band 1)	..	..	..	..	..	30
Variegated siltstones	..	..	..	..	..	10
Yellow to grey siltstones and mudstones	..	..	..	..	..	80
Sandstones (base not seen)	..	..	..	..	..	130
						377

The Danissa section shows the relationship to the underlying and overlying formations and gives the most reliable indication of the thickness of the Danissa Beds. A thickness of

approximately 370 feet corresponds roughly with that determined by Dixey (1948, p. 40) who estimated that the beds are approximately 300 feet thick. The sequence at Golberobe is interrupted by faulting and good cliff sections are not exposed.

At the northern end of the Danissa hills a good gully section is exposed and consists of alternating light- and dark-coloured beds of calcareous mudstone, sandstone and thin marls and shales. Screens conceal the lower slopes but blocks of limestone indicate the presence of thin limestones at or near the base of the sequence whilst at Tifo these limestones can be seen *in situ*. The limestone is unlike the Jurassic limestones and is considered to represent the base of the Marehan Series in the area.

Locally the lowest part of the Darissa Beds exposed is a grit band which probably corresponds to the coarse calcareous sandstone containing one-inch pebbles seen by Dixey (*loc. cit.*). A thin section of specimen 15/193, from nine miles west of El Eli, shows that the grit contains angular and sub-angular strained quartz grains, some of which are composite and measure up to a few millimetres in length, poorly cemented by clay containing foraminifera. The grit band was seen at the base of the Ogar Wein and Danissa hills but its extent could not be mapped because of heavy scree cover.

In the Garri and Danissa escarpments the beds contain two prominent sandstone bands which are well seen from the road north of Danissa (*see* Plate II (b)). They are mappable horizons and during the field-work were repeatedly referred to as bands one and two. Other sandstones occur throughout the sequence, as can be seen from the tabulated successions, but do not form features. White clay galls, flattened and sub-rounded in outline, are found in the sandstone beds and represent contemporaneous erosion of intercalated shaly beds. In the same escarpments a grey-green calcareous mudstone overlies a conspicuous orange-red mudstone, the former being fossiliferous and less than 10 feet thick at Tifo. The grey-green band thickens southwards and is represented in the Danissa scarp by 50 feet of mudstones overlying the orange-red mudstone.

The Danissa Beds, particularly at Golberobe and Warido, are characterized by the variegated siltstones, whose banded nature is due to great variations in iron-staining in different beds. In thin sections, e.g. of 15/172 and 15/178 from Golberobe, the siltstones are seen to contain moderately sorted angular or sub-angular quartz grains of 0.05 mm. average diameter and occasional feldspar grains. They are often cemented by calcite (15/178) which is invariably brown and cloudy due to iron-staining. Other specimens (e.g. 15/170) from the same locality have an argillaceous cement and contain authigenic limonite. In specimen 15/181 from Golberobe the allogenes include oligoclase and iron ore. Locally the iron ore is abundant and the rock is an ironstone as shown by specimen 15/171, from Golberobe, which contains fifty per cent of angular well-sorted quartz grains, 0.1 mm. in diameter, the remainder of the rock being composed of crystalline limonite. In thin section the distribution of the two minerals is found to be irregular, giving a blotchy appearance to the rock, a feature not noticeable in the hand-specimen.

Near the middle of the sequence a bright orange, extremely fine-grained siltstone at Kailta yielded well-preserved plant remains which had not previously been discovered. The same plant was discovered associated with another plant, *Psilophyllum* (?), and lamelli-branches in the grey-green mudstones above the orange-red mudstone at the northern end of the Danissa hills. A block of sandstone float from the base of the Warido hills, yielded a single plant impression. The fossil is that of a leaf similar to those in the Kailta siltstone so presumably the sandstone block has fallen down the hillside to the position in which it was found. The leaf must have fallen into water in which sand was being rapidly deposited for it is nearly at right-angles to and has displaced the bedding (*see* Plate IX).

The Danissa Beds exhibit wide lateral variation in character and sequences such as those described on p. 25 and by Dixey (1948, p. 40) are not necessarily true over a wide area, colour variation and lenticularity of the beds occurring throughout.

Palaeontology of the Danissa Beds

Fossil plants identified as *Weichselia reticulata* were found near the top of the Danissa beds. W. N. Edwards, Keeper of Geology at the British Museum (Natural History) writes: "The plant *Weichselia reticulata* is very characteristic of the lower Cretaceous, and is almost cosmopolitan. One would normally expect a deposit containing abundant *Weichselia* to be of Wealden age, but it does range upwards, though very rarely into the lower Cenomanian. It has rarely been claimed as occurring in the uppermost Jurassic, but this has not been confirmed, and the older age determination may be founded on the difficulty of assigning a precise geological age to fresh-water passage deposits between formations whose classification depends on marine fossils. Unquestionably *Weichselia* is characteristic of Wealden beds".

On the other hand de Lapparent (1952, p. 119) in describing the Nubian sandstone of the Central Sahara where *Weichselia reticulata* has been discovered, compares the occurrence with others in southern Tunisia where this plant is present in beds that extend in age from upper Jurassic to the lower part of the upper Cretaceous. He remarks that: "*Weichselia reticulata* se trouve aussi en abondance dans la série continentale wealdienne de la falaise tripolitaine et tunisienne comprise stratigraphiquement entre le Jurassique supérieur et le Cénomanién marin". Also referring to beds containing the plant and a significant vertebrate fauna he says: "Ces formes font défaut dans les horizons continentaux du Jurassique sous-jacent, mais sont pour la plupart identiques à celles du Continental intercalaire saharien" (*op. cit.*, p. 120).

In the present area, however, there is a balance in favour of a Wealden age for these beds containing *Weichselia reticulata*, particularly in view of the evidence further north-east where Kimmeridgian limestones and the Mandera Series underlie rocks equivalent to the Danissa Beds of the present area.

(2) MAREHAN SANDSTONES

Conformably overlying the Danissa Beds on most of the hills is a red-weathering pink sandstone forming a number of isolated cappings, which generally dip gently to the east or south-east. Four major sandstone bands separated by ill-exposed, variegated siltstones, probably never more than a few feet in thickness, comprise the total Marehan Sandstones formation. A measured section in the Danissa hills indicates that the thickness in this area is approximately 370 feet. Flexuring of the sandstone has yielded dips varying from horizontal to four degrees. Strong current-bedding is a common feature of the sandstones, which are well-jointed mainly in the vertical plane, thus giving rise on cliff sides to stacks, chimneys and castellated crags (*see* Plates III, (a) and (b)).

