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GEOLOGY

OF THE

KILIFI-MAZERAS AREA

DEGREE SHEET 66, S.E. QUARTER
(with colored map)

by

P.V. CASWELL, B.Sc., F.G.S., F.R.G.S.
Geologist

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FOREWORD

The report on the Kilifi-Mazeras area continues the work on the geology of Coastal Kenya begun a few years ago by Mr. Caswell, of which the first results were published in Report No. 24, on the Mombasa-Kwale area. The present account deals with the country north of Mombasa, as far as Kilifi, whereas the first report covered the country south of Mombasa. The area northwards from Kilifi up to the third parallel, and including Malindi, has been surveyed by Mr. A. O. Thompson, and a report is in course of publication.

Much of the geological work in the Kilifi-Mazeras area is a direct continuation of that south of Mombasa but in the present report the opportunity has been taken to summarize available geological and palaeontological information on certain aspects that were not dealt with fully in the first report. Again consideration has been given to the possibility of the occurrence of coal seams in the part of the coastal sediments that are equivalent in age to the Karroo rocks of southern and central Africa. As in the case of the areas to the south and west the conclusion was reached that the conditions of sedimentation at that time were not suitable for the accumulation and preservation of large amounts of vegetable matter, so that it is unlikely that workable coal seams will be found.

Mr. Caswell makes a detailed analysis of the numerous faults that occur a few miles inland between Mazeras and Kilifi, and concludes that there were three epochs of faulting. The last phase took place near the end of Tertiary times and was instrumental in determining the shape of the land near the coast today. It is shown, also, that most of the economic mineral deposits at the coast are closely associated with an intermediate set of faults, and the determination and mapping of the faults should be of assistance in prospecting the area.

Manganese and lead-zinc deposits are known in the area, and new zinc blende veins were discovered a little south of Mazeras during the course of the survey. It appears unlikely however, that the metalliferous minerals will have any economic value, unless veins are discovered underlying the manganese ore cappings or unless the newly discovered veins prove to be extensive. Limestones that form a thick band on the seaward side of the coastal hills might prove suitable for cement manufacture, and the results of analysing several samples taken during the survey are given in the report.

The survey was accomplished with the aid of a grant from Colonial Development and Welfare funds. Much of the ground covered, viz. east of a line from Mazeras to Simba hill and north of a line running westwards from the hill, is at present closed to mining and prospecting.

Nairobi,
7th October, 1953.

WILLIAM PULFREY,
Chief Geologist.

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MAP

Geological Map of the Kilifi-Mazeras area (Degree Sheet 66, S.E. quarter): Scale 1:125,000
At end

ABSTRACT

The area described in this report covers approximately 900 square miles immediately to the north of Mombasa, and is bounded by latitudes 3° 30' S. and 4° 00' S., longitude 39° 30' E., and the Indian Ocean.

The rocks exposed consist of sediments—mainly sandstones, limestones, and shales—that range in age from Triassic to Recent, and which represent continental, lacustrine, and marine conditions of deposition. A description of the rocks is given together with an account of their structures and genesis, and a correlation with the rocks of other areas is proposed. A brief account of the geological history of the area is included in which it is deduced that the majority of the sediments were deposited along the margin of a trough that was subject to infrequent flexures and fractures.

One chapter is concerned with the economic prospects of the area. Occurrences of manganese, lead, and zinc are described, and evidence is adduced to show that all the coastal metalliferous mineral deposits are genetically related. The suitability of the Jurassic limestones and shales for cement manufacture is discussed, and a short section deals with water-supply problems.

Geology of the Kilifi-Mazeras Area

I—INTRODUCTION

General Information

The area described in this report covers approximately 900 square miles and comprises the total land extent of the south-east quarter of degree sheet 66 (Kenya Colony). It is bounded by latitudes 3° 30' S. and 4° 00' S., longitude 39° 30' E., and the Indian Ocean. Most of the area is administered from Kilifi, but small portions in the south-eastern and south-western corners are administered from Mombasa and Kwale respectively. The greater part of the area is inhabited by the Wa-Giriama and their associated tribes, but there are numerous Arab and Wa-swahili settlements in the coastal strip. The land lying within ten miles of the coast forms part of the Protectorate of Kenya, which is rented from the Sultan of Zanzibar. It is administered as a sub-district, in matters over which the Sultan retains jurisdiction, by a Mudir based on Takaungu.

Communications are good particularly in the southern part of the area, where there are few places more than six miles from a motorable road. Many new roads have been constructed in recent years under the Coast Hinterland Development Scheme, and it is likely that others will be made in the immediate future.

The climate is tropical along the coast, becoming drier and hotter inland. The following table shows the rainfall recorded at different places during 1950 and 1951 together with the average annual rainfalls (1951 was an unusually rainy year in many parts of Kenya).

	Rainfall 1950	No. of rainy days 1950	Rainfall 1951	No. of rainy days 1951	Average annual rainfall	No. of years re- corded
Kilifi (D.O.) ..	37.77	110	46.47	110	36.92	32
Sokoce	30.96	86	45.84	87	46.59	31
Kibarane ..	40.20	126	48.07	129	40.98	11
Mtondia ..	*	—	44.25	130	—	1
Ganze Dispensary	22.13	112	37.33	94	35.42	11
Bamba	29.29	51	*	—	28.41	10
Jaribunyi ..	*	—	39.60	94	—	1
Chonyi	42.62	130	57.48	105	47.01	11
Kaloleni School ..	37.52	127	51.87	125	43.59	24
Giriama	*	—	51.39	92	—	1
Jibana Dispensary	*	—	52.77	94	—	1
Mazeras Railway Station ..	36.75	104	49.63	99	39.51	44
Shimo-la-Tewa ..	52.05	102	57.19	117	55.84	6

*record incomplete

Maps

As a basis for the geological map, the following topographical maps were used:—

- 1:50,000 Mombasa, E.A.F. No. 1034 (1942).
- 1:50,000 Kilifi, E.A.F. No. 1179 (1942).
- 1:50,000 Mariakani, E.A.F. No. 1137 (1942).
- 1:125,000 Mombasa, E.A.F. No. 1191 (1943).
- 1:125,000 Malindi, E.A.F. No. 810 (1942).

The first three of these maps were, for the most part, prepared from aerial photographs taken by the South African Air Force in 1942: the remainder, covering about half of the total area, were compiled from the older G.S.G.S. series of maps that was printed prior to the 1914–18 war and from field reconnaissances by the E.A. Survey Group in 1942. The representation of the northern part of the area was found to be inaccurate to a greater or lesser extent and modifications were freely indulged in during the present survey.

The geological survey was carried out between January and July of 1952. Mapping was mostly by compass and cyclometer traverses, with recourse to plane-table work wherever practicable. Traverses at one mile intervals were aimed at but, where conditions justified it, they were not rigidly adhered to. The field map was prepared on the scale of 1:50,000.

Acknowledgment

The writer is indebted to Dr. W. J. Arkell of the Sedgwick Museum, Cambridge for valuable advice in connexion with ammonite nomenclature.

II—PREVIOUS GEOLOGICAL WORK

Of the early students of East African coastal geology, the names Rich Thornton (1862)*, Baron von der Decken (1869), Joseph Thomson (1879), Walcot Gibson (1893), Stromer von Reichenbach (1896), J. W. Gregory (1896), and E. E. Walker (1903) need to be mentioned. None of these workers performed any detailed mapping in the coastlands, their reports being concerned with observations made in transit to places further afield.

Probably the first detailed stratigraphical succession of the coastal sediments to be published was that by Muff (Maufe) in 1908. His succession, which is shown in Table I, was based on a traverse along the railway-line.

TABLE I—THE STRATIGRAPHY OF COASTAL KENYA ACCORDING TO MAUFE (1908)

Pleistocene	..	Raised coral reef and Kilindini Sands (Unconformity)
Jurassic	..	Changamwe Shales with limestones near base
?Triassic	..	{ Mazeras Sandstones, with pisolitic limestone near top Mariakani Sandstones Maji-ya-Chumvi Beds Taru Grits (Unconformity)
(Duruma		
Sandstones)		
Archaeon	..	
		Gneiss

Maufe recognized the regional seaward dip and the relative age relationships of the beds, but his grouping of the pisolitic limestone (which is now known to be Middle Jurassic) with the Triassic led him to conclude that the Mesozoic sequence was conformable throughout. Maufe's collection of rock specimens is preserved in the museum of the Mines and Geological Department, Nairobi.

Noteworthy contributions to the knowledge of the Jurassic rocks were published by Fraas (1908) and Dacqué (1909 and 1910). Fraas extended his mapping of the Jurassic outcrop to include the entire Duruma Sandstone Series on account of (1) his belief that he had found in grits at Samburu a cross-section of a belemnite and an indistinct impression of an ammonite which he considered to be Lower Jurassic, and (2) the resemblance of certain of the Maji-ya-Chumvi Beds to the Changamwe Shales. This did not find favour with Dacqué who regarded the Duruma Sandstone of British East Africa as the representative of the "African Sandstone"—a non-marine, pre-Bathonian formation extending from Egypt to South Africa—and was emphatically refuted by Maufe (1915).

Gregory paid a second visit to Kenya in 1919 and in 1921 published his famous book *'The Rift Valleys and Geology of East Africa'*. Chapters IV to VII are concerned solely with coastal geology and the value of this work cannot be over-emphasized. His stratigraphical succession (see Table II) is basically similar to Maufe's but is subdivided in greater detail. To Maufe's four Duruma Sandstone divisions, Gregory added a fifth—the Shimba Grit—but removed the pisolitic limestone to the Jurassic Kambe series. He split the Jurassic

*References are quoted on pp. 52–54.

rocks into five divisions ranging in age from Bathonian to Corallian* and considered the series as a whole to rest unconformably upon the Duruma Sandstones. The Magarini Sands, which in 1893 he had referred to the Trias, he now identified as Pliocene, and assigned a group of calcareous sands from North Mombasa to the same period.

TABLE II—THE STRATIGRAPHY OF COASTAL KENYA ACCORDING TO GREGORY (1921)

Pleistocene	..	Raised Coral Reefs	
Pliocene	..	{ North Mombasa Craggs Magarini Sands	
Jurassic	..	{ Changamwe Shale Rabai Shale Miritini Shale Kibiongoni Beds Kambe Limestone	(Corallian) (Oxfordian) (Lr. Oxfordian ?) (Callovian) (Bathonian)
Permo-Triassic (Duruma Sandstones)		{ Shimba Grit Mazeras Sandstone Mariakani Sandstone Maji-ya-Chumvi Beds Taru Grit	
Eozoic	..	Gneiss	

At this stage, reference must be made to the work of C. W. Hobley to whom credit is due for the discovery of many of Kenya's coastal economic mineral deposits. Hobley made numerous excursions through the coastlands in the early part of the century and his observations are freely incorporated in Gregory's book.

In 1928 Dr. E. Parsons published a paper describing the geology of the coastal belt between the Sabaki Valley and the Tanganyika border. His conclusions differ greatly from those of earlier writers, notably in his interpretation of the structures. He postulates three major phases of compression; the first, operating from the north in pre-Bathonian times, led to doming followed by over-thrusting and the development of north-south shear-planes; the second came from the east in post-Oxfordian times and caused the Miritini Shales to be thrust westwards over the Kambe Limestones and on to the upper members of the Duruma Sandstone Series; the third, also from the east, occurred during late Cainozoic times (apparently post-Middle Pleistocene) thrusting the Kilindini Sands over the Changamwe Shales, and the Changamwe Shales over coral limestones of the Magarini Sands. The stratigraphical succession he proposed (see Table III) shows many departures from the sequence established by Gregory, the principal differences being: (a) the relative positions of the Shimba Grits and Mazeras Sandstones are reversed; (b) the Jurassic and Cretaceous rocks are combined into the "Miritini Series" and "Changamwe Series"; (c) the term "Magarini Series" is used to embrace all the Cainozoic formations from Eocene to Pleistocene; and (d) the raised coral reef is considered to be of Recent age.

TABLE III—THE STRATIGRAPHY OF THE COASTAL KENYA ACCORDING TO PARSONS (1928)

Recent	Recent Coral Reefs	
Pleistocene to Eocene	Magarini Series	{ Unconsolidated sands, pebble beds, calcareous rocks, etc.
Cretaceous to Jurassic	Changamwe Series	{ Shales with nodules and a few sandstones and calcareous bands
Jurassic	Miritini Series	{ Shales with argillaceous and coral limestones and a few sandstones

*The term "Corallian"—strictly a local formational name—was used by Gregory, and later by McKinnon Wood, as a stage signifying that the beds are equivalent in age to the Corallian Beds (Upper Oxfordian) of England. In France the Corallian Beds are often Kimmeridgian (W. J. Arkell, *Geological Magazine*, Vol. LXXI, July, 1934, p. 320).

TABLE III—(Contd.)

Triassic to Permian	Duruma Sandstone Series	{	Shimba Grit Group	{	Mazeras Sandstones and shales
			Mariakani Sandstones		Shimba Grits
			Maji-ya-Chumvi Beds	{	Upper
			Taru Grit Group		Middle
Eozoic Series			Gneisses and metamorphic rocks.		
					Lower

A monograph describing geological collections from the Kenya coastlands made by Miss M. McKinnon Wood was published in 1930. It is primarily a palaeontological report and, being the only one of its kind yet published, is of great value. A short stratigraphical section is included that is largely a recapitulation of Gregory's views, but to which minor detail has been added. The range of the Jurassic rocks is extended downwards to the Bajocian (?) or Upper Lias, and upwards to the Kimmeridgian. The existence of Cretaceous rocks, questioned by Gregory, is proved from fossils found in a small quarry north of Mombasa, and a greater sub-division of the Cainozoic is made. Reference is made to the relationship between the Jurassic rocks and the Duruma Sandstones but, although no conclusions are stated, the contact is shown in a section (*op. cit.*, p. 220) as being a normal fault.

Miss McKinnon Wood re-visited Kenya in 1930, and her second collection of rocks and fossils formed the subject of another monograph published in 1938. The most notable contribution made by her second collection was the proving of the Bajocian (Jurassic) stage.

A confidential report on the oil prospects of Kenya including chapters on coastal geology, was written by H. G. Busk and J. P. de Verteuil in 1938, and was followed in 1939 by a paper by Busk discussing the physiographical aspects of the Mombasa area. The coast ranges were regarded as being degraded horsts dating from early Jurassic times, when the collapse of Gondwanaland led to the initiation of faults of the "rift" type. The outcropping junction of the Jurassic rocks with the Duruma Sandstones was claimed to be in part faulted and in part unconformable.

Within recent years, reports of the Geological Survey of Kenya have been prepared of the areas adjoining Kilifi to the north (Thompson), west (Miller, 1952) and south (Caswell, 1953).

III—PHYSIOGRAPHY

Maufe (1908, p. 3) described the coastal belt as a series of three more or less parallel zones or plains, each slightly dissected by denudation, which rise in steps one above the other towards the interior. Gregory (1896, pp. 222–3) referred to these zones as (a) the Coast Plain, which is occupied by the Pleistocene deposits; (b) the Foot Plateau, which is practically coincident with the Jurassic outcrop, and (c) the Nyika, which embraces the ground covered by the Duruma Sandstone Series and the flat gneiss country west of it. To these three zones recent writers have added a fourth—the Coastal Range—which is used to denote the Shimba hills. Although all four zones can be recognised in the Kilifi area, they are often less well defined than to the south of Mombasa.

The Coast Plain varies from two to five miles in width and generally lies below the 100-ft. contour. Its seaward margin is composed of the Pleistocene coral reef and this is backed by a series of variable sands, also of Pleistocene age. These formations are often masked by a thin veneer of red sands and sandy clays. In its natural state the coast plain supports thick bush, but throughout most of the Kilifi area the bush has been cleared and the ground cultivated. Large sisal plantations such as the Vipingo Estates and Kilifi Plantations exemplify the cultivation.

The Foot Plateau stands at elevations of from 200 to 450 ft. and is typified by the sparsely cultivated country traversed by the main Mombasa–Nairobi road between Miritini and Mazeras. The rocks comprising the plateau are largely shales of Jurassic age, that yield a poor soil capable of supporting only stunted thorn trees and grasses. The plateau represents a late Tertiary, seaward-sloping peneplain whose surface has been dissected by numerous stream courses. Accentuating the eastern edge of the plateau is a low ridge of hills composed of Pliocene sands that rest unconformably upon the Jurassic rocks. The ridge is well developed between Mtwapa and Kilifi Creeks where it frequently exceeds the 400-ft. contour: e.g. Kidongo, 502 ft.; Mwembe Chungu, 456 ft.; Gongoni, 470 ft.; Mtoni, 530 ft.; and

Mkomani, 456 ft. North of Kilifi Creek the hills rise still higher and attain a maximum for the area of 747 ft. at Sokoke. The sands yield a fairly good soil, and support, for example, a large coconut and pineapple plantation at Sokoke.

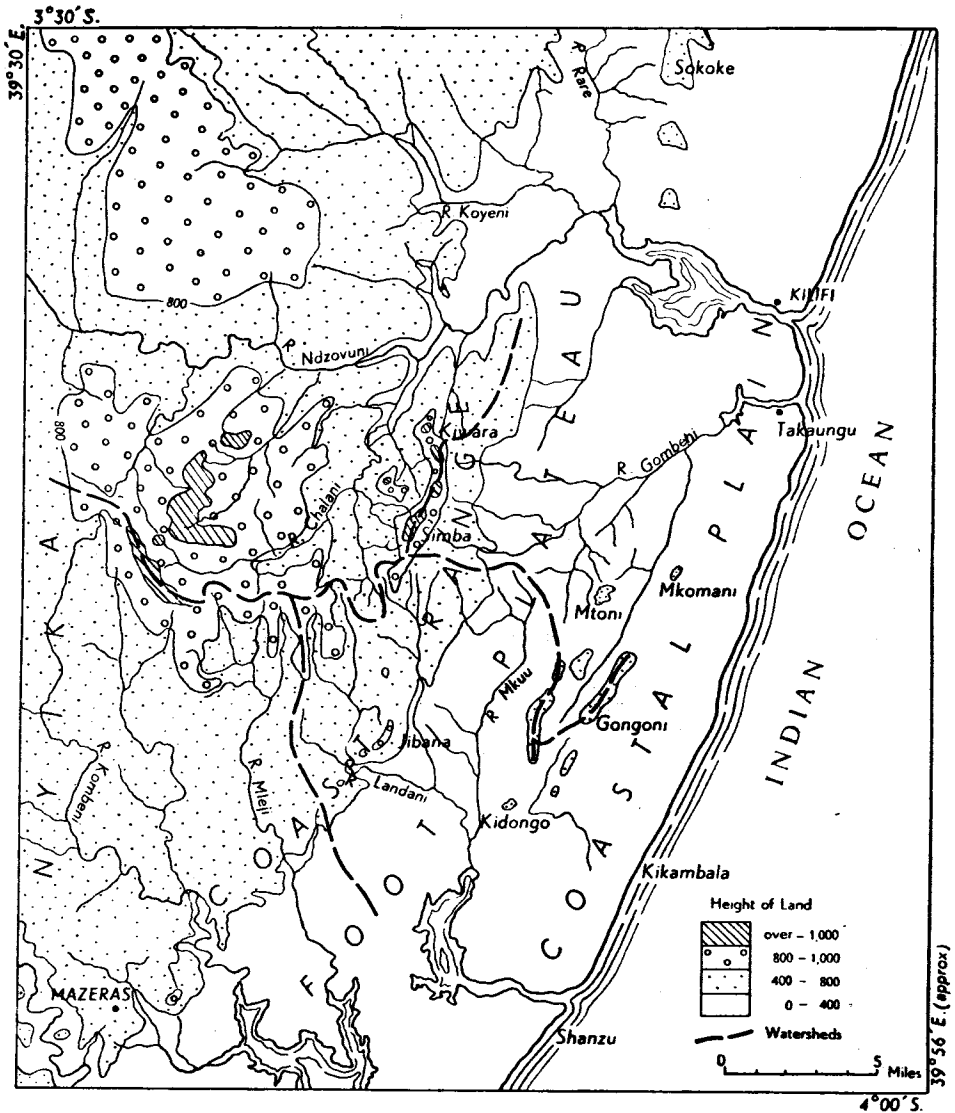


Fig. 1.—Physiographical Map of the Kilifi-Mazeras Area

The Coast Range, as developed in the Kwale-Mombasa area, is not well defined although it can be followed, almost without a break, from south to north. Only at Jibana (1,028 ft.) and between Simba (1,154 ft.) and Kiwara (1,076 ft.) does the range exceed the 1,000-ft. contour; elsewhere, apart from a few isolated summits such as Benyagundu hill and in the Chonyi area, it seldom rises above 600-700 ft. It is formed essentially of the Upper Duruma Sandstones, and apparently owes its eminence to resistant bands of grit that occur within it. The sandstones yield a light but fertile soil which has been widely cultivated for coconut plantations around Kaloleni and Ribe. Elsewhere, it is often thickly forested, and the area flanking the Ndzovuni River is the site of a flourishing charcoal-burning industry.

The Nyika occupies the lower-lying ground along the western side of the area, and extends for many miles further westwards. Characteristically it is uninspiring country—gently undulating, sparsely populated and thinly covered by vegetation.

Physiographical evolution.—An erosion surface of end-Tertiary age has been widely recognized over large areas throughout much of eastern Kenya and neighbouring territories, and is represented at the coast. Much of the Nyika can be correlated with this surface, and Caswell (1953, p. 5 and Fig. 10) showed that the planed surface of the Jurassic rocks of the Foot Plateau is its down-faulted continuation. The evidence can be summarised as follows:—

- (1) The Nyika surface terminates suddenly near Mazeras.
- (2) This surface and that on the Jurassic rocks can be easily fitted together—their present displacement is approximately 300 ft, which can be accounted for by movement along faults parallel to the Coast Range.
- (3) The Mwachi river exhibits deeply incised meanders in the neighbourhood of Mazeras suggesting that, at some stage, it had reached a state of old age in which it was graded to a base-level of erosion considerably higher than at present: this is supported by the 600-ft. nick-point which, when the original profile is projected, indicates a base-level of erosion at about 400 ft. O.D.
- (4) Down-faulting of the Foot Plateau could have produced the conditions necessary for the formation of the Upper Pliocene Magarini Sands, of which the lower three hundred feet are fluvial deposits: this, too, suggests that the sea-level in Upper Pliocene times stood at about 400 ft. O.D.

From the evidence at the coast, it is possible to date the end-Tertiary surface more accurately, for it was still in process of development when the faulting occurred. This took place in early Upper Pliocene times, if one is to accept an Upper Pliocene age for the Magarini Sands, so that the age of the planed surface is also early Upper Pliocene.

