Report No. 36

MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

MINES AND GEOLOGICAL DEPARTMENT

GEOLOGY
OF THE
MALINDI AREA

EXPLANATION OF DEGREE SHEETS 66 N.E. AND 67 N.W. QUARTER
(with colored map)

by

A.O. THOMPSON M.Sc.
Geologist

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FOREWORD

The issue of Mr. Thompson's report on what for convenience is called the Malindi area completes the publication of a series of four geological reports with maps covering most of the coastal belt of Kenya south of the third parallel. Those already published include Report No. 20 on the Mariakani-Mackinnon Road area (J. M. Miller, 1952), Report No. 24 on the Mombasa–Kwale area (P. V. Caswell, 1953), and Report No. 34 on the Kilifi area (P. V. Caswell, 1956). The geological survey of the remaining ground south of the third parallel and east of the 39th meridian has been completed, and will be published in a future report.

The western part of the Malindi area, like the areas farther south, contains Triassic rocks of the same age as sections of the Karroo system of southern and central Africa, where coal seams occur. The Malindi area rocks are, however, relatively high in the Karoo sequence as compared with the coal measures farther south and, as might have been anticipated, no trace of coal was found in them. Evidence was discovered, on the contrary, of possible marine incursions during the lower part of the Triassic period, a fact that is interesting in view of the search for oil deposits along the coast. A thin fish-bearing marine bed was discovered by Miller some years ago between Mackinnon Road and Mariakani, but the present report is the first to suggest that there may have been several marine invasions before the onset of the desert conditions of upper Trias times.

The most important mineral deposit known in the area is a barytes-lead-zinc vein at Vitengeni, some 22 miles N.N.W. of Kilifi. It is believed that it was discovered in 1919 by C. W. Hobley, originally a geologist with the British East Africa Company and at that time the Commissioner of Mines for the Government of Kenya. It was worked sporadically from 1924 to 1931, and has since been examined on several occasions by geologists and mining companies, though as yet no further production has been made. Mr. Thompson gives a full account of an examination of the mine and vein that was made some years ago, but has not been able to use information collected more recently. In part of the vein workable percentages of the mercury sulphide, cinnabar, were discovered some years ago by a company of consulting geologists and prospected by the Department. The total amount of cinnabar-bearing ground was, however, found to be small and would merit consideration only in an emergency when supplies of mercury were cut off.

Streaks of black sands containing much ilmenite and small amounts of rutile, monazite and zircon are well known along the coast near Malindi, and recently interest has been shown in the possibility of working them for the valuable minerals they contain. The beach streaks are of limited extent, and the more light-coloured sands abundantly associated with them contain only small amounts of the valuable minerals, so that careful exploration will be required before a decision can be taken on whether exploitation should be attempted.

During the survey another valuable mineral, gypsum, was discovered. It has always been assumed that gypsum was a rarity at the coast, but the examination of the former extension of Mida Creek showed that when it was drying up a bed of gypsum was precipitated. The occurrence has not been fully prospected, but it is clear that it is of moderate size and might prove useful when portland cement is manufactured at the coast. A further source of gypsum lies in the solar evaporation plant at Fundisha, where normally common salt is obtained from sea-water but where under certain conditions gypsum is precipitated and must be collected and removed from the evaporating pans.

A detailed account is given in the report of the geological evolution of the area, with its repeated changes of relative level of land and sea leading to submergence and emergence of land, several periods of faulting, and a period when at least underground volcanic activity took place.

Finally, it must be mentioned that the whole of the area is at present closed to mining and prospecting, except for ground on which mining titles are held or cases where special authority to prospect has been obtained.

Nairobi,
28th January, 1954.

WILLIAM PULFREY,
Chief Geologist.

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MAP

Geological map of the Malindi area (degree sheet 66, N.E. Quarter, and degree sheet 67, N.W. Quarter, combined); Scale 1:125,000 .. At end

ABSTRACT

The report describes an area of about 1,350 square miles of the Coast Province in Kenya Colony, lying about fifty miles north of Mombasa. It is bounded by latitudes 3° 00′ S. and 3° 30′ S., and extends eastwards from longitude 39° 30′ E. to the Indian Ocean. Physiographically the area can be divided into four major units, namely: (*a*) the Coastal plain, (*b*) the Foot plateau, (*c*) the Coastal range, and (*d*) the Nyika. The Coastal range does not present a continuous feature, and in the gaps the boundaries of the Foot plateau and the Nyika can only be arbitrarily decided.

The rocks exposed consist of sediments ranging in age from Triassic to Recent, and which represent lacustrine, marine, and continental conditions of deposition. Basic igneous intrusions, confined to small dykes and concentrated mainly in the Sabaki valley, are provisionally allocated an Upper Miocene or Lower Pliocene age.

An account of the rocks, their structures, and the economic minerals in the area is given.

GEOLOGY OF THE MALINDI AREA

I—INTRODUCTION

General Information

The Malindi area, for the purposes of this report is the north-eastern quarter of Degree Sheet 66, Kenya Colony, together with an adjoining tract of country forming the land area of the north-western quarter of Degree Sheet 67. The area is bounded by latitudes 3° 0′ S. and 3° 30′ S. and extends eastwards from longitude 39° 30′ E. to the Indian Ocean, the boundary between the two quarter-degree sheets being the 40° meridian. The area is about 1,350 square miles in extent, and is administered by the District Commissioner, Kilifi, and by District Officers, one of whom resides in Malindi. The greater portion of the area lies in the Giriama (Nyika) Native Reserve; the coastal strip, where the inhabitants are mainly *Swahili*, is under the suzerainty of the Sultan of Zanzibar.

Approximately seven months were spent in the field on geological investigations, between August, 1950 and April, 1951.

Acknowledgments

The writer is most grateful to all those persons who assisted him during the Survey, and in the preparation of this report; in particular he wishes to thank Mr. O. Knowles, former District Officer, Malindi, for his assistance during the survey period, and Dr. P. E. Kent of the D'Arcy Exploration Co., Ltd., for his permission to publish the palaeontological data on the Tertiary fossils collected from the Chui beacon and Goshi localities.

Climate and Vegetation

For the greater part of the year, the climate along the sea-shore is pleasant, though humid. In the hinterland it is hot and dry generally, but humid and enervating during the rainy seasons. The Mangea hills, the only prominent topographic feature in the district, which reach a height of over 1,700 ft. (518 m.), have a cool atmosphere. On account of their height, they attract a greater rainfall than the neighbouring country with the result that the vegetation is thick. Despite the narrowness of the hills, there are very few rock outcrops.

The *Giriama* (*WaNyika*) are mainly concentrated along the Sabaki (Galana)* river, whereas the *Swahili* live along the coast, seldom more than ten miles inland. The greater part of the coast-lands up to fifteen miles inland, is fairly heavily cultivated, but as pressure on the land increases, more and more of the inhabitants are attempting to till the land farther west.

The rainfall is good over the whole area and fairly well distributed (*see* Table I, p. 3). The large porous sandy tracts that cover much of the country absorb most of the rain rapidly. Little run-off therefore occurs, with the result that the area does not become badly infested with malarial mosquitoes except along the Sabaki river. Along the banks of this river there is a thick fringe of reeds and grass while on the alluvial flood-plains of the river, amongst the coconut groves, mosquito-breeding is common—chiefly in discarded coconut shells.

Cotton and coconuts are grown intensively on the coastal plain, and coconuts are also cultivated along the Sabaki river, and at scattered places in the hinterland. In the neighbourhood of Pumwani and Shauri Moyo, north of the Sabaki river, coconuts were cultivated extensively until a few years ago, but through a falling water-table the wells dried up and the settlements have now become derelict. Until recently deciduous fruits together with coconut palms, were grown on the top of the Mangea hills but this practice has been forbidden for the obvious reasons that soil erosion was beginning to tell on the steep slopes. The coconuts are grown mainly for the production of beer. In shallow depressions (swales between dunes) on the coastal plain rice is also grown to a small degree. Maize is not grown extensively in the district, except along the Sabaki river, and cassava is only grown in a few places. Some sugar cane is being grown along the banks of the Sabaki river near Pazziani. Fruits such as bananas, mangoes, and paw-paws flourish in the district. Both the *Swahili* and the *Giriama* keep many goats, but cattle are scarce.

*The names "Sabaki" and "Galana" are synonymous; the former name being that used by the *Swahili*, and the latter by the *Giriama*.

Despite the generally heavy rainfall, there is not much soil erosion, on account of the sandy soil which covers the greater part of the area. Where this cover is thick, as in the Arabuko–Sokoke forest, around Magarini and to the west of Dakatcha, the red sands support forests. From the Arabuko–Sokoke forest, many trees are cut for timber—particularly the *Muhuhu* (*Brachylaena hutchinsii*), which grow almost exclusively on the red Magarini sands. On the more clayey soils the wild sisal plant, *Sanseveiria*, and *Euphorbia* appear to flourish, as well as thorn bush.

Where the sand cover is not so thick, and generally of a brownish to light red colour, particularly on the Jurassic rocks and Pliocene clayey sediments, the grass and trees are not so dense, though the scrub bush remains profuse. In the southern part of the area investigated, the large bush trees are being felled, burnt and sold as charcoal—largely to satisfy the needs of Mombasa. In this section, where the pressure of population on the land is also increasing, the bush is rapidly disappearing.

Elephants frequent the forests, chiefly, whereas buck and other animals live mainly in the parts with less dense vegetation.

Maps

The geological map covers ground equivalent to sheets 192 and 193 of the Directorate of Colonial Surveys. Its topography is based on the cadastral sheets South A37/V–II–b, South A37/V–II–d, South A37/W–I–a, and South A37/W–I–c (1:62,500), on the military map "Malindi", E.A.F. No. 810 (1:125,000), and on the Geographical Section, General Staff map No. 2546, "Malindi and surrounding country" (1:62,500)—the last-named for the area east of longitude 40° E.

Reference was also made to Dr. E. Parsons's geological map of the area which was d awn on the G.S.G.S. map No. 1764, "Mackinnon Road–Malindi" (1:250,000). The contours drawn on the geological map are based on those of the maps, E.A.F. No. 810 and G.S.G.S. No. 2546. The original contours and those of certain topographic features have been modified where errors were apparent in the field, but it must be stressed that the contours of the geological map cannot be considered accurate, particularly for the area to the west of the Mangea hills. For the north-western corner of the area topographic detail was based on aerial photographs, the principal points of which are shown on the map.

Local native place names have been added to previously unnamed or incorrectly named localities. The geology of the area was plotted on a scale of 1:62,500 by means of compass and cyclometer traverses, with points fixed by re-section wherever possible. An effort was made to check ground heights by means of aneroid barometer readings (after correction for diurnal variation) based on check measurements taken periodically on the seashore at Malindi.

Communications

The district is fairly well served by roads, but they are concentrated largely on the coast plain and along the Sabaki river. Native paths anastomose across the greater part of the district except in the forest where, however, there are some motorable logging tracks. Most of the roads are unmetalled, but are passable even during the rainy seasons on account of the general sandy nature of the terrain. In the vicinity of Jilore, Shauri Moyo and Kabiboni, however, the roads can become very muddy during the rainy season on account of the underlying clayey sediments.

The crocodile-infested Sabaki river is not navigable to any extent. When flood-waters subside, the river is seldom more than a foot or two deep for the greater part of the year.

Rainfall

Figures relating to the rainfall in the Malindi area are given in Table I. Records of two stations, namely Ganzi and Bamba, outside the area are also given as no stations exist in the south-western corner of the Malindi area. These stations are very close to the southern boundary, and their data may be considered typical for the country to the north, namely the Nyika. The stations and data are classified according to the physiographic units in which they lie.

TABLE I

RAINFALL STATISTICS FOR THE MALINDI AREA

Physiographic Unit	Name of Station	Total Rainfall (inches)		Total Number of Rainy Days		Average Annual Rainfall up to 1951 (inches)	Month of Maximum Rainfall			Number of Years Recorded
		1950	1951	1950	1951		Average	1950	1951	
Coastal Plain ..	Lamu*..	Incomplete		Incomplete		35·94	May	May	May	44
	Malindi, District Office	35·40	70·63	81	111	40·38	May	May	May	57
	Malindi, Sir Ali Bin Salim School ..	35·97	64·59	116	142	44·56	May	May	May	11
	Gongoni	28·52	53·70	64	91	36·43	May	May	May	11
	Gedi	31·45	59·59	84	101	36·16	May	May	May	11
Foot Plateau ..	Kakoneni	24·13	43·48	88	106	29·04	May	March	October	15
	Dagamra	Record incomplete	38·87	Record incomplete	49	30·9	May	July	May	10
	Marafa	22·79	58·42	96	105	33·04	May	July	May	13
Nyika	Baricho	No Record	38·63	No Record	64	—	—	—	October	1
	Ganzi†	22·13	37·33	112	94	37·33	May	May	May	11
	Bamba†	29·29	Record incomplete	51	Record incomplete	28·41	May	March	May	10

*120 miles north-east of Malindi.

†Outside (south) of Malindi Degree Sheet No. 66 N.E.

Without undue generalisation, it would appear that the rainfall decreases with increasing distance from the coast, and with increasing distance northwards from Malindi. It is doubtful whether the Mangea hills are an effective barrier to the rainfall destined for the hinterland. It is noticeable that the only good bore-holes both for quantity and quality of water, namely C996 and C997 drilled in the Nyika, are to the west and at the foot of this topographic feature, where saline efflorescences were not seen. In the Nyika proper although the rainfall is about 75 per cent of that on the coastal plain, evaporation is high, and areas of salt efflorescence are met.

Drainage

As in the Mombasa area, the principal direction of drainage is to the east-south-east, following the regional dip of the sediments that form most of the area. It is notable, however, that even the Sabaki river, over short distances, pursues a course along the strike of the rocks. It appears that the possibility of variation of the direction of flow is largely controlled by flood conditions, for in the dry season, like most of the rivers in the area, it suffers from what might be called alluvial suffocation. Once the floods have subsided the river pursues a braided course in its valley. Apart from the Sabaki all other rivers are intermittent, flowing only during flood times—generally during the months of April to July. It is noticeable how once the Sabaki river has traversed the Mariakani and Mazeras sandstones its course no longer conforms as closely as before to the regional dip of the rocks. The softer Upper Mesozoic and Cainozoic rocks do not exert as strong an influence on the course of the river as the Lower Mesozoic rocks. Through Quaternary movements of the shore-line the Sabaki river has had its course extended several times—that when it was extended over the fossil coral reef (Plc on the map) being the most noticeable.

In the upper reaches of the Sabaki river, west of Shakama and at Shakahola, cut-off meanders and shallow ox-bow lakes indicate its maturity. Fish are caught by the *Wa-Giriama* in these shallow lakes. Several swamps, large ponds and lakes occur on both sides of the Sabaki river, and have been formed by the growth of natural levees along the river during periods of moderate flood. Bodies of water have thus sometimes been sealed off and are only recharged during exceptional floods. During 1951 it was reported that the flood-waters of the Sabaki river entered Lake Jilore. Shakajila, Sameta, Matolane, Dodoso, Merikano, Lake Jilore, Lake Baratumu and Lake Chem-Chem and Sameta all become highly saline in the absence of recharging. The possibility of sub-surface fresh-water recharge for Lake Jilore which is fresher than the other lakes, must not be overlooked.

Tributary streams of the rivers in the Malindi area are on the whole strike streams, following soft bands in the sediments. This generalisation is more applicable when dealing with the ground covered by the Duruma sandstone series, rather than that occupied by the Cainozoic rocks.

II—PREVIOUS GEOLOGICAL WORK

Of the many early students of East African coastal geology, few entered the Malindi district. One of the earliest was J. W. Gregory (1896, p. 45)* who in 1893 passed through Mambrui and Malindi *en route* to Mombasa from Witu and Lamu. While at Mambrui he made a branch excursion to the Magarini hills, where the British East Africa Company had some extensive plantations. As a result of this excursion he named the brilliant red sands there, the "Magarini sands", with which he grouped, however, all the sands and sandstones overlying the "Carboniferous" rocks of the hinterland, considering them therefore as probably Triassic in age (*op. cit.* p. 229), though later (Gregory, 1921, p. 77) he obtained evidence indicating that the Magarini sands in the restricted sense are probably Lower or Middle Pliocene in age. He recognised that the sands are aeolian in origin.

*References are quoted on p. 62.

The coral reef limestones and their associated sandstones along the coast at Lamu, Malindi, Mombasa, Zanzibar and Pemba were studied and described by Prof. Max Bauer (1911, pp. 3–14).

Gregory (1921, p. 24 *et seq.*) has numerous references to collections made by C. W. Hobley, who travelled into the Malindi district and beyond in the early part of the present century. It was Hobley who observed shales at Lake Chem-Chem similar to the Jurassic Chamgamwe shale near Mombasa (Gregory, 1921, p. 61), and collected limestones (also Jurassic) on the eastern flank of Mwangudo hill (*op. cit.* p. 64). He also observed that the Magarini sands overlie the "Eocene" and Miocene limestones west of Fundi Isa (Fundisha) thus putting their age as post-Miocene (*op. cit.* p. 77).

In 1919 Prof. Gregory returned on a second visit to Kenya and in company with C. W. Hobley, W. McGregor Ross, and H. L. Sikes made further journeys in the Colony. One excursion was down the Sabaki river from Voi to Lango Baya, 23 miles W.N.W. of Malindi, and from the latter place southwards along the Coastal range to Mombasa. In 1919 it is stated, C. W. Hobley discovered the deposit of barytes and galena at Vitengeni.

Dr. E. Parsons (1928) mapped the coastal strip from the Tanganyika border to the Tana river, and in his paper discussed the origin of the Great Rift Valley as evidenced by the coastal geology. His views differed greatly from those of Gregory, and his stratigraphical table shows notable variations; for example, he makes the Shimba grits underlie the Mazeras sandstones, and the upper members of the Jurassic sediments are grouped with the Cretaceous rocks of his "Changamwe Series", whereas the lower parts of the Jurassic succession are separated as his "Miritini Series". All sediments of Eocene to Pleistocene age he called the Magarini Series, and ascribed a Recent age to the coral reefs, although in his Magarini Series he included some coral limestones.

A champion of compression in Earth tectonics, Parsons postulated numerous overthrusts in the coastal rocks in Kenya. He considered most contacts between the rock groups along the coast as of this nature. He used this conclusion as supporting evidence for the hypothesis that the Gregory Rift Valley in Central Kenya originated as a result of compressional forces rather than through tension.

In 1928–9 and a second time in 1930 Miss M. McKinnon Wood visited Kenya and collected fossils in the Malindi district (McKinnon Wood, 1930 and 1938). The different fossil phyla were dealt with by various authorities and, as the reports are the only palaeontological accounts of their kind on fossils from the Kenya coastlands, they are of inestimable value. The stratigraphical sequence given are similar to those of Gregory.

In 1932, R. Murray-Hughes (1933, p. 14) made a reconnaissance through the Coast Province covering part of the Malindi district, north of the Sabaki river to Baricho, and Vitengeni. At Marafa he investigated a land-slide in a "cream coloured, argillaceous sandstone"—what is now considered part of the late Pliocene–Pleistocene (?) Marafa beds. At Vitengeni he investigated the lead mine which he stated is "a broad (14-foot) vein of baryte through which there is a sparse dissemination of zinc-blende, galena (and certain sulpharsenides of lead), and chalcopyrite. Other gangue minerals are calcite and quartz." He also stated that "the total combined-metal content was judged to be less than one per cent, but although the exposure here is of no economic value from the point of view of base metal recovery, the proof of a 'metallic' mineralisation in this zone is of considerable importance". In an unpublished departmental report, Murray-Hughes noted the absence of pyrite, which he considered would have been an indication of high temperatures of formation.

In 1935 J. de Jean examined the Vitengeni mine and a large area around it. In his report, a copy of which was furnished to the Mines and Geological Department, he noted that galena was very often found in large masses, sometimes weighing "several tons". He was very optimistic about the mine, and stated that apart from the usual minerals present, "nickel" was also found.

During 1937, C. S. Hitchen, Government Geologist, visited the mine, and in August of that year identified cinnabar discovered by Messrs. Barnard and Parsons, consulting geologists to Messrs. Lime, Ltd., in a veinlet cut by a prospecting trench. In the same year D. Harverson, Government Mining Engineer, inspected the mine with Messrs. Barnard and Parsons—the latter expending much effort in an attempt to trace a workable ore-body.

In 1937, H. G. Busk and J. P. de Verteuil spent some time on a reconnaissance survey of the Kenya Coastlands. Their findings are contained in a confidential report (1938) on the oil prospects of Kenya, a copy of which is housed in the Mines and Geological Department, though an account of some aspects of the geology were published by Busk in 1939. They observed both unconformable and faulted relationships between the Jurassic sediments and the older Duruma Sandstones. The Miocene sediments they considered as under 100 ft. (30·4 m.) thick, and the sum of the Magarini sands and recent coral beaches to be probably under 500 ft. (152 m.) thick. They attributed a Pliocene age to the Magarini sands.

During 1942, W. Pulfrey undertook an extensive examination of the Vitengeni mine and its environs, and wrote a comprehensive report on the barytes–galena mineralization, as well as on the cinnabar occurrence. This report has been summarised in the "Economic Geology" chapter of the present report (p. 48).

Prehistoric ruins at Gedi, about nine miles south-west of Malindi were examined by L. S. B. Leakey in 1947. In the following year an experienced archaeologist was appointed to investigate the ruins and has since published articles on his discoveries (Kirkman, 1949, 1950, 1953).

III—TOPOGRAPHY

Gregory (1896, p. 222) divided the coastal belt in the Mombasa area into the three physiographic units given below:—

(1) the Coastal plain

(2) the Foot plateau

(3) the Nyika

In his later work (1921, p. 46) he recognised that a discontinuous chain of hills separates the Nyika from the Foot plateau, but did not assign a unit name to it. Caswell (1953, p. 6) used the term "Coastal range" for the part of the hills (the Shimba hills) in the Mombasa–Kwale area.

Whereas all four regions can be recognised in the Malindi area (Fig. 1), the Foot plateau is largely concealed by the red Magarini sands, which abut on the Coastal range (Mangea hills). The Coastal range is not a prominent continuous topographic feature, the Mangea hills being the only notable remnants in the Malindi area. North of the Galana river the Mazeras sandstones, which compose the Coastal range in the Mombasa area, rise steadily northwards, but no sufficiently prominent hills have been carved in them to constitute a range.

The Coastal Plain

The Coastal plain is generally under 150 ft. in altitude, and widens from about three miles in the south to about ten miles near Malindi. On the seaward edge of the plain there is a coral crag (Plc) and other deposits, covered with dense bush where uncultivated. Accumulations of reddish-brown sands (Qt_3) raise the level of the Coastal plain in scattered localities, the chief of these being near Roka, Mijomboni, Kikuyuni, Ganda, Msabaha, and Merikabuni. North of the Sabaki river, and between it and Mambrui, vast accumulations of these sands have been built up into sand-dune ridges standing over 200 ft. high.

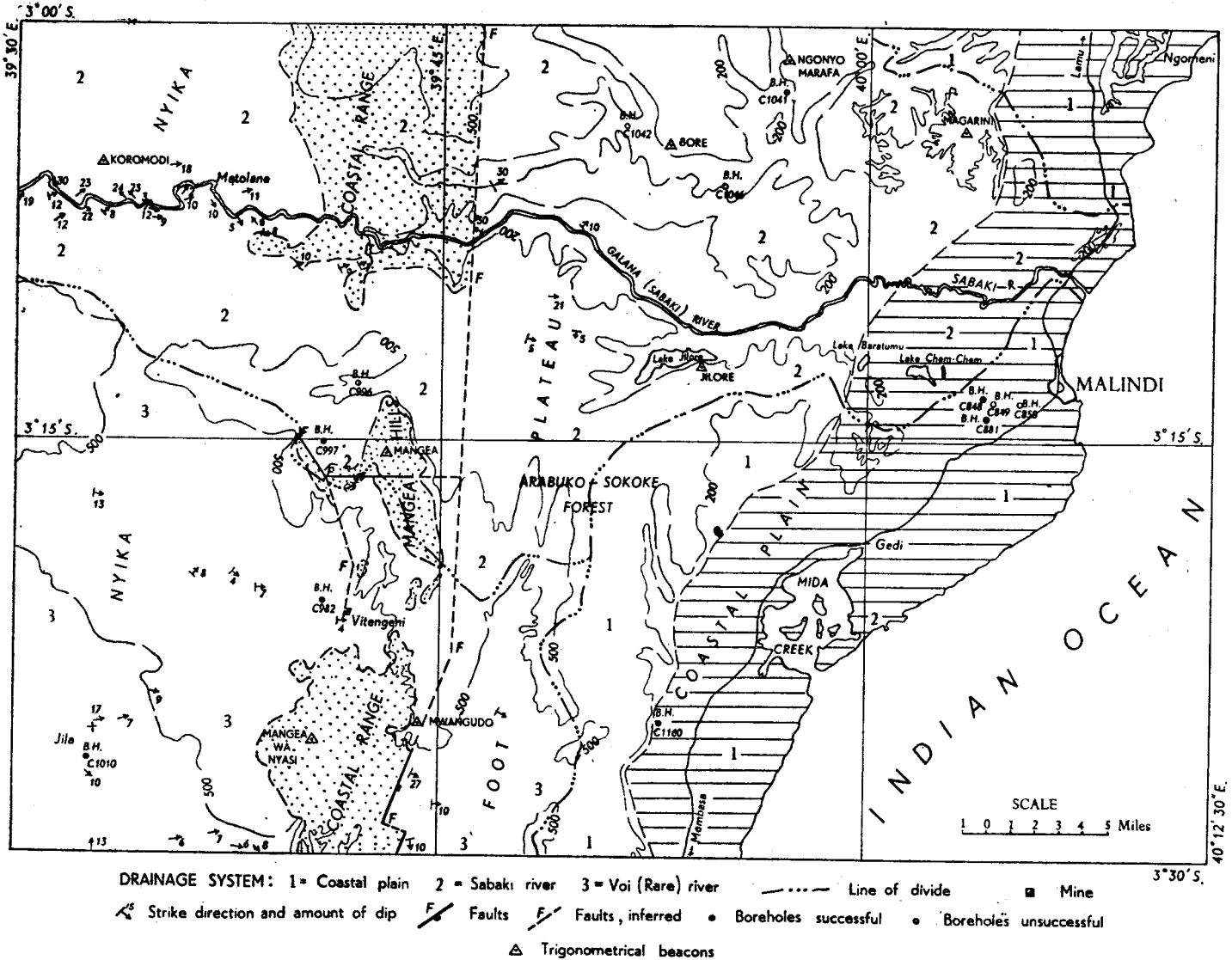

Fig. 1.—Structural, physiographic and drainage map of the Malindi district.

