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MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES

MINES AND GEOLOGICAL DEPARTMENT

GEOLOGY
OF THE
MOMBASA-KWALE AREA

DEGREE SHEET 69
(with colored map)

by

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

with

A CHAPTER ON THE ALKALINE
IGNEOUS COMPLEX AT JOMBO

by

B.H. BAKER, B.Sc.,
Geologist

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FOREWORD

Although early studies of the geology of coastal Kenya were made more than fifty years ago, and a reconnaissance map of the whole coast-belt was prepared by Dr. E. Parsons in 1926, no official mapping over extensive areas had been carried out until the work that led to the present report. The area covered by it, still in reconnaissance style, but in more detail than has been attempted before, includes the whole of the coastal sedimentary belt south of the latitude of Mombasa with the exception of the ground west of the thirty-ninth meridian. Another part of the coastal belt, but inland, straddling the railway between Mariakani and Mackinnon Road and adjoining the present map-area on the north, has already been described in report No. 20. Other reports are in hand dealing with more northerly sections of the strictly coastal belt, stretching from Mombasa through Kilifi to Malindi and further north. The production of the present report has been assisted by a grant from the Colonial Development and Welfare Vote.

Mr. Caswell gives a detailed account of the sediments that build up the coastal belt, and deduces the geographical and climatic conditions that prevailed during their formation. As a result of his research, it appears unlikely that workable coal seams will be found within the Karroo rocks, as conditions were not favourable for the preservation of vegetable matter by humification at the time of deposition of the sediments. During a later geological period igneous activity took place, notably in the south, where alkaline igneous rocks make up the large hill at Jombo. Mr. Baker gives a detailed account of the intrusions, describes other volcanic centres discovered during the course of the survey, and provides a synthesis of the information available in an attempt to account for the origin of the volcanic and plutonic rocks and their connexion with known or possible mineral deposits. The manganese laterites at Mrima, which appear to belong to a portion of the complex, have been known for many years. More recently traces of other metals, such as lead, have been found at the same locality, and during the survey the presence of some as yet unidentified radioactive mineral was discovered.

Other mineral deposits, such as lead ores in veins, and materials required for the manufacture of lime and cement are considered in the report. One of the most important minerals at the Coast, as in most parts of Africa, is water, and considerable attention is given to the possibilities of water-supply in the area, particularly with reference to the needs of the growing port of Mombasa.

Finally, it must be stated that a large portion of the area described in the report is at present closed to prospecting and mining.

Nairobi,
9th August, 1952.

WILLIAM PULFREY,
Chief Geologist.

ABSTRACT

This report describes an area of some 1,750 square miles lying in the extreme south-eastern corner of Kenya; the area is bounded by latitude 4° S., longitude 39° E., the Kenya-Tanganyika border, and the Indian Ocean.

The rocks exposed consist of sediments ranging in age from Permo-Carboniferous to Recent and which represent continental, lacustrine and marine conditions of deposition. Igneous and pyroclastic rocks are confined to Jombo Hill, an alkaline intrusion, and associated satellite vent agglomerates and dykes.

An account is given of the various rocks, their genesis and their structures, and an attempt is made to correlate them with other areas.

The economic prospects of the area are assessed and the possibility of the presence of coal-bearing strata is discussed.

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GEOLOGY OF THE MOMBASA-KWALE AREA

I—INTRODUCTION

1. General Information

The area to be discussed in this report is the total land extent of degree sheet 69 (Kenya Colony) and is bounded by latitude 4° S., longitude 39° E., the Kenya-Tanganyika border, and the Indian Ocean. It includes most of the Kwale district and parts of the Mombasa district and the Kilifi district, and falls within the Coast Native Land Unit. The land lying within ten miles of the coast is the property of the Sultan of Zanzibar but is rented from him and protected by the British Government. Together with a strip to the west of it, it is at present closed to prospecting by Government Notice No. 94 of the 4th February, 1935.

The indigenous tribes of the area are the Wa Digo, who inhabit the coastal regions, and the Wa Duruma but, particularly around Gazi and Vanga, there is a marked Arab influence. In general, the density of population decreases westwards, this being due primarily to the inland diminution in rainfall and, to a lesser extent, to the nature of the rock outcrops and their effects upon the growth of vegetation.

Communications are fairly good, few parts of the area being more than twelve miles from a motorable road. Since the mapping was completed several new roads have been constructed under the Coast Hinterland Development Scheme and, where known, their approximate positions are shown on the accompanying map.

Maps.—The geological map is based on the following topographical maps:—

1: 25,000 Mombasa, E.A.F. No. 785, 1942.
1: 50,000 Mombasa, E.A.F. No. 1034, 1942.
1: 50,000 Kwale, E.A.F. No. 1121, 1942.
1: 50,000 Coast Strip, E.A.F. No. 793, 1942.
1: 50,000 Funzi Islands, E.A.F. No. 1201, 1942.
1:125,000 Mombasa, E.A.F. No. 1191, 1942.
1:125,000 Gazi, E.A.F. No. 809, 1942.

Many of these maps, particularly those covering the area lying to the west of the Shimba Hills, were found to be inaccurate in many particulars. Time was not available to resurvey the inaccurate portions but details were modified wherever possible. Aerial photographs of the north-western corner became available at a late stage in the writing of the report and information from them has been incorporated in the map. Place names have been taken from the topographic maps and as many additional names as possible, supplied by the inhabitants, have been included.

The survey was undertaken between November, 1949, and September, 1950. Geological mapping was carried out mostly on cyclometer and compass traverses with resort to plane-table work whenever practicable. Traverses at two-mile intervals were aimed at subject to a certain degree of flexibility where the conditions seemed to justify it. Exposures are poor and, in many parts, few and far between. Dip readings were taken to the nearest five degrees except where the exposures were good enough to permit of more accurate measurements.

2. Previous Geological Work

Among the early students of East African coastal geology were Baron von der Decken (1869)*, J. Thomson (1879), Walcot Gibson (1893), Stromer von Reichenbach (1896), J. W. Gregory (1896), and E. E. Walker (1903).

Rich Thornton—Livingstone's colleague in the Zambezi expedition— who crossed from Mombasa to Kilimanjaro with von der Decken, noted silicified wood and plant remains in the Shimba Hills and, impressed by the similarity of the latter to the *Calamites* of the Zambezi Coal Measures, described the flags and sandstones of the **Coast Range as probably Carboniferous.** This conclusion was accepted by Thomson (1879, p. 558) and extended to include the coastal limestones, for he regarded their corals and marine shells as also Carboniferous.

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* References are quoted on pp. 104–106

In 1905, H. B. Muff (Maufe) of the Geological Survey of Great Britain was commissioned to examine the geology of the East African Protectorate, his report being published in 1908. He confined his activities to a traverse along the entire length of the railway-line from Mombasa to Port Florence (Kisumu), with subsidiary traverses in the Central and Rift Valley Provinces; hence his coastal work was somewhat restricted. He was, however, the first to establish a detailed stratigraphical succession of the coastal sediments (Table I).

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

Pleistocene	Raised coral reef and Kilindini sands.
Jurassic	Changamwe shales with limestone near the base (U. Jurassic fossils).
? Triassic	Mazeras sandstone with pisolitic limestone near the top.
	Mariakani sandstones.
	Maji-ya-Chumvi beds (plant remains).
	Taru grits.
Archæan	Gneiss.

Maufe recognized that the rocks dip gently, and become progressively younger, towards the coast.

Fraas (1908) reported a cross-section of a belemnite and an indistinct impression of an ammonite from grits at Samburu, assigning the beds to the Lower Jurassic. Furthermore, impressed by the resemblance of the Maji-ya-Chumvi Beds to the Changamwe Shales, he identified the former as Kimmeridgian and Oxfordian, and postulated a belt of Cretaceous rocks separating the two localities.

Dacqué (1909) classified the Duruma Sandstone as the British East African representative of the "African Sandstone", a non-marine, pre-Bathonian formation extending from Egypt to South Africa.

In 1919, Professor J. W. Gregory paid a second visit to Kenya and soon after published his famous book on the geology of East Africa (1921). Four chapters were devoted to the coastal geology of Kenya and the importance of this contribution cannot be over-emphasized. The stratigraphical succession he proposed (Table II) was basicly similar to that put forward by Maufe but greater sub-division was possible.

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

Pleistocene	Raised coral reefs.	
Pliocene	North Mombasa crags.	
	Magarini sands.	
Jurassic	Changamwe shale	Corallian.
	Rabai shale	Oxfordian.
	Miritini shale	(?) Lower Oxfordian.
	Kibiongoni beds	Callovian.
	Kambe limestone	Bathonian.
Duruma sandstone (Permo-Triassic) ..	Shimba grit.	
	Mazeras sandstone.	
	Mariakani sandstone.	
	Maji-ya-Chumvi beds.	
	Taru grit.	
Eozoic	Gneiss.	

From his sections (*op. cit.*, p. 49) it is evident that Gregory regarded the Duruma Sandstones as forming the western limb of a broad syncline whose axis corresponds roughly with the trend of the Shimba Hills, with the seaward-dipping Jurassic rocks resting unconformably upon their eastern upturned edges.

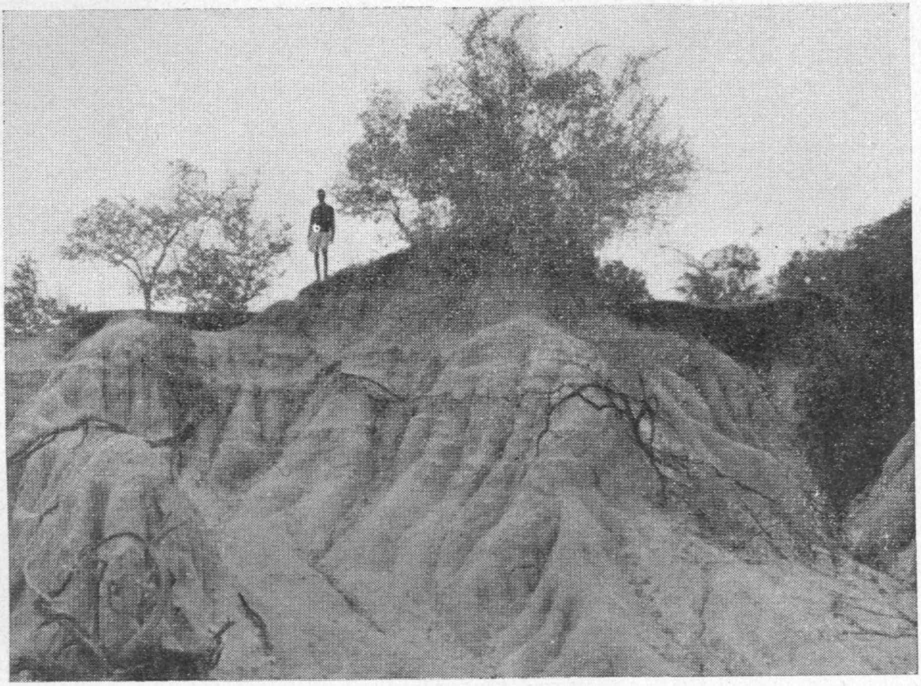
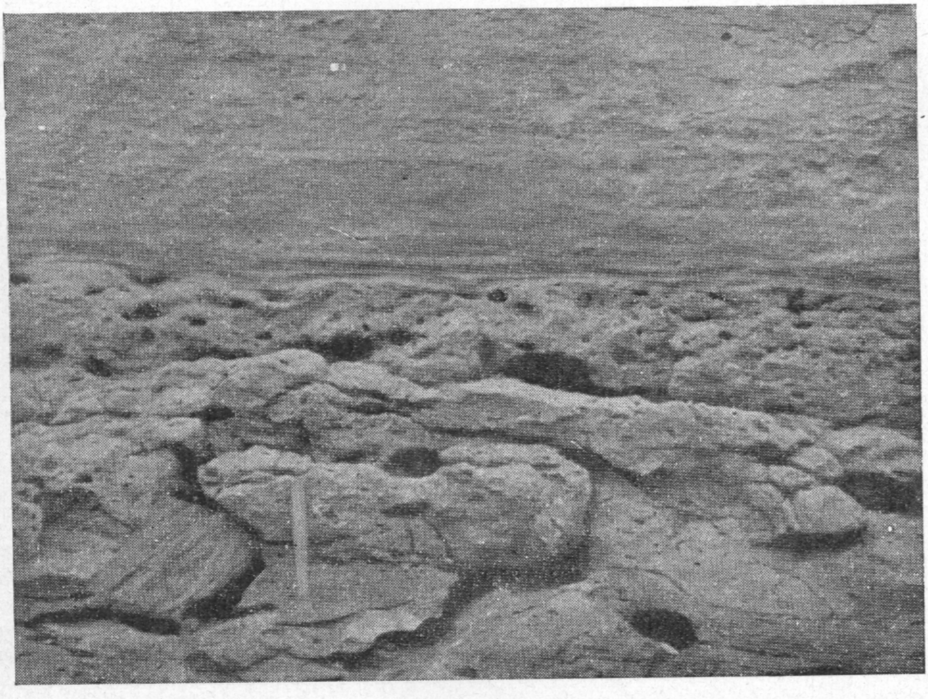


Plate 1. (a)—Erosion Pit in the Magarini Sands near Matuga.



(b)—Basa conglomerate of the Kambe Limestone with boulders of Mazeras Sandstone.

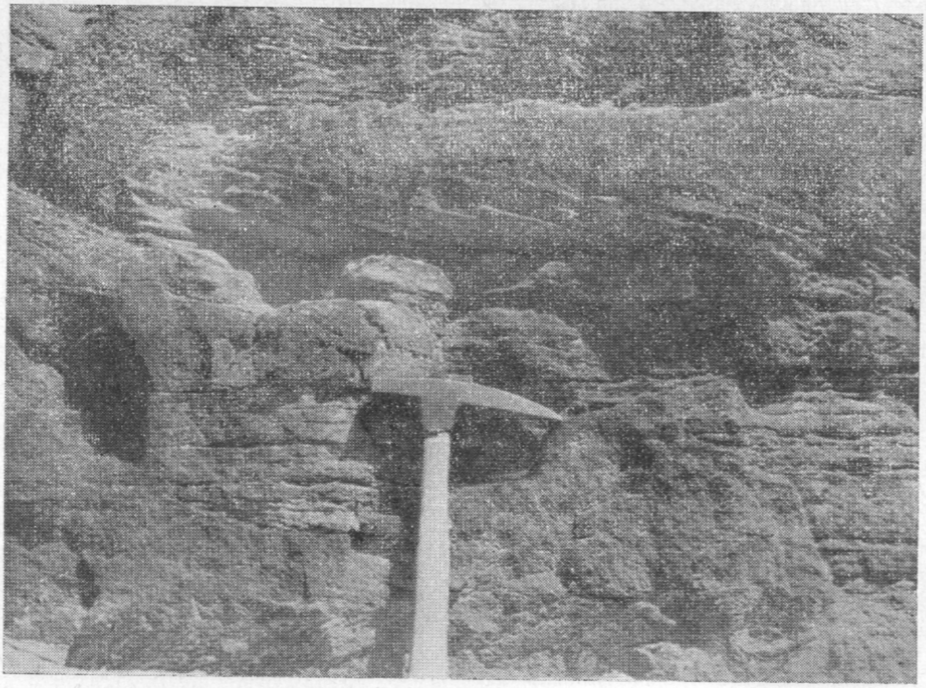
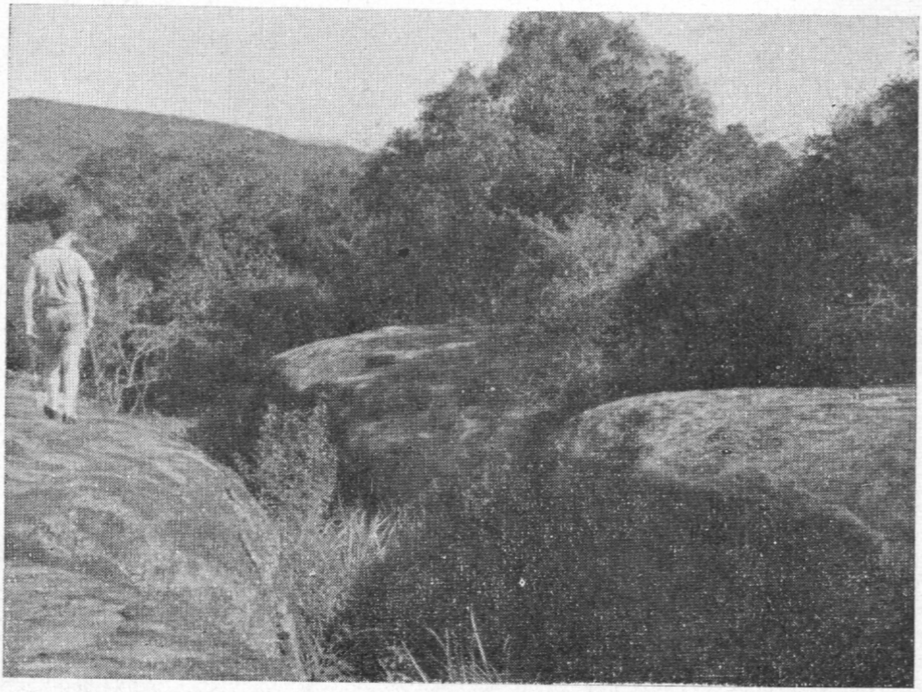


Plate II (a)—Cross-bedded Mazeras Sandstone in railway cutting east of Mazeras.