Evidence from the Mombasa-Kwale area (Caswell, 1953, p. 6) points to the existence of an older surface at about 1,200 to 1,300 ft., as is represented on the Shimba hills. The hills are capped by a band of resistant grits which undoubtedly preserves the surface although it is unlikely that it could have caused it. Its height cannot be matched with the profiles of any of the other bevelled surfaces in Kenya, so its age remains obscure, though it may be suggested that it is not older than early Tertiary. Jombo, a 1,500-ft. high hill built of igneous intrusions in the southern part of the Mombasa-Kwale area, provides a clue to this. The intrusions are presumed to be of early Tertiary age and, since they must have been emplaced below the land surface of that time, it can be assumed that the surface then stood at not less than 1,500 ft. O.D. The higher hills in the Kilifi area—Jibana, Simba, Kiwara, Benyagundu, and Kipabwane—can be regarded as the denuded remnants of this surface, which may have extended westwards to include the Taru hills and perhaps even the Voi hills. It certainly seems likely that the surface has a west to east slope, and it may be tentatively assumed that the drainage system which caused it was developed as a result of the late Mesozoic-early Tertiary up-doming which is thought to have presaged the formation of the Gregory Rift Valley.* Eastward-flowing rivers are still much in evidence in Kenya where they form a major drainage pattern, and there is evidence to suggest that this pattern was even better developed in the past.

IV—SUMMARY OF GEOLOGY

The rocks of the Kilifi-Mazeras area are wholly of sedimentary origin and range in age from Triassic to Recent; they fall naturally into three well-marked divisions:—

- (3) The Cainozoic rocks
- (2) The Jurassic rocks
- (1) The Duruma Sandstone Series.

*Dixey (1948, Fig. 1) has shown that the general direction of slope of the peneplains in northern Kenya is to the south-east, and this appears to be common to central Kenya, suggesting that the up-doming was irregular.

The Duruma Sandstone Series is the Kenya correlative of the Karroo System of South and central Africa and consists of grits, sandstones, and shales that, for the most part, were deposited under lacustrine or sub-aerial conditions. Miller (1952, p. 12) has proved the existence of a marine band in the lower part of the series, and others in the upper part have been hinted by Thompson but such intercalations constitute a very small percentage of the total thickness. The series is readily divisible into three broad lithological units with coarse sandstones and grits at the top and bottom of the succession and finer sandstones and shales in the middle. In the Kilifi area, only the upper and upper-middle units are represented.

The Jurassic rocks are entirely of marine origin and consist of limestones, mudstones, shales and occasional thin sandy beds, ranging from the Bajocian to the Middle Kimmeridgian. They share the easterly regional dip of the Duruma Sandstone Series, against which they are down-faulted throughout most of the area.

The Cainozoic rocks include a thick series of terrestrial sands and gravels that are probably of Upper Pliocene age, a Pleistocene coral reef with associated lagoonal deposits of coral breccia, calcareous sands, and beach sands, and various subsidiary sandy beds that seem to be of late Pleistocene or Recent age. They are all more or less flat-bedded, and rest unconformably upon members of the older divisions.

In a general way, the boundaries between the systems or groups and their sub-divisions run parallel to the coast-line, the rocks becoming progressively older as one travels inland.

V—STRATIGRAPHY

The complete succession in condensed form, with notes on the probable palaeogeographic events, is given in Table IV. Details of the divisions are considered in subsequent sections.

1. The Duruma Sandstone Series

Stromer von Reichenbach (1896, p. 22) proposed the name "Duruma Sandstones" to embrace the thick series of grits, sandstones, and shales of the hinterland. Later writers have adhered to this name but have split the series into four or more divisions (*see pp. 2-4*) of which the five put forward by Gregory (1921, p. 46) are the most widely known. They are, in descending order: the Shimba Grit, the Mazeras Sandstone, the Mariakani Sandstone, the Maji-ya-Chumvi Beds, and the Taru Grits. From the evidence of the Kwale area where at least two major grit bands are present in the upper part of the series, Caswell (1953) discarded the term "Shimba Grit" as a stratigraphical division and combined the grits with the Mazeras Sandstone. This unification—it is a reversion to Maufe (1908, p. 4)—has been adopted by Thompson in the Malindi area and will be followed in this report. Current practice makes use of the terms "Lower", "Middle", and "Upper" to distinguish the broad lithological differences of the series so that the succession is as follows:—

- (3) Upper — Mazeras Sandstones with Shimba Grit
- (2) Middle — Mariakani Sandstones
Maji-ya-Chumvi Beds
- (1) Lower — Taru Grits

In the Kilifi-Mazeras area, only the Mariakani and Mazeras Sandstone divisions are represented, the base of the former not being seen.

(1) THE MARIAKANI SANDSTONES

The Mariakani Sandstones outcrop in the western part of the area and consist essentially of medium-grained arkoses and flaggy siltstones, with occasional massive gritty sandstone bands. Two divisions can be recognized, the lower being characteristically light greenish-grey and blotched, whereas the upper is of a darker greenish-brown or yellowish-brown colour; they are distinguished on the map by the symbols Km and Km' respectively. Both divisions are well jointed, two sets always being present and often a third. The directions of jointing remain fairly constant throughout the area as is shown in Fig. 2, on which the lengths of the radial lines are proportional to the number of readings taken.

TABLE IV.—THE STRATIGRAPHICAL SUCCESSION IN THE KILIFI—MAZERAS AREA

Era	Period	Representatives	Lithology and Thickness	Depositional Environment	Climate	Palaeogeographic Events
CAINOZOIC	Recent	Alluvia, oyster beds and sands	Superficial sands			
	Pleistocene	Coral reef and lagoonal sands	Reef limestone, calcareous and quartz sands 300ft	Marine and lagoonal, some continental	Pluvial and inter-pluvial	Fluctuating sea-level.
	Pliocene	Magarini sands	Sands and gravels 400 ft.	Fluviatile and some continental	Wet becoming arid	Extensive erosion of Mesozoic deposits Faulting
	Miocene Oligocene Eocene	— — —			— — —	Extensive continental erosion
	Cretaceous	—			—	?Faulting? Marine limestones known from near Mombasa.
	Jurassic	Changamwe Shales Rabai Shales Miritini Shales Kibiongoni beds Kambe limestones	Limestones, shales and sandy shales 5,000 ft.	Mostly marine with some estuarine	Warm—temperature of the Jurassic sea was in excess of 75° F.	Marine invasion of the coastal lands leading to deposition of marine limestones and shales Faulting.
	Triassic	Mazeras Sandstones Mariakani Sandstones Duruma Sandstones	Arkosic grits and sandstones 3,500 ft.	Continental, deltaic and lacustrine	Generally semi-arid	Down-warping of basin of deposition
MESOZOIC						

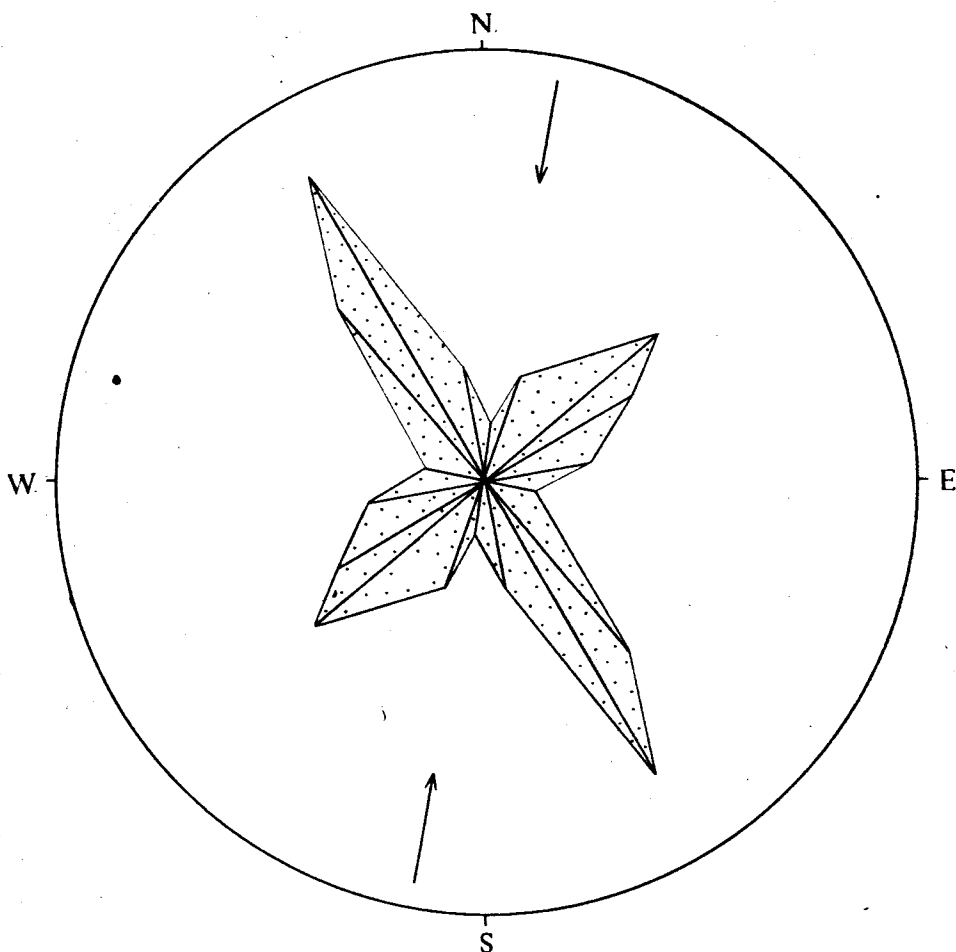


Fig.2—Directions of Jointing in the Mariakani Sandstones.
The Heavy Arrows Indicate the direction of Compression.

(a) *The lower Division of the Mariakani Sandstones*

The pale greenish-grey blotched sandstones are well exposed in the south-western corner of the area, where they have been quarried extensively for use as railway ballast and road-metal. The outcrop can be traced northwards from the railway-line for distances of up to about five miles; thereafter it continues as fingers up the river valleys for a few miles, the higher ground being capped by the younger division. The majority of the exposures show the sandstone dipping very gently northwards or north-eastwards at angles of from 1° to 3° . The rock is usually massive—although laminated layers also occur—with widely spaced joints, many of which carry secondary crystalline calcite. Bedding is frequently emphasized by slightly discordant muscovitic partings (with which carbonaceous material is often associated) that permit of the rock being split readily in one direction. The partings rarely exceed 1 mm. in thickness, but wider bands, some of them as much as twelve inches thick and containing a high percentage of finely divided mica flakes, are sometimes found. Specimen 66/425*, obtained from the top of the largest of the stone quarries behind Mazeras Mission, represents one of the thicker bands that has been contorted due to surface creep. Another band is exposed on the floor of the railway quarry near the western boundary of

*Numbers 66/425, etc., refer to specimens in the regional collection of the Mines and Geological Department, Nairobi.

the area, and a third was encountered in a well recently dug at Kaloleni. In the railway quarry, the micaceous band is associated with current-bedded, ripple-marked sandstones containing lenticular pellets of carbonaceous material.

A typical fresh specimen of the sandstone is pale greenish-grey in colour with numerous greyish-white blotches, each about the size of a small pea. Weathered specimens are yellowish-brown with chocolate brown blotches. Miller (1952, p. 13) claims that the constituent grains of the blotches are closely packed, as opposed to those of the surrounding sandstone which are separated by chloritic cement. The blotches are more or less spheroidal, but somewhat flattened on their upper and lower surfaces; they are generally individual, although the coalescence of two or more blotches is not uncommon. They occur in definite contiguous layers that parallel the bedding planes, even when they are slightly oblique current bedding surfaces. These features make it clear that the blotches are a depositional feature, and it is probable that they originated as spheres during or soon after sedimentation and were subsequently squeezed during compaction. Their mode of origin is not yet understood although several explanations have been advanced. Gregory (1921, p. 51) considered them to be aggregates of finer particles of quartz, feldspar, and epidote, three major constituent minerals of the sandstones. Microscope sections examined by the writer have not confirmed this opinion, and they would indeed be peculiar conditions of sedimentation that could lead to such regular mechanical separations. Another theory—apparently favoured by Thompson—involving a slight chemical change in the sand brought about by its passage through the digestive tracts of worms, is equally improbable. In an earlier report, the writer (Caswell, 1953, p. 11) suggested that they were caused by the initiation of local centres of leaching that left spheres deficient in certain constituents.

Microscope sections show that the sandstone is of arkosic composition, with quartz and feldspar as the dominant minerals. The ratio of quartz to feldspar is generally about 3:2 but in some specimens (e.g. 66/421, obtained from a well at Kaloleni) there is more feldspar than quartz. The grains are sub-angular, fairly well sorted, and of fine grade, the average diameter being about 0.2 mm. Much of the quartz shows strain polarisation. The feldspar is largely plagioclase of oligoclase-andesine composition, with a lesser proportion of microcline; it is usually fresh. Muscovite is commonly disseminated throughout the rocks but, as mentioned earlier, is often concentrated along certain horizons. The rarer allogenic minerals are epidote, biotite, garnet, pyroxene, zoizite, zircon, rutile, and kyanite. In the majority of cases the grains are cemented by chlorite, but in some specimens the place of the chlorite is taken by secondary calcite. Carbonaceous material is patchily disseminated throughout the succession; it is generally formless but specimen 66/421, also obtained from the well at Kaloleni, contains an impression of a plant stem.

Exposures in the Mwachi River, near the ford on the Mazaras-Kinango road, contain cannon-ball concretions that appear to be cemented by calcite with some limonite. They are extremely tough, and are apparently confined to certain beds but it could not be determined whether they are syngenetic or epigenetic origin. Being more resistant to erosion than the enclosing sandstone, they are frequently seen as small domes protruding above exposed bedding surfaces.

Near the western boundary of the area, exposures along the new Mombasa-Nairobi road reveal blotched sandstones associated with strongly false-bedded, creamy-white sandstones and thin, flat-bedded, ripple-marked sandstones. The false-bedding strikes at about 140°, the wash having come from the S.W., and is of typically aqueous origin.

Aqueous-current ripple-marks are features common to many of the strata and are particularly well developed in the micaceous beds. Specimen 66/421d from a quarry on the railway-line west of Mazaras has ripples of wavelength 31 mm. and amplitude 1 mm., giving a ripple index of 31. This figure, according to the claims of Kindle (1917), indicates an aeolian origin but this type of ripple is rare. Samples measured by Thompson from Shakama in the Sabaki valley give an average ripple index of 8.75, a figure which more closely approximates to the majority of samples from the Kilifi area.

(b) The Upper Division of the Mariakani Sandstones

The Upper Mariakani Sandstones rest conformably on the lower division and occupy most of the north-west corner of the area. They are of essentially similar constitution to the sandstones of the lower division but show a wider range of grade and colour, the latter being largely dependant upon the mica content. The lowermost beds are poorly exposed

but, from the evidence given below of a bore-hole drilled near the roadside about two miles west of Kaloleni, they probably consist largely of alternating fine sandstones and shales.

BOREHOLE NO. 166 (KALOLENI)

feet

- 0- 3 Soil
- 3- 13 Decomposed sandstone
- 13- 18 Sandstone
- 18-350 Sandstones with shale bands

Their outcrop is typified by the flat country immediately to the south of the Kaloleni-Gotani road, and extending westwards through Kinangoni and Makwala.

North of the Kaloleni-Gotani road a band of more resistant, massively-bedded sandstone that forms a well-defined feature is exposed and can be traced from Kaloleni, through Kizurini and Mwa Baya Nyundo, upon which stands the Roman Catholic Mission, towards Vilagani. Other resistant bands are responsible for the Mwana Mwinga and Kipabwani-Kinarane ridges, the latter reaching a height of 1,105 ft. at Kipabwani beacon. Only one reliable dip reading (2° to N.N.E.) was obtained from this part of the area, taken in a small stream-bed near the bore-hole referred to above. Physiographical considerations, however, suggest that the reading is of regional significance. A bore-hole drilled at Kwa Demu (bore-hole No. C 1106) penetrated 60 ft. of soft sandstones and shales, followed by nearly 250 ft. of hard sandstones which can possibly be correlated with the outcrop forming the Kipabwani ridge.

Large outcrops occur in the Ndzovuni river where it is crossed by the Gotani-Bamba road. Massive, well-jointed, fine-grained sandstones with interbedded, less massive, current-bedded sandstones are exposed dipping gently eastwards. The numerous exposures examined revealed equally numerous diverse dips that varied in direction from north-east to south-south-east, but their angles remained consistently less than 5° . The sandstones are compact and of a sugary appearance, and consist of fairly well-sorted, sub-angular quartz grains with lesser proportions of feldspar and mica. Outcrops farther downstream show equally variable dips although a mean regional dip to the north-east is suggested. Exposures in the Ndzovuni river are generally poor due to the mantle of superficial sand, but other large exposures can be seen at the crossing of the Kaloleni-Ganze road. Here the rock is a massively-jointed, false-bedded, coarse-grained, quartzo-felspathic sandstone containing a little mica and occasional small garnets just visible to the eye. Pebbles of quartz and fresh feldspar are common, and there are included pellets of shale that indicate contemporaneous erosion of the lower sediments.

To the north of the Ndzovuni river is a large tract of gently undulating, sand-covered country in which very few exposures are to be seen. The sands are the residual products of the weathering of the underlying sandstones but, although weathering has probably been acting on the rocks since Triassic times, the greater part of the sands can be ascribed to the late Cainozoic era. Thompson states that similar sands attain a maximum thickness of from 20 to 30 ft. in the Malindi area, and he has accordingly mapped them as a separate formation which he assigns to the middle Pleistocene. Whilst there are good grounds for such a policy, it was not followed in the Kilifi area since it was considered that confusion might result. Owing to the paucity of rock exposures in this vicinity, only rapid traverses were made across it, and no attempt was made to survey the topography.

The regional north-easterly dip is maintained between Bamba and Kidemu where medium-grained quartzitic sandstones, containing little or no feldspar, are exposed. To the west of Bamba the ground drops rapidly to a low-lying plain composed of fine-grained, laminated, silty sandstones, seemingly the lowest beds of this upper division. East of Bamba the regional dip swings south-eastwards and many good exposures can be seen in the Munguya-Mawe and Petunguo rivers. At both localities false-bedded, coarse-grained, quartzo-felspathic sandstones crop out and are composed of more or less equigranular, sub-angular grains. Quartz predominates, and in thin section many of the grains are seen to possess secondary marginal growths, whilst wavy extinction is equally common. The feldspar is weathered and is sometimes replaced by secondary silica, producing patches of quartzitic

composition. Among the minor allogenic constituents are small grains of pyroxene, sericitic muscovite, and biotite. The cementing minerals are chlorite, quartz, and calcite, the last two being of secondary origin.

Greenish-grey, horizontally-bedded, flaggy sandstones are exposed in a stream section near Kiti, about two miles west of Ganze. They are fine-grained and equigranular, and consist mostly of sub-angular quartz grains with some feldspar and mica, and rare grains of pyroxene and epidote. Secondary calcite is common and occurs as irregular patches, and secondary silica is present in the form of marginal growths.

In the Koyeni river, a short distance upstream of the Ganze-Kaloleni road, tough micaceous quartzo-felspathic sandstones are exposed containing ferruginous cannon-ball concretions. These have led to minor displacements of the bedding planes, yet the high percentage of secondary calcite in them testifies their epigenetic origin.

(2) THE UPPER DURUMA SANDSTONE SERIES—MAZERAS SANDSTONES

Rocks of the Upper Duruma Sandstone Series rest with a slight unconformity on the Mariakani Sandstones—in the north of the area they overlie the upper division, but in the south they overstep on to the lower division. In the south too, the contact is sometimes faulted, and there are also numerous other small faults, all with downthrows to the east-south-east.

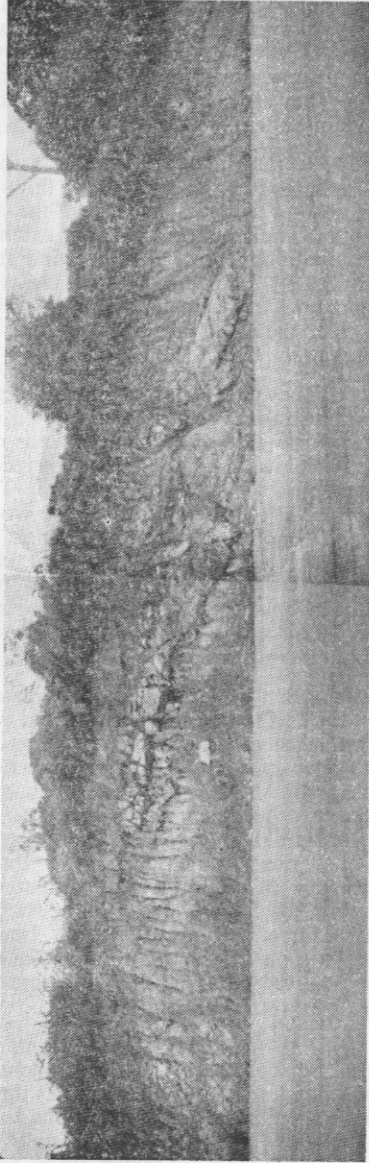
On the railway-line, the first definite exposure of Mazeras Sandstone occurs in a cutting at mile 12/7* immediately east of the Mwachi river embankment, although unconsolidated red sands which may be ascribed to either the Mazeras Sandstones or the Magarini (Pliocene) sands extend as far east as the loop. Both Maufe (1908, p. 9) and Gregory (1921, p. 50) record the first outcrop of Mazeras sandstone at mile 11/10, but the railway has been realigned since their surveys were made. Two small faults are exposed in the cutting, each with an easterly downthrow. The next cutting, immediately west of the embankment, exposes flat-bedded, massive sandstones with thin interbedded shales. In the next cutting, at mile 12/14, shales are overlain by massive, false-bedded grits, but the shales are thrown up again to the north-west by a fault trending 40° . The grits reappear at mile 13 dipping gently eastwards, so that the throw of the fault cannot be more than about fifty feet. The sandstones and grits are white or cream in colour, and consist of quartz and feldspar grains cemented by muscovite or silica. As Maufe (1908, p. 9) remarks, the muscovite forms a poor cement and the rocks crumble easily. The shales are generally yellow, grey or brownish, but are sometimes green or purple. Massive sandstones with interbedded shales are exposed between miles 13/15 and 14, just short of Mazeras Station, having an apparent gentle dip to W.S.W., but this may have been affected by creep. Immediately east of the station are unconsolidated sands which are considered as degraded sandstones of the Mazeras group, but it is likely that the station itself is on Mariakani Sandstones.