The Foot Plateau

The Foot Plateau as defined by Gregory, although present in the Malindi area, is not a clearly marked physiographic unit. Along the flanks of the Sabaki river it grades imperceptibly into the Nyika, so that the junction of the younger rocks with the Mazeras sandstone has been taken as the arbitrary boundary. Further south the red Magarini sands (Qt_1) obliterate any physiographic features that might have been assigned to the Foot Plateau. North of the Sabaki river, however, the westward extent of the Magarini sands is not as great, so that the term Foot Plateau may be applied there. The general level in this part is about 300 ft. (91 m.); in fact the Foot plateau rarely rises above this level in the Malindi district, although along the northern edge of the area it may be said to rise to over 500 ft. (152 m.) due to the accumulations of reddish-brown sands (Qr).

The Foot plateau was probably developed during Upper Pliocene or Lower Pleistocene times. It truncates unconsolidated sands, gravels and clays, probably of Pliocene age, and Jurassic sediments.

The Coastal Range

The Mazeras sandstones (Kz) which constitute the main rock type of the Coastal range in the Mombasa area (Caswell, 1953, p. 6) do not form such a prominent range of hills in the Malindi area. The main, well-defined, topographic features in the present area are the Mangea hills, which rise to 1,702 ft. (518 m.) at their highest point. North of the Galana river the Mazeras sandstones do not rise with such prominent relief as the Mangea hills —in fact, north of the Sabaki river in the area mapped, the Mazeras sandstones do not rise more than 600 ft. (182 m.) in altitude, and in the Dakatcha area are largely concealed by red sand (Qr) forming hills rising to over 700 ft. (213 m.) O.D.

Although the Mangea hills for the greater part are over 1,000 ft. (304 m.) in height, and the circumambient country about 500 ft. (152 m.) there is a thick mantle of red soil covering most of the slopes of the hills. Rock outcrops are rare. Until recently a great deal of cultivation was carried out on the top of these hills. Water was obtained from shallow water-holes on the slopes and on the crest of the hills.

The Nyika

As the Coastal range does not constitute a continuous feature between the Foot plateau and the Nyika, the latter is considered for the purposes of this report as the tract of country west of the contact between the Jurassic and Triassic rocks exclusive of the "Coastal range". Thus the Nyika bevels both the Mazeras and Mariakani sandstones. Caswell (1953, p. 6) considers that the Nyika appears to be the remnants of peneplaned surface of mid-Pliocene age. In the Mombasa area this surface rises from about 600 ft. O.D. at the western foot of the coast range to about 1,000 ft. in height on the western boundary of the Mombasa area, but west of Malindi the average altitude is about 500 ft. In the south-western corner of the area the land surface rises to about 800 ft. O.D. at a maximum. An accumulation of Quaternary reddish-brown sandy soils (Qr) partly accounts for this rise. Shallow depressions are fairly common on the Nyika, and are often used as water-holes by the natives and animals. North of the Galana river, to the north and north-east of Matolane D.C. Camp, it appears from aerial photographs (Nos. 5417 and 5442 of flight 82D/100) that the reddish-brown Quaternary sands have probably been blown into low dunes. The country is sparsely populated on the whole—the poor water probably being the controlling factor. Crops are rarely cultivated on the Nyika.

IV—SUMMARY OF GEOLOGY

The principal rock types seen in the Malindi district are of sedimentary origin and range in age from Triassic to Recent. They can in general be closely matched with those of

areas to the south and south-west (*see* Caswell, 1953, and Miller, 1952). There are three well-defined divisions, namely:—

(3) Cainozoic rocks

(2) Upper Mesozoic rocks–Jurassic

(1) Lower Mesozoic rocks–Duruma Sandstone Series

1. Lower Mesozoic rocks–Duruma Sandstone Series

The Duruma Sandstone series is only represented in the Malindi district by its upper members, namely the Mariakani (Km) and Mazeras (Kz) sandstone groups. The former are generally thin-bedded, fine-grained sandstones, with siltstones, shales, mudstones and some intercalated impure limestones. About fifty per cent of the rock specimens collected during the present survey from rocks of the group have a calcareous cement, whereas the Mazeras sandstone group is virtually non-calcareous. The Mazeras sandstones comprise coarser, cross-bedded sandstones and shales. It is with these rocks that the Vitengeni (galena-barytes) ore veins are associated.

For the most part the Mariakani sandstone group of sediments was deposited subaqueously under deltaic, lacustrine, and possibly neritic conditions, whereas the lower members of the Mazeras sandstone group were probably deposited under shallow water conditions and the upper, more massive members in an aeolian environment.

2. The Upper Mesozoic Rocks

These consist of marine limestones and shales mainly of upper Jurassic age, with occasional horizons of sandstones and sandy limestones. The older members of the sediments have only been observed in the southern parts of the Malindi area, whereas the uppermost and younger members are found in the Sabaki valley. Exposures are scarce and poor.

3. The Cainozoic Rocks

The Cainozoic rocks are more varied and comprise marls, conglomerates, limestones, sandstones, gravels, sands and clays, as well as the fossil coral reef and associated breccias. Palaeogene representatives have not so far been recognised. The oldest Neogene sediments are very fossiliferous, while the Pleistocene and Recent sediments are not quite so fossiliferous, on the whole. The Cainozoic assemblage comprises marine and terrestrial deposits, portions of which can be shown to lie unconformably upon the eroded surfaces of the pre-existing rocks in the area.

Igneous intrusions of basaltic type pierce the Jurassic sediments, and as fragments of igneous rocks are first observed only in the upper Pliocene (?) Marafa beds, an upper Miocene or lower Pliocene age is provisionally assigned to them.

V—STRATIGRAPHY

The rocks in the area mapped consist largely of sediments together with some igneous intrusions; the former can be grouped under the following three headings:—

(3) The Cainozoic rocks

(2) The upper Mesozoic rocks–Jurassic

(1) The lower Mesozoic rocks–Duruma Sandstone Series

The succession is given in Table II and each group is dealt with separately in detail below. Some of the information given in the table is based on Caswell (1953, Table III, p. 8).

TABLE II

Stratigraphical Succession in the Malindi Area

Era		Period		Local Representative	Lithology and Thickness	Environment of Deposition	Climate	Palaeogeographic Events
CAINOZOIC	NEOGENE	Quaternary		Alluvium, coastal sand-dunes (Rt), cemented beach sands, and gypsum beds (Rm)	Consolidated and unconsolidated sands up to 200 ft. thick	Fluviatile, marine, continental and littoral	Much as present day	Sea-level gradually rising
		Quaternary		Fossil coral reef and breccias, Pleistocene sands (Pls), Magarini sands (Qt_1), coquinas (Qt_2 and Qt_4), Gedi beacon sands (Qt_3)	Unconsolidated sands, coral limestones, and cemented coral sands up to 500 ft.	Neritic and continental	Pluvial and Interpluvial	Sea-level fluctuating
		Tertiary	Pliocene	Marafa beds (Tpl)	Sands, gravels, pebble beds, clays, sandstones and conglomerates up to 300 ft.	Marine-deltaic	Wet	Faulting and erosion (?) Igneous intrusions (?)
		Tertiary	Miocene	Baratumu beds (Tm)	Marls, limestones, clays and sands. Probably less than 1,500 ft. thick	Shallow-water, littoral	Warm	Erosion and deposition
Mesozoic		Jurassic	Upper	Changamwe Shales, Coroa Mombasa limestones and shales, Miritini shales (J_3)	Shales, limestones and sandy limestones	Marine	Warm	Marine invasion in the centre of the East African–Indo-Madagascan basin
Mesozoic		Jurassic	Middle	Kambe limestones (J_1)	c. 6,000 ft.			
Mesozoic		Jurassic	Lower		—	—	—	Erosion
Mesozoic		Triassic (KARROO)	Upper	Mazeras sandstones and shales (Kz)	Sandstones and intercalated shales and clays 1,000 ft.	Deltaic in lower horizons, continental in upper	Arid	Faulting and ore mineralizations
Mesozoic		Triassic (KARROO)	Lower	Mariakani sandstones (Km)	Thin-bedded sandstones shales, siltstones, mudstones and intercalated limestones 10,000 ft.	Shallow-water, deltaic, lacustrine and (?) neritic	Semi-arid	Deposition in East African Indo–Madagascan basin

Dotted lines denote unconformities.

1. The Lower Mesozoic Rocks–Duruma Sandstone Series

The Duruma Sandstone Series, according to Gregory (1921, p. 46) was named by Stromer von Reichenbach (1896, p. 22). It covers a little more than a third of the area, consisting of arkoses, sandstones, siltstones, shales, mudstones, and a few intercalated limestones. The sediments were mainly deposited under shallow water conditions and are believed to be mainly non-marine in origin. Caswell (1953, p. 9) considers that they were deposited under lacustrine, deltaic, and possibly neritic conditions. Only the upper members of the series occur in the Malindi area and the base of the Mariakani Sandstones is not visible. The other members, namely the Maji ya Chumvi and Taru Grit groups, outcrop further to the west. The greater thickness of the Mariakani sandstones in the Malindi district compared with areas elsewhere is striking.

(1) Mariakani Sandstones (Km)

Under this heading are grouped sediments of both arenaceous and argillaceous origin. The sizes of individual particles in them range from those characteristic of grits to those of clays, and in the majority of specimens the grains are cemented by calcareous matter, particularly in the grits and sandstones. In general the grains are only partly rounded, indicating a comparatively short distance of transport, possibly by seasonal rivers, but a higher degree of rounding is usually present in the grits and coarse sandstones. The greatest degree of angularity of the grains is found in the siltstones and finer sediments.

The sandstones are generally dark coloured, typical specimens being drab in colour, though grey and reddish specimens are fairly common. Blotched sandstones are common farther south in the Mombasa and Mariakani areas but were not often met in the Malindi district. Specimens of the dappled, blotched or speckled sandstones were only found in the south-western portion of the area (specimens 66/278 and 66/279*). Caswell (1953, p. 11) states that there appears to be no mineralogical reason for the blotches found in many of the beds. He points out that they are more or less spheroidal, but somewhat flattened on the upper and lower surfaces, suggesting that they originated as spheres during sedimentation, which subsequently were compressed when the material underwent compaction. He also considers it possible that they were caused by the initiation of local centres of leaching from which iron or manganese oxides were partly removed, leaving spheres deficient in these constituents. Miller (1952, p. 13) considers that "the white mottling is most probably a depositional feature. Each white blotch is flattened in the plane of the bedding suggesting that it was originally nearly spherical and has been compressed during diagenesis. Under the microscope it is seen that the white patches have their grains in contact with little cement, whilst the darker parts show well separated grains with chloritic cement in between". It is, however, believed by the writer that the blotched appearance of many of the Mariakani sandstones may be due to the slight chemical changes brought about in the sand after passing through the digestive tracts of worms, as they bored their way through the still unconsolidated sediments. Specimen 66/273 from the Vitengeni (Rare) river suggests this, for columns of sandy material occur in the specimen perpendicular to the bedding.

The older sediments, in the western part of the area, are essentially sandstones and grits with some arkoses and arkosic sandstones, while the upper and younger horizons to the east are mainly siltstones, shales, and mudstones with sandstone intercalations. The shales and mudstones are often red in colour and soft, although some well-cemented hard horizons occur. The hard siltstones are invariably chloritic, and green in colour.

Ripple-marks are not common in the sandstones, but are frequent in the siltstones. Some measurements of ripple-marks on specimens of greenish-grey siltstones about one mile (1·6 km.) west of Shakama D.C. Camp are given below.

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*Numbers 66/278, etc., refer to specimens in the regional collections of the Geological Survey of Kenya.

Wavelength (mm.)	Amplitude (mm.)	Ripple-mark Index	
4·7	0·5	9·41	Average 8·75
4·5	0·52	8·65	
5·5	0·6	9·17	
6·0	0·7	8·58	
3·8	0·5	7·60	
5·2	0·57	9·12	

Shand (1947, p. 133) quotes figures by E. M. Kindle who claims that water-formed ripples have an index of 4 to 10, but records that other observers have found water-formed ripples with values exceeding these. Shrock (1948, p. 94) quotes a similar range of indices for wave (oscillation) ripple-marks. The ripple-marks recorded above are of the oscillation type, being symmetrical in form.

Essentially the Mariakani sandstones are thin-bedded, fine-grained flaggy sandstones. Cross-bedding is common, more so in the finer sandstones and siltstones. The sandstones tend to be more massive than the siltstones, but both types are well jointed. Long rectangular joint slabs of rock, measuring in some cases up to five feet in length, one foot thick and about two feet wide, are met in the siltstones about two miles (3·2 km.) north-west of Shakama camp on the high ground above the Sabaki river. These slabs were formerly used in crude fortifications at this point. Smaller slabs of the chloritic siltstones are used as whetstones by the local Giriama natives. It is interesting also that specimens of this rock are found in the Gedi ruins, and were used by the peoples of that ancient town for the same purpose.

The majority of the sandstones are slightly calcareous, being partly cemented by calcite. Other cementing materials are chlorite, iron ores (usually limonite) and in some cases a clay mineral (Fig. 2B).

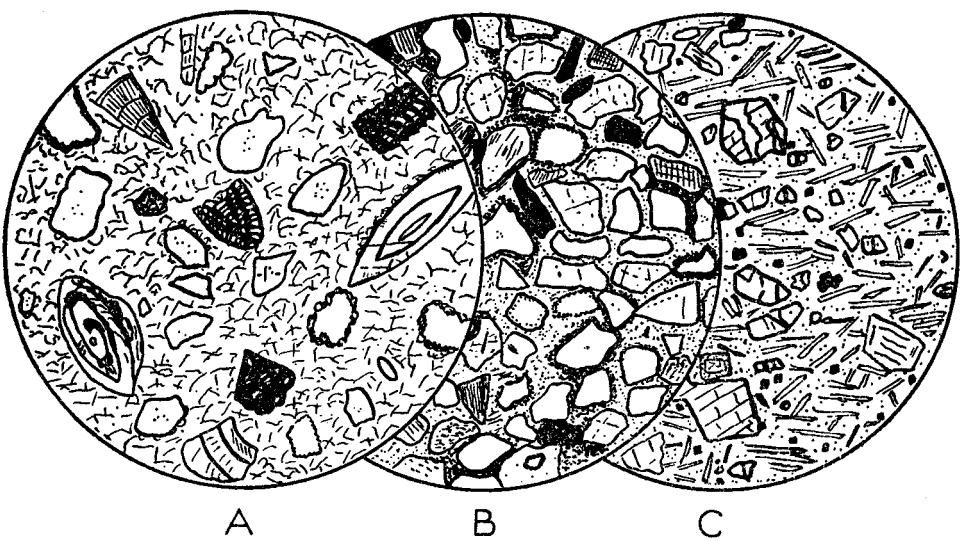


Fig. 2.—Microscope drawings of thin sections of rocks from the Malindi area.

A—Coquina, a cemented coral "sand". Specimen 66/100 Watamu. Ordinary light × 12. Showing shell and coral fragments, foraminifera and quartz grains partly cemented by calcite.

B—Mariakani Sandstone. Specimen 66/286, two miles east of Makongani. Ordinary light × 12. Showing quartz and felspar grains cemented by a clay mineral, chlorite and some iron oxide. The felspar grains are largely decomposed. Other grains are weathered mica flakes, opaque iron ores and graphite. The graphite flakes are best seen in the hand-specimen.

C—Basanite. Specimen 66/151, two miles north of Shakadula. Ordinary light × 12. Showing large subhedral insets of olivine and smaller euhedral crystals of augite in a groundmass containing well-developed prisms of labradorite felspar, grains of olivine, augite and many octahedra of magnetite. A great deal of the magnetite in the groundmass is also allotriomorphic and a brownish yellow glass and a felspathoid occur interstitially. Zoning occurs in some of the euhedral augite crystals.

The grains in the sandstones are found microscopically to be inequigranular and rather poorly sorted, and to vary in form from well-rounded to angular. The majority of the specimens show sub-angularity of the grains. The essential constituent grains are quartz and felspar with mica flakes, usually biotite and muscovite. Common accessory minerals are zircon and iron ores, with garnets, tourmaline, and hornblende occurring less frequently. Rare grains of corundum, kyanite, pyrite and graphite have also been observed.

Examples of the green chloritic siltstones are abundant near Shakama, between Matolane and Baricho, and on the lower slopes of the Mangea Hills, particularly in the watercourses which drain the western slopes east of Mwahera. An interesting specimen of one of the calcareous siltstones was collected from a gully, just over a mile S.S.E. of the D.C.'s camp at Shakama (66/332). Numerous arcuate forms composed of calcite can be seen under the microscope which are reminiscent of brachiopod valves but may be *Estheria* sp. If they are the remains of brachiopods, they indicate a marine invasion in the Mariakani sandstones, near the close of the period of sedimentation in which they were deposited. It was in the same locality that Miss McKinnon Wood found fragments of *Estheria* in some calcareous boulders which Miss M. Latham believed might correspond with *Estheria greyi* found in the Maji ya Chumvi beds along the Mombasa–Nairobi railway-line (McKinnon Wood, 1938, p. 7). On the evidence of the *Estheria* and a fossil plant found by Parsons, Miss Wood regarded the beds as the equivalents of the Maji ya Chumvi beds and considered that the Mariakani sandstones were absent at this point.

About two miles (3·2 km.) west of Shakama D.C. camp, along the high ground above the alluvial banks of the Sabaki river, another specimen (a fine-grained limestone, 66/294) was collected containing similar but not so clearly discernible forms. In the same rock there are small brown round bodies that may represent phosphatic concretions. Miss McKinnon Wood (1938, p. 7) noted that west of Shakama the Mariakani beds appear in the form of false-bedded sandstones, and it was in this tract of country that specimen 66/294 was collected. Other specimens containing similar fossils are 66/213 (a shelly limestone) and 66/233 (a shelly sandy limestone), but these are loose fragments picked up respectively on the surface near Kwa Dadu, and at the foot of the Mangea Hills near Makasidi. Thus, there may be a possibility of several marine invasions in the Mariakani sandstones but the evidence is too scanty as yet to be dogmatic.

Other impure limestones were found in the Vitengeni river, south of the Vitengeni D.C. camp, and between this river and Dulakisa, but fossils were not seen in the specimens collected. Other occurrences of impure limestones intercalated in the Mariakani sandstones are represented by specimens 66/224, 66/261, and 66/166 collected from between Kwa Dadu and Kavuluni (float), on the Mangea Hills, and north of Matolane camp respectively. Specimens 66/224 from between Kwa Dadu and Kavuluni and 66/166 from north of Matolane camp are very similar—they are yellow in colour, and consist mainly of fine-grained lime mud with irregular patches of iron and manganese ores with scattered quartz grains of silt size. Specimen 66/166 also contains patches of coarser algal limestone.

Intraformational limestone conglomerates, probably of pene-contemporaneous origin with limestones, were found in several localities, though the limestones from which they were probably derived have not been found in all cases. Such conglomerates are represented by specimens 66/171, 66/212, 66/254, and 66/295. They were collected at the following localities:—

66/171. Along the road about 4½ miles N.N.W. of Matolane camp (float).

66/212. Near the fault south of Kwa Dadu (float).

66/254. Between Vitengeni and Dulakisa.

66/295. 2½ miles west of Shakama D.C. camp (float).

A float sample of fossil wood (66/173) was found on the Mutha road about nine miles N.W. of Matolane camp. Whether it belongs to the Mariakani sandstones or not is doubtful —it may be a residual fragment from previously overlying Mazeras sandstones, which now outcrop about nine miles to the east. Even though the specimen should be derived from the Mariakani sandstone series it is doubtful whether it could be of stratigraphical value as it is not a well-preserved specimen, nor was it found *in situ*. Only slight remains of growth rings can be seen, for silicification has obliterated the bulk of the cellular structure. The alternation of the rings which is visible suggests long warm summers with short "winters", for there are wide bands up to three times thicker than adjacent thin bands. The inference rather supports Caswell's (1953, p. 12) remarks that the trees in this part of the world during Triassic times grew in an equable climate.

(2) Mazeras Sandstones (Kz)

The Mazeras sandstones are at least 1,000 ft. thick in the Malindi area. The sandstones are flaggy and cross-bedded at the base, with more massive beds at higher horizons, but even the upper horizons are commonly cross-bedded. Ripple-marks occur in the basal beds, suggesting shallow-water conditions of deposition. Intercalated argillaceous bands are not common, but where found they are generally near the base of the group. The only prominent hills in the Malindi district, the Mangea hills which rise to 1,702 ft. at their highest point, are formed of Mazeras sandstones. Gregory (1921, p. 55) stated that the upper portion of the Mangea hills is composed of his Shimba grits, overlying Mazeras sandstones with *Dadoxylon* as exposed in an 80-foot well, 1½ miles south-east by east from the summit of the hills. For want of any distinctive features whereby the "Shimba Grits" can be separated from the Mazeras sandstones, however, it is proposed that the group of upper Triassic sandstones should be considered and named as a whole, and that the term "Shimba Grits" should be discarded. In the writer's opinion the fact that the distinction between Gregory's two series is made on the presence or absence of fossil wood specimens, and not on any lithological or stratigraphical differences, detracts from the value of the separation. Caswell (1953, p. 11) clearly supports the suggestion to discard the term "Shimba Grits" for a distinct stratigraphic horizon, as in his report he includes Gregory's Shimba Grits in his Mazeras sandstones. He also recognises that there is more than one grit horizon in the Shimba hills. Should the term Shimba Grits be retained, and Gregory's basis for separation of the grits from the Mazeras sandstones in the Malindi area be adopted, the Mazeras sandstones would be of very limited extent, and subordinate to the overlying Shimba Grits, for the fossil wood specimens have mainly been found in the lowermost horizons of the sandstones.

A thin band of grey calcareous clay about four feet thick was seen intercalated in the series on the footpath between Mkondoni and Lango Baya. On account of the steep slopes and the rather thick sandy soil cover on the Mazeras sandstones, however, horizons of shales or clays would not be readily seen in this area. Sandstones appear to be more prevalent than shales although, in the Mombasa area, bore-holes drilled near Mrere revealed greater thicknesses of shales than sandstones in equivalent beds (Caswell, 1953, p. 13).

The only specimens of fossil-wood found *in situ* in the Mazeras sandstones in the Malindi area were discovered between Mkondoni and Lango Baya and near Kalaluwe, west of Dakatcha. At Mkondoni a fossil tree trunk about 13 ft. (3·9 m.) long and about 1½ ft. (45 cm.) in diameter was seen. The specimens found were orientated in a north–south direction, in agreement with Maufe's observations (Muff, 1908, p. 9) in the Mombasa area and supporting his deduction that the trees were drifted into place. Float samples of fossil wood were also found, e.g. 66/173 at a point about seven miles north-west of Matolane. Another float piece of fossil wood which is of some interest is specimen 66/327, as the cellular structure is visible microscopically. This sample was found a little east of Merikano, which is nearly five miles east of the nearest occurrence of Mazeras sandstones. Miss McKinnon Wood (1930, p. 220) also found fossil wood in the Mazeras sandstones near Baricho, which is near the fault that separates the sandstones from the Jurassic beds.

The sandstones have been involved in faults between Kwa Dadu and Mwahera on the western flank of the Mangea hills, resulting in the formation of fault breccias, represented by specimens 66/211, 66/218, 66/219, 66/221 from the vicinity of Kwa Dadu, and by 66/238 and 66/239 from north-west of Mwahera. In all cases silicification took place initially, followed later by partial ferruginization. Part of the history of the changes that occurred in the nature of the rock during the faulting can be determined from specimen 66/218. The writer believes it took place in the following stages:—

(*a*) Through movement along the fault pulverization of the quartzitic sandstone went to such a degree that its grains were largely reduced to the grade of rock flour and a mylonite was formed. Small island relics of quartz remained in the ground-up rock.

(*b*) Further movement took place and the crushed rock was broken up into irregular pieces and fissures were created. In the cavities and fissures depositions of silica took place, with fairly clear silica fringes crystallized round some of the rock fragments.

(*c*) Fracturing once more took place and silicification with turbid silica proceeded to a high degree. A slight amount of iron oxides took part in this silicification cycle.

(*d*) Finally further fracturing produced cavities in which ferruginization took place.

The mineralization that took place during faulting is particularly interesting in the case of specimen 66/221 from near Kwa Dadu. Along one of the fracture planes a few crystals of barytes ($BaSO_4$) developed prior to silicification.