(b)—Eroded Joint-plane in the Taru Grit.

A few years later Dr. E. Parsons mapped the coastal belt between the Sabaki Valley and the Tanganyika border, thus accomplishing the first comprehensive survey. His published conclusions (1928) differ greatly from those of Gregory; he cited evidence of large-scale thrusting in the coastal succession in an attempt to show that the Gregory Rift Valley in Central Kenya was of compressional origin. In his stratigraphical table he reversed the positions of the Mazeras Sandstone and the Shimba Grit, combined the Jurassic and Cretaceous rocks into the "Miritini Series" and the "Changamwe Series", and included under the term "Magarini Series" all the Tertiary formations from the Eocene to the Pleistocene. He regarded the raised coral reef as being of Recent age.

In 1930 a monograph was published on the geological collections from the Kenya coastlands made by Miss M. McKinnon Wood. It is primarily a palaeontological report with contributions on the different phyla by various authorities. It is the only report of its kind on this area yet published and is, therefore, of great value. The stratigraphical section is largely a recapitulation of Gregory's views.

A confidential report on the oil prospects of Kenya, including chapters on the coastlands, was written by H. G. Busk and J. P. de Verteuil in 1938. A discussion of the physiographical aspects of the Mombasa area was published later (1938) by Busk. The coast ranges were regarded as being degraded horsts dating from early Jurassic times when the collapse of Gondwanaland led to the initiation of faults of "rift" type.

II—PHYSIOGRAPHY

Gregory (1921, Chapters IV–VI) divided the coastal belt into three physiographic units closely related to the three chief groups of sedimentary rocks comprising the belt. These units he called (1) The Coast Plain, composed of the Pleistocene deposits, (2) The Foot Plateau, which very nearly coincides with the Jurassic deposits, and (3) The Nyika, which is underlain by the Duruma Sandstones in the present area. These units are retained for the purposes of this report and a fourth, which it is proposed to call the "Coastal Range", is added to embrace the Shimba Hills. The four units run more or less parallel to the coastline (Fig. 10).

The Coast Plain, comprising the late Cainozoic formations, rarely exceeds two to three miles in width and generally lies below the 100-ft. contour. The seaward margin of the plain is composed of the Pleistocene coral reef which, in its natural state, supports a thick, almost impenetrable bush. Inland the coral gives way to sands which have been extensively cultivated throughout much of their outcrop. Large coconut plantations flourish on the north and south mainlands, particularly near Gazi, while further to the south are the Ramisi Sugar Estates. The coastal roads from Mombasa to Malindi and from Mombasa southwards to Shimoni run along the centre of the Coast Plain throughout much of their lengths.

Behind the Coast Plain the ground rises rapidly, and often more or less abruptly, to the Foot Plateau that stands at an elevation of from 200 to 450 ft. The basis of the Foot Plateau is the Jurassic Rocks which are well-exposed in the northern part of the area, where their flat, planed-off surface slopes gently seawards from a height of approximately 250 ft. near Mwachi trigonometrical station to 120 ft. at Changamwe. Resting on the eastern edge of the plateau is a long ridge of sandy hills composed of the Magarini Sands that accentuates the margin. Further south these sandy beds extend westwards to the Duruma Sandstones and mask the Jurassic Rocks completely. Where they are present, the planed Jurrasic surface on which they rest is preserved but elsewhere it has been deeply dissected by numerous stream-courses. It would seem, therefore, that the planation of the Jurassic surface occurred immediately prior to the deposition of the Magarini Sands; i.e., in Middle Pliocene times. The Jurassic Rocks, consisting largely of impervious shales, yield a poor soil and are characterized by stunted thorn trees and patches of tall "elephant" grass. The Magarini Sands are more suited to agricultural development and a research station has been established at Matuga but, on account of their loose texture, the sands are highly susceptible to erosion and precautions should be taken in this respect.

A second steep ascent, this time of the order of 500 ft. or more, takes one up on to the Coast Range, locally known as the Shimba Hills. This horst-like eminence, composed of Mazeras Sandstone with a capping of Shimba Grit, forms the dominant physiographic feature of the area. Apart from a few isolated summits, the highest of which attains an altitude of just over 1,400 ft., the range is more or less flat-topped at a height of 1,200 to 1,300 ft. This feature is due to the resistant grit capping that protects the more easily eroded underlying sandstones. It is possible that the hills are a remnant of an old erosion surface although it is not easy to match their height with the profiles of the other surfaces recorded in Kenya. At their northern end, the hills appear to be terminated by a fault that has shifted the Mazeras Sandstone laterally westwards. The Manolo River (alternatively called the Pemba or Cha Shimba) has cut its course through the faulted zone to form the "Mombasa Gap", a feature well known to mariners. The sandstones and grits yield a fairly good soil well suited to afforestation and much of the hills is devoted to Forest Reserves. Kwale, the administrative headquarters of the greater part of the area, is situated on the top of the hills.

From the western edge of the Coast Range the topography drops steeply to the Nyika which, starting from about the 600 ft. contour, rises gradually to about 1,000 ft. on the western boundary of the area. It extends for many miles north-west of the present area and is underlain largely by Basement System rocks. The Nyika appears to be the remnants of an old peneplaned surface, considered to be of middle Pliocene age, that has subsequently been sculptured by river erosion. In the area surveyed, the inter-bedded soft shales and harder sandstones have influenced the drainage pattern producing a "trellis" effect which is reflected in the topography by a series of dip and scarp slopes. Rainfall is much lower than that on, and to the east of, the Coast Range so that most of the country is semi-arid, sparsely populated, and capable of supporting only dwarf, scrubby, generally leafless trees and succulent plants such as cacti and *Euphorbia candelabra*. The last named can usually be taken as an indication that the water-table exists at a considerable depth below the surface.

RAINFALL AND DRAINAGE

The following table shows the average annual rainfall of various places in the south Coast Province and the rainfall recorded during the year 1950. The places are listed according to the physiographic units in which they lie.

	Rainfall 1950	No. of Rainy Days	Average Annual Rainfall	No. of Years Recorded
COAST PLAIN—				
Mombasa	36·03	127	47·84	59
Gazi	43·98	99	58·98	14
Vanga	40·00	116	45·64	14
FOOT PLATEAU—				
Matuga	30·61	122	—	—
Muhaka	35·99	100	—	—
COAST RANGE—				
Kwale	41·86	124	41·30	38
Mrere	31·60	112	44·97	16
NYIKA—				
Kinango	26·27	118	34·33	7
Kibandaongo	17·01	42	—	—
Ndvaya	28·76	?	—	—
Mwangulu	36·54	116	—	—

The principal drainage trend follows the regional dip to the east-south-east with a secondary trend at right angles along the strike. The Shimba Hills form a barrier to the normal seaward courses of many of the rivers from the hinterland which are diverted either northwards into the Mwachi or southwards into the Ramisi. Drainage off the Shimba Hills is quaquaversal with a predominance on the western side into the Manolo River system. Most of the rivers are seasonal.

III—SUMMARY OF GEOLOGY

The rocks of this area are largely of sedimentary origin and range in age from Permian (or possibly Upper Carboniferous) to Recent. Three well-marked divisions can be recognized:—

(3) The Cainozoic rocks.
(2) The Upper Mesozoic rocks.
(1) The Duruma Sandstone Series.

The Duruma Sandstone Series, which is the Kenya correlative of the Karroo System of South and central Africa, consists of grits, sandstones and shales that have yielded Permain and Triassic fossils, although it is possible that the series ranges downwards to the Upper Carboniferous and upwards to the Lower Jurassic. The series is readily divisible into three broad lithological units with coarse sandstones and grits at the top and bottom of the succession, and finer sandstones and shales in the middle. For the most part the beds were deposited under lacustrine or sub-aerial conditions, the material having been derived from the Basement System rocks further to the west. A marine intercalation in the lower part of the succession is known from evidence obtained in a deep borehole drilled near Maji-ya-Chumvi (Miller, 1952).

The upper Mesozoic rocks consist of limestones and shales with occasional thin sandstones that range apparently without a break from the Bajocian to the Middle Kimmeridgian. Rocks of Neocomian age that appear to be down-faulted against the Kimmeridgian are also present. The upper Mesozoic rocks are all of marine origin.

The Cainozoic rocks include a Pleistocene coral reef with its associated lagoonal deposits of coral breccia, calcareous sands and beach sands, and a thick series of terrestrial sands and gravels that are probably of Upper Pliocene age.

The Duruma Sandstones and the Upper Mesozoic rocks have a regional dip of 5° to 10° to the east-south-east, whilst the Cainozoic rocks are generally flat-lying. The Upper Mesozoic rocks are stratigraphically unconformable upon the Duruma Sandstones but their contact is faulted throughout much of its length. The Cainozoic rocks rest unconformably upon an eroded surface of Mesozoic rocks with occasional overlap on to the Duruma Sandstones.

An alkaline intrusion at Jombo Hill, where nepheline-syenites, ijolites and melteigites outcrop, and associated vent agglomerates and dykes are the only eruptive rocks of the area. The intrusions and volcanic activity associated with them have been referred to the Cretaceous or Tertiary (Gregory, 1921, p. 192).

IV—STRATIGRAPHY

The stratigraphy of the area falls naturally into three divisions:—

(3) The Cainozoic rocks.
(2) The Upper Mesozoic rocks.
(1) The Duruma Sandstone Series.

Each division will be treated as a separate section with a detailed stratigraphical table to each. Table III shows the complete succession in condensed form with suggestions as to the prevailing climatic conditions and main palaeogeographic events.

TABLE III—STRATIGRAPHICAL SUCCESSION IN THE KENYA COASTLANDS

ERAS			PERIODS			LOCAL REPRESENTATIVE	LITHOLOGY AND THICKNESS	ENVIRONMENT OF DEPOSITION	CLIMATE	PALÆOGEOGRAPHIC EVENTS
CAINOZOIC	QUATERNARY		RECENT			River Deposits	Alluvium	—	—	
			PLEISTOCENE			Coral Reef Lagoonal Deposits	Reef limestones calcareous sands quartz sands. 300 ft.	Marine and lagoonal	Pluvial and Inter-Pluvial	Fluctuating sea-level.
	TERTIARY		PLIOCENE			Magarini Sands	Sands and gravels, 400 ft.	Deltaic and continental	Semi-arid	Faulting (?). Erosion. Faulting (?).
			MIOCENE							
			OLIGOCENE							
			EOCENE							Extensive continental erosion.
	MESOZOIC		CRETACEOUS	Upper						Faulting (?).
				Lower		Freretown limestone	Limestones and shales	Marine	? Semi-arid	Marine invasion in the centre of the basin with contemporaneous erosion of the margins.
			JURASSIC	Upper		Changamwe shale Coroa Mombasa limestone Miritini shale Kibiongoni beds Kambe limestone	Limestones, sandstones and shales, c.4,000 ft.	Marine and (?) estuarine	Warm	
				Middle						
				Lower						
		KARROO	TRIASSIC	Upper	Duruma Sandstones	Shimba grits Mazeras sandstone	Grits and arkosic sandstones, 1,000 ft.	Continental and deltaic	Generally semi-arid with periods of increased aridity	Partial collapse of the basin (?).
				Lower		Mariakani sandstone Maji-ya-Chumvi beds	Thin sandstones and shales, 6,500 ft.	Lacustrine; one marine intercalation		Continued down-warping to form basis of sedimentation.
	PALÆOZOIC		PERMIAN	Upper		Taru grits	Grits and arkosic sandstones, 500 ft.			Down-warping of continental margin.
				Lower						
			CARBONIFEROUS	Upper						
	ARCHÆAN		BASEMENT SYSTEM				Gneisses and Schists			

NOTE.—Dotted lines indicate unconformities.

1. THE DURUMA SANDSTONE SERIES

The Duruma Sandstone Series was named by Stromer von Reichenbach (1896, p. 22). It covers the greater portion of the present area and is comprised of grits, sandstones and shales that seem, for the most part, to have been deposited under lacustrine, deltaic, and possibly neritic conditions. Three broad lithological divisions are recognizable, with coarse sandstones and grits at the top and bottom of the succession and finer sandstones and shales in the middle:—

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

(1) *The Lower Duruma Series* (*Taru Grits*)

The Taru grits outcrop in the north-western corner of the area and are best seen along the Kinango-Samburu road to the north of Vigurangani. They consist of massive grey or bluish-grey quartzo-felspathic grits with subordinate bands of hard black shale and attain a thickness of at least 450 ft.

The grits are of coarse, variable texture, poorly sorted, and generally current-bedded. They are traversed by two sets of widely-spaced joints which cause them to weather into massive rectangular blocks, whose corners are then rounded by exfoliation. In some localities, such as to the west of Vigurangani, the weathering out of the joint-planes forms natural reservoirs that may be as much as a hundred feet long, six feet wide and several feet deep (Plate 2 (*b*)). The constituent grains are of variable size and are generally sub-angular. They consist primarily of quartz and microcline, with small proportions of sodic plagioclase, mica, hornblende and garnet, that are cemented together by calcite or, in some cases, quartz. With extensive weathering, the felspar breaks down and the rocks disintegrate to form a superficial covering of quartz sand. Specks of carbonaceous material are common throughout the succession and a block of coal was reported several years ago from a railway cutting near Taru (Gregory, 1921, p. 53; Miller, 1952, p. 1). These have suggested the possible existence of coal seams within the series but none have as yet been found. The shale bands are rarely seen in surface exposures but their presence is known from borehole records (see Samburu borehole log—Maufe, 1908, p. 14). They have yielded indeterminable plant remains, and from similar beds along the Sabaki river Gregory (1921, p. 54) obtained fish scales and the fresh-water bivalve *Palaeanodonta fischeri* Amal. The genus *Palaeanodonta* ranges from the Devonian to the Permain but the species *P. fischeri* is known only from beds of upper Permain age, thus providing conclusive evidence on the age of the Lower Duruma Series, or at least a part of it.

Exposures are generally poor but the regional dip appears to be in an east-south-easterly direction at about 5°. The base of the series is not seen and its relationship to older rocks cannot be determined, but the recording by Parsons (1928, p. 66) of occasional well-rounded pebbles of Basement System gneiss in the grits suggests an unconformity. More recent work by Miller in the Mackinnon Road area, however, points to the boundary being faulted. It is clear that the materials comprising the grits were derived from the gneisses, and the angular nature and poor sorting of the grains indicates that they were deposited rapidly at a place not far distant from their source. Since the only fossils so far obtained are plant remains and fresh-water shells, it is concluded that sedimentation took place under lacustrine conditions.