In the hand-specimen the sandstones when fresh are pink to nearly white and similar to the sandstones of the Danissa Beds, but natural exposures are red due to weathering. In thin section, for example of specimen 15/216 from Wergudud hill, angular to well-rounded quartz occurs in ill-sorted grains up to 0.8 mm. in diameter which are well-cemented by limonite with a little argillaceous material. A few feldspar grains are also present. The sandstones are remarkably constant in character, and contain poorly-preserved plant remains (*see* Plate X) and what are probably fish remains, all of indeterminate age. Clay galls are commonly found in the more massive bands, and iron-enriched veins are common throughout the sandstones. The ironstones of the sandy Folkstone beds of the lower Greensand are similar, and the description of them by Dines and Edmunds (1929, p. 34) applies equally to the occurrences seen throughout the Marehan sandstones. They state: "The ironstone or carstone is usually in veins not more than an inch or two thick running irregularly across the bedding. Some seams are a foot or more thick and have an interlaced or wasp nest structure". The veins in the present area are particularly well-developed in the South Ogar Wein hills, where also cylindrical ironstone blocks are frequently found on weathered surfaces. The blocks, of which an example (15/108) is shown in Plate X (d), are often perfectly cylindrical in shape consisting of a thick outer zone of ironstone with an unaltered core of sandstone. In the example figured the ironstone zone of the cylinder is seen to join an S-shaped ironstone band which bears no relationship to the bedding or jointing in the rock. Some cylinders are as much as three feet in length. Other structures are pipe-like and not so regular as the cylinders and some are segments of pipes. These structures are post-depositional features of uncertain origin but are not related to the present erosion surface.

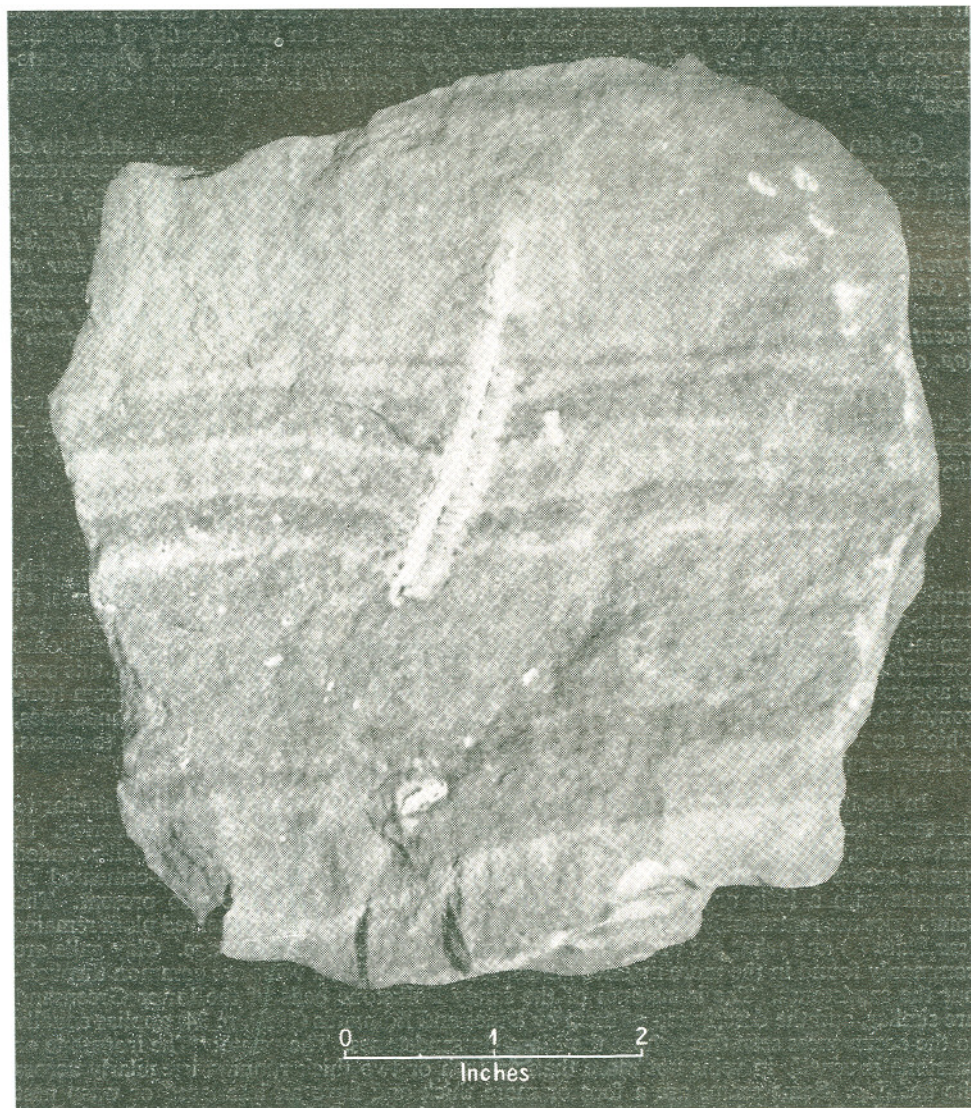


Plate IX—Impression of a leaf of *Weichselia reticulata* in Danissa Beds sandstone from Warido.