At the base of the Mangea hills, westerly dips were noted in the Mazeras sandstones, as well as on Hill "Z", south-east of Shakama camp. Gregory (1921, p. 55) inferred a westerly dip in the Mangea hills and Caswell (1953, p. 12) found similar dips in the Mazeras sandstones in the Mombasa area. It can, therefore be accepted that the base of the Mazeras sandstones has a regional dip to the west, whereas the upper portion of the group has varying dips to the north, north-east and east, though the general dip is easterly.

The Mazeras sandstones are believed to have an unconformable relationship to the underlying Mariakani sandstones in the Malindi area. Outliers of Mazeras sandstones, too frequent to be explained by faulting, occur overlying the Mariakani sandstones at varying elevations. This feature can clearly be seen when following down the Vitengeni river. The Mariakani siltstones and shales outcrop along the fault against the Jurassic (Kambe) limestone in the Waravu river, whereas higher up the slopes and along the course of the Vitengeni river the Mazeras sandstones are visible.

As has been mentioned previously, Miss McKinnon Wood (1930, p. 220) found fossil wood in the Mazeras sandstones near Baricho. As all occurrences of fossil wood have been noted near the base of the Mazeras sandstone group, the presence of the wood near Baricho suggests that the Mariakani sandstones probably lie at no considerable depth beneath the Mazeras sandstones at that locality, and that they are overlain unconformably by the Mazeras sandstones, as outcrops of the Mariakani sandstones persist considerably further to the west.

Further evidence of this unconformity was obtained near the Sabaki river. Hill "Z", south-east of Shakama camp, consists of speckled creamy-white Mazeras sandstones overlying greenish-grey chloritic siltstones belonging to the Mariakani sandstone group, while at the Sabaki river to the north of the hill the Mazeras sandstones outcrop in the river-bed.

(3) Correlation of the Duruma Sandstones

The Duruma sandstones of Kenya have been correlated by numerous authors with other stratigraphical series in various countries; it is not proposed in this report to attempt a further correlation as all data correspond closely with those in the Mombasa area. Caswell (1953, p. 15 and Miller, 1952, p. 20) have produced comprehensive tables of the correlation of the Duruma sandstones with their equivalents in Tanganyika and Madagascar, indicating their correspondence with the Karroo rocks of southern Africa. They conclude that the Mariakani sandstones are middle Triassic in age and the Mazeras sandstones upper Triassic to lower Jurassic.

2. The Upper Mesozoic Rocks—Jurassic

Rocks of Jurassic age occur east of the Duruma sandstone outcrops of the Mangea hills against which they are downfaulted. They form the "Foot Plateau", but for the greater part of their extent they are concealed beneath a thick cover of Pliocene Marafa beds and red Pleistocene Magarini sands. Exposures are very scarce; the main areas where outcrops were met are in the Vitengeni (Rare) and Sabaki valleys. It was also in these areas that the faulted nature of their contact with the Mazeras sandstones was established.

Fossils are not abundant in the Jurassic sediments but no doubt with closer examination more could be found. Miss McKinnon Wood (1930, pp. 8–9) recorded only four fossiliferous localities in the Malindi area, with limestones of Upper Jurassic (Argovian–Kimmeridgian) age from three localities near the Sabaki river, and a shale of possible Bathonian or Callovian

(Middle Jurassic or lower part of Upper Jurassic) age from near the Rare river at the southern edge of the area. A list of the fossils identified from the four localities follows:—

Locality and rock type	Fossils	Stage
(*a*) Kilifi–Ganze road; W. of the Rare river—shale (locality 47) ..	*Astarte pulla* *Posidonia ornati*	Bathonian or Callovian (?)
(*b*) N. and E. slopes of the hill upon which the former Merikano rest-camp stood—limestone (locality 57a)	*Belemnopsis tanganensis* *Pseudomonotis lieberti*	Argovian–Kimmeridgian
(*c*) About ¼ mile N.E. of Baricho rest-camp—limestone (locality 63) ..	*Belemnopsis* cf. *tanganensis* *Exogyra solea* *Pseudomonotis* cf. *lieberti* *Entolium demissum* *Placunopsis* aff. *tatrica*	Argovian–Kimmeridgian
(*d*) About ½ mile E. of location 63 above, along track from Baricho to Garashi—limestone (locality 64)	*Belemnopsis tanganensis* *Somalirhynchia africana* *Exogyra solea* *Plicatula* cf. *kobyi*	Argovian–Kimmeridgian

It will be observed that no fossils of lower Jurassic age and possibly none of middle Jurassic age were found—the oldest specimens collected by Miss Wood may be either Callovian or Bathonian, whereas all the others belong to upper Jurassic (Argovian–Kimmeridgian) horizons. The sediments would thus correspond to the Kibiongoni beds or Miritini shales, and the Coroa Mombasa limestones and Changamwe shale horizons in the Mombasa area respectively (Caswell, 1953, pp. 22–23). The general succession is as follows:—

Period	Stages	Local Representative	Lithology
Upper Jurassic	Tithonian	None found	
	Kimmeridgian Argovian Divesian Callovian	Coroa Mombasa limestones and Changamwe shales Miritini shales } J_3	Sandy limestones, siltstones and shales (c.5,000 ft. thick)
Middle Jurassic	Bathonian Bajocian	Kambe limestone } J_1	Limestones (about 600 ft. thick)

The fact that the Argovian–Kimmeridgian limestone identified by Miss McKinnon Wood west of Baricho is in close proximity to the outcrops of Mazeras sandstones, and that the Kambe limestones are not exposed or are absent from this area, are significant. Miss McKinnon Wood (1930, p. 225) also observed these facts, stating that the Argovian–Kimmeridgian limestones rest on the Duruma (Mazeras) sandstones. She recorded (*op. cit.* p. 222) the presence of Kambe limestone however, on the eastern slopes of Mwangudo hill, but stated that no fossils had yet been identified from that locality. Parsons (1928, p. 69) also recorded an oyster bed from the Kibiongoni group in the Rare valley, which he provisionally ncluded with the Miritini shales.

Thus the lower and upper stages of the coastal Jurassic sediments in Kenya, that is, the Bajocian to Kimmeridgian, are likely to be found in the southern parts of the Malindi area, whereas it appears that only the upper stages, the Argovian–Kimmeridgian, are present in the north.

Kambe limestone series (J_1)

Gregory (1921, p. 64) in describing the Kambe limestone recognised three main varieties—(*a*) dark, grey, compact, and unfossiliferous except for ammonite casts in pyritic nodules, (*b*) light grey coral limestone (coral reef), and (*c*) oolitic and pisolitic limestone, interstratified with both the unfossiliferous and coral limestones.

In the Rare valley at the fault-contact with the Mazeras and Mariakani sandstones, the lowest part of the Kambe limestone seen is represented by a drab coloured, coarsely crystalline, dolomitic limestone (specimen 66/315). It is unfossiliferous and contains a fair amount of a black opaque mineral, probably an iron ore. Weathering of the ore has produced a yellow-brown stain in many of the carbonate crystals, which are rhombohedral in form. Magnesia of organic secretion appears to have greater development in warm than in cold waters (Twenhofel, 1932, p. 350) and the growth of the Kambe limestones in a warm sea appears likely. About 150 ft. (45 m.) higher up in the Kambe series is a yellowish-drab arenaceous limestone (specimen 66/274) containing numerous small white angular to rounded felspar and quartz grains and occasional muscovite and chlorite flakes. This arenaceous limestone contains scattered remains of fossils including foraminifera and the overlying dark grey compact limestone, so typical of the variety recognised by previous authors in the Mombasa area, has a sparse microfauna, probably of foraminifera.

The second, coral limestone, variety of the Kambe limestone was not observed in the Rare river locality, but the oolitic and pisolitic variety is present (specimen 66/316). Light grey pisoliths can be seen in the hand-specimen, but the ooliths are only visible microscopically. No complete fossils have been observed in this limestone, although an occasional shell fragment is present and a small crinoid columnal can be seen in the thin section. The ooliths often enclose angular and sometimes euhedral grains of quartz, some grains being partly replaced by calcite.

Further east and in the vicinity of Dida calcareous shales are present which correspond to the Miritini shales in the Mombasa area. In was in the Rare river valley, to the south, that Parsons (1928, p. 69) found what he considered to be Kibiongoni beds. It should be noted, however, that Caswell (1956, p. 21) considers that the Kibiongoni beds are not found north of the latitude of Kaloleni, some 20 miles S.W. of Kilifi.

Miritini shales (J_3)

In a gully a little west of Dida an exposure (specimen 66/270) was found consisting of dark grey well-laminated calcareous siltstones which on weathering become a yellowish drab colour. Mica flakes are concentrated along the laminae in layers that also contain remains of shells, and quartz and felspar grains with an average diameter about 0·1 mm. constitute somewhat less than half the bulk of the rock. Some pyrites is also present, together with occasional grains of zircon and probably ilmenite. Ammonite fragments (66/275), probably *Pleurocephalites* aff. *habiensis* Spath of the Callovian stage, were collected from these shales. Miss McKinnon Wood (1930, p. 223) records some Callovian shales in the Rare valley, north of Konjora. At the Rare river crossing on the Kilifi–Ganze road at her locality No. 47 she found shales belonging to the Callovian or possibly Bathonian stage, the dating being based on the presence of *Astarte pulla* and *Posidonia ornati* and on comparison with other localities where these lamellibranchs occur together with ammonites.

The Coroa Mombasa limestone and shales and Changamwe shales (J_3)

Fossils of the Argovian–Kimmeridgian stages have not been recorded in the southern parts of the Malindi area, although Miss McKinnon Wood (1930, p. 224) found a small block of limestone of that age in the shales along the Kilifi–Ganze road west of the Sokoke plantation, south of the present area. It is presumed that much, if not all, of the upper Jurassic rocks in the southern part of the area do, in fact, belong to the Argovian–Kimmeridgian stages.

Limestones and shales of the Argovian–Kimmeridgian stage were discovered by Miss McKinnon Wood (1930, p. 224) in the vicinity of Baricho, where they are associated with igneous intrusions. As is so typical of the Jurassic sediments, exposures are, however,

rare in the Baricho area. Outcrops of limestones were seen along the Sabaki river and between Baricho and the Koromi valley on the Dakatcha road. The associated shales of the upper Jurassic sediments were only observed along the Sabaki river between Baricho and Garashi, and on the track leading from the Kakoneni–Bamba road to Merikano. Numerous fragments of limestone and siltstones occur in the area as float pieces, and fragments of the yellow fossiliferous limestone horizons, often showing fragments of belemnoidae, are particularly common.

In the vicinity of Baricho and Merikano, Miss McKinnon Wood collected the fossils that are listed on p. 16.

Along the Sabaki river at the faulted contact with the Mazeras sandstones specimens of non-fossiliferous limestones were collected. These limestones (specimens 66/237, 66/308 and 66/309) are rather impure, specimen 66/309 being considered argillaceous. Specimen 66/308 is a fine-grained intraformational conglomerate containing irregular pellets and pebbles of an argillaceous limestone in a calcareous silt matrix. The remaining limestone specimen, 66/237, is a light grey more coarsely crystalline type and contains only scattered quartz and felspar grains. The Jurassic sediments in this locality are composed of alternating bands of limestones and calcareous shales, the limestone bands being up to eight inches (20 cm.) thick. Further east the sediments become more argillaceous with only occasional thicker limestone bands, which are highly fossiliferous.

Faulting has caused the limestones which are exposed on the north bank of the Sabaki river near Baricho to dip 30° to the west, but further east they become almost horizontal, and still further east the shales have the usual regional dip of between 10° and 20° to the north-east or east. Reliable readings of dip in the shales are difficult to obtain, on account of the ease with which these sediments deform under the effect of gravity in the weathered zone.

About 500 yards north-east of Baricho village, alongside the road to Dakatcha, a band of fossiliferous limestone (specimen 66/175) was seen dipping approximately 30° E.N.E. This limestone contains numerous shell fragments. It also contains scattered allothigenous mineral grains, including relatively large fragments of garnet. Like many of the limestone bands in this area it has a dark yellowish colour.

The shales of the Argovian–Kimmeridgian stages are generally green or grey in colour when fresh and yellowish drab when weathered. Some horizons are more arenaceous, and resemble fine-grained sandstones. One such specimen (66/127) was collected from a disused road-stone quarry on the Kakoneni–Bamba road, about five miles from Kakoneni. It contains a few foraminifera, is calcareous and micaceous containing both brown and white mica, and includes greenish grey argillaceous pellets. The specimen is light grey when fresh but weathers to a drab brown colour, mottled where the mud pellets are visible.

Intercalated in these upper Jurassic sediments, stratigraphically about 3,000 ft. above the limestones, there is a horizon of brownish yellow calcareous sandstone and sandy limestones. These are best exposed on the northern and eastern slopes of Merikano hill. A float piece of similar sandy limestone (specimen 66/156) was also found on the northern slope of a hill composed of volcanic rocks, on the road from Baricho to Shakadula, but it is unfossiliferous. On Merikano hill the fossiliferous sandstone (specimen 66/129) overlies soft friable shales, and is overlain by a fossiliferous limestone (specimen 66/131) containing oyster-like pelecypods, probably *Exogyra solea*. The fossils from these two beds were submitted to the British Museum for identification, but only numerous specimens of the lamellibranch *Meleagrinella lieberti* (Muller) were identified from specimen 66/129. An upper Jurassic, approximately Kimmeridgian age, has been ascribed to these fossils. Overlying these beds at Merikano are more shales and limestones, which it is believed are equivalent to the Changamwe shales of the Kimmeridgian stage in the Mombasa area. In a gully two miles south-west of Kakoneni, near Pishi Moja, is an outcrop of these dark grey shales. No fossils have been found previously in this horizon in the Malindi area, nor were any collected during the present survey.

A peculiar feature of these shales is the direction in which they dip, viz. to the south. The probable presence of a fault nearby must not be overlooked. Although the dip of 5° is somewhat in conformity with that of the bulk of the shales in the Malindi area it is less than the average of about 10°.

In the Shakadula bore-hole, C1042, some ammonite fragments were collected from bluish-grey shale, according to the driller at a depth between 360 ft. and 390 ft. (118–128 m.) below the surface. One of these fragments is very similar to *Lithacoceras mombassanum* (Dacqué) var. *euglypha* sp. nov., collected by Miss McKinnon Wood (1930) from the Changamwe shales near Mombasa. Should this prove to be correct, then the Changamwe (Kimmeridgian)* shales are present in the Malindi district. It is reported by Miss McKinnon Wood (1930, p. 224) that C. W. Hobley recorded an exposure of similar shales at Lake Chem-Chem, 14 miles south-east of Shakadula, but it is doubtful that they are of the same age. In the writer's opinion the shales at Lake Chem-Chem are probably of Miocene age, though in outward appearance they are very similar to the Jurassic shales.

The samples of the shales in bore-hole C1042 are cut by numerous veins of calcite, with locally disseminated grains of pyrite (FeS_2). The driller also reported barytes ($BaSO_4$) but this has not been established chemically. Unfortunately the complete collection of bore-hole sludge samples is not available for examination but according to the driller the details of this bore-hole are as follows:—

BORE-HOLE C1042

0–10 ft. (0–3·0 m.)	Black clay
10–75 ft. (3·0–22·8 m.)	Yellow sandstone
75–360 ft. (22·8–110 m.)	Bluish shale
360–390 ft. (110–119 m.)	Bluish shale impregnated with barytes (?), calcite, pyrite and marcasite with fragments of ammonites.
390–400 ft. (119–122 m.)	Bluish shale

As is common with many of the Jurassic sediments the shales are calcareous.

3. Cainozoic Rocks

The Cainozoic sediments are largely confined to the Coastal plain and comprise representatives of Miocene, Pliocene, Pleistocene and Recent sediments. The succession mapped by the writer is given in Table III.

Before describing the Cainozoic rocks in detail, the position assigned to the Magarini sands and the creation of a new series—the Marafa beds—must be discussed.

Gregory (1896, p. 229) gave the name "Magarini Sands" to a belt of red sands and sandstones forming low hills which rise behind the Kenya Coast. He stated: "In East Africa a band of brilliant red sands and sandstones occurs near the coast behind Mombasa. . . . They can be especially well seen above the plantations of Magarini, and I therefore propose to call them the 'Magarini Sands' . . . they are probably Triassic. They are no doubt a desert sand, and though here and there the action of rivers and streams can be traced within them, they indicate the existence of an arid climate toward the close of the New Red Sandstone Series." In his later book Gregory (1921, p. 76) stated: "The sand is sometimes unconsolidated, but some has the coherence of rock sand. It is interstratified with layers of pebbles of harder sandstones, quartzites and cherts of the Jurassic beds and Duruma sandstone, and some pebbles from the Eozoic foundation. The grains were doubtless derived directly or indirectly from the Eozoic rocks. . . . These sands are mainly siliceous

*Caswell (1956, p. 18) abandoned the use of the terms "Coroa Mombasa limestones and shales" and "Corallian", which he had used in an earlier report (1953, p. 22). In his opinion the Coroa beds and the Changamwe shales then become together the equivalent of the Kimmeridgian.

TABLE III

CAINOZOIC DEPOSITS OF THE MALINDI AREA

Periods	Local Representative	Lithology	Environment of Deposition	Climate
(4) Recent (Holocene) ..	Recent terrestrial deposits (Rt) Recent marine sediments (Rm)	Cemented beach sands, gypsum beds and wind-blown sands	Modern conditions	Moderately wet
(3) Upper to Lower Pleistocene	Wind-blown sands (Qt_3)		Coastal wind-blown deposits	
	Coquinas (Qt_2 and Qt_4) Fossil coral reef and breccias (Plc) Lagoonal sands, etc. (Pls) Magarini Red sands (Qt_1)	Sands, clays, limestones and cemented coral "sands", etc.	Neritic	Arid
			Coastal wind-blown deposits	
	SLIGHT	UNCONFORMITY		
(2) Lower Pleistocene (?) Upper Pliocene	Marafa beds (Tpl)	Unconsolidated sands, clays, gravels, pebble beds and sandstones	Shallow-water, fluviatile and deltaic	Wet
	UN	CONFORMITY		
? Lower Pliocene .. .. Upper Miocene	Basaltic igneous intrusions		Erosion	
(1) Lower Miocene	Baratumu beds (Tm)	Fossiliferous marls, sands, clays, conglomerates and limestones	Shallow-water, littoral	Warm (?)

and the absence of shells may be explained by the removal of the calcareous material in solution. . . . Their false bedding and the nature of the pebbly layers indicate that they were formed as sandhills and river gravels between the foot of the inland plateau and the sea." On a later page (p. 77) he revised his opinion of the age of the sands, considering that they are probably Lower or Middle Pliocene.

Gregory also stated that in Tanganyika similar sands occur behind most of the coast, where they had been named the Mikindani beds by Bornhardt (1900, p. 469). Several German geologists have regarded the Mikindani beds as of terrestrial and fluviatile origin.

Parsons (1928, p. 69 *et seq.*) in the discussion of his Magarini Series, which he considered ranged in age from Eocene to Recent, recorded the same lithological characteristics as Gregory did, but also included some shelly calcareous beds and coral limestones. The latter he stated are only distinguishable from Recent raised coral reefs along the shore by their fossil content. He also noticed that the pebble beds are common at the base of the sands, but that they occur also high up in the group. The pebble beds he stated "consist of well-rounded quartz and grit pebbles, and at the base of the formation rest upon a denuded landscape."

Miss McKinnon Wood (1930, p. 225) sounded a note of doubt so far as the Pliocene age of the Magarini sands, as described by Gregory, was concerned. She stated as did Parsons, that from available evidence (that is up to 1930) it appeared that deposits of different ages are represented in the series.

Busk and de Verteuil (1938, p. 18) assigned a Pliocene age to their Magarini sands, which they stated consist of sands with bands of shelly and coral limestones. Like Parsons, they also stated that it is not always easy to separate the sands from the Recent coral beaches. Caswell (1953, p. 25) recorded the same lithological characters for the Magarini sands in the Mombasa area, but did not find calcareous beds or coral limestones. The sands, he stated, are creamy white when fresh, but are often bright red at the surface owing to concentration of ferric oxide. In common with most of the other geologists who have dealt with the Magarini sands, Caswell considered that they were deposited as river gravels and coastal dunes under conditions of intense erosion. He noted that the sands rest unconformably on a planed surface of Jurassic and Cretaceous rocks, and that they overlap occasionally on to the Duruma sandstones.

From the above it will be realised that there are differences in lithological characteristics, colour, and mode of accumulation of the sediments that have been included under the heading "Magarini Sand". Apart from these, as Miss McKinnon Wood and Parsons have pointed out, deposits of different ages are apparently represented in the series. The lower members of the "Magarini Sands" contain pebble beds as Parsons has indicated, and Caswell has remarked that the sands are creamy white in colour when fresh—only red at the surface due to ferric oxide staining. Gregory did not mention the presence of light-coloured beds and in fact, considered that the sandhills behind the coast are usually bright red in colour. Most writers are agreed generally that under the term "Magarini Sands" both fluviatile and aeolian deposits are represented.

It is proposed for the purpose of this report, to separate the two lithological types that have been included in the "Magarini Sands" by the introduction of a new name—the Marafa beds—which it is proposed should be applied to the lower fluviatile sediments. The term "Magarini Sands" is then restricted to the red aeolian deposits of middle Pleistocene age. The amended sequence is that given in Table III.

(1) The Baratumu Beds (Miocene) (Tm)

The Baratumu beds comprise the sediments in the Malindi area that are believed to be of Miocene age. The recent identification of fossils, chiefly foraminifera, from two localities in the district by Messrs. R. E. Eames and F. C. Dilley of the Anglo-Iranian Oil Company, has confirmed the Neogene (probably lower Miocene) age of part of the beds. The samples examined were collected, (*a*) from a bore-hole sludge taken from between 87 ft. and 94 ft. (26·4–28·5 m.) below ground-level in the Maziwane bore-hole, and (*b*) from near Lake Baratumu below Goshi village.

The fossils identified in the respective samples are tabulated below:—

	Name	Sample (a) Borehole C850	Sample (b) Goshi
Larger Foraminifera	*Amphistegina* (2 species)	XX*	X
	Asterigerina sp.		X
	Gypsina sp.		X
	Lepidocyclina (*Nephrolepidina*) *sumatrensis*		X
	Miogypsina (2 species)		XX
	Operculina (2 species)	X	X
	Operculinella (2 species)	X	X
	Sorites sp.		X
	Taberina malabarica		X
Smaller Foraminifera	*Anomalina* sp.	X	
	Anomalinella sp. ?	X	
	Bolivina sp.	X	
	Cassidulina sp.	X	
	Cibicides (2 species)	XX	X
	Clavulina sp.		X
	Clavulinoides sp.		X
	Elphidium (2 species)	X	X
	Eponides (2 species)	X	X
	Globigerina (2 species)	XX	X
	Globorotalia ? sp.	X	
	Globulina ? sp.		X
	Guttulina sp...	X	
	Lenticulina sp.	X	
	Loxostomum sp.	X	
	Miliolids	X	
	Nodosaria ? sp.	X	
	Nonion (2 species)	X	XX
	Orbulina sp.	X	
	Planorbulina sp.	X	
	Rotalia sp.	X	X
	Rotalids	X	
	Siphogenerina sp.	X	
	Streblus (2 species)	XX	X
	Textularia sp.	X	X
	Triloculina tricarinata		X
	Triloculina sp.		X
	Uvigerina sp.	X	
Bryozoa	*Acanthodesia* sp.		X
	Adeonellopsis sp.	X	

*Each X denotes the number of species identified in the respective samples.

	Name	Sample (a) Borehole C850	Sample (b) Goshi
Bryozoa—(*Contd.*)	*Canda* sp.	X	
	Cellaria sp.	X	
	Cellepora sp.		X
	Celleporid	X	
	Crisia sp.	X	X
	Crisisina sp.	X	
	Entalophora sp.	X	
	Hippopleurifera ? sp.	X	
	Hornera (2 species)	XX	X
	Nellia oculata	X	X
	Osthimosia sp.	X	
	Porella sp.	X	
	Poricellaria sp.		X
	Retepora sp.		X
	Steginoporella sp.		X
	Thalamoporella sp.		X
	Tubucellaria (2 species)	X	X
Echinoidea	*Cidaris* sp.		X
	Echinoid remains		X
	Genus (problematica)		X
Gastropoda	*Nassaria* sp.	X	
Lamellibranchia	*Chlamys* sp.	X	X
Ostracoda	*Bairdia* sp.		X
	Brachycythere sp.		X
	Cytherura sp.		X
	Hemicytherideis sp.		X
	Loxoconcha sp.	X	
	Trachyleberis (4 species)		XXXX
Cirripedia	*Balanus* sp.	X	
Anthozoa	Alcyonarian Spicules	X	
Crinoidia	Crinoid ossicle	X	
Decapoda	Crab claws		X

There are unfortunately no diagnostic larger foraminifera in the sample from bore-hole C850, but the assemblage of *Amphistegina*, smaller foraminifera, and bryozoa is unquestionably of Neogene age. The presence of *Tubucellaria* and an *Anomalinella* suggests that the age is lower Miocene, rather than Pliocene. The absence of the Pliocene species *Operculinella*, which was found in a sample of soil from Chui Beacon (*see* Marafa beds, p. 28) may also be significant.

The second sample contains a typical Lower Miocene assemblage, as is indicated by the presence of *Lepidocyclina* (*Nephrolepidina*) *sumatrensis*, *Miogypsina* (so far as East Africa is concerned), *Clavulina*, *Clavulinoides* and *Trachyliberis*.