(2) *The Middle Duruma Series*

(*a*) *The Maji-ya-Chumvi Beds.*—These beds, the most shaly of the Duruma Sandstone Series, overlie the Taru Grits, possibly with slight unconformity in parts although exposures are not sufficiently good to make this point certain. They consist of bluish-black, grey and greenish-grey, gritty, often micaceous, shales with inter-bedded yellowish-white silty sandstones. The shales often weather to a brownish colour and, being more easily eroded than the sandstones, they allow the formation of broad valleys along their strike. The drainage pattern generally well illustrates the lithological variations of the succession. The base of one fairly prominent escarpment, along the top of which runs the Mariakani-Kinango-Tanga road throughout much of its length, was taken as the boundary between the upper and lower divisions of the beds. It was an arbitrary arrangement but it seemed to be more consistent and more easily followed than the threefold division proposed by Parsons (1928, p. 68). It is evident from Miller's work on the core samples from a borehole near Maji-ya-Chumvi that subdivision based on the included fauna will ultimately be possible and already a threefold faunal sequence has been established:—

3. Yellowsh-white calcareous siltstones and blue micaceous shales with *Estheria* (c. 2,600 ft.).
2. Blue shales containing marine fish remains (c. 70 ft.).
1. Bluish-black gritty shales and muddy sandstones with plant remains (c. 1,900 ft.).

Stratigraphically, the *Estheria* beds correspond closely with the upper division referred to above.

Shales of the lowermost division can be seen in roadside gullies near Banga, on the Kinango-Samburu road. They are bluish-black in colour, weathering to grey, and are very thinly bedded so that they can be readily split into slabs. Plant remains are to be found in these shales; they are generally poorly preserved and rarely identifiable but the writer has obtained a recognizable leaf impression of the conifer, *Voltzia.* The frequent occurrence of rain-prints and sun-cracks shows that these beds were periodically exposed above water-level, and other impressions, more rarely found, are possibly gas pits caused by the ascent of bubbles of gas during the compaction of the sediments. The various features indicate a continuation of the lacustral environment. The water had become shallower since Lower Duruma times and occasionally retreated to expose the freshly deposited muds that were then sun-dried and cracked. These retreats were probably caused by evaporation for the rocks often contain an appreciable percentage of precipitated salts, as is shown by the salinity of the water obtained from the beds, and in more obvious form by the thin film of salt covering the dry beds of the rivers following a heavy spell of rain. It is apparent that the Lower Maji-ya-Chumvi beds accumulated slowly in a semi-arid climate.

The upper two divisions are characterized by sediments of a somewhat coarser grade. The advent of a new fauna containing marine fish indicates that a connexion with another environment was established at this stage and it is of interest to note that the fish furnish the only evidence, so far recorded, that marine horizons exist in the Duruma Sandstone Series. The rocks of the group are typically ripple-marked, current-bedded and well-jointed. Two sets of joints are always present and a third is often seen, their directions being:—E.N.E.-W.S.W., N.W.-S.E., and N.-S. They are regular, clean-cut and closely spaced, and aided by the laminar nature of the strata cause the beds to break down into rectangular, platy fragments that litter the surface. Differential weathering of these fragments occasionally causes them to assume a discoidal shape.

Near the top of the series there occurs a pebble horizon that can be seen on the Tanga road near Kinango. The pebbles are quartz and are well-rounded, attaining diameters of up to 30 mm. They are apparently of limited extent and probably represent the site of a former playa.

The age of the uppermost division is shown to be Triassic by the presence of the branchiopod *Estheria mangaliensis* Jones, a specimen of which was obtained from near the Kinango-Mariakani road. This species is known from the Triassic rocks of India and also from the Série du Kwango (U. Trias) of the Belgian Congo (Furon, p. 273). Another species found by Maufe (1908, p. 12) was identified by Newton (Geol. Mag. 1915, p. 276) as allied to *E. grayi* Jones of Permian age. Maufe (*op. cit.*, p. 12) also found plant remains at mile 38/10–11* along the railway-line that were identified by Newell Arber as *Thuyites* and *Carpolites. Estheria* is characteristic of fresh, or more rarely brackish, water so that a return to a lacustrine environment is indicated.

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* The figures 10–11 refer to the number of telegraph poles reading from the last mile post. At the time of Muff's survey there were eighteen telegraph poles to the mile.

The outcrop can be traced with little difficulty from the northern boundary of the area to the neighbourhood of Kinango but further south it becomes less easy to distinguish owing to the degree of weathering, the paucity of exposures, and the frequent covering of superficial sand. A well-developed horizon of pale grey quartzite, dipping 10° to 18° to N.N.W. is exposed in the Ramisi River to the north of Jombo Hill. It has not been possible to trace this horizon away from the river so that its stratigraphical position cannot be ascertained. It has been provisionally referred to the Upper Maji-ya-Chumvi Beds although it might belong to the Mariakani Sandstones. Fragments of a similar rock, impregnated with finely disseminated galena, occur near the Lungalunga-Kikoneni road south of Jombo.

(*b*) *The Mariakani Sandstones.*—The Mariakani Sandstones represent another series of fine-grained, flaggy sandstones and silty shales that follows conformably upon the Maji-ya-Chumvi Beds. They are more sandy than their predecessors and often more massive. In colour they are grey, greenish-grey or yellowish but attain a brownish tinge on weathering. Many of the horizons exhibit a blotched or mottled appearance and, since this is distinctive, the lowermost blotched band has been taken to represent the base of the series. They are well-jointed, ripple-marked and current-bedded but, unlike the Maji-ya-Chumvi beds, yield no traces of desiccation. Some exposures show small-scale contortions of the bedding planes such as is commonly associated with slumping during compaction of sediments.

Mineralogically the rocks are composed largely of poorly sorted, inequigranular, sub-angular quartz and felspar grains, the latter generally being considerably weathered. Mica, usually muscovite, is a common constituent of the shale horizons and it is also present in the sandstones, especially those higher in the succession. It is finely divided and occurs interstitially between the quartz and felspar grains where it makes a poor cementing material so that the rock crumbles easily to a fine sand. At some horizons the concentration of mica flakes along the bedding planes causes the rock to split readily into slabs. Grains of carbonaceous material, tourmaline, hornblende and zircon are sometimes found in the sandstones, and apatite has also been recorded. Iron and manganese staining is commonly present along the bedding planes.

There appears to be no mineralogical reason for the blotches found in many of the beds. They are more or less spheroidal but somewhat flattened on the upper and lower surfaces, suggesting that they originated as spheres during sedimentation but were subsequently compressed when the material underwent compaction. It is possible that they were caused by the initiation of local centres of leaching from which the iron or manganese oxides were partly removed leaving spheres deficient in those constituents.

The only fossils so far obtained from these beds are poorly preserved plant remains that are unidentifiable and of no stratigraphical value.

The outcrop can easily be followed in the northern part of the area but, like the Maji-ya-Chumvi beds, it becomes increasingly difficult to trace further south. The blotched sandstones, which are considered to be diagnostic of the Mariakani Sandstones, were not recognized in the southern part of the area and it is probable that the series is absent altogether. Such evidence as there is seems to show that the Upper Maji-ya-Chumvi beds lie in juxtaposition with the Mazeras Sandstone, suggesting that the Mariakani Sandstones are cut out by faulting. It may also be mentioned that the sedimentary material associated with the Nguluku agglomerate (p. 43) is composed mainly of fine-grained black shale which more closely resembles the Maji-ya-Chumvi beds than the Mariakani Sandstone.

(3) *The Upper Duruma Sandstone Series*

The Mazeras Sandstone and Shimba Grit.—Rocks of the Upper Duruma Sandstone Series give rise to the dominant topographical feature of the area—the Shimba Hills. They consist of massive, cross-bedded, quartzo-felspathic sandstones and grits with interbedded shales in the lower horizons, and attain a total thickness of at least 1,000 ft.

Their relationship to the underlying Mariakani Sandstone is not fully understood. In the north of the area they seem to be conformable with a gradation from one to the other but, further south, exposures near the Mombasa Pipe Line* and in the Manolo River show rocks of widely diverse types in such close proximity that a conformable sequence is questionable. The junction is frequently marked by an increase in the angle of dip so that the possibility of local faulting cannot be overlooked.

The lowermost beds seen, on the M.P.L. road, are coarse, dull white, felspathic sandstones that are cross-laminated and massive, and weather into huge blocks that may be as much as 20 to 30 ft. across. Overlying these are finer-grained, false-bedded sandstones with thin interbedded shales (Plate 2 (*a*)). Exposures of the succeeding horizons are scarce but it is suspected that they are dominantly shaly. Sections in the Manolo River show a series of coarse, massively jointed sandstones that continue upwards for several hundreds of feet and which, near their base, include a horizon, some fifty feet in thickness, that contains abundant fragments of silicified fossil wood. Outcrops showing this wood have been observed in many localities, but whether there is one horizon or several has not yet been determined. If there is only one, and it seems probable that this is so, then it will form an excellent marker horizon for more detailed stratigraphical surveys, although the possibility that the band is diachronous must not be overlooked. Localities where the silicified wood has been found are as follows:—

(1) Manolo valley near the Kwale-Kinango road. (c. 600 ft.)

(2) Kwale-Kinango road, one mile south of the Manolo River. (c. 600 ft.)

(3) Manolo valley, one and a half miles north-north-west of the Shimba beacon. (580 ft.)

(4) Near the confluence of the Manolo and Kitanzi rivers. (200 ft.)

(5) M.P.L. mile 12. (c. 500 ft.)

(6) Half a mile south of the Engineer's hut along the M.P.L. (480 ft.)

(7) Duruma valley near the head of Port Reitz.

(8) Eastern flank of the Shimba hills near Giriama beacon. (c. 1,000 ft.)

(9) Eastern slopes of Kivumoni hill near the summit. (c. 900 ft.)

One of the significant points about these localities is that the two recorded from the eastern flank occur at a considerably greater altitude than those on the western flank; hence if only one horizon is represented, the regional dip of the Mazeras Sandstone is westerly. The drainage supports this.

The wood is usually found as rolled fragments a few inches in diameter, but stems, and more rarely trunks, have been recorded. Maufe found several along the railway line and noted that in every case they were aligned north–south, indicating that the trees had been drifted into place and had not originally grown there. One of Maufe's specimens was referred by Newell Arber to the genus *Cedroxylon* (Maufe, 1908, p. 9). More recently found specimens have been identified with the genus *Dadoxylon* which ranges from the Trias to the Tertiary and which is represented in the Liassic rocks of Madagascar. The poor state of preservation has prevented specific identification, but one specimen shows close affinities to *D. sclerosum* (McKinnon Wood, 1930, p. 214) the type specimen of which is described from the Molteno Beds (Upper Trias) of South Africa. The main point of difference, and indeed a feature that is common to nearly all the Kenya specimens, is the absence of growth rings. This may perhaps indicate that the climate when the trees grew was equable.

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* Frequent reference will be made to the Mombasa Pipe Line in future pages so, for the sake of brevity, it will be referred to as the "M.P.L." and the road that runs alongside as the "M.P.L. road".

Overlying the wood horizon in the Kitanzi River is a series of pale greenish sandstones of from 120 to 150 ft. in thickness, overlain by a similar thickness of pale buff-coloured sandstone. The green colouration is due to finely divided chlorite that occupies the interstices between the quartz and felspar grains. Immediately below the wood horizon at this locality is a bed of marly sandstone, pale greenish in colour, that contains pellets of clay.

Near Mrere, the horizons containing the wood and those immediately above and below are not exposed, the wood horizon being inferred from float. Other float in the neighbourhood is mainly grit and there are several exposures of white quartzo-felspathic grit and quartzitic sandstone to be seen at Mrere itself. Borehole records from Mrere show that sandy clays and shales account for a large proportion of the succession passed through, yet no exposures of such rocks are to be seen at the surface. A typical borehole record (No. C. 319) illustrates this:—

FEET		
From	To	
0	12	Sand.
12	20	Sand and sandstone.
20	25	Clay and sand.
25	45	Sandstone and clay.
45	66	Clay with some sandstone.
66	77	Sandstone and clay.
77	79	Sand containing a six-inch band of coal.
79	220	Sandstone and clay.
220	280	Sandstone and clay (harder).
280	287	Grey clay.
287	298	Red clay.
298	300	Sandstone and clay.

As will be seen, this particular borehole revealed a six-inch "band" of coal but, as no trace of coal has been found in any of the other boreholes nor on the surface, the occurrence must be regarded as being of localized extent and due to the humification of one of the *Dadoxylon* trees. Doubtless there are several other similar occurrences within the fossil wood horizon but the possibility that a coal seam exists is extremely remote.

At the northern end of the Shimba Hills the sandstones are succeeded by coarse grits that show little trace of bedding. They are felspathic, the felspar being highly weathered and frequently kaolinized. From this level upwards to near the top of the series exposures are scarce, but boulders indicate that coarse sandstones and grits are represented. The uppermost exposures are of coarse, poorly-bedded grits, a hundred or so feet thick, containing wind-polished quartz pebbles of up to half an inch diameter. They are usually yellowish-white in colour but are sometimes reddish or purplish due to the surface concentration of iron hydroxide. These rocks are the Shimba grits and they form a resistant layer that caps the Shimba Hills and preserves them as a prominent feature.

The rocks of the Upper Duruma Series are composed largely of quartz and felspar grains, the latter generally weathered and often kaolinized, cemented together by mica, felspar, silica or calcite. Of these cementing materials, mica and felspar are the most common but since neither forms a good cement the rocks readily disintegrate to sand. The mode of preservation of the fossil wood indicates that silicification was prevalent during Upper Duruma times, a feature that has been noted elsewhere in beds of the same age by Stockley (1936, p. 27) and Lightfoot (1914, p. 17). Stockley suggests that silicification has occurred in two phases, the first contemporaneously with the formation of the Karroo sandstones, and the second at a later date. This would appear to be the case in the present area for some of the fault planes are silicified. Stockley (*op. cit.*, p. 28) goes on to give an interesting account of the possible mode of silicification of the *Dadoxylon* trees. In the lower horizons the grains are generally sub-angular indicating that the sediments were laid down under water, but the grains of the higher horizons show evidence of having been wind-polished. No true dreikanter were recognized although they have been recorded by earlier workers (Gregory, 1921, p. 46).

The Shimba hills present a horst-like appearance and have a broad, shallow syncline trending N.N.E.-S.S.W. throughout their length. Faulting appears to have occurred on all four sides although it is only on the northern side that the evidence is anything more than conjectural. On the remaining sides, the steepness of the slopes are suggestive of faulting although it is probable that they are caused by differential weathering of the grit capping and the underlying sandstones. In the southern part of the area the Mazeras Sandstones are masked by a covering of superficial sands, yet it is evident that their outcrop is much narrower than it is in the Shimba hills. The narrowing may be due to faulting. The most southerly exposure of the sandstone was found in a sand-pit cut into the bank of the Ramisi River near Mafisini.

The conditions of deposition of the Upper Duruma Sandstones were more variable than of the earlier members of the series. Initially they appear to have been laid down under fairly shallow water for the lowermost rocks are current-bedded. The rate of sedimentation, however, outpaced the rate of subsidence for the fossil wood horizon appears to have been deltaic. Higher still in the succession the sub-rounded nature of the grains and the high degree of cross-bedding are suggestive of sub-aerial deposition, with infrequent aqueous incursions giving rise to flat-bedded horizons. The variation in sorting of the members of whole series is illustrated in Fig. 1.

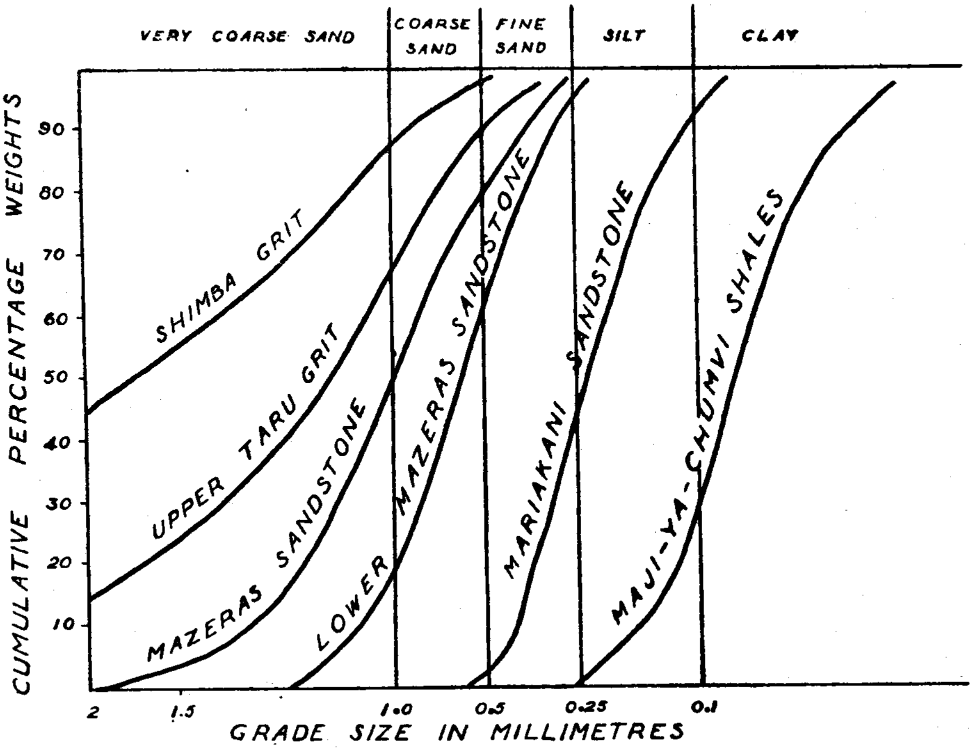

Fig. 1.—Diagram to illustrate the mechanical sorting of samples taken from the Duruma Sandstone Series.