Exposures along the new road from Mazeras towards Mombasa are equally interesting and show a similar sequence. Boulders of Mariakani Sandstone can be seen a few hundred yards down the Rabai road, and it is probable that the junction with the main road is on the same rocks. Coarse, unconsolidated sands, similar to those near the railway station, appear a short distance to the south, and beyond these—about 400 yards from the Rabai road junction—is a small exposure of typically massive Mazeras Sandstone. The exposure is a poor one that does not clearly reveal the structure, but the beds seem to dip steeply to W.N.W. Two hundred yards further on is another exposure showing coarse-grained, quartzo-felspathic sandstones, but here too the structure is not clear. Some of the boulders have polished and grooved surfaces that could be attributed to slickensiding, and the general appearance suggests the nearby occurrence of a fault trending roughly N.N.E. with a downthrow to the east.

A large exposure on the western side of the road about one mile from Mazeras, shows massive grits with interbedded shales. The latter are usually of lenticular form, but sometimes occur in spheroidal or pipe-like masses about one foot in diameter. These are particularly puzzling and until more is known of their form—end sections only were seen—no suggestion as to their origin can be given. A cutting two hundred yards farther on ex-

*Mile-posts are numbered progressively from Mombasa and there are sixteen divisions per mile. Hence 12/7 is twelve miles plus seven divisions from Mombasa.

Plate I.—Faults exposed in cuttings along the new Mombasa-Nairobi road near Mazaras.



(a) Second cutting south of Mazaras, exposing five faults in section.



(b) Sixth cutting south of Mazaras, showing one fault with drag along the fault-plane. On the right is seen a lenticle of contorted rocks, which are probably a result of contemporaneous slumping.

Photos : W. PULFREY.

poses purple shales dipping 3° N. and overlying creamy-white sandstones (Pl. 1a). A normal fault throws the shales down to the south-east and these only are exposed for a distance of about ten yards when another normal fault, striking at 40° and dipping 66° to the S.E., throws down sandstones containing silicified wood fragments. The weathered surface of the sandstone is irregular and slopes seawards, and is overlain by two generations of reddish, unconsolidated sands that are separated by a flatter, seaward-sloping surface. Another normal fault, parallel to the last, throws down a further series of greenish-purple shales which are succeeded, apparently conformably, by thinly bedded sandstones and shales. The purple shales are finally cut out by a fault dipping at 44° to E.S.E. that throws down the thinly bedded sandstones and shales, which are exposed over a distance of about twenty yards. They are gently arched and enclose a thick lenticle in which the beds have been contorted and broken, possibly due to slumping (Pl. 1b). They are succeeded to the east by the Jurassic Kibiongoni Beds which are down-faulted against them.

South-west of Mazeras, the contact between the Mazeras and Mariakani Sandstones is faulted. Massive Mazeras Sandstones are exposed in the bed of the stream that flows from near Mazeras to the Mwachi river, whereas the high ground immediately west of the stream consists of Mariakani Sandstones dipping gently inland, and which are being extensively quarried for roadstone. The stream has cut its course along the fault-zone and further evidence of faulting is afforded by a saline spring, about $1\frac{1}{2}$ miles S.S.W. of Mazeras from which sulphurous gases are emitted. Farther downstream south-westerly dips were recorded which may be due to slumping, for in the Mwachi river the dip is again to the east. Thin veins of galena and zinc blende were found in this area (see Chapter VIII).

North-east of Mazeras, the sandstone outcrop continues past Chimera and Benyagundu hills towards Ribe. The contact with the Mariakani Sandstones seems to be faulted where it crosses the Msapuni river, but an outcrop on the upthrow side of the fault extends northwards to include Rabai. The finding of a fragment of fossil wood here by Hobley is recorded by Gregory (1921, p. 48), who considered that it had possibly been carried there. This is probably correct, for the horizon appears to be too low in the succession for the wood to have been *in situ*. It is likely that the outcrop at Rabai is no more than 100 ft. thick, yet it forms the hub of a radiating drainage system that causes it to stand out as a marked feature, especially on the western side. A bore-hole (C. 606) sited on the edge of the outcrop passed through 27 ft. of weathered Mazeras Sandstone, followed by 474 ft. of light grey and brown flaggy micaceous sandstones and shales of the Mariakani series. Two nearby bore-holes (C. 575 and C. 609) penetrated nothing but Mariakani sandstones.

An old roadside quarry on the south-western flank of Benyagundu hill exposes massively jointed, coarse grits dipping at 11° on a bearing of 150° . The grit is poorly sorted and of uneven grade, with many pebbles up to 20 mm. in diameter. The grains are sub-angular and consist largely of quartz, with some mica and felspar, and are loosely cemented by secondary iron oxide. Dip readings taken in the Msapuni river due south of the quarry are variable in direction due to bending of the beds caused by faulting. There appears to be an upfaulted wedge of sandstone at this locality, and on the old Mombasa-Nairobi road it is the Kambe limestone that is in juxtaposition with the Triassic sandstones rather than the Kibiongoni Beds, as is more usual in the southern part of the area. Unfortunately the Msapuni river does not show clearly the contact between the Jurassic and Triassic rocks for, like most of the other coastal rivers, its course is often masked by talus. It seems, however, that there are two more or less parallel faults that dip eastwards, the more easterly at about 30° . The other is steeper, and in the wedge enclosed between them is a breccia containing limestone of Kambe type. To the west of the wedge is Mazeras Sandstone, and to the east shales of the Kibiongoni Beds.

Many good sections of the Mazeras Sandstones are to be seen in the Kombeni river and would repay a detailed examination. This was not possible during the survey as the river was in flood and could not be followed throughout its course, but exposures near the Jurassic contact showed the sandstones dipping south-westwards at 8° . They are strongly cross-bedded, and interbedded with shales, some of which are carbonaceous whilst others contain pyritic nodules. Numerous fossil tree trunks are exposed, some of them partly carbonized, but Maufe's observation (1908, p. 9) that they conform to a north-south alignment was not confirmed. The largest trunk observed had a diameter of $18\frac{1}{2}$ inches. There are few reliable exposures on the flanks of the valley—which are generally very steep—but outcrops of grit overlooking the river, and some 300 ft. above it, contain many small fragments of silicified wood which probably owe their presence to pene-contemporaneous erosion of the lower fossil wood-bearing horizon. The river continues to expose cross-bedded sandstones for a few hundreds of yards farther downstream but then, after a short gap in which there are no

exposures, there is a small outcrop of easterly-dipping Jurassic shales. Referring to this locality, Gregory (1921, p. 71) says that "brown shales, lithologically identical with the Changamwe Shale, rest on the Duruma Sandstone . . . and appear to represent an overlap of the shales up the Kombeni valley on to the sandstone". This relationship was not confirmed; indeed the straightness of the junction, irrespective of the rise and fall in the topography, is more compatible with a fault than an unconformity.

At Ribe, the Mazeras Sandstones form the high ground upon which stands the present Methodist Mission and the ruins of the old one, and it was near here that Hildebrandt found the fossil wood recorded by Beyrich (1878, p. 774). The eastern slope of Ribe hill is largely masked by scree, but numerous jagged pinnacles of Kambe Limestone protrude among the dense bush on the lower north-eastern slopes. The limestone-sandstone contact is faulted, and for a short distance marks the course of the Mbuzini river. Dips near Ribe are gentle but variable in direction; thus, north of the village the rocks dip to the west-south-west, west of the village they dip to the north-east, and south of the village Gregory (1921, p. 48) records them dipping to the north-west. This dip is probably caused by the small north-westerly dipping fault which can be seen in the Mleji river.

North of Ribe the outcrop swings northwards, and becomes appreciably wider due to the greater thickness of sandstone exposed. The contact with the Mariakani Sandstones which farther south had often been faulted, now appears as a gentle unconformity that can be traced through Kaloleni and Chalani towards Kitengwani. The C.M.S. hospital at Kaloleni is situated on the edge of the Mazeras outcrop and some of the latrines have penetrated the underlying Mariakani Sandstones. A thin layer of kaolinic clay marks the unconformity that separates the two formations. Bore-hole No. C. 1047, sited roughly one mile farther north on the Kilifi road, passed through the following succession according to the driller's log:—

BORE-HOLE NO. C. 1047 (KALOLENI)

Feet		
From	To	
0	10	Clay
10	106	Sandstone
106	196	Sandstone with grey shale bands
196	210	Brown shale
210	225	Grey shale
225	500	Sandstone with grey shale bands

Water struck at 33 ft., 106 ft., and 470 ft.

From the log it seems likely that the unconformity occurs at 106 ft. depth and this is strengthened by the fact that water was struck at this level, for if, as at Kaloleni, the unconformity is marked by a thin clay band, a perched water-table might be expected.

The eastern flank of the outcrop is distinguished by a range of hills, often over 1,000 ft. high, that stretches northwards to the Ndzovuni river. Many of the hills are capped by coarse grits which are probably to be correlated with the Shimba Grits (as defined by Gregory) in the Mombasa-Kwale area, but, as in that area, there is often more than one grit band exposed. On Simba hill, for example, grits occur at the top and also at about the 900-ft. contour. Of Kinangoni hill, at the southern end of the range, Gregory (1921, p. 48) writes that it is "capped by coarse breccia, which was probably formed by a layer of sandstone fragments having been cemented by ironstone and calcite", whereas Parsons (1928, p. 80) refers to the breccia as "undoubtedly a fault rock and like all other faults in this region carries manganese". He does not refer to the type of fault but from his section (*op. cit.*, section No. 4, p. 76) one assumes that he means a southerly continuation of the shear plane shown west of Jibana hill. He is, however, correct up to a point for the occurrences of manganiferous and ferruginous laterites in the coastal succession can generally be ascribed to faulting, and their presence at Kinangoni is, in itself, sufficient justification for extending the Mazeras fault (*see* p. 35) further north. The sharp changes in course of the Landani river immediately north of the hill might conceivably be due to the same fault.

Jibana hill is capped by grits containing wind-polished quartz pebbles, and, as is mentioned by Gregory (1921, p. 48), there are also small nests of white quartzite. He remarks that these are typical of desert sandstones, and considers that they originated by the infilling of hollows caused by the circular movements of grass stems under the influence of wind action.

North of Chonyi is a dip fault having a downthrow to the north-north-east, and this has locally affected the dip of the strata. Coarse-grained, gritty quarzo-felspathic sandstones

containing fragments of silicified wood are exposed in the river, which appears to have cut its course along the fault-plane.

Further north, the range between Shimba and Kiwara hills is more distinctly ridge-like with steep slopes on both flanks. No positive evidence of strike faulting was seen although there is a possibility that the eastern scarp of Kiwara is faulted; a manganese laterite occurs on the top of the hill and a fuller account of it, its genesis, and the implications of faulting is given in Chapter VIII (p. 47). Elsewhere the relief seems to have been caused solely by the erosive action of rivers, the Chalani and its tributaries in particular.

The outcrop narrows rapidly north of the Ndzovuni river due to faulting which has thrown down the Jurassic succession relative to the Triassic rocks, and the Mazeras Sandstone is almost completely cut out at the point where it is crossed by the Koyeni river. It widens again north of the Koyeni and gives rise to the flat-topped hill at Mwa Eba whose western slope is scarred by erosion gullies. The beds exposed are more or less horizontal with perhaps a slight easterly dip, and consist of massive gritty sandstones interbedded with thin, fine-grained, ferruginous sandstones and shales. The debris from the latter is of a reddish-purple colour due to the conversion of ferrous to ferric oxide on weathering. A thin section from a sample of the grits (66/415) shows it to be of quartzitic composition with large sub-rounded quartz grains—many exhibiting marginal growths—cemented by silica. There is a small proportion of interstitial limonite that was introduced prior to the silicification, and which has produced a pinkish colour.

The outcrop swings westwards to include Ganze, and two small outliers were observed at Maduma and Mwatiki. In the northern part of the area there is a closer similarity between the Mazeras and Mariakani Sandstone and it is often difficult to decide where the boundary should be drawn. This assumes an exaggerated importance on the map due to the low relief and the near-horizontality of the strata. Further east the outcrop is characterised by low ridges—often thickly wooded—of bright red sands, of which the most prominent is crossed by the Kilifi–Ganze road at Sosodima.

(3) THE SILICIFIED WOOD OF THE MAZERAS SANDSTONES

The existence of silicified wood in the Upper Duruma Sandstones has been known for many years, and it led Thornton (1862, p. 449) to refer the beds to the Carboniferous. Specimens collected by Maufe were identified by Newell Arber with the genus *Cedroxylon* (Maufe, 1908, p. 9), species of which are known from the Upper Liassic continental deposits of Madagascar where they are associated with *Araucarioxylon* (Douville, 1904, p. 211; Gregory, 1921, p. 308; Besairie, 1946, p. 15), and sometimes with *Dadoxylon* (Hourcq, 1950, p. 32). Gregory's specimens were examined by Prof. Seward who identified them with the genus *Dadoxylon* (Gregory, 1921, p. 57) which ranges from the Trias to the Tertiary. Seward noted that the annual growth rings are very ill defined and extremely narrow, which throws some light on the climatic conditions prevalent at the time of their growth. This observation is partly borne out by Dr. Williams' descriptions of the wood collected by Miss McKinnon Wood (McKinnon Wood, 1930, pp. 213–6), for in many of her specimens the growth rings are indistinct. Most of them could not be identified specifically, but three were identified as *Dadoxylon sclerosum* Walton, the type specimen of which was described from the topmost Molteno Beds (Upper Trias) of South Africa. It would seem justifiable, then, to assign the wood-bearing strata to the Upper Trias, and it is probable that the greater part of the Upper Duruma Sandstone Series belongs to the same period.

It seems likely that there is only one horizon of silicified tree trunks, although there may be several containing small angular fragments of wood. The latter almost certainly indicate intra-formational erosions resulting in fragments from the original horizons being transported and redeposited. It is also likely that the original horizon is not more than 100 ft. thick. It is less well exposed in the Kilifi area than in the Mombasa–Kwale area, and the most northerly occurrence recorded was near Chonyi, but both Gregory (1921, p. 57) and Thompson record specimens from the Malindi area. Maufe (1908, p. 9) observed that all the trunks lie in a north-south direction but this has neither been confirmed nor refuted by the present work. Proof of the observation would suggest that the trees had drifted into place and had not originally grown there. On the other hand, the beds with which they are associated are often typically deltaic, an environment more suited to the growth of forests than those signified by the remainder of the Upper Duruma Sandstones.

Several instances are known where certain of the trees have been partly humified, but they are isolated cases and there can be no possibility that a true coal seam exists; the conditions of deposition were far too rapid to have permitted such an occurrence.

(4) CONDITIONS OF DEPOSITION OF THE DURUMA SANDSTONE SERIES

The general relative consistency in grain size of the Lower Mariakani Sandstones suggests that they accumulated in a stable environment. All the rocks are, so far as is known, of sub-aqueous origin and the frequent occurrence of aqueous ripple-marks indicates that the water was shallow. The only fossils that have been obtained are obscure plant remains, and whilst the absence of marine fossils does not preclude the possibility that the beds are marine, it is likely that they were deposited under a continuation of the lacustrine conditions which prevailed in earlier Duruma times. The Upper Mariakani Sandstones, with their alternations of coarse and fine bands, indicate a less stable environment and these conditions persisted throughout Upper Duruma times. A phase of minor earth movement preceded the deposition of the Mazeras Sandstones causing the Middle Duruma beds to be slightly folded along more or less east-west trends. The warped beds were then eroded and it was upon a partly planed surface that the Mazeras Sandstones were laid down. The lowermost Mazeras Sandstones are sub-aqueous deposits, the uppermost continental, and between the two are deltaic deposits with which the silicified trees are associated. It would seem that the rate of subsidence, which hitherto had been keeping pace with the rate of sedimentation, was then outpaced and the change in environment was brought about. The probable sequence of events, together with the possible causes, have been described more fully by the writer in an earlier report (Caswell, 1953, p. 51). No reliable estimates of the thickness of either the Mariakani Sandstones or the Mazeras Sandstones can be made, but each appears to be in excess of 1,500 ft.

(5) CORRELATION OF THE DURUMA SANDSTONES

Complete correlation between the Duruma Sandstones and rocks of Karroo age from Tanganyika, Madagascar, and South Africa have been proposed by Miller (1952, pp. 17-22) and Caswell (1953, p. 17). The similarity between the Kenya rocks and those from the Morafenobe area of Madagascar is particularly striking, and forms a basis for correlation. The presence of marine bands in the Morafenobe sequence has made possible their correlation with the wholly marine Karroo succession of North Madagascar which, being fossiliferous, has been dated; hence the ages of the Duruma Sandstones can be assessed. The correlation is as follows:—

TABLE V.—THE AGE AND CORRELATION OF THE DURUMA SANDSTONES IN THE KILIFI-MAZERAS AREA

	Madagascar (Besairie, 1946)	Kilifi-Mazeras Area
Middle Jurassic	Marine limestones and shales.	Kambe Limestone
Lower Jurassic	Isalo	Mazeras
Upper Trias	Beds	Sandstones*
Lower Trias	Sakamena Beds	Mariakani Sandstones
Upper Permian		(not exposed)

Dotted lines indicate unconformities.

*Age of upper limit not known; possibly Lower Jurassic.

2. The Jurassic Rocks

The first report that Jurassic rocks are exposed in the coastal sedimentary succession was made by Fraas (1859, p. 356) who identified an ammonite that had been found by Krapf in 1857 at his mission station at Rabai. The ammonite was identified as the Callovian species *Peltoceras athleta*, but was later redetermined by Beyrich (1877, p. 97) as *Ammonites annularis*, and still later by Dacqué (1909, p. 166) as a new Oxfordian species of *Perisphinctes*, *P. krapfi*. A series of fossils collected by Hildebrandt in 1877 was described by Beyrich (1878, pp. 767-75) and assigned to two ages—Neocomian (Lower Cretaceous) and Kimmeridgian (Upper Jurassic). The Kimmeridgian age (*op. cit.* p. 769) was based on ammonites, some of which were subsequently considered by Dacqué (1909, p. 172) to be Oxfordian. A further series of fossils collected between the "Nash" (Mwachi) and "Barrette" (Kombeni) rivers was described by Futterer (1894) as representing a complete sequence from Oxfordian to Aptian, but the fossils collected by Gregory during his earlier expedition led him to propose (1900, p. 228) that the rocks represent the Callovian, Oxfordian, and Kimmeridgian stages. Added support for the Oxfordian stage came from Fraas (1908, pp. 646-9) who obtained Oxfordian ammonites from the shores of Rabai Creek. This was accepted by Dacqué (1910 (*a*), pp. 3-4) who was the first to recognise that the series extended down to the Bathonian (*op. cit.* 1910 (*b*), p. 159). A fuller review of the early evidence is given by Gregory (1921, pp. 59-63) who (*op. cit.*, p. 72) classifies the Jurassic rocks as ranging from the Bathonian to the Corallian, although he admits (*op. cit.*, p. 61) the affinities of the uppermost beds to the Kimmeridgian. A more details sequence proposed by Miss McKinnon Wood (1930, p. 221) was based on the faunal assemblage she collected during her first visit to Kenya, and this was modified slightly in her second monograph (McKinnon Wood, 1938, p. 5) as a result of the additional material collected during her second visit (Table VI).

TABLE VI.—THE JURASSIC SEQUENCE ACCORDING TO MCKINNON WOOD (1938, p. 5)

Changamwe Shales	Kimmeridgian
Coroa Mombasa and other limestones	Kimmeridgian to Corallian
Rabai Shale	Corallian to Oxfordian
Miritini Shale	Callovian
Kibiongoni Beds	Callovian (?)
Kambe limestone and Mwachi shales	Bathonian to Bajocian

Unfortunately this sequence has certain practical limitations and must be modified still further. The Coroa Mombasa and other limestones, for instance, are not only of lenticular development passing laterally into shales, but they occur at different horizons. In a classification based largely on lithologies, then, the limestones must take second place to the shales with which they are associated. There is little lithologically to choose between the upper three shale members, apart from the fact observed by Gregory (1921, p. 62) that the nodules in the Miritini Shale yield no definite fossils, while those in the Changamwe Shale often do. It is indeed this similarity that has led recent workers (Caswell, 1953, p. 22, and Thompson) to group them all together as the "Upper Jurassic Shales", referred to as J₃ on their maps. Yet when time becomes less precious and the shales can receive the detailed palaeontological zoning due to them, it is evident that they must be separated and the names previously proposed might well form the basis upon which to work. It is suggested, however, since the names are purely artificial that there should be a closer connexion between them and the recognized stages. The Changamwe Shale for example, was formerly classified by Gregory (1921, p. 72) as Corallian with Kimmeridgian affinities in its upper part, whereas it is now restricted to the Kimmeridgian. Stratigraphical evidence suggests that the Kibiongoni Beds are a facies variation of the Kambe Limestones and they are therefore classified as Bathonian in this report. Gregory (1921, p. 63) records that they were identified as such by Dacqué (1910, p. 159) although Gregory himself (*op. cit.*, p. 72) refers them to the Callovian, a view with which McKinnon Wood (1938, p. 5) doubtfully agrees.

The succession adopted in this report is given in Table VII.

The Jurassic rocks occupy the foot plateau between the Duruma Sandstone Series on the west and the Cainozoic rocks on the east and their outcrop, generally from five to seven miles in width, can be traced continuously throughout the area from north to south. Their relationship to the Duruma Sandstone Series further south has been fully discussed by Caswell (1953, p. 18) who concluded that they rest unconformably upon the sandstones, although the contact is a fault throughout the greater part of its length. This conclusion has been borne out in the Kilifi-Mazeras area.

TABLE VII.—THE JURASSIC SUCCESSION IN THE KILIFI—MAZERAS AREA

Kimmeridgian	Changamwe Shales with lenticular limestone bands
Oxfordian	Rabai Shales
Callovian	Miritini Shales
Bathonian	Kibiongoni Beds
	Kambe Limestone
Bajocian	

(1) THE KAMBE LIMESTONE SERIES

As has been recorded by earlier writers—Gregory (1921, p. 64) and McKinnon Wood (1930, p. 222; 1938, p. 5)—the Kambe Limestone occurs in three main varieties: a dark bluish-grey, compact and generally unfossiliferous limestone, a light grey coral limestone, and an oolitic or pisolitic limestone that is interstratified with the other two. Its outcrop can be followed, without a break, from the northern boundary of the area to a point immediately south of Ribe hill. Further south it is largely hidden by the Kibiongoni Beds because of faulting and appears only as small isolated outcrops.

In the north, only the dense bluish-grey variety is exposed. It is well bedded, with thin partings of shale, and dips to the east-south-east at from 10° to 15° . Near the contact with the Mazeras Sandstone, however, the dip increases rapidly to over 40° which, since this abnormally steep dip is shared by the sandstone, is suggestive of a fault. These features can be observed in the Kimbule river, about two miles south-east of Ganze. The actual contact is hidden by alluvium in a valley that has been cut along the plane of the contact.