Bore-holes C850 and C849 are the only bore-holes that did not strike water during the development of the Malindi Township water-supply scheme.

It is of interest to note that Gregory (1921, p. 74) quotes the presence of Eocene fossils in a collection made by C. W. Hobley at a place S.S.E. of Hadu (39° 54′ E., 2° 52′ S.)—a locality about twenty miles north-west of Magarini, and beyond the northern limits of the present area. The fossils were identified by R. B. Newton as follows, being dated as Eocene (Gregory, 1921, p. 384):—

Corals	*Favia somaliensis*
Gastropods	*Volutilithes* cf. *sanurensis* Oppenheim
	Campanile
Foraminifera	*Alveolina*
	Miliolina
Marine algae	*Lithothamnium*

L. R. Cox (McKinnon Wood, 1930, p. 104) later re-examined some of the fossils but considered that they are Miocene. The *Volutilithes* cf. *sanurensis* he believed to be a crushed *Strombus* cast, and the *Campanile* probably a cast of *Telescopium charpentieri*. There has been no criticism of the foraminifera identified as Eocene, but until further evidence of Eocene fossils is forthcoming, the suggestion of the presence of sediments of that age must be treated with some reserve. Miss McKinnon Wood (*loc. cit.*, p. 225) unfortunately did not visit Hobley's locality, but near Lafihi village (39° 55′ E., 2° 57′ S.) about six miles north-west of Marafa, she collected Miocene fossils from a dry watercourse. This is approximately four miles S.S.E. of where the "Eocene" fossils were collected by Hobley.

Gregory (1921, p. 74) quotes the fossils listed below from a collection made by Hobley, from a river-bed about five to seven miles west of Fundi Isa (Fundisha) on a platform about 120 ft. above sea level, a few miles north of the boundary of the present area.

Ostrea gingensis (Schlotheim)

Ostrea grypheoides (?) (Schlot.)

Lopha virleti (?) Deshayes

Amussium cristatum Bronn.

Aequipecten cf. *malvinae* (Dubois)

The fossils were dated by Newton as Miocene (Vindobonian). Criticism of the identification and dating of the fossils was made by L. R. Cox (1927, p. 16) and it was not until he had examined the collection made by Miss McKinnon Wood that the evidence of Miocene rocks west of Fundi Isa was considered conclusive (McKinnon Wood, 1930, p. 103).

Gregory's list can now be replaced by the tabulation of Miss McKinnon Wood's collections from the same locality (her Mkwajuni, localities Nos. 9*a* and 9*b*), from near Lafihi (locality 66) and from a little east of Pazziani (locality 8) (McKinnon Wood, 1930, pp. 104 *et seq.*, 169, 186, 211):—

Locality	Fossils	Type of Fossil
66	*Trochus*	Gastropod
66	*Nerita* cf. *teilhardi*	,,
66 and 9*b*	*Cerithium* (?*Ptychocerithium*) *pseudocorrugatum* d'Orbigny	,,
66	*Terebralia bidentata* Defrance	,,
66 and 9*b*	*Telescopium charpentieri* (Basterot)	,,
66 and 9*b*	*Strombus* spp.	,,
9*b*	*Cernina callosa* (J. de C. Sowerby)	,,
8, 9*a* and 9*b*	Pecten (*Amussiopecten*) cf. *burdigalensis* Lamark	Lamellibranch
8, 9*a*, 9*b*, 66	*Chlamys pusio* (Linné)	,,
	Chlamys senatoria (Gmelin)	,,
	Chlamys (*Aequipecten*) cf. *malvinae* Dubois	,,
9*b*	*Spondylus ornatissimus* A. Böhm	,,
8, 9*a* and 66	*Ostrea sublingua* d'Orbigny	,,
8 and 9*a*	*Ostrea gryphoides* (Schlotheim)	,,
	Ostrea hyotis (Linné)	,,
8, 9*b* and 66	*Ostrea folium* Linné	,,
66	*Ostrea subangulata* d'Orbigny	,,
9*b* and 66	*Cardita* sp.	,,
66	*Crassatellites* cf. *sulcatus* (Solander)	,,
9*b*	*Antigona granosa* (J. de C. Sowerby)	,,
9*b*	*Corbula socialis* Martin	,,
8 and 9*a*	*Teredo* (*Kuphus*) aff. *polythalamia* (Linné)	,,
8	*Cidaris* sp.	Echinoid
9*a*	cf. *Temnechinus rousseaui* (d'Archiac)	,,
9*b* and 66	*Echinocyamus woodi* Currie	,,
9*b*	*Breynia* cf. *carinata* d'Archiac and Haime	,,
9*b*	*Schizaster* cf. *uhligi* Scholz	,,
9*b*	*Hemiaster* sp.	,,
9*b* and 66	*Isis obliquus* Gregory	Coral
66	*Pocillopora retusa* Gregory	,,
9*b*	*Stylophora nodosa* Gregory	,,
66	*Thecosmilia pusilla* Gregory	,,
66	*Brachyphyllia lafihensis* Gregory	,,
9*a*	*Cycloseris radifera* Gregory	,,
9*b*	*Actinacis sabakiensis* Gregory	,,
66	*Dendracis bifaria* Gregory	,,
8	*Lepidocyclina gallienii* Lemoine and Douvillé	Foraminifer
8	*Operculina venosa* (Fichtel and Moll)	,,

The Miocene fossils found beyond the limits of the present area have been tabulated as well as those obtained from the Malindi area, as certain forms are common to both.

In addition to the larger fossils tabulated here, there is a rich fauna of microfossils, mainly foraminifera, as will be realised from the tabulation provided by the Anglo-Iranian Oil Co. Such fossils are particularly prolific in the Lake Baratumu area. C. D. Ovey (in McKinnon Wood, 1938, p. 98) has remarked that the "foraminiferal fauna. . . is quite typical of shallow water in tropical regions". The foraminifera collected near Goshi by Miss McKinnon Wood, *Operculina venosa* (Fichtel and Moll) and *Lepidocyclina gallienii* Lemoine and Douvillé, are abundant. *Miogypsina* sp. is common in this area, and a collection of them was obtained from a yellow sandy marl on the northern slopes of Gaji beacon hill, locally known as Goshi, but not to be confused with the Goshi hill east of Goshi village. Specimens of this foraminifer were also observed in spoil from a well dug to over 100 ft. (30 m.) depth in the Swahili settlement in Kikuyuni village. The foraminifera are associated with numerous echinoid plate fragments and spines, *Pecten* molluscs, and oyster shells. Corals and polyzoan fragments were collected in this area too. An equally rich assemblage of fossils can be obtained on the road-cutting below Goshi village. Sample (*b*) referred to above was taken from this locality.

Cox states (McKinnon Wood, 1930, p. 103) that the collection of fossils obtained by Miss McKinnon Wood indicates an Aquitanian–Burdigalian stage rather than Vindobonian as suggested by R. B. Newton, that is, lower rather than upper Miocene. Cox considers that the presence of marine upper Miocene beds has yet to be demonstrated in East Africa.

The Miocene sediments are considered to have been deposited mainly under littoral or neritic conditions. The fact that complete forms, such as echinoids, are extremely rare supports the suggestion of a littoral environment. The sediments are mainly light-coloured, composed of yellow sandy marls, marly limestones, and sands with occasional light grey or dirty white sandy marls. Calcareous sandstones are present but are not common. The sediments are lenticular in nature, and not of great lateral extent—a feature common to most of the Cainozoic rocks, No bore-holes have been drilled through these sediments, so their sub-surface geology is unknown, and as exposures are limited a complete stratigraphical sequence is difficult to construct. A typical exposure on the north-eastern slopes of Gaji hill, comprises the following horizons:—

		Ft.
Pleistocene	Red Magarini sands	116½–350 (35·4–106·5 m.)
	Quartz pebble-bed with quartz artifacts, chippings, and some ferricrete pebbles	116 –116½ (35·3–35·4 m.)
Pliocene	Grey clay	101 –116 (30·8–35·3 m.)
	Pebble conglomerate (66/320)	98 –101 (29·8–30·8 m.)
Miocene	Grey clay	93 – 98 (28·3–29·8 m.)
	White nodular marly limestone with gastropods	90 – 93 (27·4–28·3 m.)
	Yellow foraminiferous marl (*Miogypsina* sp.)	85 – 90 (25·9–27·4 m.)
	Light grey/dirty white marls, with many fossil fragments, echinoid spines and calcareous nodules	50 – 85 (15·2–25·9 m.)

Lake Baratumu black soil floor—50 ft. O.D. (15·2 m.)

The light grey/dirty white fossiliferous marls are present in the road-cutting below Goshi village on the Pazziani road, and as usual frequently include lenticles of yellow sands which are often highly fossiliferous. These yellow fossiliferous (foraminiferous) sands can also be seen on the eastern side of Lake Baratumu and on the path leading up from the lake to Kikuyuni village. At the latter place they are well exposed in a shallow pit, and *Operculina* sp. are abundant. A heavy mineral separation of a sample from the fine yellow

sandy horizons collected on the northern slopes of Gaji hill above the road to Madunguni revealed the following:—

Hornblende, numerous
sphene, numerous
garnet, few
rutile, rare
non-magnetic iron ores, rare

The *Miogypsina* sp. horizon indicates the Miocene age of these sediments also; this horizon has been recorded previously by Busk and de Verteuil (1938, p. 18) following the discovery of *Miogypsina* in sediments about 1½ miles west of Magarini hill, north of the Sabaki river. A collection was made from shales, calcareous sandstones, associated marls and the *Miogypsina* limestone, and the following fossils were identified by Professor J. A. Douglas (Busk and de Verteuil, 1938, Appendices 1 and 2):—

Gastropods	*Conus* (cast of giant form)
	Cypraea sp. (casts)
Lamellibranchs	*Ostrea latimarginata* Vred.
	Lucina sp.
	Tellina lacunosa Chemnitz (cast)
	Amussium de Stefanini Ugolini
	Amussium cristatum Bronn.
	Crassostrea gryphoides (Schlotheim)

Towards the top of the Miocene beds, lenticular bands of fossiliferous limestones are met. These are generally marly in appearance, e.g. specimen 66/122 collected from the slopes of the bluff, north-west of Lake Baratumu. This specimen reveals a host of *Operculina* sp. weathering out from the limestone. On the north side of the Sabaki river, the limestones are more massive, compact, and yellow in colour. Associated marls are grey in colour.

To the east of the now derelict Pumwani settlement a band of this yellow fossiliferous limestone, about two feet (0·6 m.) thick rests on a greenish-grey clay which is unfossiliferous, as also is the clay beneath the pebble conglomerate on the slopes of Gaji hill.

The absence of pebbles of volcanic rocks from the sediments is of interest. Shackleton (1946, p. 27) has recorded the presence of Miocene sediments, which apparently contain no volcanic material, underneath the lowest of the volcanic rocks at several places along the eastern fringe of the Laikipia lava plateau. In all cases but one the Miocene sediments are overlain by lava—a feature also observed in connexion with lower Miocene sediments around Lake Victoria (Saggerson, 1952, p. 20). Shackleton (*op. cit.*, p. 29) in comparing the Laikipian sediments with deposits of the post-volcanic period, notes the absence of laterite and red beds—a feature which he regards as suggestive of a wet climate. The lower Miocene beds in the Malindi district are also without laterite and red beds.

The regional dip of the Baratumu beds appears to be to the south-east, i.e. more or less the same direction as that of the Jurassic sediments. Only four dip measurements were, however, obtained. They range from 2° in the west, to a doubtful 20° north of Magarini hill in the east, where unfortunately no other dip measurements were obtained. The sediments are notably "clayey" and subject to distortion under slight stress, so that it is likely that higher dips recorded are exaggerated owing to slumping, especially in view of the limited nature of the exposures available. With exposures extending over nearly nine miles (14·4 km.) and assuming that the lowest dips are the most valid there is thus a possibility of a minimum thickness of 1,600 ft. of beds being exposed. It is evident that the high dip north of Magarini has no regional significance and probable that the sediments were deposited on an uneven surface, so it is tentatively suggested that the total thickness of the Baratumu beds does not exceed 1,600 ft. (488 m.). Unfortunately the junction between the Baratumu beds and the Jurassic sediments is concealed by the younger Marafa beds, so that a final estimate of the total thickness is not possible. Busk and de Verteuil (1938, p. 18) considered that the sediments are under 100 ft. (30·5 m.) thick.

South of the Sabaki river the Baratumu beds were not seen exposed at an elevation greater than 100 ft. (30·5 m.) whereas north of this river they occur at an elevation greater than 200 ft. (61 m.). Further north and beyond the limits of the present area, Hobley's "Eocene" beds (pp. 383–384) which are now considered to be probably Miocene lie at an elevation of about 250 ft. (76 m.) (Gregory, 1921, p. 73). Erosion and not differential uplift, is believed to be responsible for these differences in the heights of the outcrops.

(2) The Marafa Beds (Tpl)

As has been mentioned on a previous page, the Marafa beds are sub-aqueous deposits of probably late Pliocene to early Pleistocene age. They are essentially light-coloured, white to creamy-white, with occasional lenticular bands of red and purple sands and clays. The sands, clays and pebble beds are false-bedded, and are essentially non-calcareous.

A sample of soil taken from the vicinity of Chui beacon by the writer proved to contain fossils which have recently been identified and dated as Pliocene by Messrs. R. E. Eames and F. C. Dilley of the Anglo-Iranian Oil Company. This discovery indicates the presence of fossiliferous horizons in the Marafa beds. The field evidence suggests that the horizons are of limited extent, and have accumulated locally.

The fossils identified in the soil collected near Chui beacon are tabulated below:—

Larger Foraminifera	*Amphistegina* (2 species)
	Borelis pygmaea
	Heterostegina sp.
	Operculinella sp.
Smaller Foraminifera	*Bolivina* (3 species)
	Cibicides sp.
	Clavulina sp.
	Cribroelphidium sp.
	Elphidium sp.
	Eponides sp.
	Globulina sp.
	Massilina sp.
	Nonion sp.
	Quinqueloculina sp.
	Siphogenerina sp.
	Streblus (2 species)
Bryozoa	*Canda* (2 species)
	Cellaria sp.
	Crisia sp.
	Hornera sp.
	Nellia oculata
	Retepora
	Thalamoporella sp.
	Tubucellaria sp.
Ostracoda	*Bairdia* sp.
	Loxoconcha sp.
Cirripedia	*Balanus*
Anthozoa	Alcyonarian spicules

Previously species of *Nummulites* (*N. viquesneli*, *N. bagelensis*, and *N. bayhariensis* according to Eames and Dilley) had been identified in this material which accordingly was dated as Eocene. Eames and Dilley state that the genus *Nummulites* as correctly defined is not, however, present in the sample, and it seems that *Operculinella* (which is abundantly represented) may have been mistaken for it. It is understood that no sections of these

nummulite-like forms were made; two of these species of nummulite mentioned above have megalospheres between 0·5 and 1·0 mm. in diameter, whereas the megalosphere of the *Operculinella* is only 0·1 mm. in diameter. It is a very common species, as yet found only in the Pliocene of East Africa by the Anglo-Iranian Oil Company's geologists. The suite of foraminifera and bryozoa in the Chui beacon material is definitely Neogene, and the *Heterostegina* is a Pliocene species. There can be no doubt, therefore, that the sample is of Pliocene, not Eocene, age.

Lithologically there is little whereby the Pliocene sediments can be distinguished from the Miocene. Exposures of either group of sediments are not common. Between Sabaki village and the Sabaki river a poor exposure of sediments, including some of possible Pliocene age, has the following sequence:—

		Ft. in.
Pleistocene	(6) Reddish-brown sand	12 0 (3·6 m.)
	(5) Pebble bed	4 (0·1 m.)
	(4) Grey buff sand	4 0 (1·2 m.)
Pliocene (?)	(3) Yellow fossiliferous marly limestone	4 0 (1·2 m.)
	(2) Yellow fossiliferous sandstone (66/123)	4 0 (1·2 m.)
	(1) Yellow buff sands (?) (largely concealed by talus and alluvium)	75 0 (22·8 m.)

Level of the Sabaki river.

The Sabaki river here is about 20 ft. (6·0 m.) above mean sea-level.

Caswell (1953, p. 26) in discussing comparable sediments in the Mombasa area considers that they were deposited in river-beds and as coastal dunes under conditions of intense erosion.

A basal conglomerate on the northern slopes of Gaji hill west of Lake Baratumu contains foraminifera and gastropods which have probably been derived from the underlying Miocene (Baratumu) beds. As has been mentioned by previous authors, the conglomerate contains pebbles derived from the Archaean, the Duruma sandstones and the Jurassic rocks. Specimens 66/116 and 66/320 are typical examples, and contain large well-rounded quartz pebbles in a calcareous fossiliferous matrix. In both specimens numerous foraminifera represented by *Miogypsina* sp., *Operculina* sp., and possibly *Nodosaria* sp., are visible.

The Marafa beds are well exposed in an erosional scarp north of Marafa village, from which they take their name (Plate I, Fig. 1). The beds are, on the whole, unconsolidated and easily eroded. Caswell (1953, p. 26) has referred to their peculiar mode of erosion where cirque-shaped "pits" are formed with narrow ridges and earth pillars, in the Mombasa area near Tangila hill. One such earth pillar (Plate I, Fig. 2), almost 100 ft. (30·5 m.) tall can be seen in an erosion scarp at Ulaya Nyari, S.S.W. of Marafa. The cap protecting this pillar is formed of a ferricrete band about 12 ft. (3·7 m.) thick. As a result of the easy erosion of the sediments, the headward progression of a tributary stream of the Koromi river breached and drained Lake Madina, north of Marafa, in 1948.

A typical section of the Marafa beds was seen and measured in the erosional scarp at Ulaya Nyari. The section is as follows, the top of the scarp having an altitude of 273 ft. O.D.:—

	Ft.
Bright red sand	16 (4·88 m.)
Red, nodular, ferruginized sand with ferricrete pebbles	12 (3·65 m.)
Red mottled, white soft sandstone	7 (2·13 m.)
Slightly indurated, nodular, light greyish-white clayey sand	4 (1·22 m.)
Light greyish-white soft clayey sand	5 (1·52 m.)
Slightly indurated light greyish-white nodular clayey sand	5 (1·52 m.)
Soft white clayey sand—weathers pink	17 (5·18 m.)
Nodular, creamy-white to grey, clayey sand	2 (0·6 m.)
White, iron-stained, brown, yellow and red clayey sand, with some patches of grey clay	21 (6·4 m.)
Brown, cross-laminated, coarse sand—pebbly in places	4 (1·22 m.)
White clayey sands—soft sandstone in patches	16 (4·88 m.)

Sandstones (specimens 66/141, 66/142 and 66/143) are not common in the Marafa beds. Those collected and examined microscopically reveal angular to sub-angular quartz grains and scanty felspar grains, cemented by a light-brown isotropic clay mineral. Heavy minerals are not abundant in those sandstones—those seen are sphene, hornblende, and zircon. Sludges obtained from the bore-holes drilled near Ganda for the Malindi water-supply, contain numerous grains of garnet. A heavy mineral separation of sludge from 92 to 105 ft. (28–32 m.), collected from bore-hole C969, revealed the following heavy minerals—magnetite, ilmenite, garnet, tourmaline, chlorite, sphene, zircon and rutile.

Locally the Marafa beds are extremely clayey, and roads traversing them are almost impassable during the wet season when unmetalled. A random sample collected from a white hill in the Marafa beds about eight miles to the north of Marafa village and beyond the limit of the present area was examined and analysed by A. J. Campbell, the ceramic specialist of the East African Industrial Research Board. It contained approximately 40 per cent kaolin and 60 per cent of a very fine sand, which might be suitable as a glassmaker's sand. Millot (1949) in a systematic petrographic study of the argillaceous rocks found that kaolinitic beds are characteristic of the lacustrine or fluvio-lacustrine continental facies, deposited under acid leaching conditions. For the Marafa beds or the kaolinitic sediments in them to have accumulated under such conditions, bodies of fresh or brackish water must have existed in close proximity to the sea. Such conditions could have existed where offshore bars were built up on a nearly horizontal submarine profile and lagoons developed behind them. The acid environment of sedimentation would explain the general absence of calcareous sediments and fossils from the beds laid down in the lagoons. On the other hand, the kaolinitic sediments may have been derived from kaolinized rocks which in the Malindi area would probably be the Duruma sandstone series, which largely accumulated as a lacustrine continental facies.

After the close of the lower Miocene sedimentation uplift of the Kenya coastlands exposed the sediments to erosion. It was on the eroded surface produced that the Marafa beds were subsequently laid down unconformably, the first bed being the basal pebble conglomerate. During the period of deposition the coast was drowned to an extent probably not exceeding 350 ft. Drowning of the Sabaki valley extended far up the river and to the west of the Coast range. The Marafa beds were laid down in the valley, and remnants of these Pliocene sediments can still be seen at a few localities. The most westerly occurrence seen during the present survey was on the flank of the valley between Matolane D.C. Camp and Sameta swamp, where about 6 ft. (2 m.) of earthy sediments with calcareous nodules are exposed. South of the Seventh Day Adventist Mission School, about four miles west of Shakama D.C. rest-camp, about 46 ft. (14 m.) of Marafa beds are exposed on the southern flank of the river. Here the sediments are akin to those across the river and are drab brown in colour and slightly clayey. Calcareous nodules are also present. On the north-west slopes of Merikano hill a further occurrence of the Marafa beds was seen, where they are in contact with the Argovian–Kimmeridgian Jurassic sediments. Here the red Magarini (Pleistocene) sand is exposed in a 16-ft. section overlying grey mudstones and drab unconsolidated sands.

Thus the Marafa beds overlap on to the Jurassic and Duruma sandstone sediments. They cover the Miocene-Jurassic junction. thereby concealing the relationship between these two groups of sediments.

The Marafa beds in the Malindi district probably do not exceed 350 ft. in thickness. Caswell (1953, p. 26) in the course of his discussion of his (Pliocene) Magarini sands in the Mombasa area, which the writer considers are equivalent to the Marafa beds in the Malindi area, states that 300 ft. (91 m.) are represented in the vicinity of Tangila hill. According to his stratigraphical table (*op. cit.* Table III, p. 8) he considers that the total thickness of these sediments in the Mombasa-Kwale area is 400 ft. Busk and de Verteuil (1938, p. 18) state that the total thickness of the Recent coral beaches and their (Pliocene) Magarini sands is probably under 500 ft. (152 m.).

(3) Pleistocene Deposits

(*a*) *The Magarini Sands* (Qt_1) *and the Red-brown Sands* (Qr)

The Magarini sands as defined by the writer are wind-blown unconsolidated sands which accumulated as coastal-dunes during the Pleistocene period, when the sea-level was approximately 120 ft. (36·6 m.) above present-day mean sea-level. They are generally a

vivid red colour and take their name from Magarini hill, where they are well exposed. They are also well-developed in the Arabuko-Sokoke forest, where they reach a height of over 700 ft. O.D. (213 m.), and are between 300 and 400 ft. (91–122 m.) thick. A bore-hole (C1159) drilled for Kaj Hansen, Ltd., in the Sokoke forest near Dida pierced at least 150 ft. (45 m.) of red sands. Unfortunately the samples from this bore-hole are missing and only the driller's log is available.

The sands on the whole are even-grained, and well sorted. The heavy minerals in them are mainly black opaque iron ores, probably ilmenite and magnetite, numerous rutiles and zircons. The quartz grains are encrusted with a thin film of ferric oxide. which is generally worn off when the grains are transported by water—the streams traversing the Magarini sands frequently contain white quartz sand. Lamination in the Magarini sands was not seen, and little cementing of the grains was observed. Where it does occur it is generally near the top of the dunes where ferric oxides are forming a ferricrete crust.

Occasionally the red Magarini sands appear to grade in depth into lighter-coloured unconsolidated sands. It is believed that these lower sands in which quartz pebbles are often found, are in fact the uppermost horizons of the Marafa beds. An example of this apparent passage can be seen in a cliff south of Madunguni. It is considered that similar cases occur in the Mombasa area, where Caswell (1953, p. 26) regards the red colouration of the sands as due to the concentration of ferric oxide at the surface.

The presence of a discontinuous ferricrete layer seen at the base of the red Magarini sands is considered to indicate a change of climate which produced the red Magarini sands in contradistinction to the underlying light-coloured sediments. In the Marafa scarp this ferricrete layer is about 1 to 2 ft. (0·3–0·6 m.) in thickness, while at Ulaya Nyari the iron-cemented sands are about 12 ft. (3·6 m.) thick. The cementation of the red sands has not, however, been as complete at Ulaya Nyari as at Marafa. The ferricrete layer is considered to represent an old land surface on which red wind-blown dune sands—the Magarini sands—accumulated. At Magarini hill exposures of the underlying light-coloured Marafa beds are not so distinct as in the Marafa and Ulaya Nyari scarps.