(4) *The Age and Correlation of the Duruma Sandstones*

There is little definite evidence on the age of the Duruma Sandstones; such fossils as have been identified are widely scattered throughout the succession so that only a broad sequence can be given. The issue is further complicated by the wide stratigraphic range of many of the genera represented. The rocks, however, show a marked lithological similarity to their equivalents in Tanganyika and Madagascar where fossil evidence is more complete, so that some indications of their age can be put forward.

In the Tanga Province of Tanganyika, Stockley (1936, p. 7) has divided the corresponding rocks into three lithological divisions:—

(3) Irregularly bedded sandstones and grey shales.

(2) Dark carbonaceous shales and flagstones.

(1) A basal conglomerate, arkose, coarse sandstones and carbonaceous shale.

These correspond to the Mariakani Sandstone, Maji-ya-Chumvi Beds, and Taru Grits respectively. A coarse sandstone, which is faulted against the other divisions, is reported from Kilulu and Kirimba Hills and is doubtless to be correlated with the Mazeras Sandstone. The Tanga Beds have yielded *Ullmannia, Voltzia,* an uncertain *Eretmophyllum, Glossopteris,* and the reptile, *Tangasaurus menelli* (see Stockley 1936, p. 8). This reptile is also found in the Upper Sakamena Series of Madagascar where it is assigned to a Middle Beaufort (Lower Triassic) age.

In Madagascar, both marine and continental facies are represented, each with their own faunal suites. Infrequent marine intercalations in the continental deposits permit the two facies being correlated and it has therefore been possible to erect a fairly comprehensive stratigraphical table. Three divisions are recognized:—

(3) Isalo Beds.
(2) Sakamena Beds.
(1) Sakoa Beds.

The following table (based on Besairie, 1946, p. 17) shows the ages assigned to these divisions together with their dominant lithologies (continental facies).

TABLE IV—KARROO SUCCESSION OF MADAGASCAR

Jurassic ..	M. Bathonian L. Bathonian Bajocian ..	Isalo III ..	Similar lithology to Isalo II but with fewer fossils. *Corbula* bed at top overlying Dinosaur bed.
	U. Lias .. Up. M. Lias ..	Isalo II (c.3,000 ft.)	Cross-bedded grits with green and red clays. Fish, fossil wood and reptiles.
	Lr. M. Lias .. L. Lias ..	Isalo I (300–1,500 ft.).	Massive cross-bedded grits. Unfossiliferous.
Triassic ..	Upper ..		
	Lower ..	Sakamena beds (600–2,400 ft.)	3. Shales and clays with *Estheria*. 2. Shales with reptiles (fish in marine bands). 1. Plant-bearing shales. Basal conglomerate.
Permian ..	Upper ..		
	Lower ..	Sakoa beds (c. 2,400 ft.)	4. Marine limestones with Productids.
Carboniferous			3. Lower red beds. 2. Coal measures. 1. Black shales with tillites.

NOTE.—Dotted lines indicate unconformities.

In attempting to fit the Duruma Sandstones into this table there are several similarities that commend themselves. The Maji-ya-Chumvi Beds find their equivalent in the Sakamena group; both contain plant-bearing shales at their base, and the fish horizon and the *Estheria* shales are also represented in both localities. The Isalo sandstones have points in common with the Mazeras sandstones in that both are composed of massive cross-bedded grits containing silicified wood. But whereas the main fossil wood horizons of Madagascar occur in the Lias, it is more probable that those of Kenya are referable to the Upper Trias. It will be remembered that the holotype of *Dadoxylon sclerosum*, of which a specimen has been found in Kenya, was described from the Molteno Beds (U. Trias) of South Africa. Krishnan (1949, p. 256) refers to *Dadoxylon* occurring in the Raniganj Stage (uppermost Permian) of the Damodar Valley, some 100 miles to the north-west of Calcutta. Hence the Mazeras Sandstone is tentatively correlated with the Isalo I, with a doubtful extension up into the Isalo II stage.

The Mariakani Sandstones do not appear to have their lithological counterpart in Madagascar. They undoubtedly have closer affinities to the Sakamena than to the Isalo Groups, and furthermore the coarse Isalo facies of Madagascar rest unconformably upon the finer-grained Sakamena Group. It has previously been suggested that the same relationship obtains in Kenya between the Mazeras and Mariakani Sandstones (*see* p. 12). For these reasons it seems preferable to include the Mariakani Sandstones with the Maji-ya-Chumvi Beds as being the correlative of the Sakamena Group.

At the base of the succession, the Taru Grit can be correlated with the Sakoa Group with perhaps a slight extension into the Lowermost Sakamena Group.

The complete correlation, as far as can be judged at present, is given in Table V. This also includes the South African representatives, their correlation with Madagascar rocks having been previously established by Besairie (1930, p. 45).

The similarity between the successions of Kenya and western central Madagascar, both in respect to lithologies and thicknesses, is striking. Those familiar with Du Toit's theories on continental drift will recall that it was postulated that Madagascar was, until Jurassic times, attached to East Africa. Central Madagascar is shown on his map (Du Toit, 1937, p. 76) as being opposite to Southern Kenya, whereas northern and southern Madagascar are opposite to Somalia and Southern Tanganyika respectively. The evidence from the present area supports this hypothesis. An interesting point connected with it is the distribution of the coal-measures. In Madagascar, coal-bearing-beds are known only from the southern part of the island whilst in East Africa the most northern occurrences are recorded from Southern Tanganyika. Under Du Toit's hypothesis these two coal-bearing areas can possibly be correlated, and the absence of coal from central Madagascar might be taken as an augury against coal measures being present in Kenya.

2. THE JURASSIC AND CRETACEOUS ROCKS

Rocks of Jurassic and Cretaceous age occupy the foot plateau between the Coastal Tertiary series and the Duruma Sandstones. The outcrop can be traced from the northern boundary of the area southwards to a few miles beyond the Kwale-Mombasa road where it disappears beneath the Tertiary sands. No trace of it has been found beyond that point but it is reasonably certain that it does extend into Tanganyika to join exposures of the same age near Tanga.

The rocks consist of limestones, sandstones and shales. The succession is as shown in Table VI.

This succession differs from that proposed by Miss McKinnon Wood (1930, p. 221) in that her pre-Bathonian shales are now included with the Kambe Limestone. The evidence for a Bajocian horizon rests on a single ammonite, provisionally identified by Dr. Spath as *Dorsetensia sp. juv.* c.f. *edouardiana* (d'Orbigny) (1930, p. 32), obtained from shales near the M.P.L. suspension bridge. The shales are interbedded with bands of hard grey limestone but neither have yielded fossils to the writer. There seems little doubt, however, that they belong to the Kambe Limestone Series which has therefore been extended downwards to include part of the Bajocian stage.

TABLE V.—PROVISIONAL CORRELATION OF THE KARROO SYSTEM

AGE			SOUTH AFRICA		MADAGASCAR	TANGANYIKA			KENYA COASTLANDS
						Songea (Stockley, 1932, p. 618)	Tanga		
Iurassic ..	U. Bathonian				Marine limestones and shales				Kambe limestone.
	M. Bathonian				Isalo III				
	L. Bathonian								
	Bajocian ..								
	U. Lias ..				Isalo II				
	M. Lias ..								
	L. Lias ..	KARROO SYSTEM	4. Drakensberg volcanics 3. Cave sandstone 2. Red beds 1. Molteno beds	Stormberg Series	Isalo I	Manda beds K.8. (with U. Bone bed)	Sandstones of Kilulu and Kirimba hills	DURUMA SANDSTONES	Mazeras sandstone.
Triassic ..	Upper ..		3. Upper ..	Beaufort Series		Kingori sandstone K.7.			?.....?.....? Mariakani sandstones.
	Lower ..		2. Middle ..		Sakamena beds	L. Bone bed, K.6.	U. Tanga Beds		
Permian ..	Upper ..		1. Lower ..			Ruhuhu beds, K.5.	M. Tanga beds		U. Maji-ya-Chumvi beds. Fish beds. L. Maji-ya-Chumvi beds.
	Lower ..		Ecca Series		Sakoa beds	U. Coal Measures, K.4. Marls, K.3. L. Coal Measures, K.2.	L. Tanga beds		Taru grits.
Carboniferous	Upper ..		3. Upper shales .. 2. Boulder beds .. 1. Lower shales ..	Dwyka Series		Basal sandstones and conglomerates, K.1.			
						Archæan Gneiss			Archæan Gneiss.

NOTE—Dotted lines denote unconformity.

TABLE VI—THE MESOZOIC SUCCESSION IN THE MOMBASA–KWALE AREA AND ITS CORRELATION WITH S. ENGLAND

	SOUTHERN ENGLAND		COASTAL KENYA	
	Stages	Generalized Succession	Succession	Stages (Spath*)
L. Cretaceous	Neocomian	Wealden beds	Freretown limestone	Neocomian.
Upper Jurassic	Purbeckian	Purbeck beds	Not exposed.	Tithonian.
	Portlandian	Portland stone Portland sand		Portlandian.
	Kimmeridgian	Kimmeridge Clay	Changamwe shales	Kimmeridgian.
	Oxfordian	Corallian beds	Coroa Mombasa Limestones and shales	Argovian.
		Oxford clay	Rabai shales	Divesian.
	Callovian	Kellaways beds	Miritini shales	Callovian.
Middle Jurassic	Bathonian	Cornbrash	Kibiongoni beds Kambe limestone	Bathonian.
		Great Oolite		
		Inf. Oolite		Bajocian.

*Spath, in McKinnon Wood, 1930, p. 68.

The disposition of the Jurassic rocks in the northern part of the area is shown in greater detail in Fig. 11 which also attempts to delimit the various stages in accordance with the palaeontological evidence known at present. The section accompanying the figure is based on meagre evidence and is included for illustrative purposes only; it should not be relied upon for the purposes of sinking boreholes, or other economic projects.

(1) *The Relationship of the Jurassic Rocks to the Duruma Sandstones*

Maufe (1908, p. 10) subdivided the Kambe limestone into a lower, greyish pisolitic variety that he assigned to the upper part of the Mazeras Sandstone, and an upper, hard, grey, compact and fossiliferous variety that he assigned to the "Changamwe Shales". Hence he concluded that the Jurassic rocks and the Duruma Sandstones were conformable.

Gregory (1921, p. 69) regarded the two limestone varieties as being in the same formation and frequently interbedded, the pisolitic variety being younger. He noted the difference in dips between them and the Duruma Sandstones, the overlap of the limestone on to different members of the sandstone, and an apparent unconformity in the Landani Valley (near Kambe) and concluded that the two series were separated by an unconformity.

Parsons (1928, pp. 70-82) postulated numerous great overthrusts from the east, one of which had thrust the Jurassic rocks over the Duruma Sandstones. Referring to the Mwachi River sections he stated (p. 73) "at the Public Works Department Quarries a few beds of Kambe Limestone rest apparently conformably upon the Shimba Grits; but less than half a mile southward along the strike, where the Duruma River enters the Mwachi River, these limestone beds are replaced by a fault breccia consisting of limestone with large angular blocks of Shimba Grits".

Miss McKinnon Wood (1930, pp. 221–4) examined Parsons's fault breccia and, noting the absence of any crushing, considered it to be a basal conglomerate. She appears to agree with Gregory in that the junction is unconformable yet, in her section (p. 220), she shows a normal fault.

Busk (1939) states, "The outcrop of the junction with the underlying Duruma Sandstone is irregular, sometimes being faulted and sometimes occurring as bays or inlets into the old land".

From the foregoing it will be seen that all possible relationships have been catered for. The most valuable sections for studying the problem are to be seen in the Jivani and Mwachi Rivers and along the railway line. In the first locality the limestone is seen to be downfaulted against the Mazeras Sandstone. The fault is normal, striking roughly N.N.E. to S.S.W. with a dip to the S.S.E. as far as can be judged, of 80°. Several similar parallel faults, with throws of only a few feet, occur in the Jurassic rocks immediately to the east. The throw of the major fault cannot be measured but from the degree of brecciation it can be imagined to be of some magnitude, possibly measurable in hundreds of feet.

In the Mwachi Valley the section has been cut to sea-level and the entire Kambe Limestone series is exposed. In the Mbombe River (Duruma River of Parsons), near to where it joins the Mwachi, Jurassic rocks rest directly on coarse-grained Mazeras Sandstone. A basal conglomerate, some 40 to 50 feet in thickness, is exposed, consisting of boulders of Mazeras Sandstone, some of them more than 2 ft. in diameter, enclosed in pisolitic and coral limestone interbedded with thinly laminated shale. Miss McKinnon Wood's observation on the absence of any crushing is supported by the present survey as is her opinion that the contact is unconformable. The unconformity slopes at an angle of 8° in an east-south-easterly direction. It can be seen in the quarry beside the Mwachi river and followed upstream to about the 100 ft. contour, beyond which the section is masked by vegetation. There is no evidence of faulting within the exposed section but a short distance upstream, near the first bend in the Mwachi River, there is a deep steep-sided gully such as might have been eroded along a fault plane.

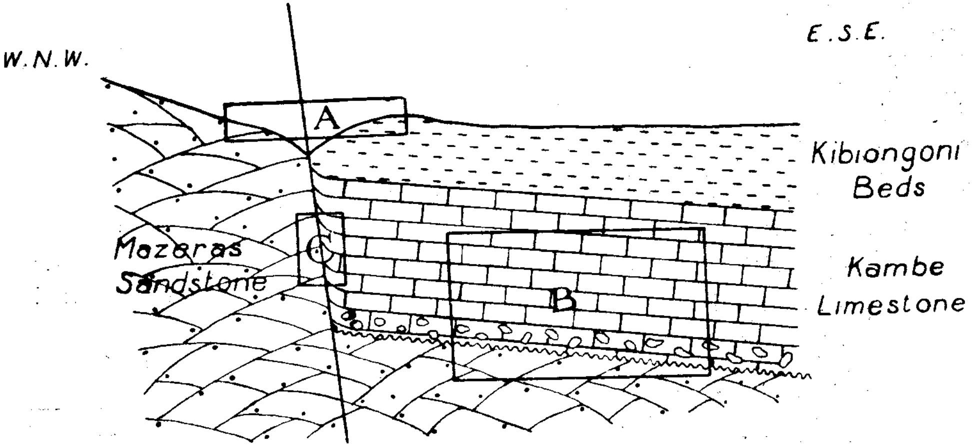

Fig. 2.—Diagram to illustrate the relationship of the marine Jurassic rocks to the Mazeras Sandstone. (Horizontal Scale about 6 in. = 1 mile.)

A.—Section exposed along the railway-line and along the new Mombasa–Nairobi road.
B.—Section exposed in the Mwachi River.
C.—Section exposed in the Jivani River.