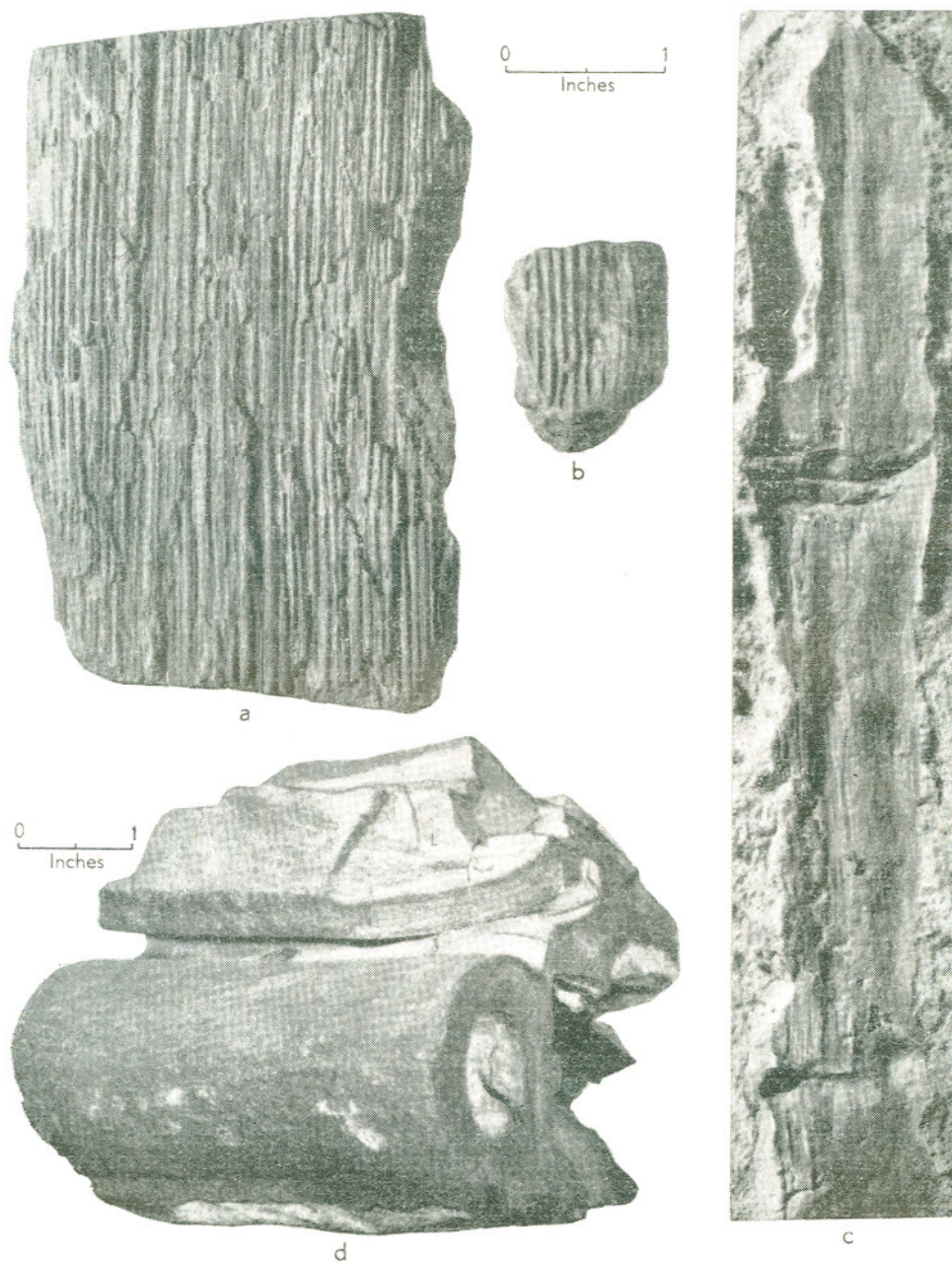


Plate X—Fossil wood in Marehan sandstones from the Danissa hills.

- (a) and (b) Fossil wood
- (c) Stem impression showing nodes.
- (d) Ironstone cylinder.

4. Geological History of the Takabba-Wergudud area during the Jurassic and Cretaceous Periods

By the close of Middle Lias (lower Jurassic) times the Basement System rocks in the area mapped had been worn down to a surface of an undulating nature possessing a few hundred feet of relief, as evidenced by the outlier Itailale (*see* p. 4). This surface was probably similar to the floor on which the basal Karroo sediments of the Congo Basin were deposited (Veatch, 1935, p. 45), where there was an average relief of 600 feet. Du Toit (1937, p. 122) has suggested that Madagascar was still part of the African continental mass as late as the Permian, during which period, according to that writer, the break-up of Gondwanaland was initiated. Initial downwarping probably began in the Permian or Trias, as the continental Lugh and Adigrat sandstones were then laid down in the Abyssinian trough to the north of the present area. The Mansa Guda beds (Ayers, 1952, p. 6) may be the equivalent of these sandstones in Northern Kenya and the Duruma Sandstones their equivalent in coastal Kenya. It is considered that the final break did not occur until after the close of the Trias, as correlatable continental sediments were apparently laid down up to that time in a restricted basin between west Madagascar and East Africa, as they were then mutually situated according to Du Toit and Miller (1952, p. 22). Du Toit (1937, p. 124) postulated that India was joined to Madagascar up to the mid-Cretaceous. The initial split would, therefore, have been between an East African and an Indo-Madagascan block, the fracture occurring approximately along the line of the present East African coast. It is suggested that this movement left a zone, lying parallel to the break and stretching north-north-eastwards from Wajir in an unsupported condition, causing it to sag, thus emphasising the Abyssinian trough. Thus it is considered that two parallel troughs were initiated in the Permo-Trias, one between Kenya-Tanganyika and Madagascar and the other stretching north-north-eastwards from Wajir, with a probable connection between the two south of Wajir. Permian and Trias marine deposits in the Sakoa and Sakamena Series of Madagascar (Besairie, 1930, Plate I) and in the Maji ya Chumvi beds of Kenya (Miller, 1952, p. 16) show that the marine invasion of the coastal trough was the earlier, later spreading, perhaps *via* the Wajir area, to join the Abyssinian trough. The south-westerly limit of this trough was probably determined by the high ground of the Cherangani, Sekerr, Chemorongi, Karissia and Nyiro hills. The Karissia (8,104 feet) and Cherangani (11,541 feet) hills are bevelled by erosion surfaces which are residual upon and 2,000 to 3,000 feet higher than the Cretaceous surface (Dixey, 1948, p. 14 and Fig. 1; Miller, 1956, p. 5) indicating that high ground existed in these areas during the Jurassic period. Sekerr (10,920 feet), Chemorongi (8,898 feet, and Nyiro (9,203 feet) being composed of Basement System rocks are probably also bevelled by the pre-Cretaceous surfaces.