On and associated with this ferricrete layer at the base of the red sands, poor artifacts were found on the slopes of Goshi hill above Lake Baratumu, and elsewhere along the high flanks of the Sabaki river. Dr. L. S. B. Leakey of the Coryndon Museum, Nairobi, who examined the artifacts, considers that they may belong to the Levalloisian culture of upper middle Pleistocene age, but further collections of better specimens are necessary to verify this conclusion. The artifacts were hewn from quartz pebbles which militated against good fashioning. Occasionally an artifact was found in the base of the red Magarini sands, suggesting contemporaneous deposition of portions of the sands with the discarding of the artifacts. Where this has taken place the artifacts may have been transported, or through later wind action the Magarini sands may have spread over a land surface that was once trodden on by ancient Man. Red sands may have started to accumulate in lower Pleistocene times, and the reddish sands in the lagoonal Pleistocene sands (Pls) are considered to be the re-worked equivalents of the lower Magarini sands. The anomalous condition whereby the artifact and ferricrete layer of upper middle Pleistocene (?) age occur at the base of the red Magarini sands of what appear to be pre-upper middle Pleistocene age is explicable by the possibility that the overlying red sands may, in fact, have been re-worked and re-deposited over this horizon so that they are actually younger than their apparent equivalents elsewhere. There are no means in the field of distinguishing the portion of the sands that has been re-worked from that which initially accumulated. It is considered that, although the bulk of the red Magarini sands accumulated as coastal dunes when the sea level stood at 120 ft. O.D., that is, contemporaneously with the growth of the mid-Pleistocene coral reefs, sands of several ages may have been included under the heading of Magarini sands.

During middle Pleistocene times, when coastal dunes were accumulating along the shore-line, superficial deposits of red and reddish-brown sands and soils (Qr) were also developing in the hinterland. To avoid concealing the picture of the rocks they overlie these sands and soils have not been assigned a separate colour on the map, but are distinguished by letter symbols. In places the surficial sands may be about 20 to 30 ft. (6–9 m.)

thick, but generally they do not exceed 5 ft. (1·5 m.). They vary in colour—being brownish where they overlie the Mariakani sandstone group, yellowish-red on the Mazeras sandstones, and in a few localities they are as intensely red as the Magarini sands in the Sokoke forest. Between Kakokeni and the Mangea hills, and around Dakatcha, they are thick and brick-red in colour when dry.

Like the Magarini sands, these sands are associated with imperfect artifacts and a discontinuous ferricrete layer. Frequently at their base a thin quartz pebble-bed, in which the artifacts often occur, can be seen.

The reddish-brown sands mantle a great portion of the Malindi area, concealing most of the geological junctions. They rest unconformably on all the pre-existing rocks. Like most superficial deposits their development has taken place over a wide range of time—probably continuously since Pleistocene times.

(*b*) *Contemporaneous and Post-Magarini Pleistocene Deposits*

Grouped under this heading are sands, the fossil coral reef, and associated breccias. Lithologically many of the sands are similar to those already described, but stratigraphically they are younger.

Contemporaneously with the accumulation of the Magarini coastal dunes, while the sea-level was about 120 ft. (36·5 m.) above present sea-level, sands were accumulating on the terrace cut by the sea during this period. These sands (Pls) accumulated between the Magarini dunes and the off-shore coral reef that was growing further to the east.

(i) *Pleistocene Sands* (Pls)

The Pleistocene sands are generally light yellowish and frequently contain well-rounded quartz pebbles. They are difficult to distinguish from the Marafa beds for, like them, they are clayey. Caswell (1953, p. 27) considers that they accumulated as lagoonal sands—a view with which the writer concurs. Near the coral reef they are mixed with calcareous fragments derived from its disintegration. Numerous wells dug between the fossil coral reef and the Magarini dune sands all reveal the variable nature of the sands. A typical section is as follows, the details being obtained from a newly dug well in the Gedi Agricultural Settlement, about half a mile (0·8 km.) from Gedi towards Mida:—

Ground level	Feet
Fine buff to yellow sand	0–12 (0–3·66 m.)
Buff to grey clayey sand with some grey clay lenses ..	12–29 (3·66–8·8 m.)
Coarse quartzo–felspathic sand	29–35 (8·8–10·6 m.)

At 35 ft. depth lumps of coralline limestone were encountered, and slightly saline water was struck.

In some cases sand from the Magarini dunes was washed into the lagoons and incorporated in the lagoonal deposits. Patches of reddish-brown sand can be seen on the surface at the foot of the dunes and a little farther to the east, in places where it is unlikely that they could have been deposited by stream action. Brownish sands were also seen in a well which was being dug at Kikuyuni village during April, 1951. The section in the well is as follows:—

	Feet
Dark grey sand	0–7 (0–2·13 m.)
Light grey sand	7–11 (2·13–3·34 m.)
Grey slightly sandy clay	11–13 (3·34–3·95 m.)
Grey sand with red iron-stained patches and quartz pebbles	13–14 (3·95–4·25 m.)
Grey clay with lenses of brown sand	14–17 (4·25–5·18 m.)
Grey slightly clayey sand	17–23 (5·18–7 m.)
Grey sandy clay with iron-stained patches	23–44 (7·0–13·38 m.)

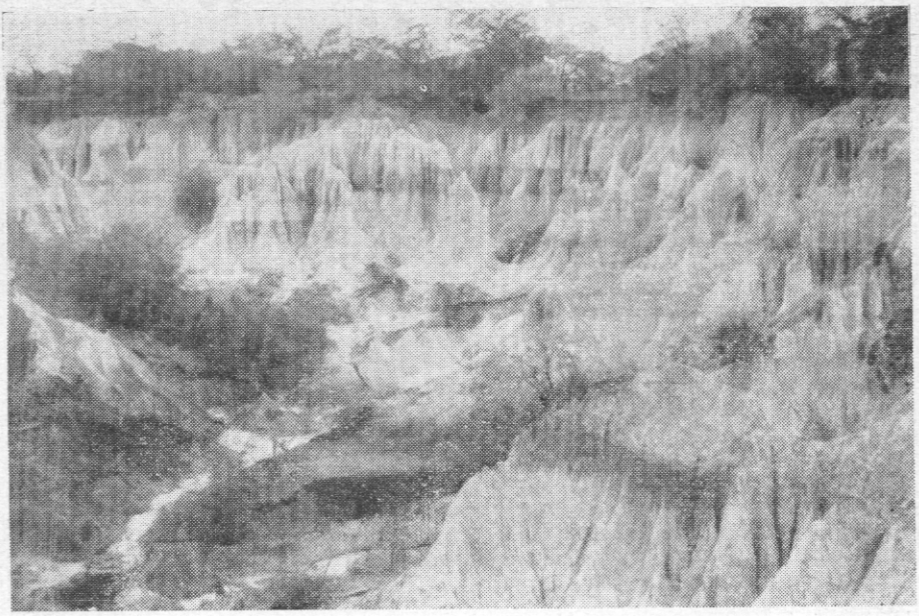


Fig. 1.

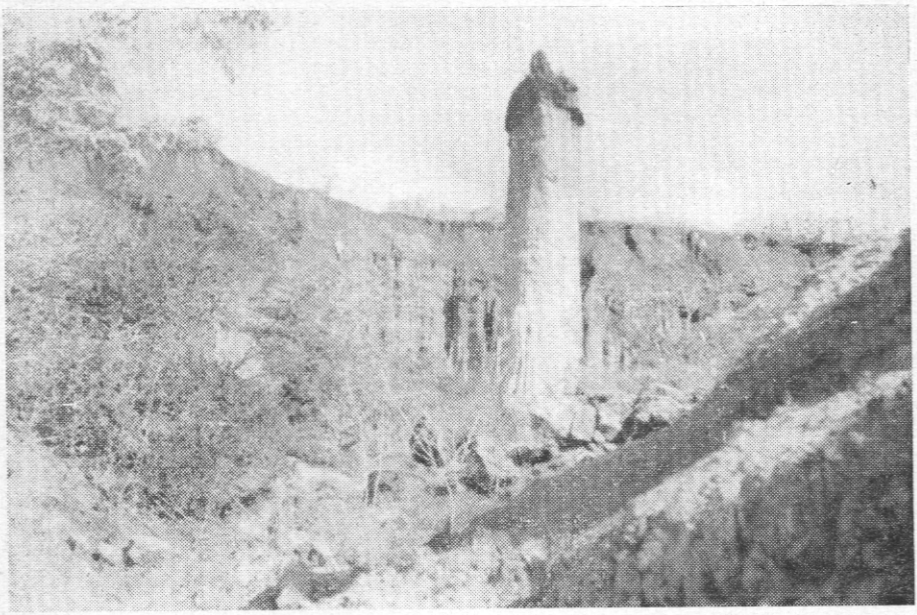


Fig. 2.

Plate I.—Erosion scarps in the Marafa beds in the Malindi area.

Fig. 1.—Marafa. Note the capping of ferricrete and reddish-brown sands covering the light-coloured Marafa beds.

Fig. 2.—Ulaya Nyari, about four miles S.S.W. of Marafa, with "earth" pillar. The red sand and ferricrete layer is much thicker here than at Marafa.

(Photos: A. O. Thompson)

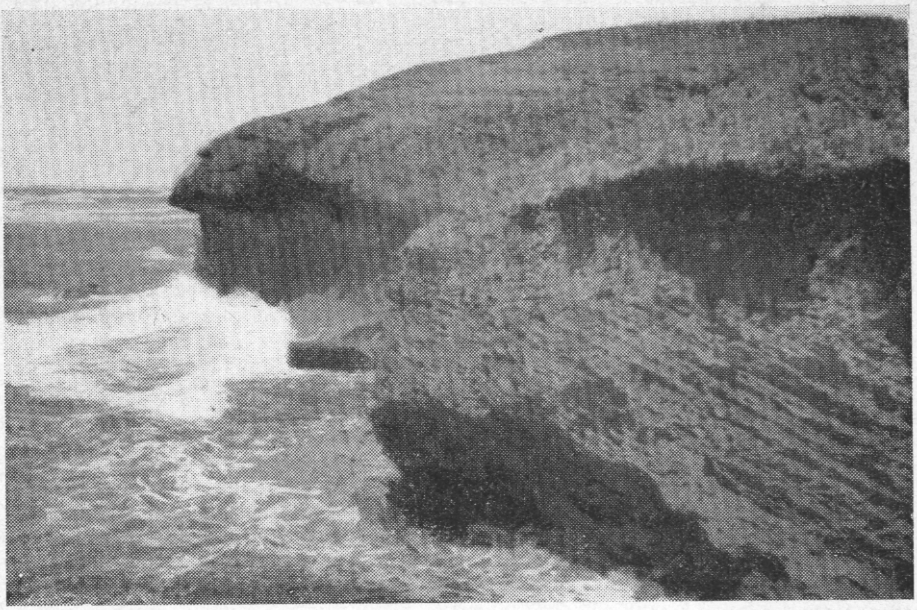


Fig. 1.

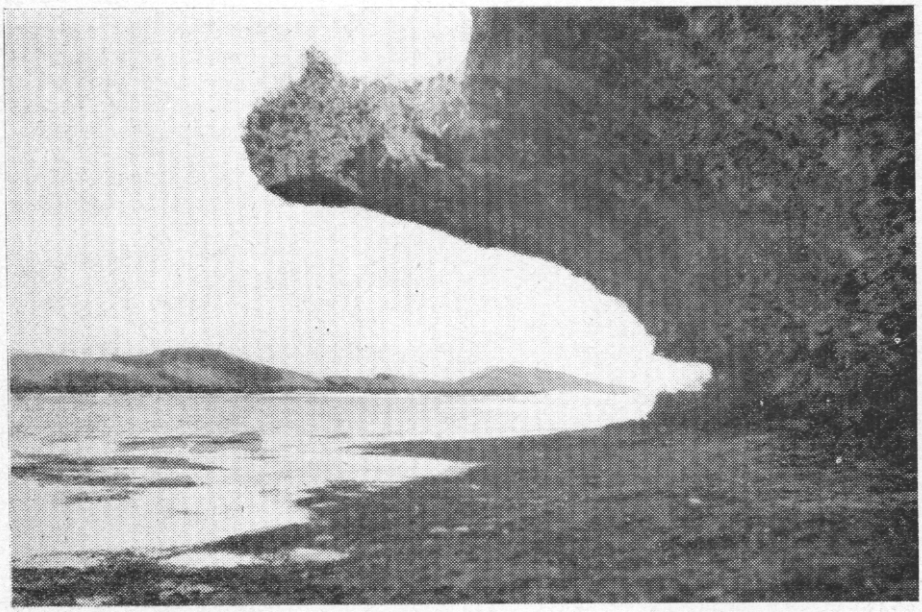


Fig. 2.

Plate II—Pleistocene "coral" limestones, Malindi area.

Fig. 1.—Cemented "coral sands" (coquinas), showing cross-bedding. Watamu headland, about 14 miles south of Malindi.

Fig. 2.—Undercutting of the fossil coral reef. Watamu bay. The chain of islands in the distance is composed of coquinas.

(Photos: A. O. Thompson)

(ii) *Fossil Coral Reef and Coral Breccia* (Plc)

The fossil coral reef extends throughout the whole length of the coast in the Malindi district, except to the north of Mambrui. It varies in outcrop width from about 600 yards (548 m.) north of Malindi to about four miles (6·4 km.) between Msabaha and the coastline.

On the weathered surface it is often covered with lichens and is light to dark grey in colour, but the fresh exposed surface is light yellow or dirty white. Solution of the calcareous material of the limestone has taken place locally, leading to the formation of sink-holes in the reef which are often filled with iron-stained sands. The iron oxide staining has frequently spread to the adjoining limestone.

Krenkel (1924) divided the fossil coral reef limestones into the "Riffkalk" which is the true coral reef and the "Rifftrümmerkalk"—the coral breccia. Superficially there is practically no means whereby the true reef limestone can be distinguished from the coral breccia. Microscopically the breccia is seen to be cemented by calcite, which may or may not be iron-stained. Fragments of coral, gastropods, molluscs and some foraminifera are frequently seen in the breccias, as well as quartz, hornblende, garnet, magnetite, occasional microcline felspar grains and a few biotite flakes. Specimens 66/188 and 66/322 from near the bridge over the Sabaki river, are typical examples of these coral breccias, the latter showing some mixing with fragments of limestones from the Baratumu Miocene beds. Stratification in the breccia can be seen in an undercut cliff on the north side of the Sabaki river, about 1½ miles (2·4 km.) west of the bridge over the river near its mouth. The breccia is lying practically horizontal.

Although the terms "coral reef" and "coral breccia" are used, it is of some import to note the paucity of corals both in the field and under the microscope. Corals constitute a very small proportion of the so-called coral reef along the Malindi coastline—probably not more than 20 per cent—the remainder comprising calcite, quartz grains, numerous shell fragments, and a microfauna. Under the microscope it is often difficult to distinguish the coral reef from the coral breccia, so that a distinction can be made only on field evidence, and this in the Malindi area is rare. Strictly the coral reef could better be named a "coquinoid limestone" where nearly complete cementation of the material has taken place. The following definition of a coquinoid limestone is given by Pettijohn (1949, p. 301), namely that it is a [cemented] deposit consisting of coarse shell fragments which have accumulated in place. The term has not been adopted in this report, however, as the name "coral reef" is in common use locally, and as it was considered that some confusion might arise with the term "coquina", which it is proposed should be adopted for a certain type of cemented coral "sand" in the Malindi area.

Dolomitization does not appear to have taken place to any large degree in the fossil reef or breccia in the Malindi area. More intensive sampling and analysis are necessary, however, to establish this conclusively.

Gregory, (1921, p. 78) while considering the variations in the level of the coral reef, records that the reefs are lower at Malindi than farther south. West of Mambrui the highest he records is 40 ft. (12·2 m.), whereas on Mombasa island at least 80 ft. (24·4 m.) has been recorded for the height of the coral reef. Caswell (1953, p. 29) reports a maximum height of the reef, near Ngombeni, of 85 ft. (25·9 m.). Near Kibongo, about two miles (3·2 km.) south of Malindi the coral reef surface is about 70 ft. (21·4 m.) above sea-level. (There is no reef opposite the Malindi hotels.) Gregory (*loc. cit.*) considers that this variation in the height of the recorded levels of the coral reef must have been due to movements of the land and not to a rise or fall of the ocean surface, but Caswell (1953, p. 29) believes that the reef has been considerably eroded so that it is not unreasonable to assume that where fully developed its top once stood as much as 100 ft. (30·5 m.) above present sea-level. It is considered that the differences of level reported by Gregory are more likely to be due to erosion rather than to unequal uplift of the land.

(iii) *Coquinas* (Qt_2 *and* Qt_4)

Coquinas are clastic deposits and the name is applied to more or less cemented, coarse shell debris that has been washed together by wave or current action (Pettijohn, 1949, p. 301). Fay (1920) defined a coquina as a "coarse-grained, porous, friable variety of limestone, made up chiefly of fragments of shells of living or recently extinct species of molluscs and of coral cemented together as rock". The rocks in the Malindi area to which it is proposed

the term "coquina" should be applied, are white, porous, friable and coarse-grained. The calcareous cement in the majority of the exposures has only partly cemented the grains, with the result that the rock is easy to quarry. It is for this reason that it is the chief building stone in the Malindi area, where it is quarried, for example, on the landward side of Watamu headland. Formerly it was also quarried at Vasco da Gama headland, near Malindi. The coquinas in the Malindi area often contain a rich microfauna—chiefly foraminifera (Fig. 2A). Angular quartz grains are commonly present but generally form less than 20 per cent of the bulk of the rock.

Contemporaneously with the growth of the coral reef, "sands" accumulated on the coastal shelf, grains being derived largely from the disintegration of the coral reef and shells, together with allogenic minerals such as quartz, hornblende and garnet, These "sands" probably accumulated as off-shore bars during upper middle Pleistocene times. As they became exposed during the subsequent marine recession, accretion took place to produce dunes up to more than 60 ft. (18 m.) in height, which were cemented by the action of percolating rain-waters. The Watamu headland is composed of such cemented "sands" (Plate II, Fig. 1) and stands 61 ft. (18·6 m.) high. The numerous mushroom-shaped islands in the vicinity of Watamu are all composed of these coquinas, and their linear pattern suggests that they form part of the same original off-shore bar and dune.

The shape of the islands has been produced by the undercutting effect of the waves, the undercutting being naturally greater on the seaward side. As the coquinas are not so well consolidated as the fossil coral reef, the undercutting does not proceed to such a great degree as in the reef limestones (Plate II, Fig. 2). On account of the coral reef on the seaward side of these islands, no storm-wave platforms have been developed on them—the reef reducing the force of the storm-waves on their landward journey.

The Watamu and Vasco Da Gama headlands, composed of coquinas, are land-tied by loose sands, probably of Recent age. Miss McKinnon Wood (1930, p. 226) stated that the reef forms the Vasco Da Gama headland. The false-bedding, so typical of the coquinas (Plate II, Fig. 1), in the rock at Vasco Da Gama headland indicates its clastic and allothigenous origin.

As in the case of the coral reef surface solution of the calcareous cement has taken place in the coquinas, producing sink-holes. Cases were observed where some of these sink-holes had become subsequently filled with red sand. Staining by iron oxide of the adjoining coquina has resulted (specimen 66/104).

The coquinas probably belong to two different ages. Those that are quarried as building-stone at Kibongo hill, and those at Kilimanjaro and near Roka, overlie the fossil coral reef at altitudes of about 100 ft. (30·5 m.), whereas the islands around Watamu, and the Watamu and Vasco Da Gama headlands stand on a platform of the coral reef exposed at low-tide at the present time. The former coquinas were probably initiated when the 120-ft. (36·6 m.) coastal terrace was cut, and the latter on one of the lower terraces, probably the level marked B (−25 ft.) on the submarine profiles of Fig. 3, p. 47. A study of the micro-fossils may verify this statement.

(*c*) *Upper Pleistocene Sands—Gedi Beacon Sands* (Qt_3)

During the slow retreat of the sea from the 120-ft. (36·6 m.) terrace in upper Pleistocene times, the loose sands on the sea-floor were probably accumulated in low ridges. As some of these ridges became exposed, wind increased their height by piling up the loose sand. Locally the sands so accumulated reach fair heights—at Gedi Beacon hill, of which the summit is 131 ft. (40 m.) above O.D., they are about 70 ft. (21·4 m.) thick. The sands, which are unconsolidated and generally brownish-red in colour, appear to contain no fossils. Where they have not been blown into dunes they present the typical "swell-and-swale" topography so characteristic of slowly emergent coastlines (Johnson, 1919). The rice crop in the Malindi area is cultivated in the hollows of such ground. Sands which probably also belong to this group are those of the long red sand dunes which have been piled up between the mouth of the Sabaki river and Mambrui.

(4) Recent Sediments

(*a*) *Recent Marine Sediments* (*Rm*)

Sands constituting the tombolos, which tie the Watamu, Vasco Da Gama and Ras Ngomeni headlands to the mainland are probably of Recent age. They are generally but not always unconsolidated, white or light grey in colour, and often support a good cover

of vegetation. Around Watamu village dense coconut groves are present on these sands, which rise only about 6 ft. (1·8 m.) above high tide mark. They are mixed with wind-blown beach sands, which contain numerous shell and coral fragments as well as many foraminifera. The shores of Mida Creek are flanked by these white sands, which here, are rich in mollusc shells; it is on these sands that the mangrove trees grow.

Along the beach in the south-eastern corner of the area surveyed, the beds of this age are cemented by calcite and consist of dirty-white, laminated, coquinas (specimen 66/288), which are rather more quartzose than the coquinas described on an earlier page. On Silversands beach, south of Malindi township, a well-cemented black beach concentrate outcrops at low-tide (specimen 66/107). A slide of this rock shows an abundance of garnet and opaque iron ore grains (magnetite and probably ilmenite) cemented by calcite. Hornblende, quartz, sphene and a few grains of rutile, felspar, staurolite, epidote, kyanite, augite and enstatite are also present. Chemical tests indicated that the specimen contains abundant titanium but none of the rare metals (cerium and yttrium groups) nor zirconium. It is not radio-active. Similar minerals are also present in a beach concentrate sand found between Silversands beach and Casuarina point. Beach sands in Natal, South Africa, where reserves of such titanium sands are large, contain the same suite (Frankel *et alia*, 1951). It is doubtful if reserves in the Malindi district are likely to be as great.

Elsewhere along the beaches in the Malindi area other recent cemented sands occur, such as near some of the Malindi hotels, where they are occasionally exposed. These sands are generally a pale yellow or buff colour, comprising large rounded quartz and felspar grains partly cemented by calcite into a sandstone. Hornblende grains are also present but no fossils such as foraminifera were observed.

To the east of Janaheri on the bar linking Ras Ngomeni to the mainland, a grey cemented sand (specimen 66/321) was found containing numerous gastropods and a rich microfauna was found in the debris from a well. The calcite in it is turbid, and the quartz and felspar grains are of greatly varying size. The fauna suggests that the Ngomeni tidal flats were formerly of greater extent—a statement also applicable to Mida creek. Heavy mineral residues extracted from the sands consist mainly of hornblende grains with fewer grains of garnet, magnetite, rutile, sphene and zircon. The bulk of the sand grains is quartz with a few felspars.

A former arm of Mida creek once extended as far south as Roka. Through the accumulation of wind-blown recent sands and detritus washed in across this arm, a salt-water lagoon was formed, isolated from the rest of the creek. With natural draining and evaporation a deposit of gypsum accumulated in the basin so formed and, in a well a little west of Roka village, a four foot (1·2 m.) bed of gypsum crystals can be seen immediately below ground surface. About 500 yards (457 m.) north of this well on the same low ground gypsum crystals are exposed on the surface, and it is believed that the gypsum bed extends even farther. Incorporated in the gypsum bed are numerous small gastropod shells and other microscopic mollusc shells similar to those found at the present-day along the shores of Mida creek.

(*b*) *Recent Terrestrial Deposits* (*Rt*)

Along the coast, between the mouth of the Sabaki river and Mambrui and between that village and Ras Ngomeni, there are wind-blown white or creamy-coloured unconsolidated sands which have accumulated in dunes generally over 100 ft. (30·5 m.) in height. The dunes are aligned parallel to the coastline.

The sands are derived in the main from the sands brought down by the Sabaki river and deposited at its mouth. Their marked presence to the north of the river is striking—a feature controlled by the stronger monsoon winds from the south-east and by the northwardly set of the along-shore currents. The sands are composed of coarse quartz grains associated with smaller grains of hornblende and a weakly magnetic iron ore, probably ilmenite. The coarse quartz grains are largely angular and sub-angular in outline, and not well-rounded as is usual in wind-blown sands, probably owing to the short distance that they have been carried by wind.

Other smaller deposits of wind-blown sands of Recent age are to be found in small bays elsewhere along the coast in the Malindi area, and more often than not, they have accumulated on the northern side of the bays. These sand-dunes, on account of the porosity of the sands, permit practically no run-off of rain-water, and many successful wells yielding fresh water occur at their base, often within a few feet of the shore-line.

In the hinterland where the reddish-brown sands (Qr) are not thick, grey to black clayey soils have developed. They have usually formed in areas of poor or internal drainage

(4) Igneous Intrusions

Miss McKinnon Wood (1930, p. 224), in her discussion on the igneous rocks in the Malindi area, stated that Parsons discovered intrusions in the Sabaki and Koromi valleys, as well as east-north-east of Shakadula. From their relation to the Upper Jurassic limestones she considered that they are of post-Kimmeridgian age, and probably Cretaceous. She also stated and showed in a section that an outcrop of igneous rock occurs in the Magarini sands about two miles (3·2 km.) west of Garashi, the implication being that the igneous rock is intrusive into the Magarini sand, which she considered to be probably Miocene to Pliocene in age. This is thought, however, most unlikely for the small hill formed by the intrusion is surrounded by alluvium of the Sabaki river, and owes its preservation to the resistance of the rock to weathering in comparison with the surrounding softer rocks. The remaining exposures of this dyke are partly concealed by the reddish-brown sands (Qr) which are considered to be contemporaneous with the Magarini sands.