Along the railway-line the lowermost Jurassic beds exposed are sandy shales and thin argillaceous sandstones belonging to the Kibiongoni Beds, which can be seen in a cutting immediately west of the loop where they dip gently seawards. In the next cutting, some fifty yards to the west, are massive flat-bedded Mazeras Sandstones and subordinate shales. A steep narrow valley running S.S.W. separates these cuttings so the junction between the two formations is not seen. In view of the dip of the Jurassic beds however, and the fact that some three hundred feet of Kambe Limestone underlie the Kibiongoni Beds, it is evident that the Jurassic rocks cannot possibly overlie the Mazeras Sandstone normally. Hence the junction must either be faulted or the Jurassic rocks were laid down against a cliff of Mazeras Sandstone. From the evidence of the Jivani River one must suspect the former and some support for this suspicion is afforded by the several small strike faults, also noted by Gregory (1921, p. 50), that are exposed in the Mazeras Sandstone further west along the railway-line. The relationship is shown diagrammatically in Fig. 2. Two other points need to be mentioned. Fraas (*see* Gregory, 1921, p. 53) reported a cross-section of a belemnite and an indistinct impression of an ammonite from grits near Samburu, and concluded that Lower Jurassic rocks are present there. The statement was rejected by Maufe and doubted by Gregory. Recent work (Miller) indicates that the report was incorrect and no credence is attached to it. The second point concerns boulders of limestone found by Gregory (1921, p. 68) on the western side of the Shimba Hills along the second and third miles of the M.P.L. Gregory puts forward strong evidence for these boulders having been *in situ* and, although their existence has not been confirmed by the writer, they are nonetheless accepted.

It is concluded, therefore, that the land surface formed by the Triassic rocks was much the same in middle Jurassic times as it is now—a high coastal range backed by a lower-lying hinterland plateau with a river system from the hinterland cutting through the coastal range and forming the Mombasa Gap. The Jurassic sea lapped against the Coastal range on its eastern side and flooded through the gap on to the low-lying land beyond. The lithology of the Jurassic rocks, as will be discussed later, lends support to this conclusion. Subsequently, possibly due to the break up of Gondwanaland, faulting occurred which threw down the Jurassic succession in relation to the Triassic so that throughout the greater part of its length the junction now appears as a fault.

(2) *The Kambe Limestone Series*

After the deposition of the Duruma Sandstone Series there was a stratigraphical break of unknown duration. This was followed by a marine invasion that took place in Middle Jurassic times when a series of limestones, sandstones and shales were deposited unconformably upon the Mazeras Sandstone. The angular unconformity between the two series is slight so that little earth-movement took place during the interval. The earliest rocks known to have been laid down in the Jurassic Sea are the Kambe Limestones, a series of limestones with interbedded calcareous shales that attain a maximum thickness of about 400 ft. They have at their base a conglomerate, 40 to 50 ft. thick, composed of blocks of Mazeras Sandstone, some of them as much as 2 ft. in diameter, set in a matrix of coral and unfossiliferous limestones (Plate I (*b*)).

The Kambe limestone occurs in three main varieties:—

(*a*) A bluish-grey, compact, calcitic mudstone of lithographic texture that is well-bedded, though occasionally massive, and contains thin partings of shale. It is tough and breaks with a conchoidal fracture. There are infrequent thin stringers of crystalline calcite running irregularly through the rock suggesting that the original sediment was an aragonite mud and that the calcite crystallized in the shrinkage cracks formed when the aragonite inverted to calcite. The calcite stringers constitute planes of weakness and allowance should be made for them if the rock is used for building purposes. This variety of the limestone is generally unfossiliferous.

(*b*) A facies variety of (*a*) that contains an abundant fauna, particularly corals, which are sometimes in sufficient profusion to warrant the rock being termed a "reef" limestone. Associated with the corals are polyzoa, brachiopods and molluscs, but the compactness of the rock renders their abstraction for specific identification practically impossible.

(*c*) A lighter grey, oolitic limestone that is interbedded with the other two. This variety is probably of lenticular development for it sometimes occurs above, and sometimes below the other types. Thin sections show that the ooliths were precipitated around minute quartz grains that were doubtless derived from the

Duruma Sandstones. Other grains of quartz occur interstitially to the ooliths and show, by their subangular forms, that they were transported by water. Hence the oolitic variety was formed at localities where rivers discharged sand into a sea already highly charged with calcium carbonate.

Studies of oolites that are being formed at the present day show that they share several common features—they are all marine; they are all forming under shallow-water conditions; the water is kept constantly in motion by wave or current action so that the ooliths, too, are in motion and thus attain their spherical form: and the climate is such that a high rate of evaporation brings about a concentration of the dissolved salts. These features are analogous to the conditions necessary to promote the growth of coral reefs, which are also present in the Kambe limestone group, so that one can obtain a fairly comprehensive picture of the palaeogeography and palaeoclimatology of the Middle Jurassic System in East Africa.

The Kambe Limestones can best be seen in the Mwachi River section, a few hundred yards upstream of the bridge that carries the M.P.L. Above the basal conglomerate is a thick development of oolite and this is overlain by a thin band of tough limestone containing the rugose coral, *Pleurophyllia hobleyi*. At the top of the section is a thick development of compact limestone with interbedded calcareous shales. The shales have yielded the small lamellibranch *Posidonia ornati* Quenstedt to earlier writers, but none were found during the present survey.

To the north of the Mwachi River, the limestone can be traced to within a short distance of the railway-line where it disappears beneath the overlying Kibiongoni Beds. No exposures of limestone are to be seen along the railway-line itself, but it appears once more from beneath the Kibiongoni Beds a short distance north of the new Mombasa-Nairobi road and continues in the direction of Kaya Kambe.

South of the river it forms a well-marked ridge of hills, running S.S.W., that lies a mile or so to the west of the M.P.L. road. Several small streams flow off the ridge and one, the Jivani, cuts straight through to expose the faulted relationship of the limestone to the Mazeras Sandstone (*see* page 19). The lowermost beds exposed in this section are oolites and these are overlain by a considerable thickness of well-bedded compact limestone with interbedded shales. No fossils were seen in the section although they doubtless could be found by more detailed search.

Where the M.P.L. road crosses the ridge, between the engineer's hut and the Mwachi River, well-bedded compact limestone with shale partings is exposed. Most sections show the limestone dipping E.S.E. at 5° but some show a north-easterly dip of 5°. This irregularity is local and may be due to minor faulting, although no other evidence of faulting was observed nearby. Gregory (1921, p. 67) cites evidence from Mteza to suggest the possibility of a fault that skirts the southern shore of Port Reitz, and although his suggestion was not proved during the present survey the fault would, if produced westwards, pass close by the sections showing the north-easterly dips.

From this point southwards to the engineer's hut, the M.P.L. road runs along the western foot of the ridge and many large blocks of limestone occur throughout its length. Several of the blocks contain a rich fauna that includes corals (mainly *Diplarea*), polyzoans, crinoid ossicles, brachiopods and pelecypods. The rock is compact and massive so that it is again difficult to remove the fossils for specific identification. The ridge is composed of compact limestone in its lower part, succeeded by oolites at about the 600 ft. contour and these are in turn overlain by a further series of compact limestones.

Near the engineer's hut the Kambe Limestones are terminated suddenly by a dip fault that throws them against the Mazeras Sandstone. Specimens of the coral *Kobya rossi* were found near this locality. No other outcrops of Kambe limestone have been found in the area; the limestones occurring nearer to the coastline and mapped by Parsons as of Kambe age are now classified with the Miritini and Changamwe Shales.

The Bajocian-Bathonian age of the Kambe Limestones has been determined from the ammonite fauna, several of the Kenya species having been described from beds of Bajocian-Bathonian age elsewhere. A description of the ammonites collected by Miss

McKinnon Wood, together with their stratigraphical significance, is clearly set out by Spath in the McKinnon Wood monograph (1930). Writing in the same monograph (p. 95), Weir states that the brachiopod and mollusc fauna from the Kambe Limestone is more suggestive of a Callovian age, but he submits to Spath's opinion in deference to the more overwhelming evidence of the ammonites. The corals are of no help in this matter since all are new species.

(3) *The Kibiongoni Beds*

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

The base of the Kibiongoni Beds is marked by a conglomerate, roughly one foot in thickness, composed of sub-angular pebbles of limestone and quartz set in a limonitic matrix, and this is overlain by a series of thin, current-bedded, sandy shales with interbedded micaceous and ferruginous sandstones. Near the top is a fairly massive eight-foot band of ochreous sandstone which is resistant to weathering and remains as large blocks on the surface, so that it can frequently be traced as a datum horizon. Many of the beds are ripple-marked and some are rain-pitted, so it is evident they were laid down in a coastal environment, probably under estuarine conditions. Preliminary work suggests that the Kibiongoni Beds are of restricted development, being most prominent in the neighbourhood of the railway line, and it is anticipated that further research will show that they are a facies variation of the Kambe Limestone.

The best exposures occur in the cuttings along the new Mombasa-Nairobi road, and along the railway-line immediately west of the loop. The former show sandy shales dipping seawards and cut by a normal fault trending N.N.E.-S.S.W. with a small throw to the E.S.E. The Kambe Limestones are not exposed along the new road so that the Kibiongoni Beds should be in direct contact with the Mazeras Sandstone. This cannot be observed, however, owing to a deep gully, devoid of exposures, that runs along the junction. No fossils were found at this locality.

In the railway cuttings, similar conditions obtain. The Kibiongoni Beds and the Mazeras Sandstone must be in direct contact although their actual junction is obscured. At this locality, the beds have yielded indefinite pelecypods and some poorly preserved rhynchonellids, one of which showed affinities to that described by Weir (McKinnon Wood, 1930, p. 79) as *R.* cf. *quadriplicata*. A more lengthy search in these cuttings would doubtless produce a more comprehensive fauna.

South of the railway-line, the outcrop can be traced via Tsulajimba hill to within a short distance of the Manolo River where it is terminated by a fault that throws it down against the Mazeras Sandstone.

Lack of fossil evidence precludes an age being assigned to the Kibiongoni Beds. Originally identified as Bathonian by Dacqué, they were later regarded by Gregory (1921, p. 72) as Callovian, a view to which Miss McKinnon Wood (1930, p. 221) doubtfully subscribed. Yet the specimen of *R.* cf. *quadriplicata* was stated by Miss Muir-Wood (McKinnon Wood, 1930, p. 79) to be dissimilar from any of the Callovian material at the British Museum. In view of this and the possible stratigraphical equivalence of the Kibiongoni Beds and the Kambe Limestone, the Kibiongoni Beds are provisionally grouped with the Kambe Limestone in the Bathonian stage.

(4) *The Upper Jurassic Shales and Limestones*

The Kibiongoni Beds appear to grade upwards, by a diminution of their sand content, into a thick series of shales and thin lenticular limestones that extend up into the Kimmeridgian. Sub-division of the series has been made into the four stages indicated in Table IV (p. 18), but lithologically they remain fairly constant throughout the succession. The shales are generally dark grey to black in the lower horizons, becoming a more greenish grey, or even yellowish, higher up; on weathering they frequently assume a lighter grey or brownish tinge. They are sandy, calcareous, sometimes ferruginous and more rarely micaceous, and contain bands of nodular clay ironstone and muddy limestone. Septarian nodules are present throughout the succession but are more common in the higher horizons where they often contain included ammonites.

Limestone bands can be observed at several localities. The lowest occurs near the base of the Miritini Shales and can be seen east of the M.P.L. between miles 13 and 16. Another band forms the lowermost Jurassic horizon seen on the eastern flanks of Lunguma Hill. Limestone is quarried at Mwamtsola, on the Mombasa–Kwale road. It is an oolitic variety with included pellets of clay and grains of quartz. The outcrop, which is in the form of large weathered blocks, can be followed southwards for upwards of half a mile but there is no trace of it to be seen immediately to the north. The limestone contains abundant fragmentary fossils but rarely anything sufficiently complete to permit identification. An Argovian age is doubtfully assigned to it by Weir (McKinnon Wood 1930, p. 91) on the evidence of a belemmite, *B. tanganensis*, that ranges from the Argovian to the Kimmeridgian. Associated with the belemmite is *Entolium demissum*, a pelecypod that ranges from the Trias to the Cretaceous. Small limestone outcrops occur west of Mtongwe, south-west of Makupa Causeway, on the shores of Port Tudor north of Changamwe, and on the Coroa Mombasa. There are doubtless others. It is seldom possible to trace these various limestone outcrops for more than a short distance, partly due to the shortage of exposures but also to the probability that they are of lenticular development and pass laterally into shales.

The Upper Jurassic Shales are fossiliferous throughout and have yielded an abundant and varied fauna, particularly ammonites, of which 118 species are described by Spath in the McKinnon Wood monograph (1930). Commenting on the fauna, Spath (*op. cit.* p. 68) remarks that the majority of the ammonites are referable to two horizons—the Callovian and the Lower Kimmeridgian (*tenuilobatus* zone). Other ammonites indicate the presence of the Bajocian, the Bathonian, the Argovian, and the Middle Kimmeridgian, but no ammonites from the Divesian stage were recorded. This is hardly surprising since Miss McKinnon Wood restricted her activities to two main areas, the first near Mombasa and Changamwe and the second around the head of Port Reitz. Gregory (1921, p. 62) refers to ammonites found by Fraas on the shores of Rabai Creek that indicate an Oxfordian age, and several other ammonites were found at localities intermediate between those of Miss McKinnon Wood during the course of the present survey. The latter have not yet been identified specifically but it is anticipated that they will furnish evidence of the Divesian stage. Fragments of carbonized fossil wood occur at some localities but it is not certain whether they represent the remains of Jurassic trees or whether they are reworked fragments from the Mazeras Sandstone. The latter is considered more probable.

The outcrop of the Upper Jurassic Shales can be followed southwards from the northern boundary of the area to near the Maragoyo River. On its western margin it overlies the Kibiongoni Beds and on its eastern and southern margins it disappears beneath a superficial cover of Tertiary sands. There is little doubt that, if these Tertiary sands could be stripped off, it would be possible to follow the Jurassic rocks southwards into Tanganyika.

Throughout the greater part of the succession, the beds conform to the regional dip of 8° to E.S.E., but exceptions occur near Mombasa. At Shimanzi, the western extremity of Mombasa Island, a dip of 35° to S.E. has been recorded near the contact between the Jurassic and Tertiary rocks, and a dip of 20° to E.S.E., is recorded from a limestone band on the track to Nguu Tatu, some two miles north of Nyali Bridge.

(5) *Comparison of the Jurassic Rocks of Coastal Kenya with those of other Areas.*

The present state of our knowledge of the Jurassic rocks of coastal Kenya is so limited that any attempt at correlation with other areas can only be on a broad and largely speculative basis. As yet, the McKinnon Wood monograph (1930) provides the only comprehensive account of the fauna which, as comparatively few species are described, cannot be satisfactorily used for correlation purposes.

Elsewhere around the Indian Ocean, Jurassic rocks have been described from Madagascar, British Somaliland, Suez and Cutch. They are also known from Tanganyika and the Northern Province of Kenya.

In Madagascar, the Karroo sediments extend upwards to the middle Bathonian, which is partly of continental and partly of marine facies (Besairie, 1946, p. 17). A marine transgression in Upper Bathonian times covered most of the western portion of the island and sedimentation appears to have continued unbroken up into the Cretaceous. The rocks are composed largely of mudstones with oolitic and normal limestones at the base (Upper Bathonian) and other limestone horizons in the Upper Divesian and Kimmeridgian. Pyritized fossils occur in the Callovian.

A summarized account of the succession at Cutch is given by Krishnan (1949, pp. 380-384). A complete sequence from the Lower Bathonian to the Aptian is represented, the total thickness being approximately 6,300 ft. The beds consist of shelly and coral limestones at the base overlain by limestones and shales—some with ferruginous nodules—that extend to the top of the Bathonian. The Callovian is dominantly a yellow limestone, the Divesian a series of gypseous shales, and the Argovian is oolitic. Upwards from the Argovian the beds are largely sandy, some of them unfossiliferous.

The faunas of Cutch and Madagascar have many points in common and there can be little doubt that they belong to the same province. A brief comparison is given by Besairie (1936, p. 67). The coastal Kenya fauna also appears to belong to the same province.