The initial sediments in the Kenya part of the Abyssinian trough were the Mansa Guda beds which were considered by Ayers to have been derived directly from Basement System rocks lying immediately to the west. Similar beds were laid down in the same trough further north, in British Somaliland, where the earliest deposits are interbedded sandstones and conglomerates, the forerunners of a marine transgression (Somaliland Oil Exploration Co. Ltd., 1954, p. 6). Further downwarping in Domerian or probably Toarcian times led to the invasion of the trough by the sea. As the Mansa Guda conglomerates do not outcrop in the present area it is probable that they are overlapped by marine limestones which here rest directly on the Basement System. The presence within these limestones of oyster-beds, sandy horizons and shelly bands together with their generally oolitic nature is indicative of a shallow-water depositional environment.

The fine-grained ripple-marked sandstones and siltstones of the Golberobe Beds indicate a change from a marine to an estuarine environment, though incursions of the sea are marked by the beds containing a marine fauna of lamellibranchs, brachiopods, echinoderms and belemnites. Oyama (1954) who has studied the ecology of modern pecten has shown that an abundant supply of oxygen is a controlling factor in the distribution of this bivalve, the pecten generally being found where turbulent waters converge. The *Meleagrinnella* band within the Golberobe Beds is regarded as a fossil thanatocoenosis varying in purity but usually containing various other molluscs comparable with the Nanao Formation cited by Oyama (*op. cit.*, p. 98). It seems likely, therefore, that the *Meleagrinnella* band presents an original sandy bank into which the shells were washed, and is indicative

of a very shallow-water environment. Estuarine conditions are further suggested by the less calcareous nature of the Golberobe Beds, the upper Daua limestones and Danissa Beds, as the formations are traced southwards from Asahaba, the increase in sandy beds and the thickening of the plant-bearing grey-green calcareous mudstone of the Danissa succession being typical. The conditions that prevailed subsequently in the area mapped are not known, as any beds laid down were later covered by the transgressive Cretaceous rocks and are still hidden beneath them. The older Cretaceous rocks containing plant remains are again indicative of estuarine or deltaic conditions. The "raising" above water-level of the Golberobe and Danissa Beds from time to time is indicated by the presence of clay galls which were formed by the desiccation and breaking up of thin mud layers.

Although the Marehan series shows a coarsening in grain size upwards it does not imply a further downwarping of the basin, but rather an advance of the shore-line facies to the north-east consequent upon the in-filling of this south-western extremity of the Abyssinian trough. During this period deposits were formed on a gently sloping floor on which slumping of water-logged sediments took place. This is not inconsistent with evidence elsewhere, for example Kuenen (1950, p. 246) records hydroplastic deformation that took place on slopes of as low as one degree. Cross-bedding becomes evident in the upper part of the Danissa Beds, the majority of fore-set beds dipping to the north or north-west, indicating deltaic in-filling towards the north.

The Marehan sandstones mark an intensification of the deltaic depositional conditions which existed during the formation of the Danissa Beds. In the sandstones the material is coarser than before, being of medium sandstone grade, ripple-marking and false bedding assume a much larger scale, and individual sandstone bands are more massive and of greater thickness. The formation in this area consists of four main sandstone beds separated by siltstone intercalations and marks alternating periods of greater and lesser river activity. During the intervals of lesser activity desiccation of muds occurred and was followed, on intensification of activity, by their erosion and deposition as clay galls in sediments that then formed. The continuing presence of plant remains in the sandstones lends further confirmation of the non-marine origin of these beds. The lack of any deposits overlying the Marehan Sandstones suggests that they mark the final in-filling of the south-western end of the Abyssinian trough, which occurred in Cretaceous times.

5. Recent Deposits

Recent deposits in the area mainly consist of surface sands, which are a product of weathering of the sandstones and Basement System rocks. These sands, which are as much as fifty feet deep near the hills, cover most of the eastern half of the area and completely obscure any underlying rocks. Where red sandy soils are present in the western half of the area they probably indicate in many cases underlying Basement System rocks.

Grey soils alternate with the red soils in the west and it is suggested that they have originated by deposition mainly along old water-courses and by leaching of the soil, in which water has remained longer than in the better drained red soils. They are distinct, however, from the present river alluvium in the Lak Suri, which is darker in colour and is more nearly a black cotton soil.

Calcareous soils, and concretions in the soil (kunkar) are commonly associated with the limestones. They invariably cover limestone outcrops and in many instances the only indication of limestone are these calcareous surface deposits. Small gullies on the hills at Golberobe and Dahani contain boulders of Recent breccia consisting of blocks of Jurassic limestone cemented by ferruginous calcrete. Specimen 15/156 from Dahani, in thin section, shows sub-angular oolitic and fossiliferous limestone fragments cemented by iron-stained calcrete, which has formed pisolitic structures around the fragments, and contains angular quartz grains, rare large sphene grains and oolitic growths with ill-defined structures.

During the survey four flint implements fashioned by pre-historic men were found lying on the surface at the western foot of the Danissa and the Garri hills. These were sent to Dr. L. S. B. Leakey of the Coryndon Museum, Nairobi who described them (*in litt.*) as follows:—

"The four specimens . . . are not sufficiently diagnostic to allow of a detailed report.

Only one specimen is a finished tool and this is of the type which is normally found with the Stillbay culture of Somaliland. It is in fact a Stillbay point and typologically it is of Early Stillbay type. It is not possible, however, to say that the specimen represents an early stage of the Stillbay, for all the later stages of this culture usually contain a proportion of these less evolved forms, so that the specimen may come from a more evolved series.

Of the other three specimens, two are waste flakes, whilst the third (the largest of the four specimens) is a heavily utilized blade-flake, which again could come from any stage of the Stillbay culture.

The most that can be said, therefore, is that the material represents a stage of the Stillbay culture, and of the Somaliland branch of this culture, and that the age is therefore somewhere in the second half of the Upper Pleistocene".

6. Structure

Basement System

The Basement System gneisses exposed at Kubi Muchgurreh on the Takabba-Wajir road form part of a syncline whose axis trends N.N.W.-S.S.E., the northward extension probably passing between Takabba and Kublishen (see Fig. 4). This cannot be proved, however, because of the heavy alluvial cover in that part of the area. At Uwa the gneisses dip 10° to the north-east, the plunge of lineation being about 6° to the south-east. The Basement System trend seen in this area is similar to that in other parts of Kenya east of the Rift Valley and is known as the Mozambiquian trend, which was first defined by Holmes (1951).

The Dahani fault is the only fracture that is known to displace the Basement System gneisses, although several lines on the aerial photographs probably indicate faults in these older crystalline rocks.

The paucity of Basement System exposures makes it impossible to draw any definite conclusions from the joint directions which were measured in them.