The writer considers that the intrusions are post-lower Miocene (post-Baratumu Beds) and pre-Marafa beds (pre-upper Pliocene) in age. Until more conclusive evidence as to the age of the Marafa beds is available, the age of the intrusions is provisionally placed in the upper Miocene or Lower Pliocene. It will be noted that this is somewhat in conformity with the age of the start of the Gregory Rift Valley vulcanicity. There is no reason to believe that all the dykes are not consanguineous and derived from the same source of magma.

Unfortunately Parsons does not describe these occurrences in his paper (1928) although on his map (*op. cit.*, p. 67) he shows a large igneous intrusion north of the Sabaki river between Shakadula and Marafa. On a fair copy of his field map presented to the Mines and Geological Department, Nairobi, he shows some igneous dykes, one on the western slopes of Mwangudo hill, and another in the Sabaki valley between Shakama and Mkondoni. The former dyke was not seen during the present survey, and the latter is probably the occurrence described as nepheline basalt by Miss McKinnon Wood (1930, p. 217).

A list of the localities where igneous rocks were observed during the present survey follows:—

Locality	Present Survey Specimen No.	Identification	McKinnon Wood, 1930, 1938	
			Specimen Locality	Identification
1. Shakama D.C. Camp ..	66/328	basanite	58	nepheline basalt
2. Between Garashi and Baricho	66/144	olivine nephelinite	65	nepheline basanite
	66/145	basanite		
3. Hill on north side of Baricho–Shakadula road	66/148	olivine nephelinite	88	ankaramite
4. About 2 miles north of Shakadula	66/151	basanite	90 and 91	olivine trachy-basalts
5. Between Mkondoni and Lango Baya 6. Mkondoni 7. Between Garashi and Baricho (one occurrence)	No specimens collected (float blocks only)		92	nepheline basanite

The specimens of igneous rocks collected by Miss McKinnon Wood were described by Miss A. Neilson (in McKinnon Wood, 1930, p. 217) as follows:—

(*a*) Specimen 58—stated to be from the Merikani–Shakama road near Mkondoni but, from the position marked on Miss Wood's map (Plate XXIII), probably corresponds with specimen 66/328 collected during the present survey near the D.C. camp at Shakama—nepheline basalt (=basanite of present account).

(*b*) Specimen 65—from hillock two miles (3·2 km.) west of Garashi—nepheline basanite.

A specimen collected near Mkondoni by Miss McKinnon Wood later, at her locality 92, was described as nepheline basanite by Tyrrell (in McKinnon Wood, 1938, p. 13). From the position marked on the accompanying map (*op. cit.*, Plate XII), it appears that this is not the same place as her earlier locality No. 58. Locality 92 probably corresponds with the Mkondoni locality referred to in the tabulation given above, from which no specimen was collected.

Essentially the rocks are olivine-bearing basaltic rocks with varying proportions of nepheline, i.e. they are basanites or olivine nephelinites according to whether or not they contain plagioclase felspar. The specimens collected during the present survey between Garashi and Baricho (66/144, an olivine nephelinite and 66/145, a basanite) as well as that collected from the hillock alongside the road between Baricho and Shakadula (66/148, olivine nephelinite) are those that show nepheline in any quantity. The nepheline in these specimens was checked in thin section by the methylene-blue staining method, described by Shand (1939, p. 508).

Specimen 66/144 was collected from the same locality as Miss McKinnon Wood's No. 65. Although the writer's three specimens were collected from three different localities, the N.W.–S.E. alignment of the exposures suggests a single dyke. Miss McKinnon Wood (1930, p. 225) stated that the intrusions appear to be associated with faulting, but no critical evidence was seen during the present survey.

A specimen of basanite, 66/151, was collected from the eastern flank of a tributary to the Koromi river about two miles north of Shakadula. The minerals in the rock are described in the sub-title of Fig. 2C. The presence of brown interstitial glass probably indicates that the specimen was taken near the edge of the intrusion. The locality is near Miss McKinnon Wood's Nos. 90 and 91 (1938, p. 112), in the neighbourhood of Mwambiri, where she collected olivine trachybasalts. Tyrrell identified as ankaramite* a rock collected by Miss McKinnon Wood (1938, p. 113) at her locality No. 88 (Shakadula) in the Koromi valley about four miles north-east of Baricho rest camp, west of the track to Shakadula. Specimen 66/148 was the nearest to this locality collected during the present survey and is identified as olivine nephelinite. Another specimen (66/328) of basanite collected during the present survey was taken from an outcrop on a hillock about 400 yards north of the Shakama D.C. camp where Miss McKinnon Wood (1930, p. 225) found only loose boulders. It is nearest her locality No. 58 where the igneous rock was identified as nepheline basalt by Miss Neilson (*op. cit.*, p. 217). It contains large euhedral and partly resorbed crystals of olivine with iddingsite along the fractures. Phenocrysts of augite are also present with numerous subhedral grains of the same mineral in the ground-mass. Opaque iron ores, probably magnetite, are also present, as is common in most of the other specimens collected. Felspar prisms probably anorthite, are scarce. Felpathoids are present interstitially. Other interesting features are overgrowths of augite with perfect shape, occurring on "rounded" olivines; xenocrysts of quartz surrounded by zones of (1) yellow glass, (2) augite crystals (in the case of one small xenocryst there is now no quartz, only the two zones); and occasional highly resorbed augites.

Of interest is the occurrence of a "tuff" identified by Miss Neilson from Miss McKinnon Wood's collection. A specimen (66/311) was collected from the same locality, that is, at the D.C. camp, Baricho, during the present survey, but is believed to be a fault-breccia that formed along the Duruma–Jurassic fault contact. It is considered that the "tuff" identified by Miss Neilson was, in reality, a fault-breccia also.

VI—STRUCTURE

Much has been written on the coastal structures in Kenya, particularly those in the more accessible parts around Mombasa. In general, the structure of the country in the Malindi area is in conformity with that already observed around Mombasa. The fault

*A melanocratic basaltic rock, poor in plagioclase and richer in augite than in olivine.

trends show a marked similarity, and minor folding, although not as distinct, appears to be comparable with that observed farther south (Fig. 1). Caswell (1953, p. 49, *et. seq.*) has dealt recently in some detail with the structures in the Mombasa–Kwale area, where all members of the Duruma Sandstone Series are present, and for an analysis of the structures in the Lower and Middle Duruma Sandstone groups, which are not present in the Malindi area, his and Miller's (1952) report on the Mariakani–Mackinnon Road area should be consulted.

Only the upper horizons of the middle Duruma sandstones occur in the Malindi area. They exhibit a regional dip of about 8° E.S.E. Dips are generally greater along the western boundary of the area and tend to flatten towards the east—a fact noted also by Busk and de Verteuil (1938, p. 15). Just beyond the bounds of the present area, along the Sabaki river near Kisiki cha Kizungu a westerly dip was recorded, whereas within the area the nearest dip readings were easterly. The presence of a fault here may be suspected. Gregory (1921, p. 55) reported the presence of gneiss from about 39° 25′ to 39° 30′ E. just west of Janjani, suggesting a fault of some considerable throw, or an unconformable contact. Gregory implied the latter. Recent mapping by L. D. Sanders has shown that the Duruma sandstones are faulted against Basement system rocks between 39° 12′ and 39° 17′ E. West of the inlier it has been possible to map numerous faults.

An examination of aerial photographs of the north-western corner of the Malindi area revealed a change in strike direction of the Mariakani sediments along the Sabaki river. This was borne out in the field. The strike of the beds in the most westerly portion, which dip in the region of 20° N.E., changes farther east in the vicinity of Shakahola to one of a more northerly character. The dips of the sediments decrease at the same time. This change in strike is believed to be due to a slight disconformity in the sedimentary sequence; it is reflected in the course of the Sabaki river. Farther south, other changes in strike directions suggest minor folds in the sediments rather than disconformities. Caswell (1956, p. 35) in a later paper reporting on the area between Kilifi and Mombasa suggests the presence of broad shallow anticlines and synclines in the Mariakani sandstones along the Kenya coastlands. He refers to the S.E. regional dip and infers that a synclinal axis occurs in the Kilifi area in the vicinity of the Kabanini ridge. The regional dip to the south-east in the southern parts and to the north-east in the northern parts of the Malindi area suggests the presence of an anticlinal axis in the vicinity of Mangea hill, although anomalous dips occur on either side. The trend of the axis would thus be easterly, but beyond this, the writer believes that at this stage the evidence is too scanty to be dogmatic. It must also be borne in mind that in this locality too, an E.W. fault cleaves the Mangea hills.

In the south, near Jila, a minor fold in the form of a small dome is inferred from field evidence. The inference has been reached, however, from observations of surface dips in an area where the beds are rarely exposed to any appreciable extent, and it is possible that distortion of the beds, by movement of the more argillaceous members under slight pressure, may account for the appearance of a low dome in this area. Caswell (1953, p. 49) has also noticed that the surface dips in these rocks frequently conform in a modified degree to the topography. This distorting effect by movement of the more shaly beds in the Mariakani sandstone group is believed to be responsible for the westerly dips recorded at various places in the Malindi area, particularly along the Sabaki river.

Caswell (1953, p. 12) noted local steepenings of the dips near the junction between the Mariakani and Mazeras sandstones, but this has not been noticed in the Malindi area.

Where faults in the Mesozoic rocks have been observed they appear to be normal. They tend to follow two main trends, viz. (*a*) north-south, and (*b*) east-west. Where it was possible to see the fault-lines, the following directions were obtained:—

Fault	Direction	Throw (approx.)
(1) Duruma–Jurassic contact in the Rare river	22° E. of North	?
(2) West of Kwa Dadu bore-hole C997 ..	42° W. of North	200 ft.
(3) Vitengeni galena-barytes vein	10° E. of North	small, probably less than 100 ft.
(4) Jilore fault	10° W. of North	20

The strikes of other, inferred, faults are as follows:—

Fault	Direction	Throw (approx.)
(i) Mangea hills	88° W. of North	400
(ii) Duruma–Jurassic contact in the Sabaki valley	8° E. of North	
(iii) Mwahera fault-breccia	25° W. of North	

From the above it can be seen that the bulk of the observations reveal a major N.–S. trend with subsidiary trends along N.W.–S.E. and E.–W. It will be noted that the fault contact between the Duruma sandstone series and the Jurassic sediments in the east, and in the south in the Rare valley, is in conformity with the major trend in the Mombasa area viz. N.N.E.–S.S.W., whereas the faults farther north trend approximately N.–S. The Mangea hills are considered by the writer as the remnants of a horst. The main fault on the eastern side of the hills is not seen, however, but its presence can be inferred from the strike of faults in the Vitengeni (Rare) river to the south, and in the Sabaki river to the north of the hills. The foot of the hills on the eastern side is covered with a thick mantle of reddish-yellow sandy soil derived from the hills, which also obscures the Jurassic sediments in this part.

On the western side of the hills, evidence of faulting is clearer. To the west and south-west of Kwa Dadu a small fault-scarp of about 20 ft. in height can be seen, and to the north-west of Mwahera evidence of this fault is gained from a ferruginized fault-breccia. In the writer's opinion, the faulting on the western side of the Mangea hills is connected with the fault-zone at the Vitengeni mine. The presence of barytes in the Kwa Dadu fault seems to support this.

The Kwa Dadu fault strikes N.W.–S.E. and appears to be normal. The strike of the Mwahera breccia is N.N.W.–S.S.E.

Striking almost E.–W. is another fault with a throw of about 400 ft., which cleaves the Mangea hills. The group of hills on the south of the fault is on the upthrown side, creating a topographic anomaly as the southern hills are the lower in altitude. The water-course on the eastern slope follows the fault-line fairly closely. The presence of other smaller faults in the northern block is probable as dips in the Mazeras sandstone there are very irregular in comparison with those in the southern block.

The eastern extension of the E.–W. fault which cleaves the Mangea hills is unfortunately concealed beneath a thick cover of Magarini sands. It may be this fault, however, that is responsible for the fact that only the upper stages of the Jurassic sediments are exposed in the northern parts of the area. If this is correct the fault is dated as post-Jurassic in age.

Pre-Jurassic faulting is believed to have occurred to the west of the Mangea hills. This is the near-N.–S. faulting with which the Vitengeni galena-barytes vein in connected. The Kwa Dadu fault of N.W.–S.E. trend, on account of the occurrence of barytes crystals in the fault breccia, can probably also be connected with the same epoch of faulting. No barytes has been recorded from the Duruma-Jurassic faults and it is, therefore, considered that the boundary faults are not of the same age as the mineralized faults.

So far as can be seen the Cainozoic rocks are not much faulted—only one fault was seen in them, near Jilore. On account of their rather unconsolidated nature, and the frequent extensive cover of Magarini sands, exposures of faults would not be expected, so only inferences can be made as to the presence of faults in these rocks.

Mention may be made of what may be a small thrust fault, viz. the Jilore fault. Movement has taken place over a distance probably not exceeding 50 ft. (15·2 m.) along a fault-plane striking at 170° and hading 30° to the east. Grey sands and clays belonging to the Pliocene Marafa beds on the eastern side of the fault abut against sand containing red iron-stained patches, which probably belong to the uppermost horizons of the Marafa beds, on the other side of the fault. The lateral extension of this minor fault could not be seen and no great importance is attached to it, as it may be the result of contemporaneous slumping in the unconsolidated Marafa beds.

Stockley (1928, p. 52) has recorded evidence of faulting in the late Miocene in Zanzibar. The rifting in the Gregory Rift Valley is also believed to have reached its maximum intensity during this period.

The following sequence and ages for the faults in the area is suggested:—

(*d*) Jilore	Post-Marafa (upper Pliocene or lower Pleistocene (?))
(*c*) Rare and Sabaki rivers (Duruma–Jurassic contact)—rejuvenation	Pre-Marafa (lower Pliocene (?))
(*b*) Mangea hills and Silala dam ..	Post-Jurassic
(*a*) Kwa Dadu, Mwahera, Vitengeni and Rare – Sabaki rivers (Duruma–Jurassic contact) ..	Pre-Jurassic (J_1) sedimentation. End Triassic–lower Jurassic (?)

Caswell (1956, p. 38) has put forward the following ages for the coastal faults in the Mombasa and Kilifi areas:—(*a*) mid-Triassic, (*b*) post-Cretaceous, (*c*) mid-Pliocene. The similarity between the ages postulated for the faults in the Kilifi, Mombasa and Malindi areas is noteworthy, and until more evidence is forthcoming it would appear that tectonic movements took place during the following periods:—

(*c*) Lower or Middle Pliocene

(*b*) Post-Cretaceous

(*a*) End-Triassic

VII—GEOLOGICAL HISTORY

It can be accepted, in view of the sediments found, that towards the end of the Palaeozoic era a gentle downwarping of the margin of East Africa was initiated. Such a downwarping between Kenya and Madagascar could perhaps have developed as a secondary depression in the aftermath of the "Gondwanide" folding along the Samfrau orogenic zone (Du Toit, 1937, p. 80). Du Toit (*op. cit.*, p. 81) recognised the East African–Madagascan trough as being an exception, for he said: "Over the foreland proper, the successions are conspicuously thinner, while overlaps and unconformities are common and sometimes widespread, exceptional being certain troughs in East Africa and Madagascar, which suggestively adjoined the Indo-Madagascar gulf." That this gulf was not directly linked with the Samfrau geosyncline but rather with the northern Laurasian (Tethys) geosyncline is evidenced by the European genera of fossil plants, *Ullmannia* and *Voltzia*, found in the Duruma Series of Kenya and in equivalent rocks in Tanganyika and Madagascar, but unknown elsewhere in Africa (Du Toit, 1937, p. 122).

The Duruma sandstone series consists of the sediments deposited on the western margin of the Kenya–Madagascar trough; those deposited on the eastern margin are to be seen in Madagascar. The sediments are considered to have been deposited in environments that were sometimes marine, sometimes lacustrine and sometimes terrestrial. The Mariakani and Mazeras sandstones, which are the only parts of the series represented in the Malindi area, mark the later stages of the warm and semi-arid conditions that existed in Permian times and attained their maximum in the Mazeras group (upper Triassic–(?) lower Jurassic). Towards the close of this period of aridity, the shallow lakes decreased in size and dried up, and an increase of aeolian deposition took place. This is noticeable in the Mazeras sandstones for in the upper horizons at least this group is typically non-calcareous, whereas the Mariakani sandstones are generally calcareous and intercalations of impure limestones are present. These sediments also contain soluble salts, which can commonly be seen in the dry season as efflorescences on outcrops.

After the close of the Mazeras sedimentation and presumably after uplifting of the sediments and before Middle Jurassic (Bajocian) times, probably during the Lower Jurassic,

fracturing took place along lines with N.–S. to N.N.E.–S.S.W. orientation. It was probably at this time that the galena-barytes mineralization took place along some of these fractures and faults. No such mineralization has been recorded along the Duruma-Jurassic boundary faults—the inference being that the faults, as seen in the Rare and Sabaki rivers, are younger than the Jurassic sediments. It is believed, however, that the Jurassic rocks were deposited on the down-thrown side of a fault, and the boundary fault between the Jurassic and Duruma sediments is considered to have undergone rejuvenation, probably in Pliocene times—prior to the deposition of the Marafa sediments. That some faulting took place prior to the Jurassic sedimentation is also suggested by evidence from the Mombasa area (Caswell, 1956, p. 38).

The apparent absence of mineralization along the boundary fault between the Jurassic and Duruma sediments may be because the original fault-line is at considerable depth, concealed at present by the Jurassic sediments, or that mineralization only took place along some of the faults and fissures that developed before the initiation of the Jurassic sedimentation.

The Coastal range, it is believed, was in existence in Middle Jurassic times and was much the same as it is now—coastal hills backed by a low-lying hinterland plain. It is considered that, after the close of the Mazeras and Shimba grit sedimentation, a gentle monocline developed along the margin of Kenya. Along the axis of the monocline, which was orientated in a general N.–S. direction, fault-splinters would probably develop in places. Erosion by rivers, which would be particularly active along the eastern face, led to the deposition of boulders in certain localities (Caswell, 1953, p. 19). It would be on such a topography that the middle Jurassic sedimentation was initiated. Where no fault-scarps were in existence, the contact between the Jurassic rocks and the Duruma Sandstone series would be normally unconformable and would be particularly noticeable near and in valley mouths where basal conglomerates and tongues of the Jurassic rocks would be laid down. Along the fault-splinters the junctions would also be unconformable, but as a result of subsequent erosion might appear as faulted contacts.

In the Malindi district, so far as exposures are available, it appears that the relationship between the Duruma and Jurassic sediments is a faulted one.

In middle Jurassic, probably Bajocian, times the sea invaded the coastlands in the Malindi area, when dolomitic, pisolitic, and arenaceous limestones were deposited. The fragmentation of some fossil shells and the occurrence of pisoliths suggest that the waters were not quiet. The nature of all the rock types points to their deposition in a shallow warm sea. In the Callovian stage of the upper Jurassic, the sea, in which sediments continued to be deposited, appears to have deepened for calcareous shales, siltstones and shales containing fossils are present.

As has also been observed in the Mombasa area, this deeper water environment of the Callovian stage did not continue for long (Caswell, 1953, p. 52). In Argovian times, there was a renewal of shallow-water conditions when impure fossiliferous limestones, sandy limestones, sandstones, sandy shales and siltstones were laid down. This alternation of sediments persisted into the Kimmeridgian stage when the period of Jurassic sedimentation apparently came to a close. Rocks of Cretaceous age have not been recorded from the Malindi area.

With the close of sedimentation in upper Jurassic times uplift once more took place and erosion set in. Faulting also took place, probably in Cretaceous times, but certainly between upper Jurassic and lower Miocene times, whereby the Mangea hills were cleft, and the Jurassic sediments in the southern part of the area were raised relative to those in the Sabaki drainage area. The erosion in this interval reduced the surface of the Jurassic sediments approximately to a plain rising nowhere more than 400 ft. (121 m.) above sea-level, on which the Marafa beds were ultimately laid down. The Mazeras sandstones of the Mangea hills were, of course, also subject to erosion, but on account of their resistant nature in comparison with the Mariakani sandstone series to the west they withstood the levelling effect of the erosion cycle during Cretaceous times.

TABLE IV

Earth Movements and Events in the Malindi Area

Period		Local Representative	Earth Movements and Events	Pluvials, etc.
Recent		Wind-blown sands (Rt) Marine sands (Rm)	Sea-level as at present day Silting up of Mida Creek, etc.	
Pleistocene	Upper		Silting up of Mida Creek starts Sea-level rises to present-day level	Post-pluvial
		Coquinas (Qt_4)	Terrace cut Sea-level drops to about −25 ft. O.D. Coquinas accumulate	Gamblian
		Gedi beacon sands (Qt_3)	Sea level rises to about 25 ft. O.D. (?) Wind-blown sands accumulate on coastal plain	3rd Inter-pluvial
	Middle	Gedi beacon sands (Qt_3)	Wind-blown sands start to accumulate Sea-level drops; platform cut at about −130 ft. O.D.	Kanjeran
		Coquinas (Qt_2) Magarini sands (Qt_1) Lagoonal sands (Pls) Fossil coral reef (Plc)	Coquinas accumulate as off-shore bars Wind-blown sands accumulate as dunes Lagoonal sands accumulate Corals grow Sea-level rises to about 120 ft. O.D.	2nd Inter-pluvial
	Lower		Marine platform cut on which coral grow Marine recession	Kamasian
		Magarini sands (?) (Qt_1)	Magarini sands start accumulating	1st Inter-pluvial
		Marafa beds (?)	Marine recession End of Marafa sedimentation	Kageran

TABLE IV—(*Contd.*)

EARTH MOVEMENTS AND EVENTS IN THE MALINDI AREA—(*Contd.*)

Period			Local Representative	Earth Movements and Events	Pluvials, etc.
Pliocene	Upper		Marafa beds (Tpl)	Unconsolidated shallow-water sediments accumulate	
	Lower			Uplift, erosion, faulting and igneous intrusions (?)	
Miocene	Upper				
	Lower		Baratumu beds (Tm)	Marine invasion; shallow-water sediments accumulate	
Oligocene					
Eocene					
Cretaceous				Uplift, faulting and erosion (?)	
Jurassic	Upper		Changamwe shales Coroa Mombasa limestones and shales Miritini shales } (J_3)	Fluctuations of sea-level Shallow- and deep-water sediments accumulate	
	Middle		Kambe limestone (J_1)	Shallow-water deposition	
	Lower				
Triassic	Upper	KARROO	Mazeras sandstones (Kz)	Uplift, erosion, faulting and ore mineralization Aeolian deposits accumulate Shallow-water sediments deposited	
	Lower	KARROO	Mariakani sandstone (Km)	Uplift and erosion Deposition in lakes and shallow seas Deltaic environments	

Dotted lines denote unconformities.

The levelling process of the Cretaceous erosion cycle probably persisted into early Tertiary times. In lower Miocene times the marine advance that took place extended over the eroded topography on to the Jurassic rocks. This marine transgression was not great and as the drowned topography was of low relief, with the pre-existing rivers such as the Sabaki in a state of near old age or maturity, deposits of fine texture were laid down. Sands, clays, sandy clays, marls and limestones typify the Miocene sediments. The presence of echinoderm spines and plates and shell fragments in some of the sediments suggest a turbulent environment which, together with the variable nature of sedimentation, led to the lenticular character of the beds. It is doubtful if the sea advanced beyond the 300 ft. O.D. level.

Probably in upper Miocene or lower Pliocene times new earth movements (when igneous intrusions were emplaced) created a state of disequilibrium which resulted, probably in late Pliocene times, in the rapid deposition of a group of ill-sorted unconsolidated sediments—the Marafa beds. The intrusions are nepheline-bearing rocks that invaded the Duruma and Jurassic sediments and possibly the younger rocks, though they have not been observed in the Baratumu beds. Caswell (1953, p. 53) for the Mombasa area, postulated a renewed movement along the Rabai fault accompanied by a retreat of the sea at this stage. The resultant increased erosion gradient, he claimed, furnished the conditions necessary for the accumulation of the Pliocene sediments, that is the equivalents of the Marafa beds in the Malindi area, and thereby at the same time accounted for their development only on the eastern side of the Shimba hills.

With the increased topographic gradient the erosion which took place in upper Pliocene times permitted coarse boulder and pebble beds, gravels, sands and clays to be laid down on the eroded surface of the Jurassic and Miocene sediments. The new sediments were derived largely from the Duruma sandstones, particularly the Mazeras group, with some admixture from the Basement System rocks—a feature that Gregory (1921, p. 76) observed in what he named the Magarini sands. The sediments were deposited partly under deltaic conditions, and probably locally, on account of the nearly flat profile of the shore, under salt lagoon conditions. Fine clays, kaolinitic rocks, fine sands and fossiliferous beds accumulated as lenticular beds in the lagoons.

With the close of the Marafa sedimentation, the sea then retreated to a level below present sea-level—probably about −200 ft. (61 m.). A marine platform was cut which varies in width, as evidenced by the width of the fossil coral reef. The cutting of this platform probably corresponds with the Kamasian pluvial in upper Lower Pleistocene times.

During the following (second) interpluvial, drowning of the coastlands took place once more during which time a marine terrace about 120 ft. (36·6 m.) above present sea-level was cut. Along the new shore-line coastal dunes were blown up, which form the bulk of the red Magarini sands. In the Arabuko–Sokoke forest these sands accumulated at altitudes over 700 ft. (213 m.)—at Sokoke beacon just beyond the southern limits of the present area they reach 747 ft. (228 m.) O.D. In the hinterland, reddish-brown sands and soils, partly wind-blown, were also accumulating, while in some localities ferricretes and calcretes were being formed. In the sea the coral reef was growing and between the coral reef and the shore-line the Marafa beds were being re-worked and, near the coral reef, were mixed with coral breccia. Undercutting of the Magarini sands probably also took place so that parts of them were incorporated with the marine sediments (Pls) then forming.