South of the Koyeni river the outcrop is transferred, or swings, eastwards and a much greater width of limestone is exposed. Two converging north-westerly-trending faults are shown on the map to account for this swing, but although field evidence supports the existence of the more northerly of the two, the southerly fault is based solely on the anomalous strike of the limestone in the Ndzovuni River. Such a strike could conceivably be due to a slight flexure of the beds, but one of the most remarkable features of the Kambe Limestone is its overall consistency of strike, both in this and the Mombasa-Kwale area. A great thickness of limestone—possibly in excess of 1,000 ft.—is exposed in the Ndzovuni river section west of Jaribunyi. The river follows a large meander and has cut deeply into the outcrop to form a gorge over 200 ft. deep. On the inside of the largest meander there is a river terrace that stands at least 150 ft. above the present river-bed; this could doubtless be correlated with the terraces in the Mwachi river described by Caswell (1953, p. 53) but topographic data on the Ndzovuni river is as yet insufficient to make any comparisons possible.

South of Jaribunyi the limestone gives rise to a more or less flat-topped ridge that is often capped by Pliocene Magarini Sands. The eastern flank of the ridge, near the boundary between the limestone and the overlying shales, is frequently abrupt suggesting a fault scarp, but no traces of faulting were seen. It is possible that this feature represents an old cliff which was formed when the sea stood at a higher level than it does at present. The limestone in this region is fractured considerably and is shot through with veins of secondary calcite. Extensive infiltration of limonite has also occurred, the limonite having been derived from the former cover of iron-bearing Magarini Sands. In one locality about three miles south of Jaribunyi dispensary, the replacement by limonite of an oolitic limestone has proceeded almost far enough for the resulting rock to be termed an ironstone (see Chapter VII).

In the Cha Simba area the limestone outcrop widens to over two miles and the rock has an estimated thickness in excess of 1,500 ft. It appears to rest unconformably on the

Mazeras Sandstones and there is no evidence of faulting along the junction. It is of interest to note that in this area the limestone is found at heights of over 800 ft., whereas in those places where a faulted contact is suspected the limestone rarely rises higher than the 450-ft. contour. Good sections can be seen in the valley of the Maweni river that flows eastwards from Simba hill to join the Gombeni river. Most of the exposures, particularly those in the lower part of the section, show the dense bluish-grey variety of limestone dipping east-south-east at from 15° to 22° . A suprising feature of the limestone is the relatively low sand content, even in the lowest layers. The actual base is not exposed, but it can be estimated that only the bottom twenty feet or so are concealed. A huge blocky mass of limestone, rising to 100 ft. or more, is exposed at the roadside immediately east of Simba hill. Solution has taken place along the bedding and joint planes giving them emphasis and producing the blocky effect.

Southwards from Mwarakaya the outcrop narrows and it is usually a palish grey variety of limestone, often containing corals, that is exposed. The surface of the rock has been weathered considerably and the limestone appears as jagged pinnacles and crags which protrude, some of them to over 40 ft., from a reddish marly loam that is extensively cultivated by the natives. The "karst-land" topography can be followed to Kambe where it was observed by Gregory (1921, p. 65) and so impressed him that he proposed (*op. cit.*, p. 63) that the limestone series should be named the Kambe Limestone.

The limestones swing round Jibana hill to produce a "bay window" pattern, and it was at first thought that this was due to the unconformable overlap of the limestones on the Mazeras Sandstones, as was put forward by Gregory (1921, p. 70). The steepening of the dips near the contact, however, and the abnormally high seaward dips in the Mazeras Sandstones suggest that the contact is faulted, although it is doubtful whether the post-Jurassic faulting has played more than a small part in the present dispositions of the outcrops. Field evidence in this vicinity is scanty, and the only river that traverses the entire succession—the Landani—is so choked with debris that little can be seen of the section. About one hundred yards upstream of the Ribe-Mwarakaya road, the river flows under an impressive arch of limestone that is dipping at 25° to the south-east. Beyond the arch the river course widens suddenly such as might have been caused by erosion along the limestone-sandstone contact, but no conclusive evidence of a contact was seen. The first definite exposure of sandstone occurs some two hundred yards farther upstream, dipping at 25° to east-south-east. In discussing this section, Gregory (1921, p. 70) stated that the limestone could be seen abutting against the sandstones, although the latter's structure was masked by talus; he concluded that the limestone was deposited upon a worn surface of the sandstones. Parsons also examined this section and concluded (1928, p. 73) that the limestones are thrust over the sandstones; his section (*op. cit.*, section No. 4, p. 76) illustrates this. He goes on to say (*op. cit.*, p. 79) that, downstream, the river has cut through the limestone and its bed everywhere consists of sand with occasional outcrops* of grit, one of which is seen near the first outcrop of the Miritini Shales. From this he argues that there is insufficient space between the Duruma Sandstones and the Miritini Shales for the limestone outcrop unless the sequence is assumed to be faulted. This critical section was examined by the writer who was unable to find any grit that was without doubt *in situ*. It is true that the river bed is sand-covered and there are also numerous boulders—some of them very large—of grit, but it is evident that the boulders were derived from Jibana in post-Jurassic times.

South of Ribe hill the limestone pinches out completely and the Kibiongoni Beds are brought into direct contact with the Mazeras Sandstones. Parsons (1928, p. 80) reports a faulted contact between the Miritini Shales and the Shimba Grits in "a small left bank tributary of the Mleji river", and he records a lenticular occurrence of Kambe Limestone—the source of a copious fresh-water spring—in the fault plane. He adds that "similar lenticular occurrences of limestone, frequently brecciated, are seen along the eastern face of the Ribe range, and in the Mleji Valley", the fault-zone at the latter locality being the site of a sulphurous saline spring. The faults, as shown on his map (Fig. 1), are of a thrust or shear type. The existence of faulting in this neighbourhood is accepted, but it is considered that the faults are all of a normal type. A short distance to the west, near the confluence of the Mleji and Chonyi rivers, a small fault in the Mazeras Sandstone is exposed dipping at 45° to the north-west. This fault does not disprove the possibility of thrusting since the relative ages of the faults are not known, but the occurrence is suggestive.

Occasional small outcrops of limestone appear farther south, wedged between the Kibiongoni Beds and the Mazeras Sandstones, and it is suggested that these represent

*Writer's italics.

lenticles that were caught up in the fault-plane. The most prominent can be seen on the old Nairobi-Mombasa road, west-south-west of Benyangundi hill. The limestone is of the coral variety; its outcrop can be followed in the low ground to the north of the road, but not in the river section to the south where the Kibiongoni Beds are in juxtaposition with Mazeras Sandstones.

No Kambe limestone is exposed in the cuttings along the new Nairobi-Mombasa road; neither does it crop out along the railway-line, although a boulder was found at mile 13/1 on the Mazeras Sandstone outcrop. The possibility that the boulder had been carried there, perhaps during the construction of the railway-line, cannot be overlooked, although it does not appear that this was the case. It is more likely that it is a remnant of the original limestone outcrop, most of which has since been eroded consequent upon Tertiary faulting.

From the evidence of both the coral and oolitic varieties it is clear that the limestone series was deposited in a warm shallow sea, and the comparative absence of sand suggests that the coast bounding the Jurassic sea was of low relief. Yet if this were so it would be expected that the limestones, and certainly the succeeding shales, would have considerably overstepped the present outcrops of the Duruma Sandstones, and some trace of their former cover, either in the form of outliers or residual boulders, should be found. None have as yet been proved and it is therefore concluded that the present western limit of the Jurassic outcrop approximates to the western limit of deposition.

(2) THE KIBIONGONI BEDS

The Kibiongoni Beds were named by Gregory (1921, p. 63) to embrace a belt of shale, yellow micaceous sandstones, cherty mudstones, and shelly sandstones that appear to rest conformably upon the Kambe Limestones. They are probably the yellow sandy marls with obscure cephalopods and plant remains that were recorded by Dacqué (1910, p. 159) and identified as Bathonian.

The basal bed was not seen in the Kilifi-Mazeras area but, from the Mombasa-Kwale area, Caswell (1953, p. 22) records that it consists of a conglomerate, roughly one foot in thickness, composed of sub-angular pebbles of quartz and limestone set in a limonitic matrix. This is succeeded by thin, current-bedded, sandy shales with interbedded micaceous and ferruginous sandstones. Near the top of the series is a massive band, about eight feet thick, of tough calcareous sandstone which weathers out as large boulders. These can often be traced for several miles and are shown on the map as a line of heavy dots. Microscope sections show that the boulders are composed of unequal sized, sub-angular grains of quartz (20 to 30 per cent), oligoclase and some microcline (5 to 10 per cent), biotite (uncommon), and opaque iron ores, set in a groundmass of calcite (about 50 per cent) and chlorite. Shell fragments are common in some sections and are generally filled with crystalline calcite. Shells enclosing quartz grains are not rare, and in one case a grain shows a secondary marginal growth that has penetrated the shell. With weathering, the calcite is dissolved out from the surface layers and replaced by limonitic earth producing a resemblance to ochreous sandstone.

Many of the beds are ripple-marked and some are rain-pitted, indicating that they were deposited in a neritic environment, probably partly under estuarine conditions. They are best developed in the south of the area, bordering the railway-line, where they attain a thickness of at least 300 ft. They thin out northwards and were not recognized beyond Mwarakaya, although Parsons (1928, p. 69) records an oyster bed from the group in the Rare valley. This locality is referred to by McKinnon Wood (1930, p. 223) as being to the south of Didia, and therefore beyond the northern boundary of the present area, but she mentions other localities to the east of Viambani and Mtanganyika. The first of these was not confirmed during the present survey, and the second occurs too high in the succession for the beds to belong to the Kibiongoni group.

There appears to be an inverse relationship between the relative thicknesses of the Kibiongoni Beds and the underlying Kambe Limestones. In the Mwachi river, south of the railway-line, the limestones have a measured thickness of about 450 ft. (Busk and de Verteuil), and the Kibiongoni Beds have an estimated thickness of over 300 ft., whereas east of Cha Simba the limestones are considered to be at least 1,500 ft. thick and there are no Kibiongoni Beds. It is suggested, therefore, that the Kibiongoni Beds represent a facies variation of the limestone formed in the estuaries of rivers that discharged sand and silt into the Jurassic sea. This enables the beds to be classified with the Bathonian stage as was originally proposed by Dacqué.

(3) THE UPPER JURASSIC SHALES

The Kibiongoni Beds seem to grade upwards, by a lessening of their sand content, into a thick series of shales with thin lenticular limestones that extend up into the Kimmeridgian. Various sub-divisions of the series have been proposed, but without adequate fossil evidence they are all difficult to follow in the field and the series is therefore considered as one unit in this report. It forms a belt of country varying from three to eight miles in width whose peneplaned surface has been considerably dissected by countless small streams.

The best exposures occur in the cuttings along the new Mombasa-Nairobi road; elsewhere they are seldom seen to advantage. Small outcrops are scattered throughout the area in stream sections or minor road-cuttings, but the shales are generally too weathered to be of value. They are indurated and well-laminated, and usually grey in colour, although they are sometimes yellowish or brownish. Whilst sandy, ferruginous, and sometimes micaceous bands are known, the majority of the shales are calcareous, and in places the calcareous content is sufficiently high to form argillaceous limestones. These are of lenticular development, and appear to be rarely more than 100 ft. thick. Septarian nodules occur throughout the succession, especially in the higher horizons, where they often contain included ammonites.

(4) PALAEOLOGY OF THE JURASSIC ROCKS

Excellent accounts of the palaeontology of the Jurassic rocks are contained in the McKinnon Wood monographs (1930 and 1938), copies of which are housed in the Coryndon Museum, Nairobi, and the library of the Mines and Geological Department, Nairobi. The ammonites collected by Miss McKinnon Wood during her second visit are omitted from the 1938 monograph, but were identified and referred to by Dr. Spath in his "Revision of the Jurassic Cephalopod Fauna of Kachh".

The evidence for the Bajocian stage formerly rested upon a single ammonite which was provisionally identified by Spath (McKinnon Wood, 1930, p. 32) as *Dorsetensia* sp. juv. ? cf. *edouardiana* (d'Orbigny). It was confirmed by ammonites in the second McKinnon Wood collection (Spath, 1933, p. 815), and also by a rich lamellibranch fauna collected from boulders on the old Mombasa-Nairobi road near Benyagundu hill (Loc. 118, Kaya Mriali of McKinnon Wood, 1938, p. 22). The latter was identified by Dr. Weir in the 1938 monograph who states (*op. cit.*, p. 21) that it is "overwhelmingly European in affinities", and "yields a number of forms that definitely signify a pre-Bathonian age". These, with their respective ranges, are as follows:—

Variamussium pumilum (Lamarck), U. Lias-Bajocian

Velata cf. *gingensis* (Quenstedt), U. Bajocian

Plagiostoma subcardiiformis Greppin, U. Bajocian

P. cf. *semicircularis* Goldfuss, Bajocian

P. aff. *alticosta* Chapuis and Dewalque, Bajocian

Whilst, in general, brachiopods are less reliable for chronological purposes, some of the specimens collected from this locality, and also from Loc. 38 (nr. Kaya Chonye), show a closer external resemblance to the earlier Upper Aalenian (top lower Jurassic) forms. Their internal structures, on the other hand, are apparently more consistent with the Bathonian and later forms. The Bajocian species *Terebratula woodae*, for example, is claimed by Weir (McKinnon Wood, 1938, p. 33) to have several internal features in common with *Somali-thyris macfadyeni*, a species described by Dr. Muir-Wood (1935, p. 124) from beds of Oxfordian age in British Somaliland, and to resemble even more closely *Sphaeroidothyris indica* from the Attock District of the Punjab (Muir-Wood, 1937).

The Bathonian stage was first recognised by Daqué, and by Gregory (1921, p. 64) who collected some ammonites that were identified and described by Spath (1920). The specimens included:—

Phylloceras aff. *kudernatschi* Hauer

Phylloceras sp. ind.

P. cf. *kunthi* Neumayr

P. cf. *disputabile* Zittel

Sowerbyceras sp. aff. *tortisulcato* d'Orbigny sp.

Lytoceras cf. *tripartitus* Raspail sp.*

Hecticoceras sp. juv.

*This species was provisionally referred by Spath to the genus *Protetragonites*. It is now classified with the genus *Nannolytoceras*, the genus *Protetragonites* being apparently confined to the Cretaceous.

In his conclusions, Spath remarks that *Lytoceras tripartitus* was most relied on in determining the age of the fauna, this being supported by *Phylloceras kudernatschi* and *P. disputabile*. In general, *Sowerbyceras* and *Hecticoceras* are more typically Callovian, but they are known from the Bathonian. Added support came from three other species collected by Miss McKinnon Wood and described in the 1930 monograph: these are:—

Holcophylloceras zignodianum (d'Orbigny)

Oppelia sp. ind.

Stephanoceras cf. *tenuicostatum* Hochstetter

Further specimens of *Phylloceras disputabile* were obtained but in the 1930 monograph they are classified as *Calliphylloceras* cf. *disputabile* Zittel, the new sub-family Calliphylloceratinae having been erected by Spath during his revision of the Jurassic cephalopods of Kachh (Cutch). The many corals that have been collected from the Kambe Limestones are all new species that were first described by Gregory (1921, pp. 83–8; McKinnon Wood, 1930, pp. 203–8). A significant feature pointed out by Gregory (McKinnon Wood, 1930, p. 185), is that whereas five of the eleven Kenya genera are found in pene-contemporaneous deposits at Kachh, there is not one species common to both localities. An even more striking difference exists between the Bathonian corals of Kenya and the Callovian corals of Somaliland in that few of the genera are common. This, Gregory believed, indicates that the Bathonian sea of Kenya had only minor connexions with the seas of India and Somaliland; that there were connexions of some sort is, of course, known from the ammonites.

The separation of the Upper Jurassic stages depends largely on the evidence of the ammonites which, says Spath (McKinnon Wood, 1930, p. 68), can mostly be assigned to the Callovian or Lower Kimmeridgian. There is, however, evidence of the presence of the Upper Oxfordian and Middle Kimmeridgian, though there is none of the Lower Oxfordian. It is the writer's opinion that this will be remedied when a fuller fossil collection has been made. Reference to Miss McKinnon Wood's locality map (1930, Pl. XXII) shows that there is a large tract of country around the western end of Port Reitz which she apparently did not visit, and which, from its stratigraphical position, might be expected to yield a Lower Oxfordian fauna. Mention should be made, however, of Weir's reference (McKinnon Wood, 1938, p. 24) to a new ammonite locality recorded from this area by Mayer-Gürr (1935) which is claimed to have yielded an Upper Oxfordian-Kimmeridgian assemblage. The Rabai Shale of Fraas, which one would have thought to be Lower Oxfordian on account of the ammonite genera *Peltoceras* and *Macrocephalites* recorded from it (Fraas, 1908, pp. 646, 649), contains *Belemnopsis tanganyikensis* Futterer which Weir (McKinnon Wood, 1930, p. 90) claims to be restricted to the Upper Oxfordian and Kimmeridgian.

Callovian faunas have been obtained from several localities in the Kilifi–Mazeras area, of which the first would appear to be that collected by the Rev. Charles New (see McKinnon Wood, 1930, p. 67) from “8 to 10 miles north-west of Mombasa”. There are eight ammonites including—

Hecticoceras sp. ind.,

Kamptcephalites ? sp. ind.,

Indosphinctes sp. ind. nov. (?),

Binatisphinctes cf. *arlti* (Krenkel),

which are undoubtedly Callovian, whilst

Lithacoceras jelskii (Siemiradzki)

is of Oxfordian or lowest Kimmeridgian age. From Loc. 41 (McKinnon Wood, 1930), in the bed of the river between Mtanganyika and Wangwane beacons, the following two Callovian forms were obtained (McKinnon Wood, 1930, p. 66):—

Choffatia aff. *furcula* (Neumayr),

Phyllophyceras (?) sp. juv. ind.

Two new localities are quoted in the later McKinnon Wood monograph (1938, p. 22), both of which yielded Callovian faunas. Locality 117, described as being south of the new Mombasa–Mazeras road (it is now the old Mombasa–Mazeras road), yielded the following ammonites—

Phylloceras cf. *semiplicatum* Spath,

Hecticoceras sp.,

Kamptcephalites aff. *magnumbilicatus* (Waagen),

Choffatia recuperi (Gemmellaro) var.;

whilst the following were obtained from locality 115—

Indocephalites sp.,
Pleurocephalites ? sp. ind.,
Choffatia aff. *lateralis* (Waagen),
Grossouvria sp. juv.,
Pachyplanulites cf. *subevolutus* (Waagen).

Pachyplanulites subevolutus is typically a Lower Kimmeridgian form (Spath in McKinnon Wood, 1930, p. 44) and its association with a Callovian assemblage is difficult to explain. Four small ammonite fragments were obtained from shales in the Rare river, just north of Konjora (McKinnon Wood, 1930, Loc. 45), including—

Pleurocephalites sp. juv.,
Alicidia ? sp. ind.*

They are associated with the small lamellibranch *Posidonia* cf. *ornati* Quenstedt, a species which ranges from the Lower Bajocian to the Callovian, and which is widely distributed in beds of these ages in East Africa.

It would appear that no Upper Oxfordian ammonites have been described from the Kilifi area, although Krapf's specimen was at one time assigned to this stage. Originally it was identified by Fraas (1859, p. 356) with the Callovian species *Peltoceras athleta*, but it was later redetermined by Beyrich (1877, p. 97) as *Ammonites annularis*, also a Callovian form. It was advanced to the Upper Oxfordian by Dacqué (1909, p. 166) who described it as a new species *Perisphinctes krapfi*, and it has now reached the Lower Kimmeridgian with Spath (McKinnon Wood, 1930, p. 45) referring to it as *Dichotomosphinctes krapfi* (Dacqué). When it is remembered that the specimen is claimed to have been collected at Krapf's mission station at Rabai, which is situated near the boundary between the Mazeras and Mariakani Sandstones, it is evident that no stratigraphical significance can be attached to it. (Perhaps "collected" should be interpreted literally as it arrived one day in his offertory box.)

The presence of the Kimmeridgian stage was first recognized by Beyrich (1878, p. 769) who identified Hilderbrandt's fossil collection, which included—

Aspidoceras iphiceroides (Waagen),
A. acanthicus (Oppel),
Phylloceras cf. *silesiacum* (Oppel),
Perisphinctes pottingeri (Sowerby).

That some of the species, such as *Perisphinctes pottingeri*, are Oxfordian and not Kimmeridgian was remarked by Dacqué (1909, p. 172), who earlier (in Fraas, 1908, p. 647) had doubted the existence of Kimmeridgian rocks in the Mombasa area. Rocks of such age had for long been accepted by Gregory for, among the ammonites he collected in 1893, Crick (in Gregory, 1900, p. 226) had identified *Aspidoceras acanthicus*, and *A. longispinum* had formed the basis for Futterer's Kimmeridgian horizon (1894). Spath (McKinnon Wood, 1930, pp. 58–9) relates both of these forms to the species *Acanthosphaerites longispinus*.† Miss McKinnon Wood's Kimmeridgian collections in the area came mostly from the neighbourhood of Nguu Tatu. Three localities are given—Locs. 11a, 11b, and 11c, the first two being described in the 1930 monograph and the last in the 1938 monograph. They have yielded the following ammonites:—

Loc. 11a—

Phylloceras aff. *saxonicum* Neumayr,
Taramelliceras cf. *kachhense* (Waagen),
Lithacoceras sp. ind.,
Katrolliceras sp. ind.,
Subdichotomoceras sp. ind.,
Waagenia sp. nov.,‡
W. aff. *hybonota* (Oppel).

**Alicidia* was twice preoccupied and is replaced by *Paralicia* (see Arkell, "The English Bathonian Ammonites," *Palaeont. Soc.*, 1951, p. 52).

†*Acanthosphaerites* is a synonym of *Aspidoceras sensu stricto* (see Arkell, "The Ammonites of the English Corallian Beds", *Palaeont. Soc.*, 1940, p. LXVII).

‡*Waagenia* is preoccupied and invalid and has been replaced by *Hybonoticeras* (Breistroffer).

Loc. 11b—

Holcophylloceras mesolcum (Dietrich),
Hemilytoceras cf. *fraasi* (Dacqué),
Aspidoceras aff. *iphiceroides* (Waagen),
A. deaki (Herbich).

Loc. 11c—

Holcophylloceras mesolcum (Dietrich),
Pachysphinctes major Spath,
P. habyensis Spath,
Katrolliceras spp.,
Waagenia aff. *hildebrandti* (Beyrich),
Aspidoceras wynnei (Waagen).