Mesozoic Sediments

The Middle Jurassic limestones exposed in the Ovrk escarpment all decline gently eastwards with an average dip of three degrees. Eastwards the limestones and sandstones have been thrown into a number of south-easterly pitching folds of large wave-length but small amplitude, the dip of beds rarely exceeding 5° . Of these folds the strongest is the Ogar Wein syncline which is first evident in the Sagari hills, dying out as it approaches the Danissa hills east of Gamul. The synclinal axis has been displaced to the north-east in the Ogar Wein hills. Dips in the north Ogar Wein hills are of the order of one or two degrees to the south-west becoming horizontal in the extreme north of the hills and in Khaiyu. Just north of the present area in the neighbourhood of Agarjeis dips are low to the east. This evidence combined with the arcuate nature of the limestone outcrop to the south-east between the Ogar Wein and Garri hills suggests a broad anticlinal warp of low amplitude pitching to the south-east, parallel with the Ogar Wein syncline. It is probable that another south-easterly pitching syncline, the El Wak syncline, exists between El Eli and Wergudud. As no more than 400 feet of Marehan Sandstones has been measured throughout the area and the dip on the Warido escarpment, if projected from the base of the Warido hills to the vicinity of Wergudud, would necessitate the existence of nearly 4,000 feet of sandstone, the presence of a synclinal structure in the area mentioned must be invoked. A flattening of the dips to horizontal just east of Warido would also satisfy these conditions. A subsidiary folding, the axial trend of which is north-east to south-west, is found in the Sagari and Danissa hills. As the two fold systems are not in juxtaposition their relative ages cannot be determined. As the fold axes in the Jurassic sediments have approximately the same strike as those in the Basement System rocks it is possible that the later deformation was controlled by the disposition of the earlier rocks.

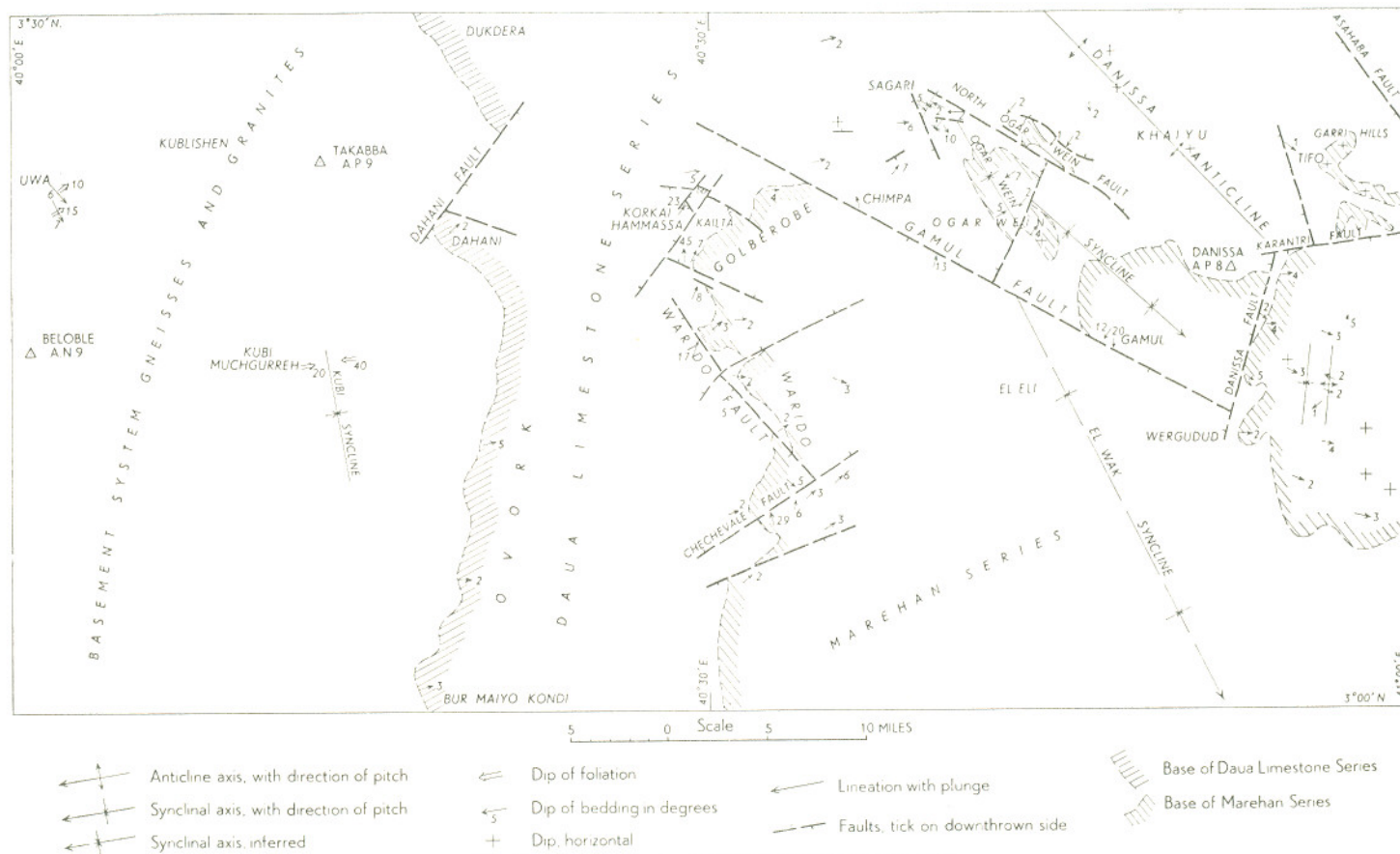


Fig. 4.—Structural map of the Takabba-Wergudud area.

The area is affected by a considerable number of faults of moderate throw trending approximately N.E.-S.W. and N.W.-S.E. with the former in nearly every case cutting the latter. Where dips of over 10° are seen they are invariably associated with these faults. The Danissa fault has downthrown the Marehan sandstone to the west where it is exposed on Wergudud hill, its northerly extension being responsible for the westerly-facing fault-line scarp of the Danissa hills. The existence of this fault at Wergudud is proved by a bore-hole (N.F.D. 6) which was drilled through 540 feet of sandstones. The northerly extension of the Danissa fault, which dies out near Tifo, is displaced to the east by the Karantri fault in the lower Karantri valley. Both the Karantri and Danissa fractures are hinge faults, increasing in throws to the east and south respectively. The throw of the Danissa fault decreases from approximately 250 feet at Wergudud to not more than 50 feet at Tifo. The Karantri fault increases in throw from 100 feet north of Danissa to 400 feet at the eastern boundary. South of this fault the base of the Marehan Sandstone falls from 2,450 feet in the west to 2,250 feet in the east while north of the fault it remains horizontal at 2,650 feet (see Plate II (b)). A N.N.W.-S.S.E. fault at Asahaba has downthrown some 300 feet to the south-west, the Limestone-Danissa Beds junction being seen a little east of the north-east corner of the area.