The Jurassic rocks of British Somaliland (Macfadyan, 1933, p. 27) range upwards from the Callovian (?) and pass conformably into the Lower Cretaceous. They consist of alternating groups of limestones and shales, the former being thin-bedded, grey or brownish, and somewhat argillaceous, and the latter fine-grained, olive or grey, and occasionally gypseous. Several of the species of the fauna found in the beds are common to the Near East (Abyssinia, Sinai, Lebanon and Arabia) whilst practically none are known from Coastal Kenya, Madagascar or Cutch, and very few from Europe. This is particularly true of the brachiopods and has led some writers (Dacqué and Krenkel) to postulate an Ethiopian Province.

Preliminary work on the fauna from the Northern Frontier District of Kenya shows that it has close affinities with British Somaliland but little with Coastal Kenya, so that it would seem that the Jurassic rocks of northern Kenya represent the southernmost extremity of the Ethiopian Province and that the basin in which they were deposited was not connected directly with the Madagascar-Coastal Kenya-Cutch Province.

A marine connexion between Madagascar and Baluchistan is known to have existed in Lower Jurassic times (Spath in McKinnon Wood, 1930, p. 68), and by Bajocian times the connexion had extended to the East Indies. It appears that this marine transgression reached coastal Kenya in Upper Bajocian times, Cutch during the Lower Bathonian, and Madagascar during the Upper Bathonian. As has been stated previously, the Upper Jurassic successions are complete in both Madagascar and Cutch whilst in Coastal Kenya the uppermost stages are not seen. It is not known whether they are overlapped by the Cretaceous rocks or whether they are faulted out, but the present survey suggests that the latter alternative applies.

(6) *The Lower Cretaceous (Neocomian) Rocks. The Freretown Limestone.*

The existence of Cretaceous rocks in coastal Kenya was first recognized by Hildebrandt (1877) who collected several fossils from the north mainland which he assigned to two ages: Kimmeridgian and Neocomian. One of his specimens was originally identified as *Exogyra* cf. *couloni,* but was later redetermined and figured by Müller (in Bornhardt, 1900, p. 549) as the middle Neocomian species, *Ostrea minos* Coqu. An account of the range and distribution of the species was given by Dietrich (1918, p. 247) who reclassified it with the genus *Exogyra.* Gregory was unable to confirm this occurrence but further specimens of the species were found by Miss McKinnon Wood (1930, p. 97 and p. 225) and Parsons (*see* McKinnon Wood, 1930, p. 97), and others were found during the present survey. Associated with *E. minos* is *Lithophaga ferreti* (Rochebrune) (McKinnon Wood, 1930, p. 97) a mytilid that is also recorded from the Neocomian of Somaliland, and, from a thin section of one of the limestone specimens taken during the present survey, a foraminifer that is tentatively identified as *Nodosaria* cf. *affinis*.

The Freretown Limestone is exposed in a small, disused Public Works Department quarry half-a-mile west of the turn-off to Bamburi on the Mombasa-Malindi road. The rock is a well-bedded, compact, slightly siliceous, muddy limestone with thin partings of sandy shale and stringers of crystalline calcite. The beds dip at 15° to W.S.W. which, in the normal course of events, would carry them beneath the Kimmeridgian limestones further to the west. Obviously this cannot be—unless the succession is inverted, and there is no evidence for that—and it is inferred that the Cretaceous rocks are down-faulted against the Jurassics. Large isolated blocks enable the beds to be traced for a hundred yards or so to the north of the quarry and the configuration of the ground suggests that they might extend a short distance westwards, but their exact limits are not yet known.

(7) *Palaeontology*

An excellent account of the palaeontology of the Jurassic and Cretaceous rocks is contained in the McKinnon Wood monograph (1930), a copy of which is housed in the Coryndon Museum, Nairobi. The ammonite fauna is described by Dr. L. F. Spath, the brachiopods and molluscs by Dr. J. Weir, and the corals by Prof. J. W. Gregory. An extraordinary feature of the fauna is the apparent absence—or at least, scarcity—of foraminifera. None are described in the monograph and only one was found during the present survey.

3. The Cainozoic Rocks

The Cainozoic rocks are confined to the coastal strip and include representatives of the Pliocene, Pleistocene, and Recent periods. The succession adopted in this report is as follows:—

Recent		Alluvia. Oyster Beds.
Pleistocene	Upper	Red wind-blown Sands.
		Kilindini Sands.
	Middle	North Mombasa Crag.
		Raised Coral Reef.
	Lower	Flat-bedded yellowish sands and clays (?).
Pliocene	Upper	Magarini Sands.

(1) *The Magarini Sands*

The Magarini Sands form a belt of low hills running parallel to the coast and at a distance of roughly two to three miles from it. They rest with slight unconformity upon a planed surface of Jurassic and Cretaceous rocks and occasionally overlap on to the Duruma Sandstones.

It was from the Duruma Sandstone Series that the bulk of the material comprising the Magarini Sands was derived, so that the deposit is dominantly quartzose. There are also fragments of Jurassic shales, rounded fragments of silicified fossil wood, and well-rounded pebbles of gneiss from the Basement System included in it. The Jurassic material is frequently coated by a thin film of colloidal silica. The deposit is generally poorly stratified, ill-sorted and unconsolidated, and varies in grade from a silty clay to a coarse boulder gravel. Scattered throughout the deposit are layers or strings of quartz and, to a lesser extent, felspar pebbles that range in diameter from 20 to 80 mm. whilst, in the lower horizons, large sub-rounded boulders up to 400 mm. diameter, invariably composed of Mazeras Sandstone, are sometimes to be seen. Several of them occur on the western flank of the outcrop near Tangila and appear to follow a definite line from the Shimba Hills near Kwale towards the creek opposite to Port Reitz aerodrome.

Heavy minerals are locally concentrated with the coarser layers but are nowhere abundant. Zircon, tourmaline, epidote, rutile, garnet, kyanite and opaque iron ores have been recognized, all of which are common to the Basement System and thereby testify their ultimate origin. Gregory (1921, p. 76) reported a few pebbles of gneiss from the Basement System included in the deposit but none were recognized during the present survey.

When fresh the sands are creamy-white in colour, but are often bright red at the surface owing to concentration of ferric oxide. They attain their thickest development in the area at Tangila Hill (426 ft. O.D.) where some 300 ft. of sediments are represented. The hills of this neighbourhood are characterized by many deep erosion pits that are caused entirely by the action of rain (Plate Ia). Initially a small gully is formed, frequently along the course of a native footpath where the grass cover has already been worn off. The soft, unconsolidated nature of the material allows the gully to be rapidly widened and deepened, and small subsidiary streamlets begin to finger in from the sides. With increased erosion the gully and streamlets cut back into the hill-slope to form a cirque-shaped pit, with narrow ridges and earth pillars—the latter often capped by a solitary boulder—marking the original divides.

In the southern part of the area the Magarini Sands cover the entire Mesozoic outcrop and abut against the Duruma Sandstones. It is extremely difficult to delimit their outcrop as both the weathered Duruma Sandstones and the Magarini Sands—which are also a weathering product of the Duruma Sandstones—bear a close resemblance to each other.

It is evident that the Magarini Sands originally masked the Mesozoic outcrop in the northern part of the area too, but the bulk of the material has been stripped off by post-Pliocene erosion. A few outliers still remain at Bombo, Sije, the northern end of Lunguma Hill, and on the eastern flanks of the Shimba Hills.

The nature and constitution of the Magarini Sands indicate that they were deposited as river gravels and coastal dunes under conditions of intense erosion. Streams rushing seawards off the Shimba Hills brought down vast quantities of debris that were scattered over the coastal plain—the course of one such stream being shown by the line of boulders north-east of Kwale referred to above—and off-shore winds played their part in the formation of coastal dunes.

Flat-bedded, yellowish sands and clays, that have previously been referred to the Magarini Sands, are exposed at the side of the Mombasa-Nairobi road between Kwa Jomvu and Miritini, and similar beds are to be seen above the junction with the Jurassic shales approximately one mile north of Changamwe Station. At the latter locality the beds contain numerous oysters which, although specifically unidentifiable and therefore of no stratigraphic value, indicate a marine environment. These beds represent conditions of deposition so distinct from those of the typical Magarini Sands that they are probably of a different age. Marine Miocene and Lower Pliocene rocks are known from near Malindi (McKinnon Wood, 1930, p. 225) and it is conceivable that these sands are also of that age, although it seems more likely that they are younger than the Magarini Sands and were deposited during the uppermost Pliocene or Lower Pleistocene Period. The evidence is inconclusive so that, although the sands are tabulated as Lower Pleistocene (p. 25), on the map they are not differentiated from the Magarini Sands.

The Magarini Sands are of post-Neocomian age but there is no positive evidence in the area to indicate at what period they were deposited. Gregory (1921, p. 77) records that the group probably overlies the Eocene and Miocene limestones west of Fundi Isa (north of Malindi), and that it is probably older than the Kilindini Sands and the North Mombasa Crag, which he regarded as late Pliocene; he concluded that it is of Lower or Middle Pliocene age. Beds of a similar lithology— the Mikindani Beds—occur in Tanganyika and are undoubtedly to be correlated with the Magarini Sands. The Tanganyika representatives have been dated as Upper Pliocene as they contain *Pecten vasseli*, a species well-known from the Pliocene deposits of the Red Sea, the Gulf of Suez and the Persian Gulf. The Magarini Sands are accordingly considered to be of

Upper Pliocene age. Parsons (1928) expressed the view that beds of Magarini type represent every horizon from the Eocene onwards, the marine Miocene beds near Fundi Isa and elsewhere being intercalations in the general non-marine sequence. The nature of the beds renders this explanation improbable for they show every indication of having accumulated rapidly.

(2) *The North Mombasa Crag, The Kilindini Sands and The Fossil Coral Reef*

In the north-west corner of Mombasa Island and on the north and south mainlands, there occurs a variegated series of beds—the North Mombasa Crag—that has yielded a fauna previously referred to the Pliocene (Gregory, 1921, p. 76 and McKinnon Wood, 1930, p. 226). Stratigraphical considerations, however, do not support a Pliocene age for these beds and, as will be seen in the discussion on the fauna, the palaeontological evidence, too, is unconvincing.

The beds are exposed in the following localities: Ras Junda (North Mainland), near Ras Makaiwe, near Shimanzi, in the cliffs behind Kilindini Harbour, and on the south mainland near Mtongwe. They consist of more or less flat-bedded, coarse calcareous sands interbedded with quartz sands, coral sands, clays, and shelly crags, and appear to grade westwards by a lessening of their calcareous content into the more quartzose Kilindini Sands. Their relationship with the fossil coral-reef to the east is less clearly seen but it seems probable that the two formations finger into each other. This relationship is supported by borehole records that show alternations of coral, coral sands, quartz sands, and clays. Borehole No. D.T. 4 of the Mombasa groundwater supply project, that was drilled near Bamburi on the north mainland, illustrates this:—

BOREHOLE D.T. 4, NEAR BAMBURI

Surface level—51·25 ft. O.D.

FEET		
From	To	
0	8	Broken coral in matrix of brown soil and sand.
8	31	Coral, compact in parts, with lenticles of true coral in a matrix of coral rubble.
31	125	Pulverized coral, coral sand, and scattered fragments of true coral.
125	130	Calcareous sandstone containing coral fragments and numerous foraminifera.
130	143	Yellow calcareous sandstone with shell fragments and foraminifera.
143	147	Unconsolidated sands with shell fragments.
147	167	Rubbly calcareous sandstone.
167	186	Dirty white sandy clay with scattered shells and plant remains; grades into a soft argillaceous crag.
186	208½	Yellow quartz sand with hard cemented sandstone bands.
208½	245	Coral limestone with cavities containing secondary crystalline calcite; some sand and calcareous sandstone bands.

It is concluded that the Kilindini Sands, the North Mombasa Crag, and the fossil coral reef are of approximately the same age. Such a conclusion greatly simplifies the palaeogeographic picture since the North Mombasa Crag and, in part, the Kilindini Sands can now be regarded as lagoonal deposits that accumulated behind the fringing reef. Erosion of the Magarini Sands caused sandy and clayey material to be transported into the lagoon whereas erosion of the reef itself led to the introduction of pulverized coral and dissolved calcium carbonate, the last-named being subsequently precipitated to form the cementing material in the calcareous sands. The possible genesis of the Pleistocene deposits is shown diagrammatically in Fig. 3.

That the Kilindini Sands were lagoonal deposits was suggested by Krenkel (1924), but this opinion differed from that of Gregory (1921, p. 77) who had considered them to be dune sands on account of some vertical calcareous tubes that he regarded as calcifications around the stems of dune grasses. If they were dune deposits one would expect to find some traces of dune bedding, yet, whilst bedding of any sort is admittedly obscure, such as can be seen is horizontal. An examination of the individual grains shows that all shapes from sub-angular to well-rounded are represented but little im-

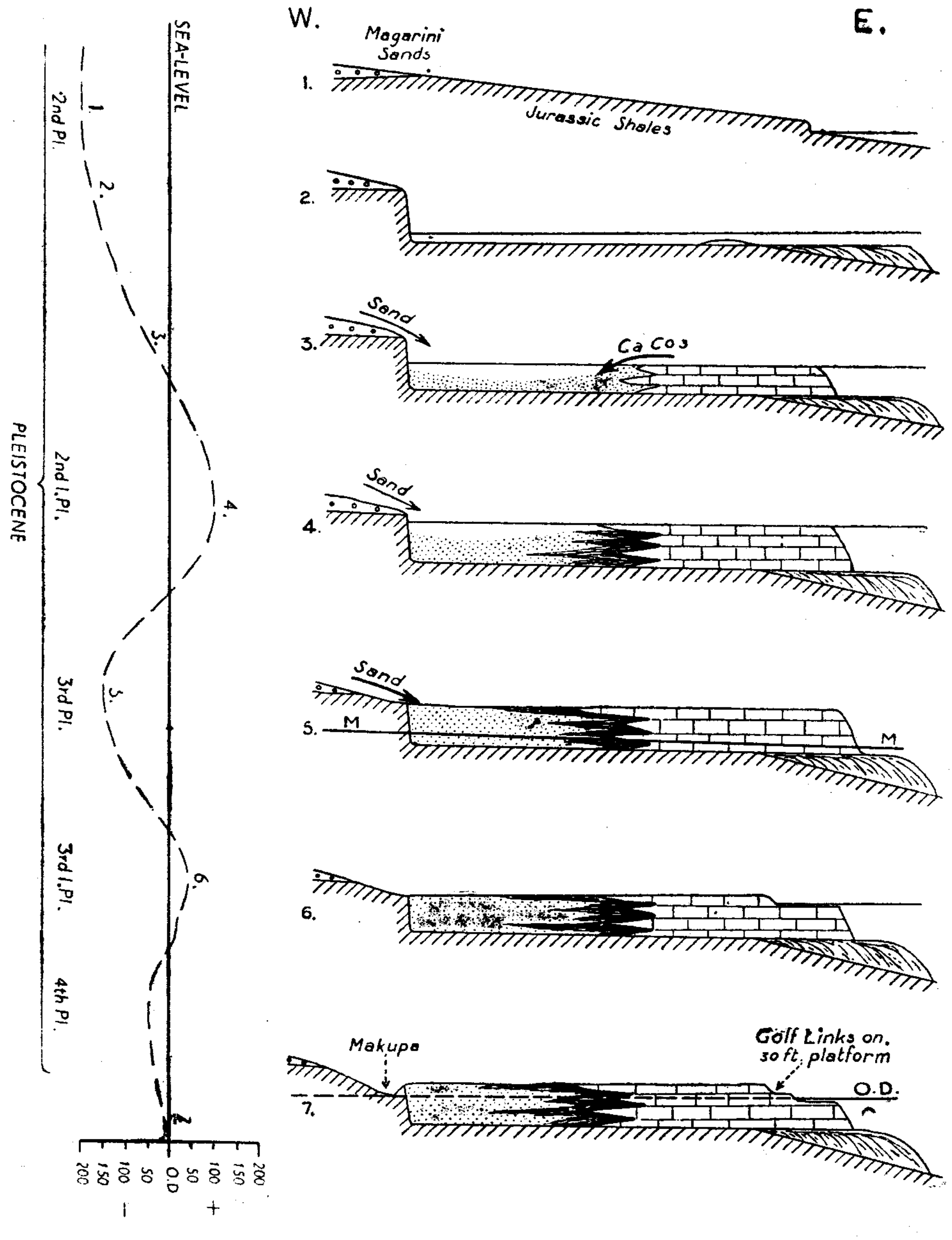

Fig. 3.—Diagram to illustrate the possible genesis and subsequent physiographical evolution of the Pleistocene deposits.