In addition, three other localities are quoted in the 1938 monograph:—

Loc. 73.—South of Makirunge, on the eastern shore of the creek into which the Mleji (Chalu) river flows—

Phylloceras isotypum (Benecke),
Holcophylloceras mesolcum (Dietrich),
Hemilytoceras fraasi (Dacqué),
Pachyplanulites aff. *subevolutes* (Waagen),
Dichotomosphinctes cf. *krappi* (Dacqué),
Prososphinctes ? sp.,
P. sp.,
Discosphinctes sp.,
D. aff. fraasi (Dacqué),
D. cf. lusitanicus (Siemiradski),
D. arussiorum (Dacqué),
Planites aff. *ernesti* (de Loriol),*
P. cf. polyplacoides (Fontannes),
Aspidoceras sp. ind.,
A. iphiceroides (Waagen),
A. aff. longispinum (Sowerby).

Loc. 75.—Shimo-la-Tewa Creek, below Kidutani beacon—

Hemilytoceras fraasi (Dacqué),
Discosphinctes choffati (Dacqué),
D. aff. capillaceus (Fontannes).

This is probably near the site described as “ten miles north-west of Mombasa and five miles from the sea-shore on a sandy, clay, soil” from which Mrs. Wake Bowell collected the two ammonites identified by Spath (McKinnon Wood, 1930, p. 67) as—

Katrolliceras cf. *pottingeri* (Sowerby),
Waagenia cf. *hildebrandti* (Beyrich).

K. Pottingeri (formerly *Perisphinctes pottingeri*) is dated as Kimmeridgian by Spath in contradiction to Dacqué's assertion (1909, p. 172) that it is Oxfordian.

Now identified as *Progeronia* aff. *ernesti*. The new genus *Progeronia* was erected by Arkell (Geol. Mag., 1953, p. 38) to embrace a group of large, evolute perisphinctids of the Lower Kimmeridgian, with biplicate and triplicate ribbing which modifies gradually as in *Arisphinctes* of the Upper Oxfordian. He points out that *Nautilus polygratus* Reinecke, the types species of the genus *Planites* de Haan, is an *Orthosphinctes*.

Loc. 116—about two miles north of Kwa Jomvu railway station, which would be about half a mile south of Jomvu—

Hemilytoceras fraasi (Dacqué),

Dhosaites ? sp. nov?.

The occurrence of Kimmeridgian rocks as far west as Jomvu is surprising; one would not have expected beds at that horizon to be younger than Oxfordian or perhaps even Callovian. This is supported by Dr. Arkell who, in a written communication, states that *Dhosaites* is Upper Oxfordian.

Further Ammonites from the Mombasa-Kwale Area.

The following ammonites, kindly identified by Dr. W. J. Arkell, were collected by the writer during the survey of the Mombasa-Kwale area (Geological Survey of Kenya Report No. 24, 1953). They were obtained from three localities:—

Loc. 1.—In a tributary of the R. Majera, $\frac{3}{4}$ miles north of Tangila beacon, in a rusty-weathering, non-calcareous clay ironstone—

Perisphinctes (*Perisphinctes*) *anabreviceps* (Dacqué),

P. (*P.*) *virguloides* (Dacqué non Waagen) (= *dacquei* Spath non Steiger),

P. (*Arisphinctes*) *orientalis* (Siemiradzki),

P. (*Kranaosphinctes*) cf. *africanus* (Dacqué),

P. (*Dichotomosphinctes*) cf. *dobrogensis* (Simionescu),

P. (*D.*) spp. indet.,

Prograyiceras bassei (Basse and Perrodon),

P. aff. *alfuricum* (Boehm),

Epmayaites cf. *sublemoini* (Spath),

E. cf. *axonoides* (Spath).

This is a typical Upper Oxfordian assemblage of the *transversarium* (*plicatilis*) zone and Dr. Arkell comments that it is interesting because of the mixture, all in the same matrix, of well-known Perisphinctids with the southern Mayaitids. Also from Tangila, but occurring in different matrices, are the following—

fragment of a giant round-whorled Perisphinctid, indet.,

Perisphinctes (*Orthosphinctes*) aff. *tiziani* (Oppel), which typically is found in the *bimammatum* zone of the Upper Oxfordian;

Aspidoceras cf. *richthofeni* (Müller) which should be Kimmeridgian;

fragments of giant *Euaspidoceras* cf. *acuticostatum* (Young and Bird), a species which typically occurs in the *cordatum* zone at the top of the Lower Oxfordian.

Loc. 2.—Port Reitz, in a small creek immediately west of Mtongwe—

Perisphinctes (*Arisphinctes*) *orientalis* (Siemiradzki),

P. sp., probably inner whorls of *P.* (*A.*) *orientalis*.

Loc. 3.—Port Reitz, from the brickyard and pier near Port Reitz Hotel, in a rusty, non-calcareous clay ironstone—

Perisphinctes (*Arisphinctes*) *orientalis* (Siemiradzki),

P. (*Perisphinctes*) *virguloides* (Dacqué non Waagen),

P. (*Kranaosphinctes*) *africanus* (Dacqué),

P. sp. indet., inner whorls,

Prograyiceras bassei (Basse and Perrodon).

In a limestone matrix—

Perisphinctes (*Kranaosphinctes*) cf. *promiscuus* (Bukowski),

P. (*Dichotomosphinctes*) cf. *kreutzi* (Siemiradzki),

P. sp. indet.

The age of both of these localities is given as Upper Oxfordian (*transversarium* zone) although it seems unlikely that the three species preserved in limestone from Port Reitz are from the same horizon.

(5) AFFINITIES OF THE FAUNA

A summary of the faunal affinities is given by Gregory (McKinnon Wood, 1930, p. 4) from which the following remarks are taken. The Bathonian corals are specifically, and often generically, distinct from their counterparts in Kachh and Somaliland suggesting that sea communication between these places was restricted, although the distinctions may have been due solely to differences in bathymetric conditions. There is no great resemblance between the Callovian ammonites of Mombasa and those of Kachh and Madagascar, and the Oxfordian forms are even more distinct. The Kimmeridgian ammonite fauna has more in common with that of Europe than that of India, a feature shared by the entire mollusc and brachiopod assemblage. The question then arises whether there was a direct marine connexion between East Africa and the Mediterranean, or whether it was only indirect via the Himalayan region. Perhaps more will be known of this when a fuller investigation of the Jurassic fauna of north-east Kenya has been made. Current opinion, as shown by Kent (1952, Pl. II), suggests that the connexion was direct.

3. The Cainozoic Rocks

The Cainozoic rocks are confined to the coastal strip and include representatives of the Pliocene, Pleistocene, and Recent periods.* The succession given in Table VIII is adopted in this report.

TABLE VIII—THE CAINOZOIC ROCKS OF THE KILIFI—MAZERAS AREA

Recent		Alluvia
	Upper	Red wind-blown sands Raised alluvial deposits
Pleistocene	Middle	Kilindini Sands North Mombasa Crag Raised Coral Reef
	Lower	Magarini dune sands (?)
Pliocene	Upper	Magarini Sands (fluvatile)

This succession is somewhat simplified for it is realised that greater sub-division is possible than was actually attempted. As all the sand deposits were derived originally from the same provenance, distinctions between those that have been re-worked only once and those that have been re-worked several times are difficult to make without recourse to specialised examinations of the heavy mineral contents.

(1) THE MAGARINI SANDS

The Magarini Sands were named by Gregory (1896, p. 229) to designate a belt of brilliant red sands that occurs behind Mombasa and extends northwards to the Tana river, and which is particularly well developed on Magarini hill, north of the Sabaki valley. He then regarded them as Triassic. Recording his later researches (1921, pp. 76–8), he broadened his definition to include bands of pebbles derived from the Archaean gneisses, the Duruma Sandstones, and the Jurassic beds, and re-classified them as of Lower or Middle Pliocene age, having originated as sand-hills and river gravels between the foot of the inland plateau and the sea. Mention is made of their similarity to the Mikindani Beds of Tanganyika which were described by Bornhardt (1900, p. 469) as of marine origin and of Pliocene or Pleistocene age. Subsequent writers have agreed with Gregory's lithological descriptions, but the age of the beds has been quoted as "Eocene to Recent" (Parsons, 1928, p. 64) "Miocene to (?) Pliocene" (McKinnon Wood, 1930, p. 218), and "Pliocene" (Busk and de Verteuil, 1938, p. 18). Together with Parsons, Busk and de Verteuil refer to "bands of shelly and coral limestones" within the series which they claim can only be separated with difficulty from the raised shore reef. It is generally accepted that both fluvatile and aeolian deposits are represented, and recent work points to an upper limit for the fluvatile deposits being placed at about 350 ft. to 400 ft. O.D.

*Miocene beds, containing *Pecten*, *Plicatula mombasana* Cox and the foraminifer *Operculinella* have since been discovered in the neighbourhood of Kilifi Creek and Bandari ya Wali (F. E. Eames and P. E. Kent, "Miocene beds of the East African Coast", *Geol. Mag.*, vol. XCII, 1955, p. 344).

The principal outcrop in the Kilifi-Mazeras area forms a prominent ridge that extends throughout most of the coastal strip at a distance of from two to four miles inland. It attains its maximum height at Sokoke beacon (747 ft.), but elsewhere it seldom rises above the 500 ft. contour. The western flank of the ridge is usually steeper than the eastern, and in places it has been eroded into deep alcoves and gullies. The most marked of these occurs practically on the northern boundary of the area and exposes a section of at least two hundred feet. Bright red sands comprise the uppermost part, and overlie yellowish-white sands that show traces of dune-bedding. The junction is not well defined—in fact it appears to be gradational—but it reflects the topography to a modified degree, a feature which suggests that the red coloration is due, at least in part, to the effects of weathering on the sands, with the surface concentration of ferric oxide. The lowermost beds are of coarser grade, and contain numerous sub-rounded, quartzose pebbles from the Mazeras Sandstones. Other erosion alcoves occur on the western flank of the ridge behind Vipingo Estate, but elsewhere little is seen of the Magarini Sands apart from the deep-red soil cover.

Minor outcrops are frequently found as outliers resting on the Jurassic rocks further west, and occasionally they overlap the Duruma Sandstones. It is evident that these outliers are the remnants of a once much larger outcrop that covered all the Jurassic rocks and abutted against the Duruma Sandstones. This condition still obtains in the southern part of the Mombasa-Kwale area (Caswell, 1953, p. 25), and also in the Malindi district, for it was their position there, intermediate between the Duruma Sandstones and the Jurassic outcrops, that led Gregory (1896, p. 229) to suppose that they were also intermediate in age—i.e. Triassic. The outliers on the shales are particularly easy to recognise, partly from their position on the hilltops but more so from the difference in vegetational cover. The shales themselves are capable of supporting only grasses and occasional thorn trees, whereas coconut palms and cashew nut trees flourish on the sands; hence the presence of coconut palms on the hilltops of the shale outcrop can be taken as a certain indication of the occurrence of a Magarini Sand outlier. In the limestone country a distinction should be made between the Magarini Sands and *terra rossa*. The latter, usually of a deeper red colour, results from the weathering *in situ* of the underlying limestone and consists largely of clay, with some ferric oxide, but very little sand. Where they overlap the Duruma Sandstones, the Magarini Sands are especially difficult to delimit since the constituents are the same in each case. Moreover, being so close to their provenance, the Magarini Sands contain many large boulders of Mazeras Sandstone, so that it is often only from the field relationships that their presence can be detected. For instance, when boulders and other material of Mazeras Sandstone type are seen resting upon Jurassic rocks, it can be assumed that they arrived there during Pliocene times and are therefore referable to the Magarini Sands. It is suggested that this lack of ease of distinction led Parsons (1928, p. 78) to state that Shimba Grits can be seen resting upon Kibiongoni Beds in the Msapuni river, leading him to propose a thrust fault to account for the apparent stratigraphic inversion.

From the foregoing remarks it will be clear that the Magarini Sands are essentially of quartzose composition, and were derived from the extensive weathering of the Mazeras Sandstones. In its lower part the deposit is usually creamy-white in colour, and of widely variable grain size, although the majority of the material falls within the very coarse sand or granule grades (1 to 2, and 2 to 4 mm. diameter respectively). Crude stratification is shown by numerous layers of pebbles that are interbedded with the sands. The pebbles are generally well-rounded and consist mostly of quartz, but Gregory (1921, p. 76) recorded some of Archaean gneiss. Sub-angular silica-coated fragments from the Jurassic rocks are common in the lower layers, their greater angularity indicating that they were transported a shorter distance. Also interbedded with the sands are lenticular bodies of clay, and clay particles are frequently found mixed with the sands. Sometimes they bind the sands into weakly coherent sandstones, but for the most part the deposit is unconsolidated. Of the individual grains, quartz is by far the most abundant, but feldspar is common. Many of the feldspars are weathered and localised patches rich in kaolin are sometimes met with. Thompson records a sample from north of the Malindi area that, upon analysis, was found to contain roughly forty per cent kaolin and sixty per cent very fine quartz sand. Small red almandine garnets and black ilmenites are the commonest allogenites, but zircon, rutile, epidote, kyanite, sphene, and tourmaline are also known. During periods of heavy rain, many of these heavier fractions are washed out and transported by rivers to be re-deposited by processes of natural separation in the littoral zone of the beaches. Thin veneers of black sands can often be seen at Kilifi, but a closer examination reveals that most of the grains are dark red garnets.

From the nature of the beds, it is evident that they were deposited as river gravels under conditions of intense erosion. They are of the piedmont type and, as will be discussed

more fully later, they owe their origin to the lowering of the edge of the continent due to renewed movement along the Triassic-Jurassic fault-zone. The maximum thickness of the beds would therefore be influenced by the throw of the faults. There is evidence to suggest that this is of the order of 300 ft., a figure which amply satisfies the thickness of the fluvialite deposits. A well-known feature of piedmont deposits is their cyclic pattern of rapid building and removal, and the Magarini Sands are approaching completion of that cycle. Most of the deposit has already been removed, and the many deep erosion alcoves testify that removal is still in progress.

Overlying the low gravelly beds is a series of sands, usually bright red in colour, whose traces of dune-bedding indicate that they accumulated through wind action. Their age is uncertain, but it has been the custom of earlier writers to group them with the fluvialite deposits, a policy which is followed in this report. To have done otherwise would have necessitated the mapping of many more boundaries for which, since the main purpose of this reconnaissance was to assess the economic potentialities of the area, there seemed no necessity. There is some justification for this, for in neither this nor the Mombasa-Kwale area was there seen any sign of a break between them. Furthermore, as was suggested on page 28, the coloration is considered to be due to the weathering of the sands *in situ* and not a depositional feature. The sands are well sorted, and consist essentially of rounded quartz grains of medium grade. Heavy minerals are scarce. There is no definite evidence to indicate the thickness of the sands although it is probably in excess of 300 ft. at Sokoake beacon.

From evidence in the Malindi area, Thompson has split the Magarini Sands according to their origins. The term "Magarini Sands" he restricts to the wind-blown variety which he considers to be of Middle Pleistocene age, having accumulated as coastal dunes pene-contemporaneously with the growth of the coral reef. For the underlying fluvialite deposits, he proposes the name "Marafa Beds", and these are referred to the Upper Pliocene. The two divisions are often separated by an eroded surface which, he claims, is in places marked by a thin layer of ferricrete that slopes seawards to about 120 ft. O.D. Upon its lower end there have been found some poor artefacts, ascribed provisionally to the Levalloisian culture (Upper Middle Pleistocene), and it is upon their dating that the age of the red sands is based. Yet whilst this evidence proves the age of some of the red sands, it does not necessarily prove the age of all of them. It is conceivable that the red sands originally accumulated shortly after the deposition of the fluvialite deposits; that subsequent erosion removed part of them, locally exposing the fluvialite deposits; that a ferricrete layer developed on the eroded surface on which artefacts were lost or discarded and that further erosion of the original red sands led to the redistribution of some of the material on top of the ferricrete. This conception seems to fit the observed facts, for some sections show a distinct break between the red sands and the fluvialite deposits, whereas others show a gradational contact. The process of redistribution of the red sands may have happened several times. That it occurred at least twice is suggested by the two erosion surfaces exposed above the Mazeras Sandstone in the new Mombasa-Nairobi road section (see p. 14); both surfaces are overlain by red sands which must, therefore, be of two different ages. Other evidence is afforded by the admixture of red sands in the Middle Pleistocene lagoonal deposits and the occurrence of superficial red sands which overlie the coral and are therefore of post-Middle Pleistocene age.

Perhaps the strongest evidence for a stratigraphical break between the red sands and the underlying pebble beds is the widely differing climatic conditions that were necessary for their deposition. The development of fluvialite deposits is favoured by heavy rainfall, whereas dune deposits are typical of an arid climate. Cases are known where dunes have been formed in association with fluvialite deposits, but they are generally of localised extent and confined to the valley-flat environment; these conditions are not satisfied by the Magarini dunes, and it is possible that the dunes are of Lower Pleistocene age. The reasons for this presumption are as follows: the age of the fluvialite deposits is assumed to be Upper Pliocene on account of their lithological similarities with the Mazingini Beds of Zanzibar and the Mikindani Beds of Tanganyika, both of which have been so dated by Stockley (1928, Table IV). At this time the sea-level stood at approximately 300 to 350 ft. O.D. as is suggested by (1) the maximum height at which the deposits appear to be found, and (2) the 350 ft. nick-point in the Mwachi river. The onset of the first pluvial period in Lower Pleistocene times caused a drop in sea-level to below the present level, and the fluvialite deposits were subjected to continuous active erosion, hence no marked erosion surface was developed. The sea-level rose again to about 200 ft. O.D. during the first interpluvial period (evidenced by the 250-ft. nick-point, T₃, Caswell, 1953, Table VII), and it is suggested that it was then that the bulk of the dune sands accumulated. The gradual rise in sea-level would

proportionately reduce the erosion of the fluvial deposits, whilst at the same time the increasing aridity would favour the formation of dunes; a certain degree of mixing of the materials of the two types of deposit can therefore be expected.

(2) THE MIDDLE PLEISTOCENE DEPOSITS

Under this heading are grouped the North Mombasa Sands or Crag, the Kilindini Sands, and the fossil Coral Reef. The first of these—termed “sands” by Gregory (1921, p. 75) but “crag” by McKinnon Wood (1930, p. 225)—was referred by these writers to the Pliocene on account of its fossil assemblage, whilst the other two were placed in the Pleistocene. It is now known that all three formations were deposited pene-contemporaneously in Middle Pleistocene times, the sands and crag accumulating as lagoonal deposits behind a fringing reef. A diagram showing the possible genesis and subsequent physiographical evolution of the deposits is given by Caswell (1953, Fig. 3, p. 28). It is considered that a wave-cut platform was formed at about -150 to -200 ft. O.D. during the second pluvial period, and that the coral reef grew on that platform during the succeeding inter-pluvial period, as the sea level was rising. The erosive action of waves on the growing reef led to the introduction of calcareous material into the lagoon, whereas the erosion of the Magarini Sands and other rocks on the mainland, both by wind and stream action, led to the introduction of sand and clay. Thus, although the over-all picture shows an easterly increase in the lime-sand content, vertical sections show inter-mixing and inter-fingering of the various materials. This can be clearly demonstrated by an examination of the logs of the bore-holes that were drilled near Bamburi in connexion with the Mombasa ground-water project. Hypothetical sections through portions of the Pleistocene deposits based on the logs of some of the bore-holes are given in Fig. 3.

The Pleistocene deposits occupy the physiographical zone which Gregory (1896, p. 222) termed the “temborari” or Coast Plain. It is generally from two to three miles wide, and seldom rises above the 100-ft. contour other than where dunes of a later age have been formed. The outcrop of the coral reef itself is probably not more than half a mile wide and it is often less, but it is backed by a coral breccia—the “Rifftrümmerkalk” of Krenkel (1924)—having a similar appearance, and it is the combination of these two that is coloured on the map as Pleistocene coral. The maximum height at which the coral was recorded in this area is 95 ft.—at Kilifi—but, as was suggested previously (Caswell, 1953, p. 29), it probably once stood as much as 100 ft. above the present sea-level. On the other hand, a bore-hole drilled near Bamburi was still in coral at 194 ft. below present sea-level so that the total thickness of coral must be 300 ft. or more. By assuming that the average rate of upward growth of a coral reef is about 1 foot per 200 years, Caswell (*op. cit.*, p. 30) estimated that at least 60,000 years were required for the complete reef to grow. It is probable, however, that this estimate is too high. Many workers have investigated the rate of coral growth, and an average of the figures quoted by Twenhofel (1950, pp. 236–238) and Kuenen (1950, pp. 420–1) is about one foot in ten years. Yet, as Kuenen points out, reefs as a whole must grow much more slowly, probably much less than one cm. per year. At this rate, it would have taken a minimum of 10,000 years for the Pleistocene coral along the Kenya coast to attain its known thickness.

Of the coral species that comprise the reef, the following have been identified (McKinnon Wood, 1930, pp. 186–94; 1938, pp. 94–6):—

- Tubipora purpurea*, Pallas.
- Stylophora pistillata* (Esper).
- S. palmata* Blainville.
- Pocillipora verrucosa* (Ell. and Sol.).
- Mussa corymbosa* (Forsk.).
- Coeloria arabica* Klunzinger.
- C. arabica* var. *leptochila* (Ehrenberg).
- C. lamellina* (Ehrenberg).
- Leptoria phrygia* (Ellis and Solander).
- Prionastraea tessera* (Ehrenberg).
- Favia speciosa* (Dana).
- Orbicella laxa* Klunzinger.
- Goniastrea favus* (Forsk.).