Ayers (1952, p. 18) considered Gamul as part of the south-eastern limb of an anticline with its W.N.W.-E.S.E. axis passing to the north of the hill. Field evidence collected during the present survey has led the writers to believe that a major fault exists along this line. At Gamul, south-westerly-dipping Danissa Beds steepen in the southern part of the hill as though they were dipping into a fault (see Plate II (a)). Eight miles north-east of El Eli a small hill of north-easterly-dipping Marehan sandstone is nearly in juxtaposition with limestone, and some small limestone blocks were picked up on its northern face. At Chimpa, the hill, some 200 feet high, is formed of northerly-dipping limestones, yet Marehan sandstone outcrops immediately at its foot on the south side, a fact that can only be explained by a fault with a downthrow to the south-west. At Golberobe the Marehan sandstones and the Golberobe and Danissa Beds are abruptly terminated against the fault, with limestones at the same elevation in the hills one mile to the north. The section A-B, as shown on the Wergudud sheet, indicates that the throw of the fault is approximately 2,000 feet. Displacement of beds along the line of this fault was indicated by geophysical work carried out during 1951.

Another major fracture parallel to and six miles north of the Gamul fault cuts across the northern end of Sagari and along the southern flank of the north Ogar Wein hills. This fault has a maximum downthrow of about 350 feet to the north-east in Ogar Wein, decreasing to less than 100 feet in Sagari. A second smaller parallel fault of 100 feet throw, also to the north-east, occurs two miles further north. The Sagari hills have also been affected by small faults which downthrow to the south and south-west, causing dips higher than normal.

The Warido-Golberobe hills form a normal easterly dipping cuesta transected by a system of N.W.-S.E. and N.E.-S.W. faults. In the majority of cases those of north-westerly trend downthrow to the south-west and are cut by the north-easterly faults, which in turn usually downthrow to the north-west. The N.W.-S.E. faults are five in number lying approximately parallel to the Gamul fault, all but one downthrowing in the same direction as that major fracture. The principal north-west-trending fault, the Warido fault, which passes along the foot of the Warido escarpment has downthrown some 350 feet on its south-western side Golberobe Beds which cap small, and in two cases, conical hills. At its southern end the Warido fault is cut off by the north-easterly trending Chechevale fault. A block, capped by Marehan sandstone, has been let down in the westerly acute angle formed by these fractures. Another fault, nearly parallel to and three miles south of the Chechevale fault, has downthrown on its southern side the Marehan sandstone, which forms the small isolated hills of Abulo and Aradi. Warido and Golberobe are separated by a deep north-easterly cleft on the south side of which the base of the Golberobe Beds swings back up the valley, while on the northern side it descends directly into the valley floor. This anomaly is caused by a fault which follows the line of the valley, downthrowing the beds on its north-western side. It also displaces the Warido fault. In the Korkai Hammassa-Kailta locality a system of cross-faults has served to isolate patches of Golberobe Beds which now cap outlying hills formed mainly of limestone. These faults have no great throw.

At the point where the Lak Suri breaks through the western escarpment at Dahani, the base of the limestone has been stepped back about four miles to the north-east. A minor fault of the Gamul trend along the course of the Lak Suri has at Dahani isolated a small conical peak of limestone which lies to the north of the fault.

Joint directions in the Mesozoic sediments were observed on the hill masses but particularly in the Marehan Sandstones, and are shown in Fig. 5. It can be seen that the principal direction is on a bearing of 130° , with a subsidiary trend on a bearing of 30° . These joint trends are particularly well-marked in the field, the Danissa hills exhibiting the best examples. Here the stream directions are often determined by the north-easterly joints, the streams having excavated gorge-like valleys. The nearly vertical joints (130°) often have smooth iron-stained and silicified faces but there is no slickensiding which would indicate movement along them.

As the faults displace the folds it is evident that the folds are the older structural feature. To produce such a fold system a gentle compression must have acted from the N.E. or S.W., the minor N.E.-S.W. folds resulting from accommodation to the major compression. The major faulting is generally nearly parallel with, or at right-angles to the axes of folding. Most probably the faulting and folding are unconnected and are an indication of two phases of tectonic activity which occurred at different times. The fault and joint pattern is consistent with a system produced by either N.S. or E.W. compression or tension. Faulting