With the approach of the Kanjeran pluvial period which followed, the sea-level began to drop—its retreat appears to have been gradual for it was then that the swell-and-swale topography developed. Off-shore bars accumulated on account of the nearly horizontal profile of the sea-floor, and fine coral debris, shell fragments, and foraminifera were incorporated in the offshore coquinas. As the sea-floor sediments became exposed to sub-aerial erosion, the wind built up deposits of sands of which the Gedi beacon sands are an example.

Recession of the sea continued during the Kanjeran pluvial and reached a maximum during that time. The sea-level dropped to below present sea-level, causing the Sabaki river to breach a channel through the fossil coral reef. The drop in level probably corresponds with the benches on the sea-floor at −115 ft. and −145 ft. respectively marked A on the submarine profiles of Fig. 3. Of note are the off-shore bars that developed on the edge of the continental shelf. In the Mombasa area bore-holes between Mombasa island and

the mainland have also shown the effects of this drop of a sea-level to about −130 ft. (39·5 m.) (Sikes, 1930, p. 4). At this time too the fossil coral reef was breached opposite the Sabaki river, and in the vicinity of Mida creek by streams which now appear as shallow, sand-choked dry water-courses.

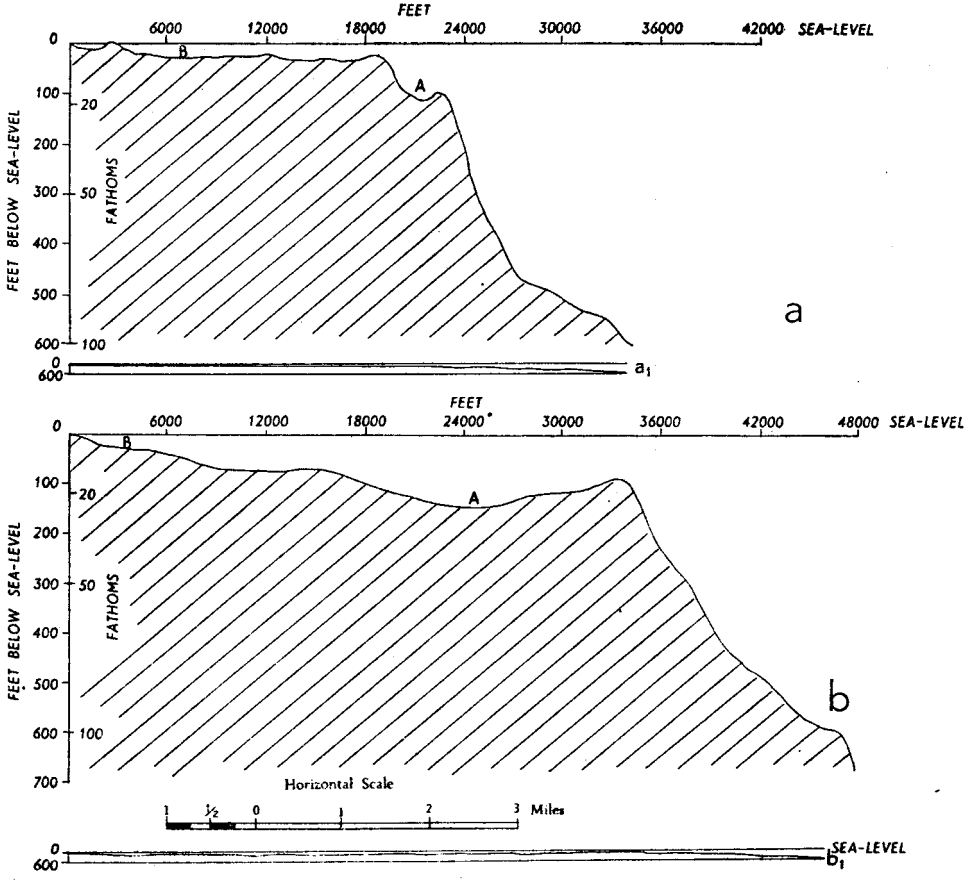


Fig. 3.—Off-shore submarine profiles, Malindi area.

a—E.-W. section-line from a point east of Gedi beacon. Note that the vertical scale is greatly exaggerated: a true-scale drawing of the same section is given at a_1.

b—E.-W. section-line from the Malindi hotels. The plat forms A and B represent bevels cut during Middle Pleistocene and Upper Pleistocene times respectively. A is the −115-ft. level, and B the −25-ft. level. True-scale section at b_1.

After the breaching of the fossil coral reef by the Sabaki river a positive movement in sea-level took place once more. A few small indistinct terraces about 25 ft. (7·6 m.) above sea-level were cut in the fossil coral reefs, along the coastline in the southern part of the area. This was during the third interpluvial period, when erosion of the 120-ft. terrace continued and Man wandered over the area, leaving behind him crude artifacts chipped from quartz pebbles. Although these artifacts are commonly seen near or at the base of red sands in association with quartz pebbles, they are more than likely post-Magarini sand in age, that is, of Kanjeran or post-Kanjeran age. It is believed, in any case, that they were discarded on a land surface that developed some time after the cutting of the 120-ft. (36·6 m.) terrace.

A slight recession of the sea-level later took place, probably during the Gamblian pluvial, when cliffs were cut on the seaward side of the fossil coral reef. A platform was cut at a level not much below present sea-level, and probably corresponds with the −25-ft. level of the sea-floor, marked B on the submarine profiles (Fig. 3). At this stage, off-shore bars were built up and the "sands", etc., that accumulated, after cementation, now con-

stitute the coquinas of the Watamu headland, with its string of islands, and Vasco Da Gama headland at Malindi. Slight rejuvenation of the Sabaki river and its tributaries took place at this time—resulting in the initiation of the inland lakes, such as Jilore, Chem-Chem, Merikano, and Sameta.

The final phase was a rise of the sea to its present-day level, in the post-pluvial period, when the Watamu off-shore bars were breached and eroded. The effect on the Sabaki river was to reduce the grade a slight amount so that, in the writer's opinion, during periods of flood particularly, natural levees were built up along its flanks, thereby sealing off backwaters and damming tributary streams. Lakes Jilore, Chem-Chem, Merikano and Sameta thus came into being. The lakes are still subject to flooding from the main valley—as was Jilore during exceptional floods in 1951.

Where the off-shore bars were breached and islands formed, sandspits accumulated between the islands and the shore, forming tombolos, i.e. that some of the islands were land-tied. Watamu headland, Vasco Da Gama Point and Ras Ngomeni are examples. This process of land-tying is still in progress for over the coral reef at Watamu beach sands are creeping out towards some of the northern islands in the bay. Silting up of the Mida creek is also taking place and mangrove swamps are extending. North of the Sabaki river, dunes of white sand are accumulating parallel to the shore-line. Sand-bars in the sea coupled with the growth of the coral, it was reported by the local Africans, have in the case of Mambrui rendered the harbour unsuitable even for dhows. Off-shore bars, of which North Reef and Leopard Reef are examples, are accumulating at the present time. These, about two miles (3·2 km.) off-shore, are visible at low spring tides opposite Casuarina Point, south of Malindi. Another outcome of this slight drowning was flooding of areas of Mida creek which when dammed off by wind-blown sands, became natural salinas and resulted in the accumulation of a gypsiferous bed at Roka. Thus the present-day shore-line of Kenya, in the Malindi district exhibits phenomena resulting from both emergence and submergence (Table IV).

VIII—ECONOMIC GEOLOGY

1. The Vitengeni Lead Mine

The Vitengeni lead mine, 22 miles N.N.W. of Kilifi, is the main mineral occurrence of economic importance in the Malindi district. At the time of the present survey the mine was in disuse; no buildings were in existence, and the deepest workings were flooded. Pulfrey, after an exhaustive study of the mine and the geology of the environs, compiled a comprehensive report (1942A, unpublished) on the galena-barytes vein and other associated minerals. As the mine was not working at that time and was flooded he also was unable to examine most of the underground workings. A summary of his report is given below:—

The deposit is stated to have been discovered by C. W. Hobley in 1919, and was first pegged in 1922 by C. Cottar. By the latter part of 1924, Cottar was using a 10-ton an hour mill and shipping concentrates to Europe. The approximate amounts and estimated values of the minerals exported up to 1929 and including a shipment made in 1931 were as follows:—

Mineral	Tons shipped	Metal yield	Estimated Value when worked
Galena	209	176·4 tons lead 1,421 oz. silver	£5,276* £183
Zinc Blende	30·16	not known	£330

*The value of a similar quantity of lead in 1952 would have been about £29,000.

The grade of ore was stated by Cottar to be 2·5 per cent galena per ton, and the concentrates shipped varied between 82 and 85 per cent lead content. The silver content of the lead varied between 6 and 8 oz. per ton. It was judged that about 7,000 to 8,000 tons of ore and rock were excavated during Cottar's operations.

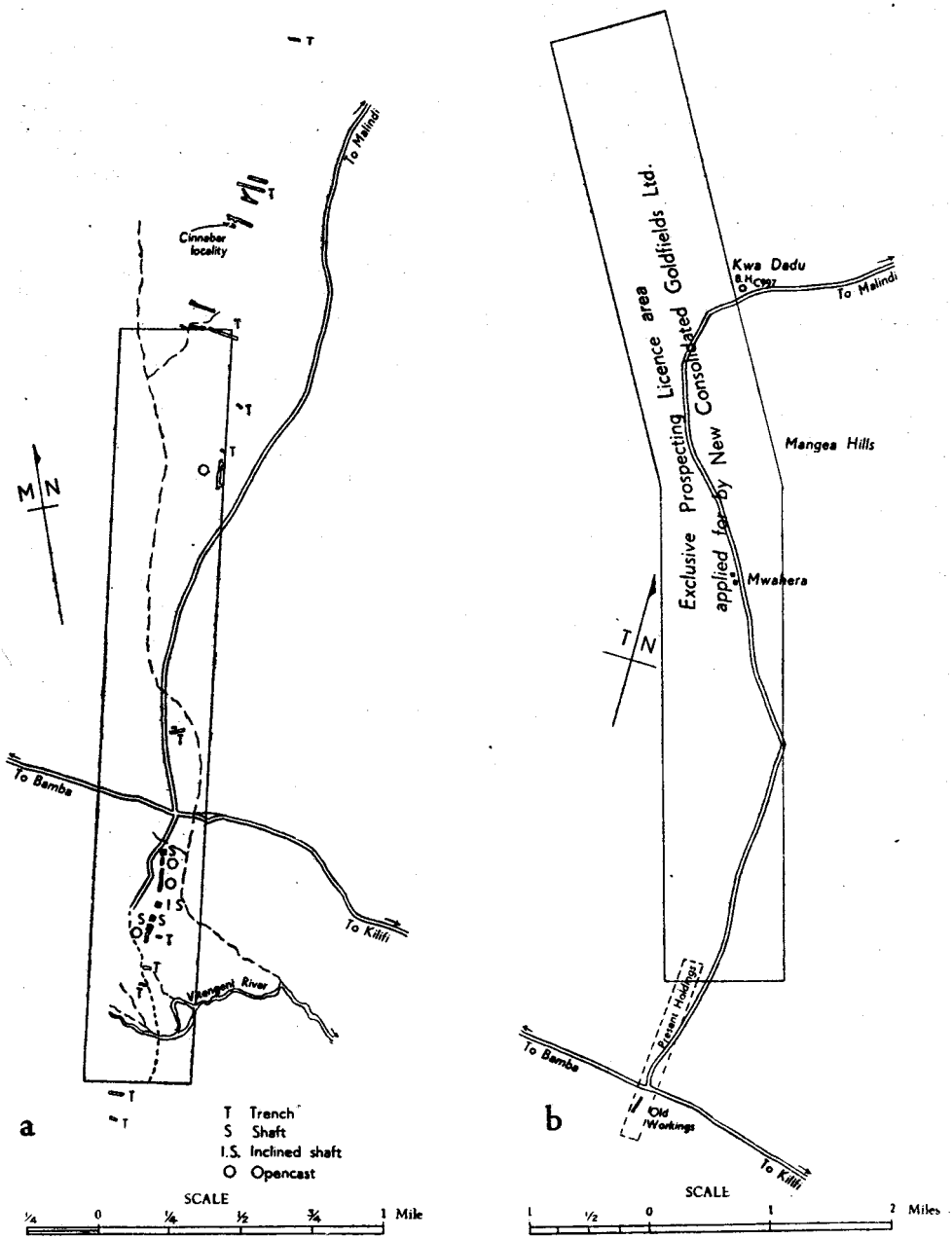


Fig. 4.—Vitengeni lead mine.

(a) Map of mining locations and prospects.

(b) Map of mining locations and proposed exclusive prospecting licence area (1953).

The greatest depth reached by the two shafts (Fig. 4) was probably about 100 ft. and it appears from records that the greater part of the stoping was carried out between the 30- and 60-ft. levels, and in the main opencast.

Further work was carried out at the mine by Messrs. Lime, Ltd., between March and September, 1937, while holding the Cottar claims under an Exclusive Prospecting Licence (E.P.L.). A considerable amount of re-excavation and excavation was carried out notably at the inclined shaft, which was deepened to 57 ft. with drives to the north and south at an intermediate level, and some ore was stacked. The company estimated that the reserves of ore proved were 1,000 tons with 4 per cent galena content. In June, 1938, the area covered by Messrs. Lime Ltd.'s E.P.L. was closed to mining and prospecting.

An Exclusive Prospecting Licence (No. 86) covering an area of 160 acres, was held by P. E. Andersen and Transcandia Ltd., from 15th July, 1948 until it expired on 14th August, 1951, after claims had been pegged. Transfer of locations 34/1–10 and 35/1–3 held by the above company and Mr. Andersen, to Vitengeni Ltd., was effected on 14th May, 1952.

An option to prospect for a period of two months was granted to Macalder Mines Ltd., on 1st December, 1948. This company prospected, by means of trenches and inclined core drill-holes, an area about the old Cottar workings, until the end of December, 1948. During this period 62 samples were taken in all. Of this number, 47, representing 26 sections across the vein on the 50-ft. level and sub-levels, for a length of 424 ft. (129 m.) sampled, gave an average width of 7·6 ft. (2·3 m.) assaying 5·5 per cent lead. Only about 25 per cent of the vein sampled was exposed to its full width, which averaged 14·7 ft. (4·45 m.).

The conclusion was reached that the property was worthy of considerable further exploration.

In August, 1952, an agreement was signed between Vitengeni Ltd., and the Colonial Development Corporation in association with New Consolidated Goldfields Ltd. for a three-year option on the property. These companies, with New Consolidated Goldfields as the active prospecting partner, have carried out a programme of inclined core-drilling and general prospecting since that date on the Vitengeni Ltd. holdings. A certain amount of drilling was effected in the vicinity of the Cottar workings, where beds of sandstones and shales, predominantly the latter, were encountered with stringers and thin veins of less than 6 inches (15 cm.) thickness of barytes and quartz with some galena and chalcopyrite.

An application for an exclusive prospecting licence for an area of approximately eight square miles, north of the Vitengeni Ltd. holdings, was made by New Consolidated Goldfields Ltd. on 20th May, 1953, and authority to prospect in that area was granted on 20th August, but the application was withdrawn on September 15th.

Prior to Dr. Pulfrey's investigations in 1942, the mine had been visited by geologists on five occasions. In 1928 Dr. E. Parsons commented briefly on the occurrence, stating that the ore was a quartz vein in a fault, close to and parallel with a great N.–S. fault, one of a system cutting the Coastal belt into strips. In 1932, R. Murray-Hughes, then Government Geologist, examined the mine more closely and noted the absence of pyrite. His modified views were later included in the Annual Report of the Mining and Geological Department for 1933. J. de Jean examined the mine and a large area around it in 1935, and his remarks are contained in an unpublished report, a copy of which was furnished to the Mines and Geological Department. In 1937, D. Harverson, then Government Mining Engineer, and Messrs. Barnard and Parsons, mining consultants to Messrs. Lime Ltd., also visited the mine—the latter expending much effort in an unsuccessful attempt to trace a workable ore-body outside and to the north of the claim area.

(1) The Geology of the Vitengeni Mine

The country-rocks of the mine and the adjacent prospects consist entirely of sediments of the Duruma Sandstone Series, of Triassic age. The sediments comprise thinly bedded sandstones, siltstones and mudstones, belonging to the Mariakani sandstone group, with grits and sandstones probably of the Mazeras sandstone group. Pulfrey (*op. cit.*) stated that it was not clear to him whether the frequent juxtaposition of argillaceous and arenaceous rocks is always due to faulting (as is fairly evident in some cases) or whether it is sometimes

due to exposures of normal interbedded sediments—a view shared by the writer. The sediments at the main opencast are largely greenish-grey blocky mudstones or siltstones containing fine quartz grains and packed sericite flakes, together with small brownish patches now composed of a sericitic mineral which Pulfrey thought might represent some low-grade metamorphic development. Similar greenish-grey siltstones are found in the Mariakani sandstone group elsewhere in the Malindi area. Silicification of the sediments has taken place to a small extent. Pulfrey noted fragments of these silicified sediments enclosed in the veins and sometimes the wall-rocks near the veins are completely replaced by granular mosaics of quartz.

The grits are prominent in the northern part of the prospect area, and consist of angular quartz grains associated with felspar grains set in a matrix of sericite, chlorite flakes and a kaolin mineral accompanied by a small proportion of calcite. Grains of graphite were also observed in these grits. Scattered small patches of barytes were noticed by Pulfrey in the matrix of a grit exposed in the northern cross-trench of the opencast.

The superficial deposits around the mine consist of sandy clays and clayey soils, frequently containing calcareous concretions and small ferricrete pellets. Small fragments of barytes are found as float underlying the sub-soil, especially near any vein; these fragments provide a useful indicator of where further work can be carried out.

Igneous rocks

No igneous intrusions are known in the environs of the mine, although Parsons mapped a dyke near Mwangudo hill, as has previously been stated. Apart from this dyke the only other occurrences known are the basanites and olivine nephelinites along the Sabaki river and north of it (*see* p. 38). Hot and sulphurous springs, signs of waning igneous activity are found at Mweza, Maliama, and Makongeni, 10 miles approximately S.S.W., 13 miles approximately S.S.W. and 21 miles W. by S. of Vitengeni mine according to Parsons map.

The fault-zone

The ore deposits appear to be confined to a narrow belt running almost N.N.E.–S.S.W. over several miles. There is some evidence that the ore-belt is connected with faulting. The following criteria are available:—

(*a*) the abnormal juxtaposition of shales with sandstones or grits, e.g. at the inclined shaft, in the trench south of the main opencast, and in the northern opencast, etc.

(*b*) slickensiding.

The presence of barytes crystals in the fault breccia along the Kwa Dadu fault-line is also indicative of the association of the mineralization with faulting. Slickensides can be observed at several places on the foot-walls of the veins, and in addition in the veins themselves. The faces on which the slickensides are developed strike and dip generally with the trend of the veins whilst the striae and grooving pitch northwards. The angle of the pitch is usually steep, between 70° and vertical, though at the inclined shaft slickensides were noted pitching at 45° only.

The nature of the faulting, on comparison with that farther north, appears to be normal with a downthrow to the west. The faulting, though probably initiated prior to mineralization, continued to operate after the veins had been deposited. In this connexion the fact that there has been relative movement of the east side of the ore-zone to the north may also be of importance.

(2) The Ore Veins

Nature, Structure and Extent

The ore-bodies are veins of lenticular habit deposited in fissures along the fault-zone. The strike of the belt of veins is about 17° E. of North, and the general dip is about 70° to the east, though the dip and strike of any particular vein may vary widely from these figures. In width the veins vary from stringers to giants of 20 ft. (6·1 m.) though no vein as wide as the latter can now be examined. The width of the belt through which veins are distributed

has never been determined. According to de Jean it is between 120 and 140 ft. (36–42 m.), and from data gathered during Pulfrey's investigations it was found to be certainly 25 ft. (7·6 m.).

The walls of the veins are usually distinct, though in places, e.g. in the hanging-wall at the main opencast there is a tendency for many anastomosing veinlets to be given off from the main vein, so forming stockworks. Occasionally the wall-rock is heavily mineralized with galena over a narrow width. In one such case seen, the adjacent barytes was not mineralized.

The maximum concentration and thickest veins occur at the Cottar mine, stretching from the south edge of the main opencast to the third opencast, i.e. over a distance of about 850 ft. (259 m.). South of the main opencast the veins split up rapidly and there is no doubt that between the opencast and the south edge of the claims there is little hope of finding workable ore-bodies.

Approximately 1,200 ft. (366 m.) north of the third opencast thick veins have been exposed by trenching. Here, however, mineralization is considerably less intense than at the mine and it is doubtful whether these veins, which may prove to be "blows" of small strike extent, can be considered as of economic interest. It is worthy of note, however, that Parsons who had access to these veins at greater depth than is now possible, noted on his map that one of the veins here is "well mineralized".

Another 2,300 ft. (701 m.) farther north a long strike working has been excavated on veins running about N.–S., i.e. somewhat across the main direction of the belt. Barnard and Parsons on their map indicated two veins here "8 ft. and 6 ft. highly mineralized," but they could not be seen during Pulfrey's visit. It appeared then that there is a southern vein, 4 ft. (1·2 m.) in width, and a northern vein split into two, one part 2 ft. (0·6 m.) and the other one ft. (0·3 m.) in width. It appeared unlikely that these veins would extend far.

North of the claims, about 2,800 ft. (854 m.) from the opencast just discussed, another vein "blow" has been exposed in trenches. Here the strike is again across the belt, namely about 15° to 25° west of north. This "blow" is of interest as it is a complex vein in which quartz figures largely as well as barytes, the normally predominant gangue mineral. Moreover the quartz, which in parts is liberally sprinkled with small inclusions of dark-blue mudstone country rock, is veined by galena-bearing barytes, while the major barytic section of the vein is cut by quartz stringers. The main barytes vein (2–3 inches) cutting the quartz is rich in galena, probably exceeding 10 per cent, though assays indicate that as a whole the complex contains a small percentage only.

Further afield from the stretch described above—about 9,500 ft. (3 km.) in extent—no evidence of ore-bodies was obtained, though the report on de Jean's prospecting led to the hope that some would be found. Five localities, apparently those described by de Jean were examined.

At Gagossi, about two miles (3·2 km.) north of the claims, thin veinlets (2–3 inches) of barytes in fine-grained indurated sediments are exposed in a trench. To the south of the claims four localities in eastern Fuladoya yielded the following evidence (considered from north to south):—

(*a*) approximately one mile from the mine, shallow trenches which apparently unearthed only surface deposits.

(*b*) approximately 1½ miles (2 km.) south of the mine, stringers of comb-quartz with a little barytes up to 2 inches (5 cm.) in width in grit are exposed at the surface and in a trench.

(*c*) approximately 2¼ miles (3·6 km.) from the mine several trenches which apparently cut surface deposits mainly; a small amount of barytes float was found.

(*d*) approximately 2½ miles (4 km.) from the mine, veinlets up to ½ inch (1 cm.) thick of barytes in grit exposed in a trench.

While of no immediate economic interest these exposures indicate the persistence of the zone of mineralization, and give hope that other ore-bodies may eventually be found along the fault-belt.

There is not much evidence regarding the behaviour of the veins in depth. However, when prospecting was undertaken by Macalder Mines, Ltd., in 1948 and 1949, it was concluded that cleaning out of the bottom of the drive, approximately 45 ft. (13·7 m.) below the ground surface at the main shaft, would have shown the vein to have pinched out at this point. It was also considered by the above company. that the barytes gave way to quartz in depth, although some core drill-holes intersected galena 95 ft. (29 m.) below surface. Thus it would appear that the veins swell and pinch with depth, and may decrease in quality.

Mineralogy of the Veins

The primary ore minerals are galena, zinc blende, and chalcopyrite.

Galena (*PbS*)

This is the most abundant ore mineral. It occurs in coarsely crystalline masses, usually in aggregates up to a few inches across, as grains, and occasionally in finely granular patches. The aggregates are irregular in shape and commonly moulded by barytes cleavages. Rarely the galena appears to have crystal shape. It occurs almost exclusively in barytes.

Blende (*ZnS*)

The zinc blende when weathered is of a dull grey colour and is frequently coated by a bloom of bluish-white smithsonite ($ZnCO_3$). When fresh it has a resinous appearance and is browish with points and patches of clear yellow and red (ruby blende) and rarely green, and in thin section is transparent. It is thus evident that it contains little iron.

The blende is almost always found associated with white granular or comby quartz, though it was also noted occurring in barytes. Crystallized blende was not observed. It occurs usually in irregular coarsely crystalline aggregates and occasionally in impersistent bands.

Chalcopyrite ($CuFeS_2$)

Chalcopyrite was usually found as pin-points and small aggregates, though Cottar reported cross-cutting a vein of chalcopyrite 16 inches in width. It occurs enclosed in quartz, in barytes, not infrequently in galena, and sometimes as minute grains in blende. Almost always it is irregular, though in one case, crystal faces partly enwrapped by blende were observed.