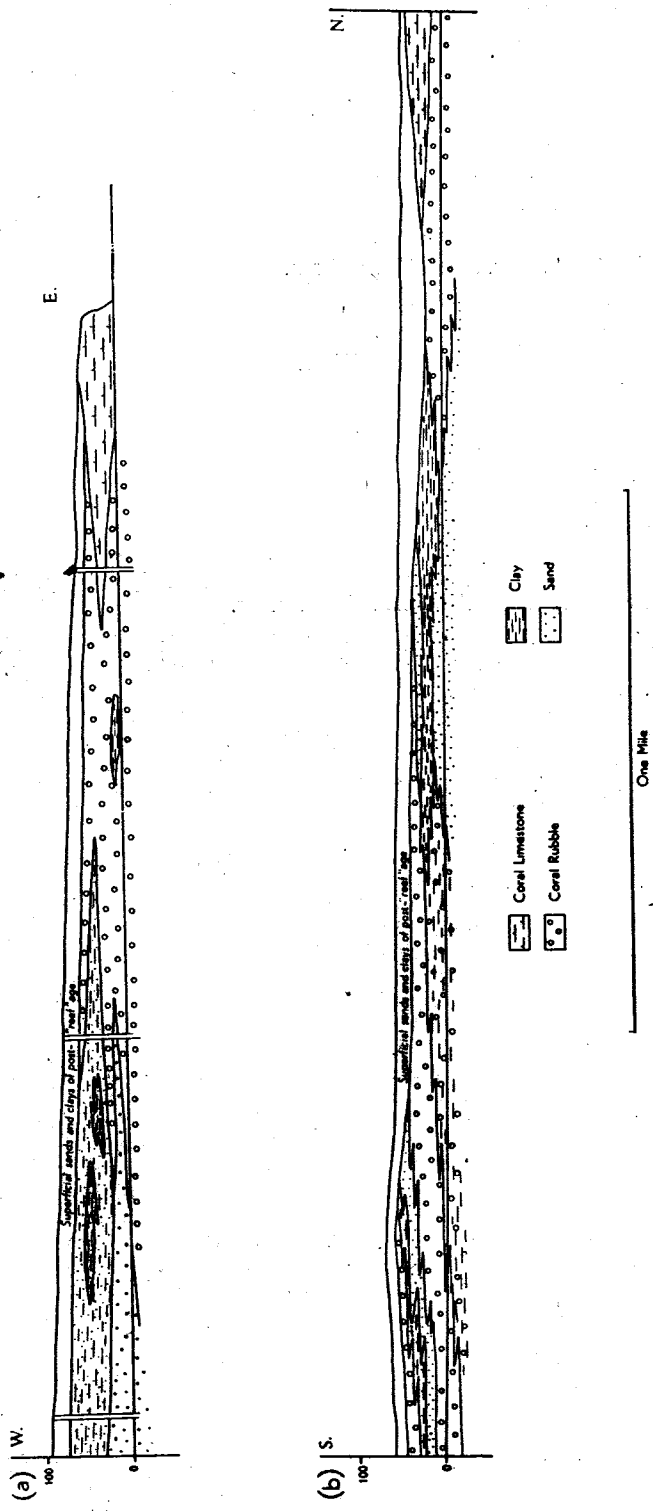


Fig. 3.—Section through the Pleistocene Deposits of the Kilifi-Mazeras Area. The upper section is Normal to the Coast, and the lower parallel to the Coast

Cyphastraea serailia (Forskal).
Echinopora ehrenbergi Milne-Edwards and Haime.
Galaxea fascicularis (Ellis and Solander).
G. lamarcki Milne-Edwards and Haime.
G. clavus (Dana).
Leptastraea transversa Klunzinger.
L. purpurea (Dana).
Diploastraea heliopora (Lamarck).
Fungia fungites L., var. *agariciformis* Lam.
F. patella (Ellis and Solander).
Madrepora cf. *subtilis* Klunzinger.
M. pharaonis Milne-Edwards and Haime.
Porites echinulata Klunzinger.
P. lutea Milne-Edwards and Haime.
P. sp.
Pachyseris speciosa (Dana).
Montipora sp.

It appears that all these species, with the exception of *Pachyseris speciosa*, are still living in the Red Sea and along the East African coast.

Reef and shelly limestones of Pleistocene age, the "Azanian Limestones", are known from both Pemba and Zanzibar, and are described by Stockley in his report on the geology of the Zanzibar Protectorate (1928). Referring to the Pemba beds, he says (*op. cit.*, p. 36) "It is possible to recognize two sets of limestones, an older series consisting of molluscan and coral remains, and a younger consisting only of corals. These correspond to the Azanian rocks occurring in Zanzibar at the levels 75 ft. and 30 ft.; but in Pemba they are found at the 40 ft. and 25 ft. levels". He concludes from this that there was differential subsidence between Pemba and Zanzibar, and a comparable conclusion was reached by Cox (though he claimed differential elevation) in the stratigraphical summary that prefaced his report on the palaeontology of the Zanzibar Protectorate (Cox *et al.*, 1927). Gregory, too, held the view that the reef owes its present position to an uplift in Pleistocene times, and he cites evidence (1921, p. 79) of different reef levels to show that the uplift was irregular. It is now known that there was no such uplift, and that the various events which took place in Pleistocene times were due solely to oscillations in the level of the sea. That there are two limestones in Pemba and Zanzibar is not disputed, although it is conceivable that another explanation of their relative ages and origin is tenable. It is known from evidence at Mombasa that the growth of the reef was followed by a retreat of the sea to a level some 150 ft. below that of the present day (Caswell, 1953, p. 53). The rivers were rejuvenated, and cut deep channels through the newly-formed reef and lagoonal deposits—two of them, the Mwachi and Kombeni, cut the deep channels that now flank Mombasa Island. Following this, in upper Pleistocene times, there was another rise in sea-level to about 30 ft. O.D. which cut the 30-ft. platform on the seaward side of the island (the Mombasa golf course is laid out on this platform). It is cut solely in the coral limestone, but one has to go only a short distance inland to meet exposures of the coral breccia. Is it not possible then, that the same thing occurred in Pemba and Zanzibar, but that there the coral-breccia contact more closely approximates to the limit of the 30 ft. platform? In his description of the Younger Azanian of Zanzibar, Stockley (*op. cit.*, p. 40) says that shelly limestones, calcareous breccias, and purely coral limestones are included, which suggests that some of the lagoonal deposits are also represented. Certainly the lithological differences upon which Stockley bases his subdivision in Pemba do not appear to apply to Zanzibar, and it may be doubted whether such sub-divisions are justified. On the other hand, the fact that there are no raised reefs of Upper Pleistocene age in coastal Kenya does not preclude the possibility that there are such reefs in Pemba, and there would appear to be no reason why reefs should not have grown up to 30 ft. O.D. when the sea-level stood at that height.

At present, relatively little reef-building activity can be seen, although there are many flourishing colonies of corals and polyzoa in the deeper inshore pools. Throughout most of its length, the coastline is bordered by an off-shore reef lying anything up to two miles

distant. Most of it is dead and subject to active wave erosion; in fact, in many places it is exposed above sea-level at low tide. Whether or not the reef is growing seawards below low tide level was not investigated, but it is likely that it is.

That the so-called "North Mombasa Crag" is essentially a marine deposit is known from the rich assemblage of marine fossils obtained from it. These fossils—they are mainly molluscs—are confined to certain horizons, usually those that are more calcareous: the more sandy horizons are seldom fossiliferous. It seems likely to the writer that the animals lived outside the reef and that some of their shells were washed into the lagoon from time to time when the growing reef was particularly subject to wave erosion. Perhaps this explains why many of the fossils are poorly preserved. It has previously been remarked that an examination of the fauna has led the majority of earlier workers to refer the beds to the Pliocene. In his introduction to the chapter on the Pliocene mollusca collected by Miss McKinnon Wood during her first visit to Kenya, Cox (McKinnon Wood, 1930, p. 114) states that of the 44 species definitely identified, 24 are living at the present day, and adds that if this proportion (55 per cent) is characteristic of the whole fauna, a Lower or Middle Pliocene age is indicated. The fossils collected during Miss McKinnon Wood's second visit included many additional species characteristic of a later age. Weir, who described them, quotes the following percentages of living species:—Mombasa Island, loc. 4-61: loc. 136-663: Mainland—78. These figures would presumably be indicative of an Upper Pliocene, or perhaps an Upper-Middle Pliocene age. Yet, in view of the conflicting stratigraphical evidence, it may be doubted whether the percentage method forms a reliable basis for age determination. It is well known that a particular species that attains its maximum numerical development in, say, Java during the Pliocene, may not attain its maximum numerical development in the Red Sea until the Pleistocene. Hence, in order to assess the age of a certain horizon, it would seem to be essential that the ranges of the fossils in the particular province in question should be considered in relation to the ranges of the same fossils throughout the world: only by this means can account be taken of migration. It is suggested that the point in the time scale where the relationship is closest gives the fairest indication of the horizon's age. In the case of the "North Mombasa Crag", it will be seen from the distributions of the species listed in the McKinnon Wood monographs (1930 and 1938) that whereas many are known from beds of early Neogene age throughout the world in general, relatively few are known from beds of that age in East Africa. The actual figures are as follows:—

	Distribution	
	World	E. Africa
Recent	57	46
Pleistocene	44	42
Pliocene	37	23
Miocene	22	8

These figures are cumulative; i.e. species which range from Miocene to Recent are included in the totals for each period, and so on. Shown graphically, as in Fig. 4 the relationship is more clear, and suggests a Pleistocene age for the beds.

Few macro-fossils were obtained from the crag in the Kilifi-Mazeras area, but numerous micro-fossils were collected from several localities. Frequently these occur in great profusion as "nests" in which individual foraminifera are loosely cemented together by calcite. Most of the specimens can be identified with *Amphistegina radiata* as described by Ovey (McKinnon Wood, 1938, p. 103). This species is characteristic of a warm shallow sea.

The "Kilindini Sands" are generally unfossiliferous. Gregory (1921, p. 77) considered that they were formed as calcareous dunes, on account of their containing some vertical calcareous tubes which he claimed originated by calcification around the stems of dune grasses. Krenkel (1924), on the other hand, suggested a marine or fluvio-marine origin in the lagoon behind the fringing reef, a view that had been advanced earlier by Maufe (1908, p. 5). Their explanation is the more probable, at least for the greater part of the deposits, although there are portions which might have accumulated through wind action.

The sands are composed of unevenly-graded sub-rounded quartz grains and, for the most part, are poorly consolidated. Occasional bands, which are invariably horizontal, are

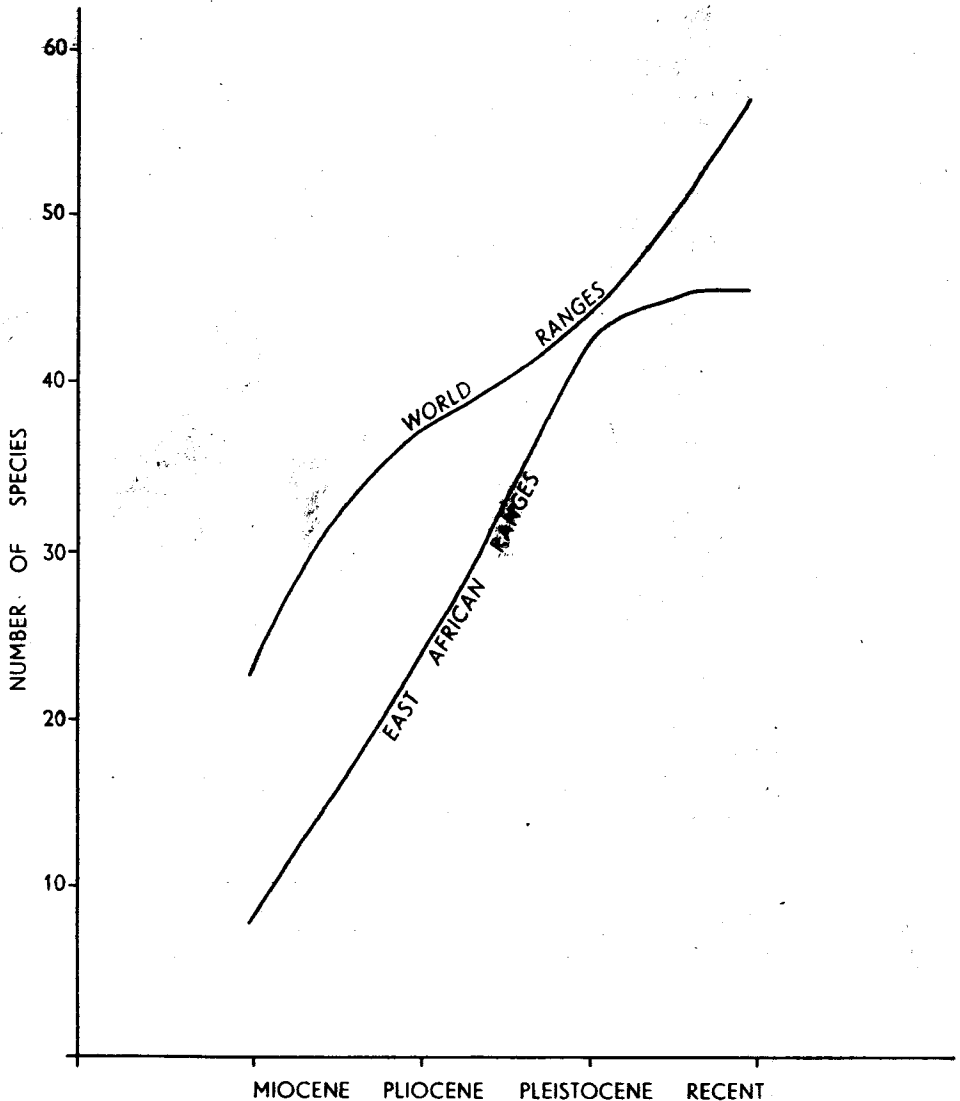


Fig. 4.—The Age Distribution of the Fossils Collected from the "North Mombasa Crag"

cemented by calcite into a semi-coherent sandstone. Heavy minerals are uncommon, but amongst those that have been observed may be mentioned the following: garnet, kyanite, tourmaline, and epidote.

A Pleistocene age for the sands was advocated by Maufe (*op. cit.*, pp. 4–5) and Krenkel (1924), and substantiated by McKinnon Wood (1930, p. 226) who obtained Pleistocene fossils from a hard sandstone band near the top of the cliffs at Makupa (Mombasa Island).

THE UPPER PLEISTOCENE DEPOSITS

(a) *Raised Alluvia*.—Thin sandy deposits occur in the southern part of the area where they border the more easterly of the two creeks which converge on Port Tudor. They rest unconformably upon Jurassic shales, and like the outliers of Margarini Sands described on p. 28, their limits can be determined by a change in vegetation. That they are probably of Upper Pleistocene age can be judged from the height at which they occur—rarely over 100 ft.—for were they older, they would surely have been washed away by the Middle Pleistocene

sea. Yet, the fact that they occur at heights up to 100 ft. precludes the possibility that they are marine, since the sea has never reached that height since Middle Pleistocene times; hence they are tentatively regarded as alluvial deposits.

(b) *Red Wind-blown Sands*.—The Middle Pleistocene deposits are frequently masked by a thin layer of red and reddish-brown sands and sandy clays. Often these are no more than a foot or so thick, but in places they form dunes rising to over 50 ft. above the general level of the plain. The best examples are the low hills immediately to the south of Takaungu, and the hill (146 ft.) at Kilifi on which the beacon is erected. Elsewhere it is less obvious how the beds were deposited, but for the sake of simplicity they are grouped together under one heading. Also, overlying the coral and associated deposits, is a thin veneer of sandy-clay of a brighter red colour. This originated through the weathering of the underlying deposits and is not included in the group.

Miss McKinnon Wood (1930, p. 227) refers to an oyster bed in the Senawe (Mwakuhenga) river to the west of Takaungu, and another in the river that flows into Kilifi Creek near Ngwawane. From them she collected specimens of *Ostrea gryphoides* and *Ostrea turbinata*, and thereby deduced a Pleistocene age. Neither of these localities was found during the present survey, but the excellent preservation of oysters collected by the writer from similar beds in the Mombasa area (Caswell, 1953, p. 30), suggests that they are of Recent age.

(4) RECENT DEPOSITS

One of the characteristic features of the Jurassic shale outcrop is the large number of alluvium-filled valleys that dissect it. These valleys were carved during phases in the Pleistocene period when sea-level stood lower than it does today, and were partly filled again by aggradation when it rose. Hence in cross-section, they are typically steep-sided and flat-bottomed. Doubtless most of the alluvium accumulated during Pleistocene times, but as the larger rivers show evidence of present-day aggradation the deposits are referred to the Recent.

VI—STRUCTURE

Various aspects of the structure of the area have already been referred to in previous chapters. In a broad way, the rocks dip gently towards the coast, so that the formations become progressively older as one proceeds inland, a feature that had been recognised by most of the earlier writers.

Confirmation of the unconformable overlap of the Mazeras Sandstones on to the Mariakani Sandstones proves that a minor phase of earth movement occurred during the interval between their depositions: that is, in Middle Triassic times. The movements gently folded the Mariakani Sandstones along more or less east-south-easterly trends, producing broad and shallow synclines and anticlines. The beds have a regional dip to the north-east throughout the greater part of the area, and it is only in the northern part that they swing south-easterly, a direction that is maintained in the southern part of the Malindi area. This dip, too, is common to the Kwale area (Caswell, 1953, p. 49). It seems, then, that an anticlinal axis passes through the south-western corner of the area, and a synclinal axis through the northern part, possibly through the Kabanini ridge, although there are a few anomalous dips north-east of Bamba that do not fit in with the suggested axis. The compressional forces which led to the folding must have been directed from the north-north-east or south-south-west, and it was these forces that are presumed to have produced the two major joint directions in the Mariakani Sandstones (see Fig. 2, p. 9). Such movements were recognised by Parsons (1928, p. 83), although he considered that they occurred at a later date, between the depositions of the Duruma Sandstones and the Jurassic rocks. He also claims that they were of a sufficient intensity to cause over-thrusting of the Mariakani Sandstones and Shimba Grits on to the Maji-ya-Chumvi Beds near the Tanganyika border, and the development of great more or less north-south tear-faults throughout the coastal succession. The over-thrusting was rejected by Maufe, Wayland, and Gregory (see McKinnon Wood, 1930, p. 2), and again by Caswell (1953, p. 49), and neither Miller, Thompson, nor the writer have found any evidence to suggest the presence of tear-faults.

Such faults as are known from the coastlands are all normal, and it is likely that they can be assigned to three major phases of activity. That the third phase took place in Middle Pliocene times is suggested by the nature and distribution of the Magarini Sands. The fluvial deposits, of which there are some 200–300 ft., are known only from the seaward

side of the Mazeras Sandstone outcrop, and their lithology indicates that they accumulated rapidly under conditions of intense erosion. This could only be brought about by a no less rapid change in environment and, of the various possibilities by which this could occur, an increase in the erosion gradient is the most plausible. To account for such an increase, a lowering of the coastal strip by faulting is postulated.

Two other coastal features can also be explained by this hypothesis. Firstly, it is possible to match the sub-Magarini erosion surface with that of the Nyika, and secondly, the differences in altitude between those portions of the Kambe Limestones that have been down-faulted and those that have not can be explained. These differences in height amount to about 300 ft. in the case of the erosion surfaces, and about 350 ft. in the case of the limestones, so that it can be suggested that the throw of the fault is of the order of 300 ft. This figure is supported to some extent by the thickness of fluvial deposits which accumulated east of the faults. Furthermore, evidence from the Mwachi river shows that, prior to the faulting, the river was graded to a base-level of erosion at about 400 ft. (Caswell, 1953, p. 53), so that, consequent upon the faulting, sub-aqueous deposits could be expected to occur up to that level but not above it; this is borne out by field evidence (*see* p. 29). From these various view-points, there seems to be a strong case for mid-Pliocene faulting.

Evidence for the earlier phases is less sound, although there are several factors that can be put forward in their favour:—

(1) Whereas the Jurassic-Triassic boundary fault is generally marked by a prominent escarpment, there is no such feature to indicate the other faults, which suggests that they are older.

(2) It has been suggested that the throw of the Pliocene fault is of the order of 300 ft.: this figure is wholly insufficient to satisfy the demands made upon the coastal faulting. Near Mazeras, for example, some 450 ft. of Kambe Limestone, a much greater thickness of Mazeras Sandstone, and possibly some Mariakani Sandstone as well are missing from the succession. To account for this, down-faulting having a total movement of no less than 1,000 ft. is required, of which all but 300 ft. took place in pre-Pliocene times.

(3) The majority of the economic mineral deposits that occur within the coastal sedimentary series are closely associated with faulting—many of them are, in fact, emplaced in fault-planes. Yet no deposits have been found associated with the Jurassic-Triassic boundary fault, despite the fact that this is the most widely proved of all the coastal faults. This points to there having been two phases of faulting with the mineralization having occurred during the interval.

The ages of the older phases of faulting are not known, but it can be tentatively suggested that they took place as a result of the break-up of Gondwanaland in Mesozoic times. There is evidence, that will be discussed more fully in Chapter VIII, to suggest that a phase of faulting preceded the deposition of the Jurassic rocks, and that a further phase followed the deposition of the Cretaceous rocks. The principal trend of these faults is northerly to north-easterly, and this is shared by the more important of the younger faults. Secondary trends are more easterly, often south-easterly.

In the case of the faults near Mazeras it was not possible to measure their throws, but the relatively slight bending of the beds adjacent to the fault-planes suggests that none of them is very large. Neither is it possible to show all the faults on the map, for in addition to those referred to above, there are several minor slips with throws ranging from a few inches to a foot or so. The significant feature is that all are normal faults, and all have downthrows towards the coast.

Dips recorded from the Mazeras Sandstones are variable and frequently inland. This was noted by Gregory (1921, p. 70), and by Caswell (1953, p. 49) who considered them to be due to a slight marginal up-tilting of the strata on the up-throw sides of faults consequent upon the relief of stresses brought about by the faulting. The Jurassic rocks, and the Kambe Limestones in particular, show a general consistency in strike direction with low dips to the east-south-east. Such variations as occur can usually be ascribed to faulting. The Cainozoic rocks are normally flat-bedded, and there is no evidence to indicate that they have been subjected to any tectonic activity.

A structural map of the area is presented in Fig. 5.