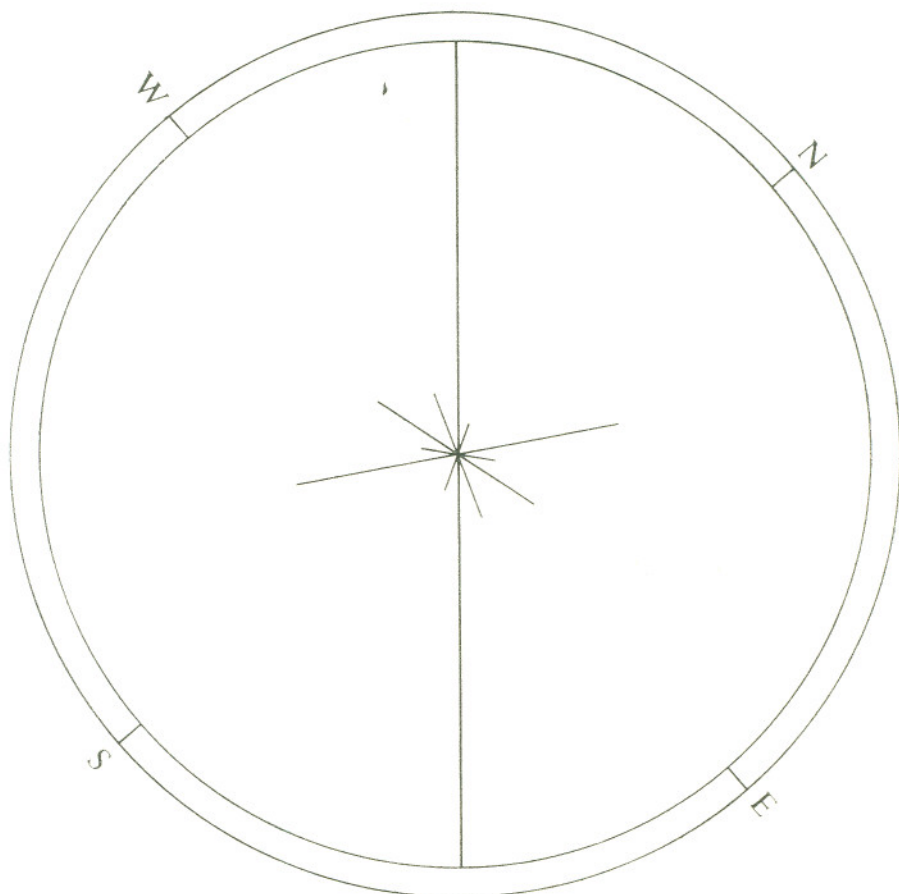


Fig. 5.—The prevalent joint directions in the Takabba-Wergudud area.

of early Cretaceous age has affected the Jurassic marine beds in British Somaliland (Somaliland Oil Exploration Co. Ltd., 1954, p. 7) and it seems likely that faulting in the present area will belong approximately to the same period. As the youngest beds affected by faulting are of lower Cretaceous age the fracturing must have occurred subsequent to that period. In the chapter on physiography it was demonstrated that the sub-Miocene surface has not been disrupted since its completion and it is, therefore, evident that the faulting occurred during late Cretaceous or early Tertiary times. Du Toit (1937, p. 125) states that: "the break [in deposition] represented by the Oligocene suggests that Madagascar became reunited to Africa temporarily". Such a reuniting would be likely in the writers' opinion to induce a compression in the present area from the south. It is therefore postulated that such compression or a subsequent period of tension, in Oligocene times, was responsible for the faults and joints that affect the rocks of the Takabba-Wergudud area.

VI—ECONOMIC GEOLOGY

1. Oil

The presence of 11,000 square miles of Jurassic-Cretaceous sediments in the north-eastern part of Kenya, together with vague and unsubstantiated reports of oil seepages there, has led to considerable speculation in the last twenty years on the possibility that the beds might contain commercially exploitable oil deposits. In consequence F. M. Ayers was sent to this district during the period 1950–52 to make a geological reconnaissance, with a view to ascertaining the oil possibilities of the area. His conclusions are published in Report No. 22 of the Geological Survey of Kenya.

Just under 1,600 square miles of the Takabba-Wergudud area are underlain by sediments of Jurassic-Cretaceous age, in which, however, no oil or gas seepages or surface bitumen deposits were seen. Thus the possibility of finding oil must be deduced from a consideration of the sedimentary succession, lithology and structure of the area. The controlling factors that govern the existence of an oil-field are the presence of a source rock, a reservoir rock, a structural or stratigraphical trap and an impermeable cover. The degree to which these conditions are satisfied in the area mapped is considered in the following paragraphs:—

- (a) *Source rocks.*—Any organic marine limestone is nowadays considered to be a suitable source rock. Some 3,500 feet of limestone containing thick beds of organic (shelly) facies are believed to be present in the area mapped, although they are not everywhere exposed.
- (b) *Reservoir rocks.*—Marine limestones that contain oil are considered to be combined source and reservoir rocks. the oil being contained in pore spaces between oolites, within fossils, in joints, or in solution cavities and cavities resulting from dolomitization. The oolite limestones of Ovrk and Warido have the inter-oolite spaces filled with calcite, reducing porosity to a minimum, while dolomitization of the limestones was not seen. Jointing and fossil cavities were observed in the limestones but no surface phenomena such as swallow-holes, which would indicate the presence of large subterranean solution caverns, appear to exist. The inter-bedded sandstones of the Golberobe beds, within the upper part of the limestones might prove to be a useful reservoir rock if oil had been generated in the limestones below.
- (c) *Structural and stratigraphical traps.*—Possible structural traps suitable for the retention of oil in the area are the Danissa anticline and in the vicinity of major faults, especially around Wergudud. Stratigraphical traps formed by the lensing-out of potential reservoir rocks in impervious strata are due to lateral variation of facies. No such lateral variation of any particular horizon in the Daa or Marehan Beds has been traced during the present survey. Unconformities occurring in sedimentary series provide good traps in several parts of the world but, it is considered that no suitable unconformity exists within the succession under consideration.

(d) *Impermeable cover*.—The only potential sealing rocks present are the shales of the middle and upper parts of the Daua Limestone Series, which outcrop north of the present area but have not yet been proved to exist further south. According to Ayers (1952, p. 10) the Middle Shales as exposed consist of dark grey shales, in part gypsiferous, becoming interbedded with thin argillaceous limestones towards the top. They may be as much as 300 feet thick. Brownish-green to grey foraminiferal and gypsiferous shales comprise the Upper Shales. The deepest section exposed is 60 feet, their total thickness being unknown. Beneath the Upper Shales lie some six-sevenths of the limestone series as exposed along the Daua river.

The Takabba-Wergudud area is, however, only a small part of the total Mesozoic basin, and it is not reasonable to draw final conclusions until the whole basin has been systematically mapped in fair detail.

The following table compares the succession in the El Dorado oil-field, Kansas, U.S.A. and that of north-east Kenya. It should be appreciated that this is an attempt to correlate types of sequences and not the age of the successions.

KENYA (Ayers, 1952, and present authors)			EL DORADO (Tiratsoo, 1951, p. 189)		
		<i>Ft.</i>			<i>Ft.</i>
Marehan Sandstones	..	400-1,800	Permian	..	(present)
Danissa Beds	..	380	Pennsylvanian shales ..	..	} 250
			and sandstones		
Unconformity					
Upper Limestones	..	520			
Upper Shales	..	100?	Cherokee shales and ..	..	} 250
			sandstones		
			Unconformity		
Middle Limestones	..	700	Mississippian Limestone ..	..	250
Middle Shales	..	300?	Chattanooga Shale	..	70
			Unconformity		
Lower Limestones (including ..	..		Viola Limestone	..	15-50
Golberobe Beds, 100 ft.) ..	..	3,500	St. Peter Sandstone	..	65
Didimtu Beds	..	75	Arbuckle Limestone	..	350-1,000
Unconformity			Unconformity		
Mansa Guda Formation					
Basement System			Basement System penetrated ..	..	2,700-3,600
			at	..	