Ore minerals of secondary origin are common, as would be expected as the ore so far has been worked only in the oxidised zone. The following species were observed:—

(1) *Lead minerals*

cerussite ($PbCO_3$—lead carbonate)
anglesite ($PbSO_4$—lead sulphate)
pyromorphite ($Pb_5 (PO_4)_3Cl$—Lead chloro-phosphate)
massicot (PbO—lead monoxide)
plattnerite (PbO_2—lead dioxide)

(2) *Zinc minerals*

smithsonite ($ZnCO_3$—zinc carbonate)

(3) *Copper minerals*

malachite ($Cu_2CO_3 (OH)_2$—basic copper carbonate)
azurite ($Cu_3 (CO_3)_2(OH)_2$—basic copper carbonate)
covelline (CuS—cupric sulphide)

(4) *Iron minerals*

Iron oxides

Native copper was seen as a rare occurrence. None of the secondary minerals is present in considerable amount.

The Gangue Minerals

The gangue minerals are barytes and quartz.

Quartz (SiO_2)

The precipitation of quartz apparently began before that of barytes and continued after the cessation of barytes deposition. It occurs massive at some points, but is commonly found in narrow comb-textured veinlets, in sugary quartz-blende veins in the main ore-bodies, and as crystals lining vugs in the barytes. Occasionally the quartz is present also as spongy masses of small crystals.

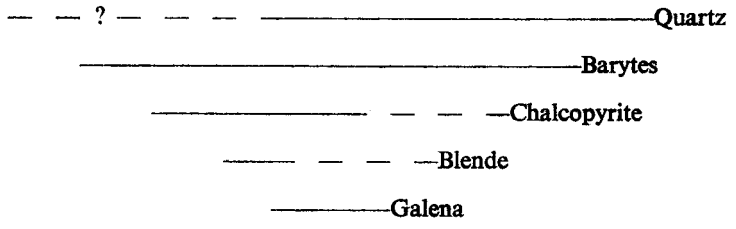
Barytes ($BaSO_4$)

The barytes is usually coarsely crystalline, and varies considerably in appearance. Rarely it is almost glass clear, but more often it is dense and white and commonly somewhat pinkish or brownish owing to the lining of cleavages and cracks by films of iron oxides. In places it is fine-grained, sometimes white sometimes grey. In one specimen two generations of baryte are present. The presumably earlier generation is greyish-white to white and contains galena and chalcopyrite, while the second generation is white, coarsely crystalline and contains galena (encrusted with successive zones of covelline, cerussite, and malachite).

The barytes is in places vuggy, and not infrequently crystals of barytes have been formed in the vugs. More rarely it is observed as coarse-grained "spongy" masses with, for example, crystals over an inch in length. In thin stringers it is commonly fibrous. Rarely the massive barytes is coarsely banded.

Paragenesis of the Ore minerals

The apparent order of development of the ore and gangue minerals may be represented as follows:—



It is possible that the deposition of quartz did not begin until the barytes had commenced to crystallize, but it is apparent that its precipitation was long continued, though usually in minor extent. It was noted veining and encrusting blende in place. Chalcopyrite appears to have been introduced at several periods and so gains a more extensive range than the other sulphides. Blende commenced to crystallize before galena, but in one case was later. It is probable, however, that the bulk of the blende was deposited some time before the end of the galena mineralization.

(3) Origin of the Ores

The ores are considered to be of hypogene origin deposited by rising hydrothermal fluids in a low temperature mesothermal (and telethermal) environment. The comb structures vugginess, "spongy" crystal masses, and occasional banding indicate deposition in open fissures, along the fault-zone, and it can hardly be doubted that deposition was from ascending hot aqueous solutions. No connexion can be proved with a plutonic mass, though there are grounds for believing that one probably exists at depth. The only major intrusive mass known at the coast is Jombo hill, near the Tanganyika border, south of Mombasa (Baker, in Caswell, 1953, p. 32, *et seq.*) but it can be presumed that the dykes of the Sabaki valley are connected with a comparable, as yet unexposed, intrusion. It is likely that the lead-barytes veins are connected with the same mass which, like Jombo hill, would probably consist of alkaline and felspathoidal syenitic rocks. It is worthy to note that among the igneous rocks, the alkaline syenites are those that most commonly carry higher proportions of barium.

(4) Tenor of Values

From assays made on samples collected during the 1942 examination it was immediately realised that as far as exposures then available went, the ore-bodies outside the immediate mine area could be neglected. In the mine itself it was found that around the inclined shaft the average value of material that had been mined and stacked was about 6 per cent lead.

At the main opencast itself it was not feasible to take representative samples but it is considered that the grade of the veins worked by Cottar was probably between 3 per cent and 4 per cent lead. If this should be true it indicates an inverse correspondence between vein widths and tenors—at the opencasts and the main shafts when the veins are widest the values are lower than at the inclined shaft where the veins have decreased in width.

Macalder Mines, Ltd., after a period of trench and first level sampling in 1948 deduced that the average value was about 5 per cent lead.

Assays of various samples obtained during drilling by New Consolidated Goldfields, Ltd., from the stringers and veins already mentioned revealed maximum values as follows:—

	%
Lead	11
Copper	6
Zinc	9
	dwts. per short ton
Gold	0·3
Silver	30·2

(5) Estimate of Possible Ore Available

Although a fair amount of prospecting has been done at Vitengeni since Pulfrey's work there in 1942, recent estimates of the possible ore reserves are not available. The following figures are thus taken from the earlier estimates, unless otherwise stated.

Lead

For the purpose of estimation during the 1942 investigation the mine only—from the south lip of the main opencast to the shaft north of the third opencast—was considered. From figures then available it was estimated that if working were continued to a depth of 500 ft. ore containing about 8,357 tons lead should be recoverable. It must be emphasized that this estimate concerns *possible* ore not probable or proved ore, and was based on assumptions of persistence of widths and values. Mention should perhaps be made here once more of the Macalder Mines Ltd., sampling programme in 1948 and the deduction that the vein probably deteriorated with depth.

Zinc

No estimation of possible tonnage could be made. It is possible that, as zinc ores are readily oxidised and transported in solution, the zinc content of the vein may be greater below the zone of oxidation than exposures would lead one to think.

Copper

It is probable that a sample of several tons of average mine ore would yield copper only to the extent of a few hundredths per cent, and it is unlikely that it would be worth recovering. A few samples assayed (in 1948) by Macalder Mines Ltd. gave up to 3 per cent copper.

Silver

Accepting Cottar's results, which showed an average of about 7 ounces silver per ton of galena (i.e. 0·026 per cent), a possible production of 67,500 oz. of silver could be anticipated should the lead obtained attain the amount estimated above.

Barytes

The predominant gangue mineral of the ores is barytes—at a rough estimate it comprises about 75 per cent of the vein matter—and in the section from a point midway between the shafts to a point midway along the large opencast trench north of the shafts, down to 200 ft. (61 m.) depth, some 13,800 tons of barytes could be anticipated.

2. Other Minerals in the Malindi Area

(1) Cinnabar (HgS—Mercuric Sulphide)

The presence of crystalline cinnabar in a thin veinlet cutting mudstones was discovered by Messrs. Barnard and Parsons in 1937, during prospecting operations a little north of the Cottar claims, at Vitengeni. The deposit on subsequent examination by the Mines and Geological Department proved to be of very limited extent, and to have shallow depth. The maximum tenor of samples was about ½ per cent mercury (Pulfrey, 1947, p. 297).

(2) Gypsum ($CaSO_4.2H_2O$—Hydrated Calcium Sulphate)

As has been mentioned in the section of the report dealing with Recent marine sediments (p. 37), gypsum was found in a shallow well to the west of Roka village. This well was dug in flat-lying ground that is considered to be a former arm of Mida creek. The well, about 4 ft. (1·2 m.) deep, exposes a bed of loosely packed gypsum crystals. The crystals are elongated, flat, and prismatic in form. A sample on analysis gave the following result:—

Lab. No. 22753	%
Calcium oxide (CaO) ..	.. 35·12
Water (H_2O) (160–180° C.)	.. 18·05
Sulphate (SO_3)	.. 40·47

Analyst: W. P. Horne.

Among the crystals are gastropod and other shells, some microscopic. Five hundred yards (457 m.) farther north of the well and in the same flat terrain gypsum crystals were seen outcropping on the surface, where the valley is about 200 yards wide. It is believed that the extent of the gypsum is even greater than the above figures suggest but no trenching could be done at the time of the survey to prove the size of the deposit. Adopting the figures quoted, it is possible that 150,000 tons of gypsum rock may be present.

At the Fundisha Salt works (Fundi Isa) at Gongoni gypsum crystals are formed under certain conditions during the solar evaporation of sea-water. These have been discarded in stacks in the past so that approximately 1,000 tons of gypsum is available at the works should a local demand arise for this product. It was stated at the works that 15 tons per month could be collected from the evaporating pans during the three dry months of each year, viz. from December to March.

(3) Black Sands (Ilmenite, Rutile, Monazite, Zircon)

Naturally concentrated black sands, commonly containing ilmenite, monazite and rutile as well as various magnetic iron minerals occur in patches along the coast in the Malindi area at various localities. Applications for exclusive prospecting licences to work these black sands have been made, but to date no exploitation has resulted. W. A. Ryan applied for an Exclusive Prospecting Licence (E.P.L.) on 6th February, 1953 for an area of approximately 0·3 square miles of the Silversands beach, south of Malindi where he had noted the cemented black sand mentioned on p. 37, but allowed the application to lapse in July of the same year. Maxwell McGuinness also applied for an E.P.L. on 1st May, 1953, to investigate the sands both black and normal, on the beaches and in the dunes, of a strip of coast north from Malindi to Kipini, covering an area of about 90 square miles. Authority was granted him to prospect on 16th July, 1953. Samples that he collected from bore-holes drilled on the banks of the Sabaki river in the Malindi area were analysed and revealed the presence of small amounts of vanadium in the concentrates. Tests have shown that the normal sands of the beaches and dunes, which have not been naturally concentrated, usually contain less than 2 per cent of ilmenite.

Pulfrey (1942 B) while investigating alleged silver-lead deposits at Gedi, examined black sands at the following localities within the Malindi area.

1. On the shore about one mile north of Malindi.
2. On the shore in front of the sand dunes about 2½ miles (4 km.) north of Malindi.
3. Sabaki river shore near the Malindi road bridge.
4. Sabaki river at Lindi, north-west of Goshi (present locality name=Dagamra).
5. Sabaki river at Kakoneni.

Only the second locality, Pulfrey considered, had at that time any possible economic significance. In this sample, 75 per cent was found to be composed of heavy minerals. Highly magnetic minerals found were largely magnetite, constituting about 1 per cent of the sample. Moderately magnetic minerals, mainly ilmenite and garnet formed about 28 per cent. Abundant dark green hornblendes and rutiles were found after magnetic treatment of the sand. The following minerals and grains were identified in the various samples, most being common to all the samples; magnetite, ilmenite, garnet, epidote, hornblende, rutile, kyanite, zircon, apatite, biotite, diopside, hypersthene, enstatite, calcite, sphene, staurolite, red iron oxide, monazite, leucoxene, barytes, anatase, tourmaline, quartz, felspar, "chert", jasper, limestone and diatoms. The commonest of the heavy minerals were the iron ores (ilmenite being considerably in excess of magnetite) and green hornblende. Garnet was somewhat less common but still very abundant. Rutile, epidote and zircon were also frequent. Other heavy minerals were scantily represented or rare.

Pulfrey (1947, p. 297) states that monazite occurs as a minor constituent of black sands found at the mouths of rivers on the Kenya coast. On his accompanying map he records their presence at the mouth of the Sabaki river but lists monazite under the heading of minerals of no present economic value.

3. Building Materials

(1) Cemented Dune "Sands"—Coquinas

At present the main building-stone used in Malindi is that hewn in quarries in the cemented "sands" or coquinas. The occurrences of this rock type are limited, but probably sufficient, at the present rate of building, for the needs of the development of Malindi and its immediate environs for the next few years. There are not many quarries within easy reach of Malindi, although in former times building-stone was cut from Vasco Da Gama headland in the township. It was probably on account of the contamination of this source of building-stone by sea-water that this quarry was abandoned. South of Casuarina Point, headlands of these coquinas also occur.

On Watamu headland, there are quarries in this type of rock opposite the village. The islands to the north and south of Watamu headland are also composed of the cemented dune "sands", and quarries have been worked on the headland opposite the Blue Lagoon restaurant. Stone is also hewn from quarries near the village of Roka. The hillock, called Kilimanjaro, is an untapped source at present, and without a deep overburden.

Unfortunately the rock of the coquinas is often penetrated by sink-holes, so it has to be carefully selected before cutting. Even so there is a large amount of waste at the quarries through careless handling and bad trimming (as is a common habit in Kenya). Trimming of the stone is done in the quarries, and the amount of chippings that accumulate reduce the efficiency of operation. The Kibongo quarries two miles (3·2 km.) south of Malindi are particularly ill-treated in this respect, so that the quarry face is seldom more than four feet in height.

The coast natives build with coral "crag" rubble, but, though of unlimited supply, this material is not considered a suitable stone for permanent buildings.

(2) Mazeras Sandstone

This stone has not been used for building purposes in the Malindi district, except as aggregate in the concrete foundations for the water tanks of the bore-holes at Vitengeni, Kwa Dadu and Kijego. It is considered that should the demand arise, it could be quarried for building purposes, but as yet its toughness militates against its use owing to the present local conception of what constitutes acceptable building material.

(3) Other Possible Sources of Building-stone

The Mariakani sandstones, which are generally more flaggy than the Mazeras sandstones, could possibly be used as building-stone, if carefully selected. At present the demand has not arisen.

Nepheline basanite was used to a small extent in the foundation of the Marafa bore-hole (C1041). It is very tough and may be suitable for road metal and could be more extensively used as aggregate in concrete work. Its distance from Malindi, which also applies to the other igneous rocks in the area, at present precludes the possibility of the use of this material for construction purposes. It is doubtful whether satisfactory use could be made of the Jurassic, Miocene and Marafa sediments for building purposes for the same reason.

(4) Sands

The shelly beach sands of Silversands beach, Malindi, and the unconsolidated sands between the coral and the shoreline have been used in cement blocks for building bungalows at Silversands.

4. Water-supply

Although there are numerous wells on the Coastal plain in the Malindi area, water nevertheless constitutes a problem of no mean dimension. Bore-holes have been drilled in the district with varying degrees of success, and data from the successful ones, as well as information obtained from the wells, point to a water-table near sea-level. The thickness of the "layer" of fresh water appears to be small, with the result that with over-pumping underlying saline water is drawn in.* Bore-holes drilled in the Nyika sediments have more often than not been saline, but it is considered that with skilful selection, areas of good water may be found. Should the density of population rise too high, the supplies of fresh water would be severely strained and would probably be inadequate.

The bore-holes drilled in the Malindi district, grouped according to the physiographic regions, and showing the sediments pierced, are listed in Table V.

Caswell (1953, p. 62) noted that results have shown that the coastal sedimentary rocks are wholly unsuitable for large-scale water-supplies. This is borne out in the Malindi area by the erratic nature of the bore-hole supplies, particularly in the hinterland, the shallow depth of the water-table, and the salinity of the water. Analyses of some of the bore-hole waters are given in Table VI.

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*Investigations recently undertaken by the Hydraulic Branch of the Public Works Department suggest that the layer of fresh-water is not thin locally, and that there are still adequate groundwater supplies for normal domestic and agricultural development for many years to come.

TABLE V

Bore-holes in the Malindi Area

Bore-hole No.	Locality	Physiographic Region	Sediments Pierced	Yield in Gallons per day
C848 ..	Ganda, (Malindi water-supply)	Coastal Plain	Pleistocene Sands and Marafa beds	201,600
C849 ..	,,	,,	Pleistocene Sands Marafa beds and Baratumu beds (?)	Nil
C850 ..	,,	,,	,,	Nil
C860 ..	,,	,,	Pleistocene sands and Marafa beds	96,000+
C881 ..	,,	,,	,,	74,400
C969 ..	,,	,,	,,	51,840
C986 ..	,,	,,	,,	144,000+
C1272 ..	Guruleni	,,	Pleistocene sands Marafa beds (?) Baratumu beds (?)	19,200
C1160 ..	Arabuko–Sokoke Forest, Roka	,,	Pleistocene sands Marafa beds (?)	25,344
C1042 ..	Shakadula	Foot plateau	Jurassic Argovian–Kimmeridgian	Nil
C1041 ..	Marafa	,,	Marafa beds	19,200
C1046 ..	Garashi (Koromi River)	,,	Marafa beds	31,680 (saline, abandoned)
C1159 ..	Dida, Arabuko–Sokoke Forest	,,	Magarini sands Jurassic beds (Callovian (?))	Nil
C996 ..	Kijego	Nyika	Mariakani Sandstones	76,000
C997 ..	Kwa Dadu	,,	,,	28,800
C982 ..	Vitengeni	,,	,,	18,258 (saline)
*107	Vitengeni	,,	,,	21,000 (saline) 8,000 (potable, abandoned)
C1010 ..	Jila	,,	,,	13,046 (saline—in use)

*As far as can be obtained from the records in the Hydraulic Branch of the Public Works Department, Nairobi, bore-hole No. 107 was originally drilled to 270 ft. (82·3 m.), saline water (21,000 gallons per day) being struck at 136 ft. (41·5 m.). The bore-hole was deepened later to 443 ft. (135·1 m.) when potable water (8,000 gallons per day) was struck at 386 ft. (117·7 m.). The saline water was sealed off, but for some unknown reason the bore-hole was abandoned.

TABLE VI

Analyses of Bore-hole Waters from the Malindi Area*

Bore-hole number, name and date of analysis	Locality	Physiographic Region	pH	(Salinity lime salts) Carbonate	(Salinity lime salts) Bicarbonate	Ammonia Saline	Ammonia Albuminoid	Chlorides as Cl	Sulphates as SO_4	Nitrites as NO_2	Nitrates as NO_3	Calcium as Ca	Magnesium as Mg
C848 Malindi No. 1—March, 1949 ..	Ganda	Coastal Plain	7·5	Nil	29·9	Trace	0·002	23·8	4·8	Trace	Nil	12·7	5·9
—July, 1949	,,	,,	7·2	,,	29·7	,,	0·002	24·8	5·12	Nil	,,	13·4	4·3
—April, 1951 ..	,,	,,	6·75	,,	30·4	0·008	0·002	21·3	6·4	Present	Present	10·3	3·0
C881 Malindi No. 5—July, 1949 ..	,,	,,	7·3	,,	31·0	Trace	0·002	12·8	3·5	Trace	Trace	7·5	2·2
C969 Malindi No. 6—August, 1949 ..	,,	,,	7·3	,,	31·0	Nil	0·002	10·0	5·5	Nil	Nil	7·5	2·4
—November, 1949 ..	,,	,,	7·3	,,	31·8	Trace	Nil	8·3	4·8	Trace	Present	6·2	3·9
C860 Malindi No. 8—May, 1949 ..	,,	,,	6·3	,,	22·0	Nil	0·002	8·0	1·6	—	Present	—	—
—May, 1949 ..	,,	,,	6·6	,,	23·6	,,	0·002	9·6	3·8	Nil	,,	Nil	Nil
—October, 1949 ..	,,	,,	7·1	,,	29·9	,,	0·002	10·9	1·6	,,	,,	,,	,,
—April, 1951 ..	,,	,,	6·7	,,	32·3	0·012	0·002	11·1	4·8	,,	,,	6·0	1·5
—August, 1952 ..	,,	,,	6·8	,,	31·7	Trace	Trace	10·7	5·6	,,	Nil	—	—
C986 Malindi No. 8a—October, 1949 ..	,,	,,	6·9	,,	29·4	Nil	0·004	11·8	1·6	,,	Present	—	—
—November, 1949..	,,	,,	6·9	,,	28·5	Trace	Trace	10·1	5·0	Present	,,	5·1	2·4
C1041 Marafa—March, 1950	Marafa	Foot Plateau	6·9	,,	40·9	0·003	0·003	21·8	16·0	Present	Present	12·2	4·5
—August, 1952	,,	,,	8·1	2·4	32·4	Trace	Trace	18·4	8·3	Nil	Nil	—	—
C996 Mangea No. 1—December, 1949 ..	Kijego	Nyika	7·6	Nil	33·7	0·005	Trace	46·0	8·0	Trace	—	4·6	6·0
—August, 1952 ..	,,	,,	8·3	4·0	30·5	Trace	Trace	31·4	8·4	Nil	Nil	—	—
C997 Mangea No. 2—December, 1949 ..	Kwa Dadu	,,	7·3	Nil	35·5	0·029	0·002	44·0	14·0	Present	,,	8·3	7·97
—August, 1952 ..	,,	,,	7·8	,,	37·6	Trace	Trace	32·7	14·8	Nil	,,	7·1	6·0
C982 Vitengeni—December, 1949 ..	Tsangal-aweni	,,	7·8	,,	56·7	0·009	Trace	204·0	8·8	Nil	—	7·8	10·0
C1010 Jila—December, 1949	Jila	,,	7·9	24·0 (?)	Nil	0·009	0·005	315·0	26·2	Nil	Nil	29·8	15·0

*Figures quoted as parts per 100,000.

TABLE VI

ANALYSES OF BORE-HOLE WATERS FROM THE MALINDI AREA*—(*Contd.*)

Bore-hole number, name and date of analysis	Silica as SiO_2	Iron as Fe	Oxygen absorbed in 4 hours at 80°F.	Total Hardness ($CaCO_3$)	Free Carbon Dioxide CO_2	Total Solids	Fluorides as F	Lead as Pb	Remarks
C848 Malindi No. 1—March, 1949 ..	4·4	0·02	Trace	56·0	Nil	94·7	Not tested	Not tested	Satisfactory water for human consumption
—July, 1949	3·4	0·01	Trace	51·3	—	101·0	,,	,,	
—April, 1951 ..	2·7	0·012	0·07	38·1	Present	82·0	0·04	,,	
C881 Malindi No. 5—July, 1949	2·2	Trace	Trace	27·8	—	63·0	Not tested	,,	Satisfactory water for human consumption
C969 Malindi No. 6—August, 1949 ..	3·8	Trace	Trace	28·62	—	57·5	,,	,,	Satisfactory water for human consumption
—November, 1949 ..	—	—	—	31·6	Nil	53·7	,,	,,	
C860 Malindi No. 8—May, 1949 ..	3·8	0·07	Trace	10·0	Present	45·75	,,	,,	Satisfactory water for human consumption
—May, 1949 ..	3·4	0·015	,,	10·0	,,	51·6	,,	,,	Hard water, the hardness being mainly temporary. Water satisfactory for domestic purposes
—October, 1949 ..	2·0	Trace	,,	21·0	Nil	55·2	,,	,,	
—April, 1951 ..	2·2	0 015	0·06	21·2	Present	61·0	0·035	,,	
—August, 1952 ..	1·4	0·07	—	13·0 (Soap)	,,	62·0	0·04	,,	
C986 Malindi No. 8a—October, 1949 ..	1·9	0·02	0·02	21·0	,,	56·5	—	,,	Hard water, the hardness being mainly temporary. Water satisfactory for domestic purposes
—November, 1949..	—	—	—	22·6	,,	56·1	Not tested	,,	
C1041 Marafa—March, 1950	1·0	0·012	0·09	49·0	,,	91·5	0·1	,,	Hard, but satisfactory for human consumption
—August, 1952	0·2	0·07	—	14·0 (Soap)	—	81·0	0·09	,,	
C996 Mangea No. 1—December, 1949 ..	1·0	0·06	—	36·2	—	132·25	Not tested	,,	Hard, alkaline and saline water. Would require softening for other domestic purposes
—August, 1952 ..	0·2	0·01	—	12·0 (Soap)	—	111·0	0·03	,,	
C997 Mangea No. 2—December, 1949 ..	2·2	0·07	Trace	53·54	—	130·7	0·05	Nil	Satisfactory water
—August, 1952 ..	0·2	0·02	—	42·1	—	113·0	0·05	—	
C982 Vitengeni—December, 1949 ..	0·65	0·12	—	60·6	—	448·0	Not tested	Not tested	A hard, alkaline and saline water. The solids may prove excessive for human consumption. The water would require softening for other domestic purposes
C1010 Jila—December, 1949	0·85	0·29	0·04	136·2	—	649·5	0·03	Nil	The amount of dissolved salts may be found to be excessive for human consumption

*Figures quoted as parts per 100,000.

It will be noted that the "hardness" and "total solids" figures for the bore-holes drilled in the Nyika are greater than those for the coastal plain bore-holes. It would also appear from the bore-holes sunk for Malindi's water-supply that those drilled nearer the sea yield poorer quality water than those farther inland. Of note also is the general increase in the chloride and sulphate contents of the water from bore-hole C848 with time, and of the increase of sulphate in that from No. C860. Whether the increases are due to over-pumping of a shallow water-table is not known, but it is a point well worth determining by means of repeated analyses at intervals. If it is proved to be due to over-pumping, the possibility of large-scale water developments on the coastal plain appear meagre—certainly so far as bore-hole supplies are concerned. The bore-holes drilled on the Nyika and the Foot plateau show an increase of alkalinity, and general decrease of the chlorides, "total hardness" and "total solids" figures with time. The sulphate content remained steady except in the case of the Marafa bore-hole, C1041 on the Foot plateau, where there was a marked decrease.

Small earth dams have been constructed successfully, in the Malindi area, but they are of limited use. More could be built on tributary streams of the major rivers but recharge for them could only be expected during periods of heavy rainfall. It is doubtful if large dams could successfully be constructed in the major rivers, namely the Sabaki and Voi (Rare) rivers, as they are subject to heavy floods during periods of rain, and the rocks in their beds are unsuitable for the foundation of large concrete or masonry dams.

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