Stage 1.—Low sea-level—formation of "Nip".

Stage 2.—Slight rise in sea-level—formation of wave-cut platform and the initiation of coral reef.

Stage 3.—Sea-level rising—upward growth of coral reef with the formation of a lagoon—erosion of the Magarini Sands and of the coral reef leads to the introduction of sandy and calcareous material into the lagoon.

Stage 4.—Sea-level reaches a maximum and terminates upward growth of coral-reef. (c. 100 ft. O.D.)

Stage 5.—Drop in sea-level accompanied by rejuvenation of the rivers. MM represents the bed of the Mwachi River. Maximum influx of sandy material.

Stage 6.—Rise in sea-level to approximately 30–40 ft. O.D. causing the cutting of a marine platform. Sea-level later dropped to below O.D. with a pause at the 10–15 ft. level.

Stage 7.—Rise of sea-level to O.D. accompanied by marine erosion that has partly destroyed the 30 ft. platform. The diagram shows a generalized section across Mombasa Island.

portance can be attached to the observation since most of the grains were derived from the Magarini Sands, which itself was derived from both sub-aqueous and sub-aerial deposits. The evidence of this area, then, does not favour a sub-aerial origin for the Kilindini Sands, although in the Malindi area, where the Pleistocene deposits have a much wider outcrop, A. O. Thompson has mapped lithologically similar sands that leave no doubt but that they were deposited as coastal dunes. Theoretically, Gregory's view is more acceptable than Krenkel's, for the erosion of the Magarini Sands would be expected to have been at its maximum during the pluvial rather than the interpluvial periods. The sea-levels during the pluvial periods were lower than the present level so that, excepting subsequent uplift of the Kilindini Sands—for which there is no evidence—most of the sands might have been deposited under sub-aerial conditions.

The Kilindini Sands are well-exposed in several large quarries on Mombasa Island immediately north of Makupa Causeway and in several other quarries on the eastern bank of Junda Creek (North Mainland). In the Junda Creek quarries the lowermost beds seen are white quartz sands that resemble a beach deposit, and these are abruptly overlain by some twenty to thirty feet of coarser calcareous sands, creamy white in colour, that have yielded an abundant marine Pleistocene fauna. Overlying the calcareous sands are yellowish-brown and red quartz sands which, judging from observations of the soils, extend eastwards to the Mombasa-Malindi road. No fossils were found in the upper division and it is thought probable that the sands were wind-deposited in Upper Pleistocene times. In the Makupa quarries, poorly-cemented quartz sand forms the bulk of the material exposed but there are two calcareous sandstone horizons, one near the floor of the quarry and the other near the top, from which marine Pleistocene fossils have been collected (McKinnon Wood, 1930, p. 226). The promontory south of Makupa shows the calcareous sandstone facies in juxtaposition with Changamwe Shales. The contact is almost vertical and, judging by the abnormally high dip of the shales, is suggestive of a fault, yet no evidence for faulting could be seen in the sands. An alternative theory, more favoured by the writer, is that the Pleistocene deposits were laid down on a wave-cut platform against a cliff of the shales.

The cliffs behind Kilindini Harbour are largely composed of the calcareous sandstone facies with pockets of fine-grained, unsorted quartz sand. In places there is a high proportion of coral rubble cemented by calcite, with large masses of fibrous aragonite giving the rock a "ragstone" appearance. Lateral variation is exhibited on a marked scale and the whole section in indicative of deposition under conditions of shallow water with variable currents. Fossils are scarce except in a few scattered localities where they are fairly numerous. Beds of a similar facies are exposed on the south mainland opposite to Kilindini Harbour. At Ras Kigangone they are sandy becoming increasingly calcareous towards Mtongwe. The littoral zone of the peninsula is characterized by an oyster bed of Recent age.

The fossil coral-reef is well-exposed on the seaward side of Mombasa Island, and in a narrow coastal strip on both the north and south mainlands. It consists of a tough white, or yellowish-white coral limestone that weathers to a dirty whitish-grey or greyish-black. Krenkel (1924) divided the limestone into the "Riffkalk", this being the true reef or bioherm, and the "Rifftrümmerkalk" which is a coral breccia representing the reef material that was eroded by wave action and redeposited on the inshore side. The reef is devoid of structure and its surface is so badly weathered that it is rarely possible to distinguish any fossil forms. It often happens that fossils from the coral breccia are in a better state of preservation than those from the reef itself. Seventeen species of coral were described by Gregory (in McKinnon Wood, 1930, pp. 187-193) of which all, with perhaps one exception, are still living in the western part of the Indian Ocean and the Red Sea. The corals, together with the fossil assemblages from the other phyla, have established a Pleistocene age for the reef.

The maximum height at which coral has been recorded in this area is 85 ft.—near Ngombeni—but, allowing for erosion, it is not unreasonable to assume that it once stood as much as 100 ft. above the present sea-level. On the other hand, a borehole drilled on the north mainland (*see* p. 27) was still in coral at 194 ft. below present sea-level so that the total thickness of coral must be of the order of 300 ft. or more. Assuming that reef-building corals grow at the rate of one foot per 200 years—an average estimate—it would have taken upwards of 60,000 years to build the entire reef. It is considered that the reef grew during one of the interpluvial periods that correspond with the three European inter-glacial stages, the durations of which are estimated by Zeuner (1950, p. 144) to be 60,000, 190,000, and 60,000 years respectively. Other factors, which are discussed more fully in Chapter VII, suggest that the reef grew during the second interpluvial stage.

The lateral extent of the reef is not easy to determine, firstly because it is often difficult to distinguish in surface exposures from the weathered surface of the coral breccia, and secondly because the width of the reef is not everywhere constant, either from place to place or throughout the vertical section. The width varies from place to place according to the suitability of the local Pleistocene conditions for coral growth, and throughout the vertical section it varies according to the rate of rise of sea-level that prevailed. With a rise in sea-level corals grow upwards in an attempt to keep pace with the rise, but with a pause in the rise they are forced to extend laterally, the extensions being subsequently covered by other sediments when the sea-level begins to rise again. Cliff sections on Mombasa Island show that the last phase in the growth of the reef was a prolonged halt in the rise of sea-level that caused a lateral extension of the reef over rather more than half of what is now Mombasa Island. The seaward limits are the Andromache and Leren Reefs which are exposed at low tide.

The formation of the coral-reef was followed by a marine regression with a subsequent rejuvenation of the river systems that cut their ways through the freshly-formed deposits. That this down-cutting extended to a depth well below the present sea-level is shown by the Mwachi channel at Kilindini. A small tributary entering Kilindini at Mweza Creek also cut deeply into the coral but its narrow channel has subsequently been filled with sand. Small marine terraces, which now support thin films of red sands, were cut into the Jurassic rocks at about the 120-ft. contour around Port Reitz, and other red sands and clays have been found occasionally overlying the coral. They may have been deposited contemporaneously with the ultimate stage of the coral growth but it is more likely that they were deposited by wind-action at a later date. It is suspected that more than one generation of red wind-blown sands may be present but this has not yet been confirmed by field evidence.

(3) *Post-Reef Deposits*

In addition to the red sands mentioned in the preceding paragraph, there are other deposits of definitely post-reef age. These include alluvia and oyster beds. The latter occur in many of the river valleys at heights of up to about 40 ft. O.D., and were first recorded by Gregory (1921, p. 74) who considered that they were the remains of heaps collected for use as lime. Specimens collected from alluvia at Jivani Kaya during the recent survey leave little doubt but that they are *in situ* and their excellent state of preservation suggests that they are of Recent age. Other specimens collected by Miss McKinnon Wood (1930, p. 227) were identified as *Ostrea gryphoides, O. turbinata* and *O. cucullata*, all species that range upwards from the Upper Tertiary.

(4) *Discussion on the so-called Pliocene Fauna of the North Mombasa Crag*

In the following list, all the specifically identified fossils that were collected from the North Mombasa Crag by Miss McKinnon Wood are shown, together with their known stratigraphic ranges. New species (i.e. species that had not previously been described from any other area) are not included as they have no stratigraphic significance. The list of fossils and their ranges is taken from the McKinnon Wood monograph.

SPECIES	Miocene	Pliocene	Pleistocene	Recent	REMARKS
Gastropoda—					
Clypeomorus tuberculatus		×	×	×	Pleist.-Rec. in E. Africa.
Bursa sp.		×			Sim. to *B. elegans* (Rec.).
Tonna variegata		×	×	×	Sim. to recent examples.
Harpa amouretta			×	×	Recent in E. Africa.
Bullus ampulla	×	×	×	×	Pleist.-Rec. in E. Africa.
Lamellibranchia—					
Anadara antiquata	×	×	×	×	Pleist.-Rec. in E. Africa.
Cucullaea concamera	×	×	×	×	Pleist. of Red Sea.
Glycymeris bonneti		×			
Modiolus metcalfei				×	
Lithophaga straminea				×	
Pecten vasseli	?	×	?		
Chlamys pusio	×	×	×	×	Pleist. of Zanzibar and Mombasa.
C. senatoria	×	×	×	×	
C. pallium	×	×	×	×	Mio.-Pleist. in E. Africa. Pleist. of Mombasa.
C. werthi		×			Known from Zanzibar.
C. bornhardti		×			Holotype described from Zanzibar.
C. nux				×	
C. inaequivalvis			?	×	One doubtful specimen from Pleist. of Mombasa.
Amusium pleuronectes	×	×	×	×	Plio. of Zanzibar.
Hemipecten forbesianus				×	
Spondylus insularis		×			Holotype described from Zanzibar.
Lima glacialis			×	×	Pleist. of Mombasa.
Ostrea gryphoides	×	×	×	×	Mio.-Pleist. in E. Africa.
O. cerata			×	×	Pleist. of Mombasa.
O. virleti	×	×	×		Plio.-Pleist. of E. Africa.
O. turbinata		×	×	×	
O. cristagalli		×	×	×	
O. townshendi				×	
O. tridacnaeformis		×			Holotype described from Zanzibar.
Thyasira tumida			×	×	Pleist. of E. Africa.
Pitar hebraeus				×	
Macrocallista florida		×	×	×	Pleist.-Rec. of E. Africa.
Antigona reticulata			×	×	
A. orientalis			×		
Clementia papyracea	×	×	×	×	
Brechites cf. *vaginifer*				×	
Cheilostomata—					
Steganoporella magnilabris	×	×	×	×	
Echinoidea—					
Temnopleurus toreumaticus		×	×	×	
Laganum depressum		×		×	Other Pliocene specimens recorded from Zanzibar.
Clypeaster reticulatus		×		×	
Phyllacanthus sp.					
Anthozoa—					
Porites nigrescens				×	
Foraminifera—					
Operculina complanata	×	×	×	×	

From this list it will be seen that the faunal distribution is as follows:—

	World	E. Africa	
Recent	33	25	representatives
Pleistocene	27	25	"
Pliocene	27	19	"
Miocene	13	6	"

Of the Pliocene representatives, three of the species, *Chlamys bornhardti, Spondylus insularis* and *Ostrea tridacnaeformis* were first described from the Pliocene rocks of Zanzibar (Stockley, 1927), their age being deduced from the associated faunal assemblage. *Ostrea tridacnæformis* has since been recorded from the *Pecten vasseli* Beds (Lower Pliocene) of Persia but, so far as the writer is aware, the ages of the other two species have not been confirmed from elsewhere and both may range outside the Pliocene. It will be noted from the remarks concerning the ranges of the species that several listed as having a wide stratigraphic range are known only from Pleistocene and Recent rocks in East Africa. Moreover, eight of the species were formerly known to exist only in the present-day seas and had not previously been found fossil so that, although their occurrence in Pleistocene rocks is feasible, it is more difficult to imagine their occurrence in Pliocene rocks. It is the writer's opinion, therefore, that this faunal assemblage is more consistent with a Pleistocene age than a Pliocene.

V—THE ALKALINE IGNEOUS COMPLEX OF JOMBO

By B. H. Baker, Geologist

1. INTRODUCTION

(1) *General Description*

The alkaline igneous complex is situated in the southern part of the area. It consists of a major intrusive body at Jombo hill, three associated satellite intrusions at Mrima, Kiruku and Nguluku hills, and subsidiary dykes. The entire complex falls within a radius of some ten miles of Jombo. (Fig. 12.)

Jombo hill is the highest peak in the area and rises to a height of 1,543 ft. O.D., 1,000 feet above the average level of the surrounding plain. It is of sub-conical shape with a summit ridge running in an east–west direction. Its basal diameter is roughly one and a half miles. The upper slopes are everywhere covered by dense forest and undergrowth which extends down to the base on the western, northern and eastern sides. The southern slope is more open but its surface is generally masked by a thick cover of tall "elephant" grass. The lower slopes are traversed by several elephant tracks which serve as good footpaths, but higher up it is often necessary to cut tracks through the undergrowth to move from point to point. The dense vegetation is a great hindrance to surveying nd geological mapping. A map of the hill was prepared on a scale of 600 feet to the inch, by compass and wheel traverses. Compass and plane-table resections were used wherever possible to check the traverses but opportunities for such checks were so few that the resultant accuracy cannot be high.

Mrima hill lies five miles S.E. of Jombo. It is a broad dome-shaped hill that attains an altitude of 982 feet. In the past it has attracted attention by virtue of the manganese laterites that cover its surface. An account of the manganese deposits is given in the economic section of this report. Like Jombo hill, Mrima is covered by dense vegetation. Exposures are few owing to a thick layer of distinctive red-brown soil caused by the weathering of the manganese and iron ores.

Kiruku hill, lying three miles north-east of Mrima, is conical in shape rising to 626 ft. O.D. and is also covered by a thick vegetation.

Nguluku hill, also of conical outline, is situated four miles north-east of Jombo and is 585 ft. high.

The surrounding area is flat-lying with infrequent broad shallow valleys that often form vleis in their lower parts. The soils are brown and sandy except in the more poorly drained areas where they are of "black cotton" type. The plain is well-grassed and covered with thorn trees and thick clumps of bush.

Mr. Caswell and the writer spent six weeks in the area during January and February, 1951. In July a further visit was made (B.H.B.) to the area to undertake a limited radioactivity survey and to collect specimens of manganese ore from Mrima hill. Access to Jombo hill was considerably assisted by a recently cut track running from Kikoneni via Gandini to join the main Tanga road near Marenyi. In addition, a second track was cut to the bottom of the hill itself from the base camp near Gandini.

(2) *Previous Work on the Complex*

It is probable that Hobley (1895) first discovered Jombo and recognized it as consisting of alkaline igneous rocks. Gregory (1900) described Hobley's specimens and, although he did not visit the hill himself, later (Gregory, 1921, pp. 191-192) he summarized all the available evidence in his book on the geology of East Africa.

Miss McKinnon Wood visited Jombo and obtained the specimens that were examined by G. W. Tyrrell (1938). Tyrrell described five specimens in detail and concluded that the intrusion was a ring-complex consisting of members of the foyaite-malignite-melteigite suite of alkaline igneous rocks.

2. GEOLOGY AND PETROGRAPHY OF THE COMPLEX

(1) *The Jombo Hill Intrusion*

The plutonic core of the complex is situated at Jombo. The entire hill is composed of plutonic rocks and for a considerable part of its extent their outer boundary may be drawn at the base of the hill (Fig. 13). The following rock types, tabulated in order of crystallization, are found on the hill:—

(*e*) Nepheline syenite;
(*d*) Malignite,
Ijolite;
(*c*) Hornblende melteigite;
(*b*) Pyroxene juvite,
Foyaite;
(*a*) Micro-foyaite,
Micro-malignite,
Hornblende micro-melteigite.

Group (*a*)—the marginal rocks—bound the intrusion on three sides. On the fourth and southern side they are not seen and a tentative fault has been drawn to explain their absence and the apparent eccentricity of the rock types.

For the purposes of this report the nomenclature used is based on that of Brögger (1921) and von Eckermann (1948). The following diagnostic table is based entirely on von Eckermann's diagram of nomenclature (*loc. cit.*, p. 15).