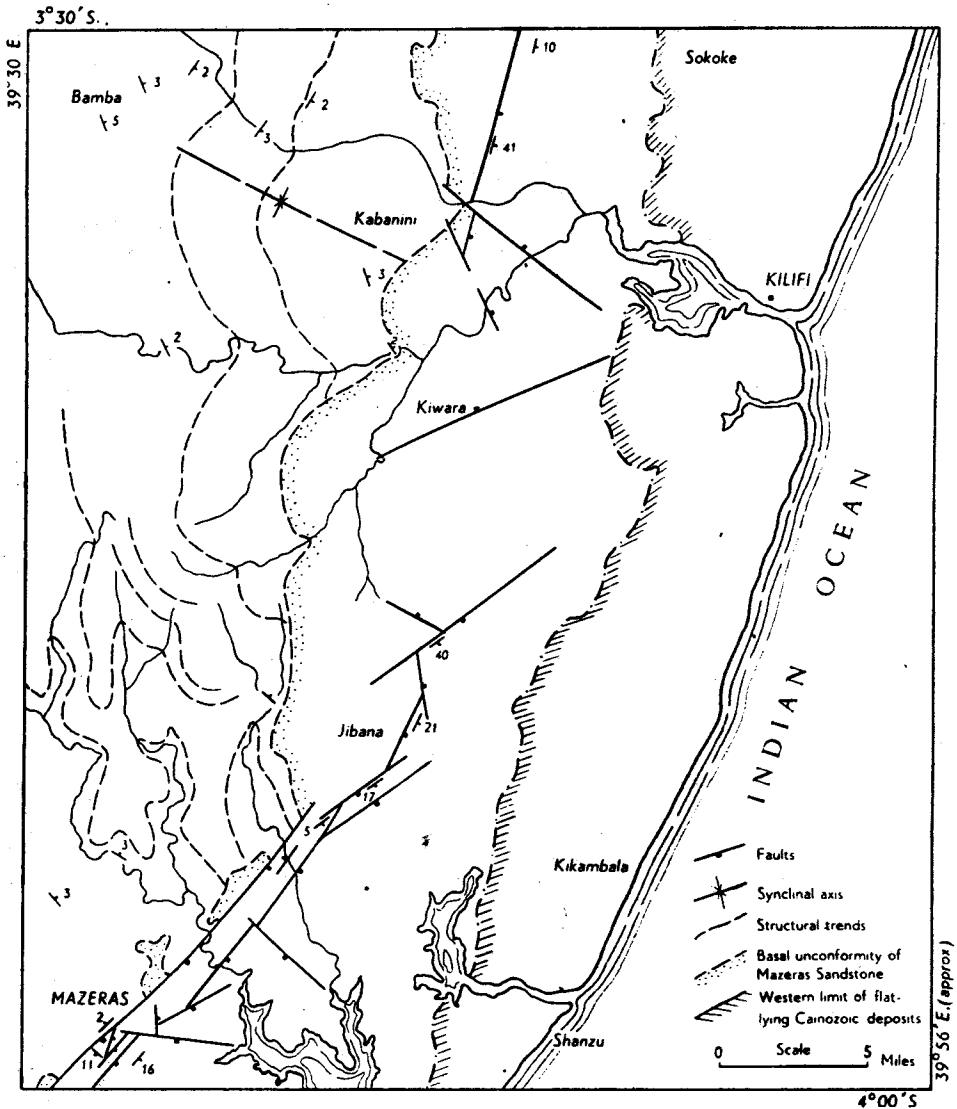


Fig. 5.—Structural Map of the Kilifi-Mazeras Area

VII—GEOLOGICAL HISTORY

Recent work points to a gentle down-warping in late Palaeozoic times along what is now the margin of the East African continent. Its effect was to form a north-north-easterly trending trough into which the drainage systems were directed, and in which the sediments carried by the rivers were deposited. These sediments form the Duruma Sandstone Series. Initially they were of coarse grade, but as a state of equilibrium was approached the deposits became progressively finer until, by Maji-ya-Chumvi times, they consisted essentially of silts. A more active phase of erosion followed, for the Mariakani Sandstones, exhibit a rhythmic sequence of finer- and coarser-grained beds, the overall grade becoming coarser higher in the succession. These conditions persisted in early Upper Triassic times when the lowermost Mazeras Sandstones were laid down, but were soon superseded by a deltaic environment that is characterised by the silicified wood horizon. The Upper Mazeras Sandstones are typically continental deposits, although it is probable that subaqueous bands are intercalated with them.

A marine invasion in Bajocian (Jurassic) times led to the accumulation of a thick series of limestones, shales and sandy shales that continued, apparently without a break, at least until the middle Kimmeridgian. A period of faulting may have preceded the invasion for there is no indication of any marked over-stepping of the Jurassic rocks on to the Duruma Sandstones. Furthermore, although the Jurassic rocks share the same direction of dip as the Duruma Sandstones, their angle of dip is greater, so that at the time of their deposition, when one assumes they were laid down horizontally—or nearly so—the entire Duruma Sandstones Series would have had a regional dip to the west. This is wholly unacceptable unless there were earth movements between the depositions of the two series. Such movements are quite feasible in the light of the continental drift hypothesis (Du Toit, 1937), and it may be envisaged that a partial collapse of the trough took place which led to slight up-tiltings of the margins. At the same time, the Jurassic sea transgressed the down-faulted central portion and lapped against the Duruma Sandstone fault-scarp. Yet, because of the westerly tilt of the sandstones the drainage was inland, and very little sand found its way into the Jurassic sea. The larger rivers would be expected to have maintained their eastward courses, and there is evidence to suggest that one river flowed seawards through what is now the Mombasa Gap. The basal members of the Jurassic series, as exposed in the Mwachi river, consist of a 50-ft. thick conglomerate which includes large boulders of Mazeras Sandstone (Caswell, 1953, p. 19), and it is in this same area that the estuarine Kibiongoni Beds achieve their maximum development. In the Cha Simba area, on the other hand, the basal Jurassic limestones are remarkably free of sand, and there are no Kibiongoni Beds present.

Continuing the synthesis, it is suggested that subsequent seaward tilting of the entire coastal sedimentary succession was brought about by isostatic rise of the continent and the weight of the accumulating Jurassic sediments, of which at least 5,000 ft. are known from Kenya. Lower Cretaceous rocks occur in the Mombasa-Kwale area (Caswell, 1953, p. 24) and it is probable that deposition was continuous between Bajocian and Neocomian times, as it was in Kachh and Madagascar; hence the combined thickness of Jurassic and Cretaceous rocks, including the uppermost Jurassic stages which are not exposed at the surface, will be considerably in excess of 5,000 ft. The Cretaceous rocks appear to be faulted down against the Jurassic rocks, so that a further phase of faulting in post-Neocomian times is indicated. This faulting is certainly pre-Upper Pliocene, and as it is in no way reflected in the topography, it is probably much older and may be provisionally assigned to the early Tertiary, or even to the Cretaceous. It has previously been suggested by the writer (Caswell, *op. cit.*, p. 52) that this fracturing occurred in the late Miocene, and thereby caused the lowering of the base-level of erosion that initiated the destruction of the Miocene surface. Stockley (1928, p. 52) has also shown that it was rift faulting in late Miocene times that led to the separation of Pemba Island from the mainland of Africa. The chain of events so far, then, appears to be as follows (*see* Fig. 6):—

- (1) Formation of a N.N.E.–S.S.W.–trending trough.
- (2) Accumulation of the Duruma Sandstone Series within the trough accompanied by continued down-warping due to the weight of the sediments.
- (3) Partial collapse of the centre of the trough due to the incumbent weight of the overlying sediments causing up-tilting of the margins and permitting the transgression of the Jurassic sea.
- (4) Deposition of the Jurassic and Cretaceous sediments accompanied by further down-warping of the trough.
- (5) Further collapse of the trough.

Throughout Tertiary times, the coastlands underwent extensive continental erosion which appears to have been accentuated in the Upper Pliocene, consequent upon a further phase of faulting (p. 35).

Fig. 6.—Hypothetical Evolution of the Kenya Coastlands

- A.—Down-warping of marginal trough with the deposition of the Duruma Sandstone Series. The N.E.–S.W. folding took place during this phase but the folds are not shown since the sections are parallel to the fold axis.
- B.—Faulting accompanied by up-tilting of the Continental Margin, and the invasion of the Jurassic Sea with the consequent deposition of the Jurassic sediments. The dashed line represents the courses of the major rivers.
- C.—Further down-warping of the trough causing a seaward tilt of the entire sedimentary succession.
- D.—Further faulting with minor up-tilting of margins.
- E.—Schematic section through the coastlands as they are seen at the present day, but without the superficial cover of the Cainozoic deposits.

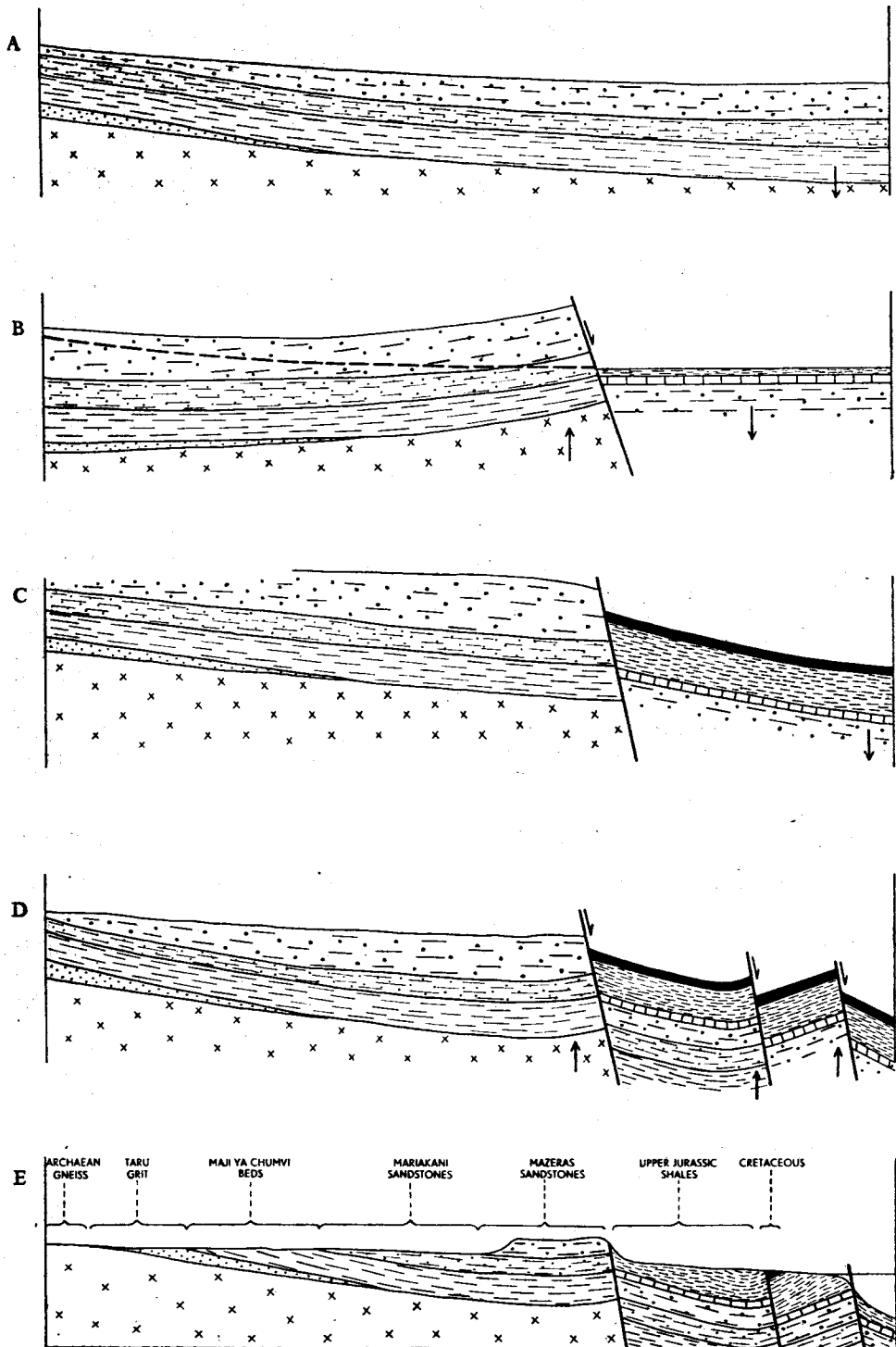


Fig. 6

The characteristic feature of the Pleistocene and Recent periods has been the marked fluctuation of sea-level. This was recognised by Maufe (1908, p. 5) and Sikes (1930), and was more fully described and correlated by the writer (1953, pp. 53-54). Table IX (p. 41) reproduces the chronology and correlation of the Pleistocene period. Little is known of what happened during the Lower Pleistocene, but it can be assumed that it was then that the bulk of the recently formed Magarini fluvial deposits was removed. This would have taken place during the two pluvial periods; it is possible that the intervening interpluvial witnessed the accumulation of the Magarini dune sands. The coral reef is considered to have grown in the second interpluvial period, with the deposition of the lagoonal deposits proceeding contemporaneously. In the pluvial period which followed, the rivers were rejuvenated and cut their courses through the Middle Pleistocene deposits to a depth well below present sea-level. There is evidence to show that the sea-level rose to at least 30 ft. O.D. in Upper Pleistocene times, but later dropped again to an unknown level below its present height to which it has risen only in Recent times. It appears that the present tendency is for the sea to continue its rise.

VIII—ECONOMIC GEOLOGY

Several deposits of minerals of economic value have been recorded from the Kilifi-Mazeras area, but it is doubtful whether many of them are of sufficient magnitude to justify development. The deposits include manganese, lead, zinc, coal, limestone (used for lime and cement), building stone, and water, their dispositions being shown on Fig. 7.

1. Manganese

It has been known for many years that a manganese laterite occurs on the top of Kiwara hill, but there is no record of its original discovery. A Mr. A. G. Anderson obtained a concession for one year, beginning on the 25th July, 1910, to prospect for manganese in an area of 300 square miles between Mombasa and Malindi (including Kiwara), with the option of a long lease. This was never taken out due, no doubt, to the unfavourable report of the mining engineer brought out by Messrs. Smith Mackenzie and Co., who had financed the project.

Mr. C. W. Hobley, then Commissioner of Mines, visited the locality in 1916 and reported that he considered insufficient work had been carried out for it to be possible to form any adequate opinion of the extent of the deposit. He referred to three samples sent to the Imperial Institute that yielded 66, 67 and 36 per cent MnO_2 respectively.

Towards the end of 1918, interest in the hill was shown by Mr. A. L. Lawly of Messrs. Pauling and Co. Ltd., of Magadi, and prospecting licences in respect of this area, another immediately to the south, and a third at Mrima hill in the Kwale District, were granted to him on the 21st May, 1919. Initially, each licence was of one year's duration, but they were subsequently renewed for a further year; they were transferred to Messrs. Bird and Co. (Africa), Ltd., on the 19th August, 1920 owing to Mr. Lawley's leaving the Colony. This firm evidently was more interested in the Mrima deposit and they again renewed their licence to prospect there, whereas the licences covering the Kiwara and adjacent areas were allowed to lapse, and were subsequently cancelled by General Notice No. 410 of the 11th April, 1921.

It appears that no further interest was taken in the hill until November, 1943, when it was visited by the Government Mining Engineer and a Government Prospector. New pits were dug and some of the old ones cleaned out (*see* Fig. 8a), and the following notes on the sections exposed were made:—

Pit 1.—9 ft. deep—

5 ft. soft red earth.

4 ft. nodular manganese ore, rather sandy grading downwards into a more or less massive *replacement** deposit.

Pit 2.—8 ft. deep—

7 ft. soft red earth.

1 ft. coarse sands with nodules of sandy manganese ore.

*Writer's italics.

TABLE IX.—PLEISTOCENE CHRONOLOGY AND CORRELATION

Period	N.W. EUROPE (based on Zeuner, 1950, Chap. V.)				EAST AFRICA		
	General Terminology	Classical Alpine Sequence	Thalassostatic Rivers	Sea-level	Terminology (Leakey, 1950)	Sea-level	Coastal features
Upper	P.G1.	Post-Glacial	Aggradation up to present sea-level	Flandrian Transgression	Post-Pluvial	Rise to O.D.	Silting up of Port Reitz and Port Tudor—Mangrove Swamps
	L.G1.	Würm Glaciation	Buried channels	Generally low	Gamblian Pluvial	?	
	L.IG1.	Last Interglacial	25-ft. Terrace 50-ft. Terrace	25 ft. O.D. 60 ft. O.D.	3rd Interpluvial	15 ft. O.D. 30 ft. O.D.	15 ft. beaches and caves. 30 ft. platform 100-ft. nick-point (T ⁶)
Middle	P.G1.	Riss Glaciation	Erosion	Very low	Kanjeran Pluvial (formerly upper Kamasian)	c. -150 ft.	Cutting of Mwachi deep channel (T ⁵) = Kilindini
	P.IG1.	Great Interglacial	100 ft. Terrace Various buried aggradations	107 ft. O.D.	2nd Interpluvial	c. 100 ft.	Growth of Coral Reef 200-ft. nick-point (T ⁴) 120 ft. Terrace
Lower	Ap. G1	Mindel Glaciation	Erosion	Very low	Kamasian Pluvial	c. -200 ft.	Cutting of marine platform upon which the coral grew.
	Ap. IG1.	First Interglacial	200-ft. platform	200 ft. O.D.	1st Interpluvial	c. 200 ft.	250-ft. nick-point (T ³)
	E.G1.	Gunz Glaciation		Lower	Kageran Pluvial	?	
Pliocene			Earlier high levels and terraces	c. 300 ft. O.D.		c. 300 ft.	350-ft. nick-point (T ²)

E.G1 = early glacial period; Ap. IG1. = antepenultimate interglacial period; Ap.G1. = antepenultimate glacial period; P.IG1. = penultimate interglacial period; P.G1. = penultimate glacial period; L.IG1. = last interglacial period; L.G1. = last glacial period; P.G1. = post-glacial period.
T = thalweg (see Caswell, 1953, fig. 15).

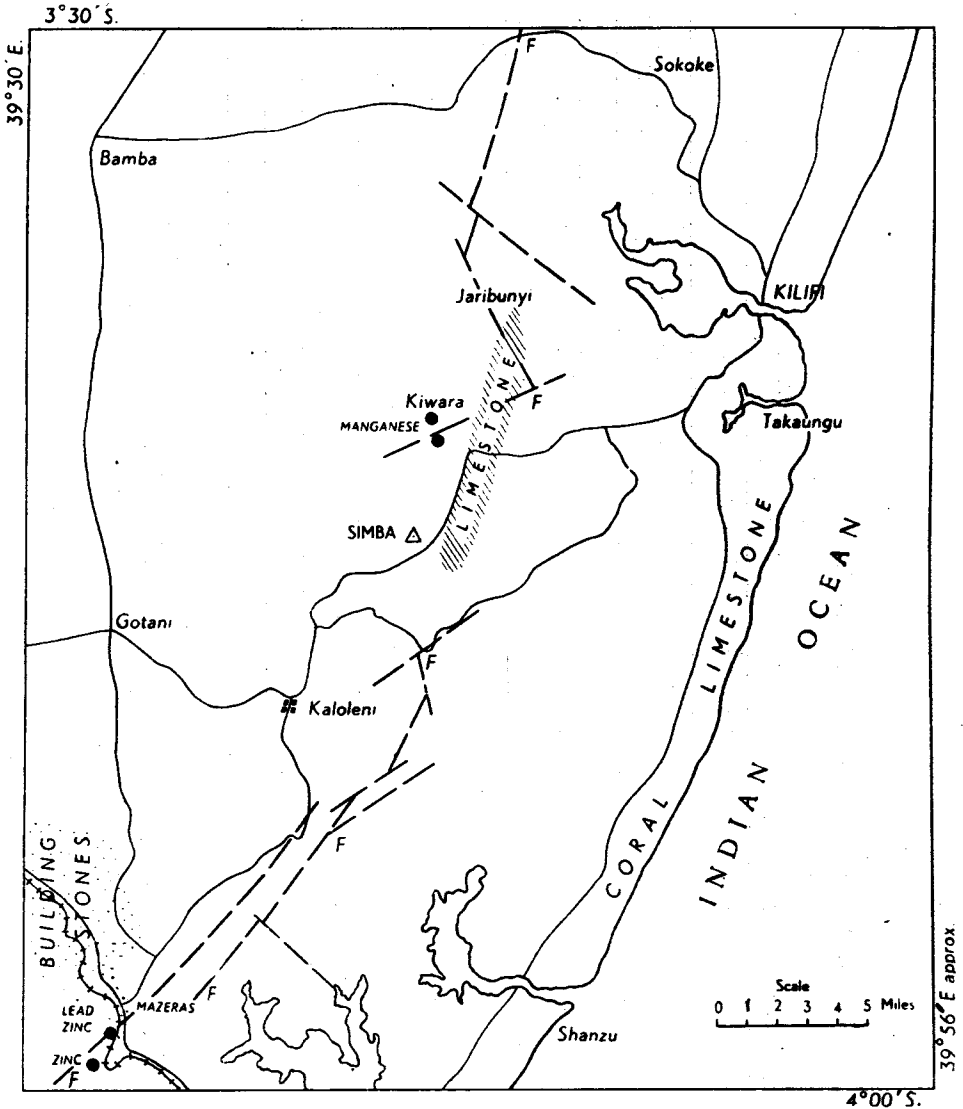


Fig. 7.—Mineral Deposits in the Kilifi-Mazeras Area

Pit 3.—9 ft. deep—

- 5 ft. soft red earth.
- 3 ft. fine sands with nodules of sandy manganese ore.
- 1 ft. thin sandstones (flaggy sandstones).

Pit 4.—10 ft. deep—

- 6 ft. soft red earth.
- 3 ft. sands with nodules of sandy manganese ore.
- 1 ft. thin sandstones (flaggy sandstones.)

Pit 5.—10 ft. deep—

- 8 ft. soft red earth.
- 2 ft. sands with nodules of massive ore grading downwards into a more or less massive *replacement** deposit.

*Writer's italics.

Pit 6.—9 ft. deep—
Red earth only.

Pit 7.—10 ft. deep—
Red earth only.

Pits A, B and C—
Old pits, not cleaned out, good quality fine-grained manganese at the surface.

Pit C.—7 ft. deep—
3 ft. soft red sands.
4 ft. soft red sands with nodules and cobbles of sandy ore, some of good quality.

Pit E.—5 ft. deep—
2 ft. soft red sands.
3 ft. soft red sands with nodules and small cobbles of very sandy ore.

Pit F.—6 ft. deep—
5 ft. soft red sands—
1 ft. red sands with occasional nodules of poor quality ore.

Pit G.—8 ft. deep—
5 ft. soft red sands.
3 ft. red sands with nodules of sandy ore.

Pit H.—5 ft. deep—
4 ft. red sands.
1 ft. red sands with nodules of poor quality ore.

Pit J.—18 ft. deep—
1 ft. manganese-stained sandstones and grits.
17 ft. unaltered sandstones and grits.

Pit K.—4 ft. deep—
3 ft. red sand.
1 ft. grit boulders with traces of ore.

Pit L.—8 ft. deep—
3 ft. sandstone boulders with traces of ore.
5 ft. red sands.

Pit M.—5 ft. deep—
3 ft. red sand.
1 ft. red sand with pebbles and small nodules of low grade ore.
1 ft. red sand.

Pit N.—4 ft. deep—
4 ft. red sands with occasional pebbles of grit, some of which are manganese-stained.

Pit O.—6 ft. deep—
3 ft. red sand.
3 ft. red sand with nodules of fairly good quality ore.

An old pit sited about 50 yards north of Kiwara beacon revealed red sands with boulders of sandstone, but no ore.

Four of the samples from Kiwara hill were analysed and gave the following results:—

	%	1 %	2 %	3 %	4 %
SiO ₂ ..		1.99	1.02	1.03	26.63
Al ₂ O ₃ ..		8.08	10.47	7.82	9.49
Fe ₂ O ₃ ..		0.48	5.55	13.35	8.14
MnO ₂ ..		69.20	68.60	63.60	43.80
MnO ..		3.36	2.65	1.33	1.54
BaSO ₄ ..		9.55	3.59	1.70	4.68
H ₂ O ..		7.08	5.63	8.85	5.17
		99.74	97.51	97.68	99.45

Analyst: Miss A. F. R. Hitchins

Calculated modes

Psilomelane ..	9.18	7.24	3.64	3.98
Pyrolusite ..	65.08	65.36	61.97	41.91
Limonite ..	0.53	6.18	14.85	8.86
Barytes ..	9.55	3.59	1.70	4.68
SiO ₂ , etc. ..	15.40	15.14	15.52	40.02
	99.74	97.51	97.68	99.45

In calculating the modes, it was assumed that the total manganese content was derived from psilomelane and pyrolusite, and that the psilomelane is barium-free. The mineral formulae used were those quoted by Bateman (1951, pp. 562, 579), i.e.