The principal oil-producing horizon of the Kansas field is the Ordovician-Pennsylvanian unconformity, the Mississippian limestone being frequently absent where oil is found in the upper Ordovician beds. Oil is also found in Pennsylvanian sandstone beds and occasionally in the Mississippian Limestone. The source beds postulated are the Ordovician limestones and possibly the highly organic Chattanooga shales. The main difference between the successions in the two areas is the presence of intra-formational unconformities in Kansas.

It should be remembered that the north-east Kenya Jurassic succession and structure have not been verified by bore-holes. Until a comprehensive drilling programme has been carried out it would be unwise to assume from superficial resemblances to producing oil-fields that the Jurassic of north-east Kenya also contains oil.

2. Water Supplies

The only permanent water supply in the entire area is at Takabba where there are numerous diggings at the foot of the rocks. Of these only those on the eastern face of the main Takabba hill contain water throughout the year, although immediately before the long rains in January and February the water supplies are sufficient to support only a score of tribesmen and their herds of camels and goats. During and after the long rains the water-holes are completely filled and occasionally overflow into a tributary of the Lak Suri, but with the onset of dry conditions, largely owing to its uneconomical consumption by the local

population, the water sinks below the ground surface and is obtained by digging out the sand between the fallen granite blocks. The reservoir which feeds these water-holes is undoubtedly the joint system which traverses the Takabba hill mass. There can be no sub-surface inflow of water from the surrounding country as the wells themselves lie above the level of the plain. Factors contributing to the presence of permanent water at Takabba are that the wells are situated at the foot of a cliff determined by a major joint in a valley, which was eroded between the two main granite hills along the joint and is now filled with sand. Both hills have nearly vertical sides and flat tops and possess a considerable catchment area which collects the rain in the joints thus protecting the water from evaporation. The run-off is at a maximum on the bare granite surfaces, facilitating rapid collection in the joint system. Rain falling upon the near-vertical slopes descends immediately into the water-diggings thus scarring the rock surface (see Ayers, 1952, Plate I, Fig. 2, p. 7). The steep sides of the rock afford shade to the wells in the early afternoon, which has undoubtedly allowed the growth of a more luxuriant vegetation including large trees, which give added shade to the wells. All these factors combined reduce the rate of evaporation to a minimum, thus providing Takabba with the only permanent water supply for approximately 100 miles.

Three bore-holes (N.F.D. 10, 10a and 10b) were sunk in the Takabba granite close to the foot of the hills in 1930. Two were only 58 feet deep, which was later considered by the P.W.D. to be too shallow to reach water, and the third, although 140 feet in depth was also dry. As water only occurs in the joints of the granite any bore-hole not penetrating a joint-plane will be dry. It is thought that the third bore-hole did not pierce a water-bearing joint fissure.

Similar water diggings occur at Beloble where, however, few of the deterrents to evaporation exist as at Takabba. As these wells do not support a population it is unlikely that a permanent water supply is present.

Elsewhere in the area underlain by Basement System rocks water can only exist in the weathered zone which in other parts of Kenya is as much as 250 to 300 feet thick. As no bore-holes have been drilled or geophysical work carried out in this area to determine water-supplies it is impossible to state with any degree of certainty whether underground water is available or not.

The base of the Dawa Limestone Series is a potential water-bearing horizon. If, as was postulated by Ayers (1952, p. 6), the Mansa Guda sediments underlie the limestones at depth then this porous formation would act as a natural reservoir for the reception of water percolating down the plane of the unconformity and from the overlying limestones. During the present survey green grass was noted growing at the foot of the Ovrk escarpment opposite Itailale, at the height of the dry season, suggesting a seepage of water from the base of the limestones. Within the limestones, water will be contained in joints and fissures, with a tendency to migrate down the dip. Shale horizons intercalated with the limestones will serve as traps and synclinal structures containing such bands present the most favourable conditions for the retention of water.

The Marehan sandstones and Danissa Beds, being sandstones and siltstones composed of fine, angular, well-cemented grains, will be poor aquifers having a low porosity and permeability. The strong jointing, however, will permit the free passage of water in a manner similar to that of the limestones. Synclinal folds traversing these beds will concentrate underground supplies of water along their axes, although percolation down into the limestones will occur to a large extent.

Many wells, of 30 feet depth, have been dug along a stream course at El Eli, suggesting that at an earlier date water was readily obtainable at this depth. After the long rains in 1953, when the Takabba pools were filled to overflowing no water was seen in the holes at El Eli, indicating a probable decrease in rainfall in the area in latter years. A similar but smaller, dry well was seen at the western foot of Golberobe. Seasonal water-holes which contain water for a few months of the year after the long rains are to be seen at Wergudud, Souli, Chechevale, Omurdudu and Asahaba. At Asahaba more extensive diggings have resulted in the formation of a small lake (see Plate I (b)) after rainy periods. At similar times of the year water may be obtained by digging into the bed of the river Karantri.

Out of seven bore-holes drilled in 1930, located at Takabba, El Eli and Wergudud, only that at Wergudud struck water, yielding 4,800 gallons per day. The records of the bore-holes are listed in the following table:—

Locality				Borehole N.F.D.	Depth in feet	Yield in gallons per day
Wergudud	..	..	..	6	540	4,800
El Eli	..	..	..	7	226	Nil
El Eli	..	..	..	8	336	Nil
El Eli	..	..	..	9	300	Nil
Takabba	..	..	..	10	140	Nil
Takabba	..	..	..	10a	58	Nil
Takabba	..	..	..	10b	58	Nil

Areas favourable for water bore-holes are: (1) the axes of the Ogar Wein and El Wak synclines, (2) immediately west of the road between Danissa and Wergudud where all dongas from the Danissa hills terminate in a discontinuous dry water-course (cf. Bore-hole No. 6 in tabulation), (3) the valley of the Lak Suri between the Ovorok and Warido escarpments. It should be noted that these localities are natural centres of population at the present time and if successful bore-holes were drilled it would obviate the necessity for the return of the population to the El Wak and Takabba wells in the dry seasons.

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