Limonite	Fe ₂ O ₃ . H ₂ O
Psilomelane	MnO. MnO ₂ . 2H ₂ O
Pyrolusite	MnO ₂

These four samples gave an average manganese (Mn) content of 40.49 per cent, a figure which compares very favourably with the average content of 21.78 per cent for samples from Mrima hill. Doubtless it would have been still higher had sample 4 been cleaned prior to analysis, for it seems clear that it contained a fair proportion of sand. On the other hand, these four samples were presumably picked for their purity and are not, therefore, representative of the entire deposit. It is unfortunate that fuller analyses were not made, for it would have been interesting to see whether other base metals such as lead and zinc are present, as they are at Mrima; the occurrence of barytes suggests that they probably are.

The manganese occurs in a more or less flat-lying bed up to 4 ft. in thickness—the average is probably about 2 ft.—that has been proved over an area of at least 1,500 x 1,000 ft. It is overlain by anything up to 8 ft. of red, unconsolidated sands, and, in pits L and M, is underlain by similar material, although in the majority of cases it is underlain by solid Duruma Sandstones. It is clear that the deposit is not a replacement, as was originally thought, but a residual resulting from the weathering of a primary deposit. Bateman (1951, p. 210) quotes four sources from which most residual manganese deposits are derived:—

- Limestones or dolomites low in alumina but containing disseminated, syngenetic manganese carbonates and oxides.
- Limestones containing disseminated introduced manganese.
- Manganiferous silicate rocks, such as crystalline schists or altered igneous rocks.
- Lode deposits of manganese minerals, or ores high in manganese.

Obviously neither (a), (b) nor (c) applies in this case, from which one concludes that the manganese was probably derived from an underlying lode, a conclusion that was previously reached in connexion with the Mrima deposit (Caswell, 1953, p. 57). In fact, there appears to be a definite genetical relationship between all the coastal metallic mineral deposits, and this will be discussed more fully in a subsequent section.

In addition to the manganese occurrence on the top of Kiwara hill, there is a similar but smaller occurrence capping the hill about half a mile away to the south-east. Two old



It cannot be doubted that these two occurrences are the remnants of a once much larger deposit, most of which has since been eroded away. Evidence of its erosion was seen in a bore-hole drilled recently at Sokoke, north-west of Kilifi, for fragments of manganese ore were found in the sludges from depths between 210 ft. and 215 ft. What remains will probably not exceed 1,000 tons so that it is unlikely that the deposit could be profitably worked.

The trend of the main occurrence is slightly east of north, corresponding with the regional strike of the Duruma Sandstone with which it is associated. The more southerly deposit is however, offset from the line of the larger occurrence due to an east-south-easterly fault which separates them, and which has lowered one relative to the other. The eastern flank of Kiwara hill is exceptionally steep and suggestive of a fault scarp, although no positive evidence for faulting was seen. Such a fault would parallel the supposed trend of the main occurrence, and could possibly have formed the medium in which the parent minerals were emplaced. The lead-barytes ores at Vitengeni and the lead and zinc veins near Mazeras, were emplaced in fault-zones with similar trends, and it has been suggested that the manganese deposits of Mrima were derived from lodes which also have the same strike.

It is considered that a detailed examination should be made of the sub-surface geology of Kiwara hill in order to prove the supposed underlying lode, for whereas the capping cannot be expected to yield more than 1,000 tons of ore, a lode might well prove a profitable venture.

2. Iron

Specimens of oolitic limestone that have been partly replaced by limonite were found in the Viambani-Marere area, about five miles north-east of Kiwara hill. Many of the ooliths have been wholly replaced and the groundmass partly, an analysis of the rock showing the presence of 7.14 per cent of iron (Fe). The replacement has affected only the surface layers of the limestone so that it is clear that it did not come about by hydrothermal processes. The most likely explanation is that the limonite originally formed part of the oxide capping of Kiwara hill, and that it was transported mechanically and re-deposited, along with vast quantities of sand from the Duruma Sandstones, during Pliocene times to form the Magarini Sands. Subsequently, downward percolating waters dissolved the iron ore, and on reaching the underlying Jurassic rocks caused the replacement of the uppermost limestone layers by the limonite. Occurrences of this sort, but in which the replacement was less pronounced, were observed at many places on the Kambe Limestone outcrop in the northern part of the area.

Clay ironstone nodules are present in various horizons of the Jurassic shales, but it is improbable that they will have any economic value.

3. Lead

Towards the end of the last century the British East Africa Company prospected for lead in the neighbourhood of Mazeras, but they did not pursue the project and it had already been abandoned when Gregory visited the site in 1893 (Gregory, 1896, p. 63). Their activities seem to have been confined to a 50-ft. adit which was driven into the hillside on the eastern bank of a stream about three quarters of a mile south of Mazeras, and a small prospect trench dug near the hill-top a short distance further east (see Fig. 8b). No mineralization is revealed in the prospect trench, but the adit shows veins of blende. In the stream section, just below the entrance to the adit, several thin veins—about a quarter of an inch thick—of galena are exposed striking slightly east of north and dipping steeply eastwards. Exposures within the adit indicate that there are two sets of veins, one dipping 38° and the other 50°, both on bearings of 120°. Four veins, two to each set, were seen in the outer half of the adit; they were all of zinc blende, but it is possible that veins of galena occur in the inner, unexplored half, for the adit has always been known as a "lead mine".

The country-rock is a false-bedded, medium-grained felspathic and micaceous sandstone considered to belong to the lower part of the Mazeras Sandstones. A north-east fault immediately to the west is postulated to separate these sandstones from the gently north-westward dipping Mariakani Sandstones which are exposed in the quarries high up on the western flank of the valley.

A small piece of Mazeras Sandstone carrying a thin vein of galena was picked up among railway ballast at a point about two miles south of Mazeras. Several small faults are exposed in the nearby cuttings and it is possible that the specimen was derived from one of these, but this was not confirmed.

4. Zinc

Zinc blende was found at two localities in the area, the first in the lead adit referred to above. Four veins are exposed, the thickest being about one inch across.

The other occurrence is in the bed of the stream that flows southwards from Mazeras into the Mwachi river, and about one hundred yards short of the confluence. A mineralized zone some 6 ft. wide and trending north-eastwards is exposed, consisting of one major vein of from nine to ten inches in thickness, and several small, more or less parallel veins

whose combined thickness amounts to about three inches. The veins are emplaced in greyish-green and purple sandy shales which are interbedded with massive, cross-bedded, coarse-grained grits and sandstones of the lower part of the Mazeras Sandstones. Associated with the veins are thin stringers of calcite and small cubes of pyrite.

5. Possible Genetic Relationships of the Coastal Metallic Mineral Deposits

A review of the mineral deposits that have been found in the coastal sediments shows that, in all cases, the minerals belong to a common suite which includes lead, zinc, copper, iron, manganese, and barytes (*see* Table X). Moreover, all deposits are emplaced in upper members of the Duruma Sandstone Series, most of them in the Mazeras Sandstones; all have an apparent north-north-easterly to north-easterly trend; and all appear to be closely associated with a zone of faulting that runs more or less parallel to the coast. In view of these similarities, it does not seem unreasonable to propose that the deposits are homogenetic and were co-emplaced within the fault-zone.

TABLE X.—THE MINERAL DISPOSITIONS IN THE COASTAL SEDIMENTS

	Lead	Zinc	Copper	Iron	Manganese	Barytes
Vitengeni (Thompson)	X	X	X	X		X
Kiwarra				X	X	X
Mazeras (B.E.A. Adit)	X	X				
Mwachi		X		X		
Mombasa Pipe Line (Caswell, 1953)	X					
Mrima Hill (Caswell, 1953) ..	X	X	X	X	X	X

A point of significance, however, is that no trace of mineralization has yet been found in the Jurassic-Triassic boundary fault, in spite of the fact that it is the most widely proved of all coastal faults. The reason for this seems to be the two phases of faulting (p. 36), the Jurassic-Triassic boundary fault belonging to the younger phase, and with the mineralization occurring during the interval.

6. Coal

Carbonaceous material is frequently met with in the Duruma Sandstones, particularly in the fossil wood horizon of the Mazeras Sandstones where very localised pockets of poor-grade coal are occasionally developed. These isolated occurrences have frequently led to the hope that coal seams of workable dimensions will some day be found. This possibility has already been fully discussed by the writer (Caswell, 1953, p. 59) with the conclusion that the conditions of sedimentation of the exposed sandstones in coastal Kenya were wholly unsuited to the development of seams. The evidence from the Kilifi-Mazeras area supports this conclusion. A thin lenticle of carbonaceous shale was observed in the Kombeni river but it was enclosed between massive, cross-bedded, coarse-grained sandstones and grits which had obviously been deposited rapidly under conditions far removed from those necessary for the formation of coal.

A small amount of coal was found in 1915 between 45 and 80 ft. below the surface in a 90-ft. well dug about four miles west of Takaungu, near Jingoingo. A sample was submitted to the Imperial Institute who reported that it was lignite with the following analysis:

Moisture (110°-120°)	..	13.00
Volatile matter	..	50.27
Fixed carbon	..	31.67
Ash	..	5.06
Sulphur	..	4.01
Calorific value	..	5440 small calories*

* A small calorie is the amount of heat required to raise the temperature of one gram of water from 0° to 1° C.

On heating, the coal evolved a large quantity of combustible gas and caked. It yielded a light brown somewhat heavy ash, which did not fuse. It is probable that the coal was derived from humified logs and other remains of trees preserved in the Pleistocene sediments. When found the coal was described as bitumen, and the belief that bitumen is present in the ground near Takaungu is still prevalent in some quarters.

7. Limestones (Cement Manufacture)

A cement factory which is being built by the British Standard Portland Cement Company at Bamburi, just beyond the southern limit of the area, is now nearing completion*. The materials to be used in the manufacture of the cement are a mixture of Pleistocene coral and Jurassic shale, both of which are abundant in the area. Hence, if the project proves successful, the industry could be expanded enormously. There are, however, difficulties to be faced in connexion with the use of the coral, for not only does it often contain an admixture of sand, but the conditions of formation of the Pleistocene deposits were such that lentils of sand may be encountered beneath an outcrop of seemingly pure coral (*see* Fig. 3, and Caswell, 1953, Fig. 4).

Such difficulties should not be met with in the Kambe (Jurassic) limestone outcrop further inland, and, with a view to the possible exploitation of this limestone in a future cement project, samples from it were collected for analysis during the course of the survey. Two localities were sampled, the first in the northern part of the area near Jaribunyi, and the second in the Cha Simba-Bundacho area, a few miles farther south. The results on the Jaribunyi samples are as follows:—

	1 %	2 %	3 %	4 %
SiO ₂	6.04	18.92	4.32	6.14
Al ₂ O ₃	0.99	2.12	0.82	1.12
Fe ₂ O ₃	0.52	0.55	0.72	0.64
MgO	1.54	0.83	0.96	2.85
CaO	49.64	42.06	51.08	47.38
Loss on ign. ..	41.00	34.74	41.50	41.02
TiO ₂	Tr.	0.05	Tr.	0.08
	99.73	99.27	99.40	99.23

Analyst: W. P. Horne.

- 1.—From near the base of the series in the Ndzovuni river gorge.
- 2.—From the top of the series near Kaya Kauma.
- 3.—From the upper part of the series to the north-west of Kaya Kauma.
- 4.—A composite sample made up of samples from 1, 2, and 3, with additional material from six intermediate horizons, mixed, in so far as was possible, in the proportions in which they occur in the field.

and from the Cha Simba-Bundacho area:—

	5 %	6 %	7 %
SiO ₂	5.08	11.32	4.04
Al ₂ O ₃	0.73	1.09	0.72
Fe ₂ O ₃	0.34	0.27	0.29
MgO	0.14	0.09	0.07
CaO	48.33	47.16	50.74
Alkalies as Na ₂ O ..	0.32	0.29	0.27
Loss on ign. ..	41.98	38.50	41.88
TiO ₂	0.05	0.08	0.03
SO ₃	0.02	0.06	0.15
S, Cl, and F ..	0.08	—	—
	97.07	98.86	98.19

Analyst: J. Furst.

- 5.—A composite sample made up of samples from 6, and 7, with additional material from five horizons representing a traverse across the entire series.
- 6.—From the Maweni river, two miles east of Simba beacon.
- 7.—From near the dam, one mile east of Simba beacon—within 50 ft. of the base of the series.

From these analyses it is clear that limestone from either of the localities, and particularly from the second, is suitable for use in cement manufacture. Other considerations—the available reserves of limestone, ease of working, transport, water-supply, etc.—also appear

*The factory began production in February, 1954, and by the end of that year the output was at the rate of 65,000 tons a year. Towards the end of 1955 the output had been expanded to a rate of 95,000 tons a year, and plans for further expansion are in hand.

to favour the Cha Simba locality. The reserves of limestone are, to all intents and purposes, unlimited; the outcrop at this locality is nearly two miles wide, at least 1,500 ft. thick, and *can be followed along the strike for many miles in both directions. Its relative inaccessibility* is one of the more serious difficulties, although this is by no means unsurmountable provided the projected scale of working is sufficiently large. It is conceivable that a branch-line could be constructed between Mariakani and, say, Kaloleni, a total distance of about ten miles across flat country, and that an aerial rope-way could connect Kaloleni with the site, a further distance of about six miles. It would, of course, be preferable if the limestone could be obtained from a site closer to the railway, and the Kambe outcrop in the Mwachi gorge, due south of Mazeras and just outside the southern boundary of this area, has been considered on at least one occasion. The disadvantage there, however, is that the limestone is more siliceous—it is largely of the oolitic variety, the ooliths having formed around small quartz grains. Moreover, the reserves are considerably less. Two analyses have been made (Wayland, 1927):—

		%	%
SiO ₂ (combined)	..	1.86	1.41
SiO ₂ (free)	..	16.76	7.85
Al ₂ O ₃	..	0.13	0.21
Fe ₂ O ₃	..	0.66	0.62
MgO	..	1.14	0.17
CaO	..	44.18	49.97
Loss on ign.	..	34.30	38.96
TiO ₂	..	Tr.	Tr.
P ₂ O ₅	..	Tr.	Tr.
SO ₃	..	0.32	0.20

99.35 99.39

Analyst: Imperial Institute.

It is possible that the second sample was taken from one of the coral limestone bands, for the silica content is lower than would have been expected from field examination of the Jurassic limestones in the Mwachi gorge.

A more serious difficulty at any locality is the apparent inconsistency of the shales, which are required to supply the aluminosilicates needed in the making of cement, at least in so far as the available analyses are concerned:—

	1*	2	3	4	5	6	7
	%	%	%	%	%	%	%
SiO ₂	58.70	56.92	57.25	62.62	80.84	58.51	62.66
Al ₂ O ₃	16.19	14.31	13.22	8.02	9.18	13.96	10.04
Fe ₂ O ₃	4.74	7.48	5.81	5.86	2.28	6.43	4.34
FeO	—	—	—	—	—	—	2.69
MgO	1.16	2.55	2.32	1.53	1.07	2.28	0.12
CaO	0.91	3.14	3.91	9.98	0.30	5.54	6.12
Na ₂ O	2.38	0.98	0.82	—	—	1.32	1.06
K ₂ O	1.30	2.18	3.32	—	1.40	1.06	—
Loss on ign.	13.38	11.23	10.89	9.47	4.48	9.84	10.06
TiO ₂	1.07	1.08	1.43	0.40	0.42	0.74	0.30
P ₂ O ₅	0.04	0.27	0.30	0.07	0.02	0.01	—
Cl	—	—	—	—	—	—	0.01
SO ₃	0.77	0.18	0.24	0.10	—	—	0.10
MnO	Tr.	0.06	0.74	—	Tr.	0.03	—
BaO	—	—	—	—	—	0.09	—

100.64

100.38

100.27

98.05

99.99

99.78

97.41

Analyst: 1–6, Imperial Institute.

7, J. Furst.

1, 2, and 3—Changamwe, (Imperial Institute, 1921, p. 304).

4.—Kipevu (Imperial Institute, 1927, p. 377).

5.—Ml. 11/5 (Imperial Institute, 1927, p. 377).

6.—Miritini (Imperial Institute, 1927, p. 377).

7.—1½ miles. west of Mitongonyi (S.W. of Kilifi).

Gypsum, a necessary constituent in cement manufacture, occurs as surficial deposits

*No. 1 is described by the Imperial Institute as "buff-coloured plastic clay containing small amounts of quartz sand".

Fig. 9.—Bore-holes in the Kilifi-Mazeras Area

in dried-up salinas near Mida Creek, south-west of Malindi, and some is at times extracted accidentally as a by-product during the evaporation of sea-water for salt at the salt-works north of Malindi. Thin bands of gypsum are occasionally found interbedded with the Jurassic shales, but no deposits sufficiently large to justify development have yet been discovered.

8. Building Stones

Few of the coastal sediments are suitable for use as building stones. Those most generally used are the Pleistocene coral or coral breccia, which are quarried at several localities along the coast. The handiness of the outcrop, and the ease with which it can be dressed are factors controlling its choice. It is cut into large blocks which, when cement-faced, makes a satisfactorily resistant material. The Pleistocene sands could probably be used as a filler and as a constituent in mortar and concrete.

9. Road-metal

The lower Mariakani Sandstones are extensively quarried at Mazeras and at other places flanking the main road and railway-line for use as road-metal. It is not ideally suited to this purpose but is probably the best available. The Mazeras Sandstones are of little value as they are generally poorly cemented and crumble easily on weathering.

10. Water-supply

Reviews of the underground water resources of coastal Kenya have been given by Sikes (1934, pp. 26-9), and Caswell (1953, p. 62). The latter approached the problem from the point of view of the depositional environments of the sediments concerned, and thereby attempted to explain the variations in mineral contents of the waters obtained from them by means of bore-holes. In general, the Mariakani Sandstones yield variable supplies of moderate to poor quality, the Mazeras Sandstones yield better supplies of better quality, the Jurassic rocks yield low supplies of poor quality, and the Cainozoic rocks yield very variable supplies of moderate quality.

Several bore-holes have been drilled in the Kilifi-Mazeras area, their positions being shown in Fig. 9. Many were abandoned for one reason or another, either before they were completed or shortly afterwards, and, although every endeavour has been made to plot their positions as accurately as possible, no guarantee of their sites can be given. The same remark applies to some of the older bore-holes whose positions have been obtained from P.W.D. records. The bore-hole statistics are as follows:—

WATER BORE-HOLES IN THE KILIFI-MAZERAS AREA

Age of rocks drilled	Bore-hole No.	Locality	Depth in ft.	Yield (g.p.d.)	Quality General	Salts (p.p.m.)
Cainozoic	C. 1853	Sokoke	400	abandoned	—	—
	C. 1079	Sokoke	?			
	18	Kilifi	540	abandoned	saline	—
	38		250	40,000	brackish	—
	48		186	abandoned	saline	—
	51		118	abandoned	saline	—
	54		282	abandoned	saline	—
	58		756	abandoned	saline	—
	64		256	9,600	brackish	—
	67		196	abandoned	saline	—
	75		192	abandoned	saline	—
	77		150	abandoned	saline	—
	C. 1722	Mkomani	200	155,520	fair	—
	C. 215	Vipingo	140	64,800	sweet	—
	C. 217		210	70,680	sweet	—
	C. 1678		305	105,600	sweet	—
	C. 1742	Kidutani	280	134,400	sweet	—
	C. 972		136	13,440	sweet	—
	C. 973		189	26,880	sweet	—
	C. 971	Shimo-la-Tewa	112	7,560	sweet	—
	C. 974		84	25,200	sweet	—
Jurassic	173	Kitengwani	550	abandoned	saline	—
	C. 923	Ganze	488	abandoned	saline	—
	C. 930		450	18,600	saline	—
	91	Bamba	283	20,000	v. poor	—
	C. 1025	Ndzovuni	455	abandoned	v. saline	—
	C. 1011	Vilagoni	480	4,000	v. saline	5,000
				(abandoned)		
	C. 1106	Kwa Demu	303	72,000	v. poor	5,185
	78	Gotani	215	14,400	poor	—
	166	Kaloleni	350	24,000	poor	—
Duruma Sandstones	C. 1047	Kaloleni	500	26,400	fair	—
	C. 1048	Kaloleni	503	32,400	fair	—
	C. 1073	Kaloleni	500	10,680	good	—
	C. 213	Mazeras	390	9,600	fair	—
	C. 575	Mazeras	222	102,288	good	—
	C. 585	Mazeras	244	9,600	v. poor	4,000
				(abandoned)		
	C. 606	Mazeras	401	9,264	fair	—
	C. 609	Mazeras	310	64,800	good	—
	C. 623	Mazeras	429	11,520	good	—

It will be noted how variable are the supplies obtained from the Cainozoic rocks both in quantity and quality, and it is not yet fully known why this should be so. The high salinity of the waters obtained from the bore-holes drilled on either flank of Kilifi Creek can be ascribed to the infiltration of sea-water, but this should not have affected those drilled further inland, such as Nos. 54, and 58. No. 58 undoubtedly penetrated the underlying Jurassic rocks, and Sikes (1934, p. 29) states that they were entered at a depth of 200 ft., which would presumably be at about -140 ft. O.D. It may be suggested that the tremendous variations in yield are reflections of the sub-Cainozoic floor, which might not be as flat as has been previously supposed. If, as is possible, the Jurassic surface was dissected by stream-courses prior to the deposition of the Cainozoic rocks, these courses could form channels along which ground-water would be directed.

Of the bore-holes drilled into the Duruma Sandstones, the majority have penetrated, either wholly or in part, the Mariakani Sandstones and this accounts for the fairly high salinities. Sikes (1934, p. 27) quotes an analysis of a sample from bore-hole No. 159, Mariakani—just outside this area—which can be considered representative of the Mariakani Sandstone supplies:—

		Parts per million
Insoluble solids	..	4.4
Soluble solids—		
Chloride		908.8
Sulphate		106.0
Bicarbonate		15.6
Silicate		25.8
Calcium		71.4
Magnesium		26.1
Potassium		41.9
Sodium		514.6
Undetermined		67.4
Organic solids		—
Total		1,782.0

The prospects for future supplies are not encouraging, but the most likely sites for obtaining reasonable supplies of good water are on the Mazeras outcrop along the eastern flank of the Simba-Kiwara ridge.

Surface supplies are of local importance but are handicapped by the fact that few of the rivers maintain a perennial flow. This has to some extent been offset by the construction of small earth dams, of which there are at least fifteen in the Kilifi-Mazeras area. There are numerous other sites, particularly on the Jurassic outcrop, where, if it is so desired, similar small dams could be built.

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