	Per cent *Soda-orthoclase*	Per cent *Nepheline*	Per cent *Pyroxene*
Pulaskite	70–90	0–5	10–15
Juvite	40–50	45–50	0–10
Pyroxene Juvite	30–45	35–45	10–30
Foyaite	25–35	25–35	25–40
Malignite	20–30	15–25	40–55
Ijolite	—	40–60	60–40
Melteigite	—	15–25	65–75

(*a*) *Marginal Rocks*

At the northern margin of the intrusion is a small knoll exposing micro-foyaite. The exposures are disconnected from the main mass but it is probable that the micro-foyaite represents a marginal facies of the main intrusion. On the eastern edge, between the main mass of the foyaites and the sedimentary wall, is a zone of banded micro-malignites and micro-melteigites concentric to the summit. The banded character of the rocks is emphasized by the almost perfect parallelism of the hornblende crystals in the hornblende malignite, which also lie in planes concentric to the summit. The banding dips inwards at angles varying from 65° to 70°. Piercing the rocks of the marginal zone are numerous small veins of aplosyenite. They rarely exceed ten millimetres in width and are always arranged radially with respect to the centre of the intrusion. Other micro-foyaitic rocks are seen as fine-grained modifications of the main mass, in the form of concentrically arranged bands with gradational boundaries. They never exceed ten feet in width.

The junction of the marginal rocks with the foyaites on the one hand and the sedimentary wall-rocks on the other was not seen although it can be fairly accurately inferred.

A table of the volumetric mineral modes* of some of these marginal rocks is given below:—

	1	2	3	4
	%	%	%	%
Orthoclase perthite ..	57·9	45·5	—	7·2
Nepheline	33·0	37·4	34·4	44·5
Aegirine-augite	8·9	7·3	50·1	12·3
Hornblende	—	—	6·9	31·3
Sphene	0·2	3·1	7·9	4·6

1. 69/282a Pyroxene juvite, near western edge of the intrusion.
2. 69/273a Micro-foyaite, northern extremity of Jombo.
3. 69/273b Micro-melteigite, northern extremity of Jombo.
4. 69/285 Hornblende micro-ijolite, near eastern margin of the intrusion.

The thin sections of specimens 69/285 and 69/286 are typical of the banded rocks of the marginal part of the intrusion. The first is distinctive in containing a high proportion of subhedral barkevikite as small phenocrysts. The barkevikite is dark greenish-brown to black and pleochroic to light greenish-brown. Most individuals have a light core and darker margin. The optic axial angle is $-2V=40^\circ$, and the extinction, $X \wedge c=12^\circ$. Very rare flecks of brown biotite penetrate the amphiboles. Small (1 mm.) columns and prisms of pale green aegirine-augite are scattered throughout a sutured groundmass of sub-hedral nepheline with rare patches of untwinned potash-felspar. The pyroxene has an optic angle $2V=60^\circ$, and extinction $X \wedge c=33^\circ$. The felsic crystals have sutured margins and an irregular replacive relationship to one another.

In hand-specimen the rock 69/286 has ill-defined light and dark grey bands, the more leucocratic bands having a coarser grain and easily visible felspathoids, while the melanocratic bands have hornblende phenocrysts reaching 15 mm. in length. A thin discontinuous urtite vein traverses the specimen. The colour variation is influenced chiefly by the size and quantity of the felspar crystals. The thin section reveals a texture strikingly similar to that of certain injection gneisses. The felsic portions have the texture and composition of nepheline-syenite, and are laminated with melanic folia which consist of closely packed aggregates of pale green to green prisms and granules of aegirine-augite. Subhedral nephelines and horneblende phenocrysts are scattered through the pyroxenic matrix. Idiomorphic wedges of sphene are common. The hornblende varies from brown to black in colour being a sodic form, probably barkevikite. Golden brown biotite is rare but always associated with the pyroxene.

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* Other modes quoted in this chapter are also volumetric

The micro-foyaite (69/273a) forming a low knoll on the northern margin of the intrusion is medium-grained and homogeneous. The rock consists of anhedral soda-orthoclase crystals showing Carlsbad twinning and equidimensional nephelines with rows of inclusions. Light green aegirine occurs interstitially to the felspars. Larger individual pyroxenes are zoned with a diopsidic core and a sodic margin. A few small aegirines are poikilitically enclosed in the felspar. Enclosed in the micro-foyaite are subangular xenoliths of hornblende micro-melteigite generally not exceeding three cm. in width, which are closely related to the banded melanic rocks of the eastern margin of the intrusion. In thin section they are seen to be composed largely of green aegirine-augite with some of the larger pyroxenes having augitic cores. Euhedral sphene is common. Anhedral turbid sodalite up to 2 mm. across is present as a late replacive felspathoid. Scattered plates of brown hornblende poikilitically enclosing granules of sphene, are pierced by it. Small wisps of green hornblende are widespread among the pyroxene aggregates from which they have been derived. Opaque-iron ores of late crystallization represent some 4 per cent of the rock.

A similar association is represented by the specimens 69/225a and 69/225b from the western adge of the intrusion. In these rocks the amphibole is a green normal hornblende of early crystallization rather than a sodic form. In a slice of 69/225a, a hornblende micro-foyaite, subhedral hornblende encloses sphene ophitically and has suffered marginal corrosion by the felsic components. A little pale green aegirine is present in the groundmass which consists of equigranular subhedral crystals of orthoclase and nepheline. An isotropic mineral (sodalite) has penetrated the intercrystalline boundaries and carries clouds of microlitic hydrated micas. Specimen 69/225b is a small basic xenolith of hornblende micro-melteigite in the micro-foyaite, containing green hornblende, aegirine-augite ($X \wedge c = 30°$), nepheline and sodalite. The hornblende and pyroxene are present in similar amounts as crystals up to 1 mm. in size, the pyroxenes being usually somewhat larger and better formed. The green hornblende appears to be a normal late reaction product of pyroxene. The small interstitial patches of clear nepheline are rare.

(*b*) *Foyaite and Pyroxene Juvite*

The rocks of the marginal facies appear to grade into coarse-grained, usually trachytoid, nepheline syenites that vary considerably in texture from place to place. The trachytoid texture shown by the large subparallel phenocrysts of orthoclase or anorthoclase is very common and is particularly well displayed among the foyaites on the northern slopes of the mountain, near the level of the 700-foot contour. The alignment of the major axes of the felspar phenocrysts is often concentric to the summit.

The syenoid rocks have a crescent-shaped outcrop. Thus, the alignment of phenocrysts, the banded character of the hypabyssal rocks and the concentric and radial vein and dyke systems all suggest the mode of the intrusion to be of ring-type as is found with the majority of alkaline complexes. The heterogeneity of the syenoid rocks precludes any speculation on the age relationship of the various textural types. The syenites include foyaite, pyroxene juvite and pulaskite, which are distinguished only by variations in texture and minor variations in mode.

In the field the foyaites are exposed as small boulders which are often not *in situ*. Their surfaces, from which porphyritic felspars protrude, the interstitial nepheline having been weathered out, are slightly weathered to a dark brown crust, but fresh rock is present approximately a quarter to half an inch below. The felspar, in crystals varying from 5 mm. to 30 mm. in length, is variably orthoclase or microperthite, or both, and is greyish-blue, sometimes having marginal inclusions of black pyroxene. Nepheline occurs between the felspars often in square or rectangular-sectioned crystals of a pale reddish-brown colour. Small, usually acicular pyroxenes, from 1 mm. to 2 mm. in length, form small aggregates coating felspar and nepheline. Honey-yellow sphene can be distinguished with a hand-lens.

It is not possible to measure the mineral mode of such coarse-grained rocks accurately without examining a considerable number of slices from each specimen. Estimated modes of a few representative examples are tabulated below:—

	1	2	3	4
	%	%	%	%
Orthoclase	68·8	70	—	—
Microperthite		—	37·1	50
Anorthoclase		—	—	
Nepheline	20·4	3	24·2	30
Sodalite		—	—	—
Cancrinite	Trace	—	—	—
Aegirine	3·7	10	—	—
Aegirine-augite		15	16·3	10
Sphene, etc.	7·0	2	1·2	10

1. 69/275a Pyroxene juvite; base of north face.
2. 69/276 Pulaskite; base of north face.
3. 69/277 Pyroxene juvite; base of north face.
4. 69/283a Pyroxene juvite; lower N.W. slopes.

The minerals of all the types of nepheline syenite at Jombo are similar and the characteristics of each of the essential minerals is described below. The sequence of crystallization is as follows: orthoclase—nepheline—pyroxene—albite.

Felspars.—The potash felspar universally forms idiomorphic porphyritic crystals varying from 5 mm. to 30 mm. in size. Following the well-established "agpaitic" order of crystallization characteristic of undersaturated igneous rock bodies, it is almost invariably the first mineral to crystallize.

Carlsbad twinning is common as is zoning of the larger phenocrysts. Typical optical properties (orthoclase of specimen 69/276) are $-\ \alpha = 1.522$, $\beta = 1.525$, $\gamma = 1.528$; $X \wedge a = 7°$, $-2V = 70°$. Some individuals are patchily perthitic the perthitic intergrowths often being marginal. Such phenocrysts are almost always accompanied by small clear albite crystals at their margins; at least two-thirds of the slices show late interstitial and marginal anhedral albite. It is suggested that the late access of sodium felspar raised the percentage of the albite molecule in the orthoclase to the point where exsolution took place, and thus the perthitic structure of the orthoclase arose. Excess albite crystallized marginally or interstitially. It is possible that some of the marginal albite may be derived from soda-orthoclase by exsolution as a result of slight cataclasis. Inclusions in the felspars consist of small idiomorphic sphenes and very rarely of isolated acicular pyroxenes.

Nepheline.—In hand-specimens nepheline forms pale reddish-brown, often idiomorphic crystals from 5 mm. to 15 mm. in diameter. In thin sections it is almost clear although alteration has taken place along cracks. In some slices a partial replacement of nepheline by sodalite, sericite, cancrinite or scapolite has taken place. Inclusions of pyroxene are common, in some cases occurring as minute needles and in others as acicular aggregates of aegirine with stellate arrangement. The nephelines have been unaffected by the albitization.

In numerous cases nepheline corrodes and replaces felspar but such replacement is very limited. Refractive index tests indicate the presence of 8 to 10 per cent of the kaliophilite molecule in the nepheline. Larger idiomorphic individuals frequently show a pronounced zoning of cryptocrystalline inclusions. Also, as in slice 69/290, a zone of small aegirine microlites near the margin of a phenocryst is seen and aggregates of small pyroxenes concentrated at the centres of the crystals are common. The zonal aegirine inclusions cannot be regarded as late replacements of nepheline but are rather a result of simultaneous crystallization. The nepheline phenocryst of slice 69/290 (Fig. 4C) is unusual in being biaxial with optic axial angle $-2V$ approximately 4°.

Pyroxenes.—The characteristic pyroxene of the Jombo nepheline syenites is aegirine-augite, though it rarely exceeds 20 per cent of the total volume of any rock. It is usually pale green with a slight pleochroism to darker green, and occurs in prisms and subhedral granules ranging from 0.5 to 2 mm. in length. It invariably crystallized after the potash felspar and nepheline to which it is interstitial. The aegirine-augite has an extinction $X \wedge c$ of 25° to 26°. A few of the aegirine-augite crystals have slightly brownish augitic cores. When in this form, they tend to form rather stout well-developed crystals.

The aegirine-augite is commonly accompanied by the more sodic pyroxene aegirine, which is usually present as pale green acicular crystals in the groundmass. It has an extinction angle ($X \wedge c$) of 8° to 10°. It is found as inclusions replacing nepheline but never lies within or replaces the felspar. It is also found as needles along cleavage cracks in nepheline.

Biotite.—Golden-brown, strongly pleochroic, biotite of composition approaching lepidomelane is occasionally found in the syenites. It never exceeds one or two per cent by volume of the rock and invariably occurs as small isolated flakes adjacent to or partly enclosing pyroxene. In a few rocks where the early pyroxene is zoned with an augitic core and more sodic margin, minute flakes of biotite are seen in the aegirine-augite margins. This suggests the general reaction:—

$$\text{Augite} + \text{Na} + \text{K} \rightarrow \text{Aegirine-augite} + \text{biotite.}$$

Accessory minerals.—Sphene is present in nearly all the syenites. It is early in the order of crystallization and nearly always idiomorphic. Where a few grains of titano-magnetite are seen sphene often occurs as clusters of crystals around them.

(*c*) and (*d*): *The Basic, Transitional and Hybrid rocks*

Most of the southern face of Jombo hill is occupied by basic rocks, mostly hornblende melteigites, with small occurrences of ijolite and malignite. At all the exposures the basic rocks are seen to be veined and partially replaced by medium-grained leucocratic syenite.

Megascopically the melteigites are compact dark grey to black rocks with grain size varying from 0.5 to 5 mm. It is often possible to distinguish felsic grains among the predominant ferro-magnesian minerals and in some cases, where the rocks are of malignitic or ijolitic composition, they are finely mottled.

The modes of some of the basic and transitional rocks are given below:—

	1	2	3	4	5	6
Nepheline	27·7	25	}20	30	19·9	21·7
Sodalite	—	—		—	—	—
Aegirine	—	—	—	10	—	2·6
Aegirine-augite	16·3	3	45	—	36·2	32·2
Augite	5·5	30	—	40	25·9	9·8
Barkevikite	39·8	40	—	—	—	—
Biotite	13·9	—	20	15	4·9	26·9
Melanite	7·8	—	—	—	6·9	—
Apatite	2	—	5	5	6·1	4·2
Sphene	1	2	10	—	—	3·1

1. 69/306 Hornblende melteigite, north-east of summit.
2. 69/296a Hornblende melteigite, south-west base of the hill.
3. 69/300 Biotite melteigite, quarter-mile south of summit.
4. 69/297 Biotite melteigite, near south-west base of hill.
5. 69/299 Melteigite, from centre of south face.
6. 69/287 Biotite melteigite, south face below east ridge.

The normal pyroxenes of these rocks are titaniferous augites with pale purplish-brown cores and green sodic margins. They occur as stout prisms, frequently idiomorphic, showing incipient alteration to brown biotite or emerald hornblende. Aegirine and aegirine-augite are found as small granules in the matrix or as mantles on augite. In thin section 69/321 the pyroxene is seen to be a very pale green non-pleochroic pigeonite with small optic axial angle and a maximum observed extinction angle of 33°.

Barkevikitic hornblende, strongly pleochroic from light honey-brown to dark brown or black, occurs in two of the rocks. It frequently has a black oxidized margin and is usually associated with biotite. In the "corona" structures discussed below it occurs in association with biotite and granular diopside.

Brown biotite is common in the melteigites and is found as strongly pleochroic flakes in the marginal parts of pyroxenes or in the "corona" structures. Some biotite occurs as large ophitic plates, as in specimen 69/323, where it has crystallized in two generations, the order of crystallization being:—Sphene—biotite I—aegirine-augite—biotite II—nepheline.

Nepheline is clear and unaltered although in a few slices it has been partly replaced by sodalite. It always occupies an interstitial situation, being anhedral and late in the crystallization sequence, in which it differs from the nepheline of the syenites where it is often iodiomorphic and early. The sodalite, which replaces nepheline exclusively, is turbid and carries clouds of small opaque iron ore grains.

A single large grain of perovskite was noted in slice 69/306. It is dark red-brown in thin section, contains inclusions of apatite and is partly mantled by sphene. Sphene and apatite are common, the latter being confined to the basic alkaline rocks. Titanomagnetite ore grains are widespread but never attain more than a fraction of a per cent in these rocks.

On the western ridge of the hill near the contact of the nepheline syenite and the melteigite, a variety of assimilation phenomena are seen. Many of the basic rocks here are fine-grained and tinguaitic in appearance and in large exposures are seen to consist of sub-rounded blocks of melteigite and malignite enclosed in and veined by heterogeneous intermediate syenitic and malignitic material. In the stream section on the lower south-west slopes of the hill a number of good exposures show similar veining. The acid veins are in the form of anastomosing and ramifying irregular stringers that locally brecciate the basic rocks and divide them into fragments of diminishing size, which are progressively incorporated into the veins as xenoliths or even xenocrysts. The basic blocks reach two or three feet in diameter and small veins traverse them irregularly, some boulders being interlaced by such veins without becoming disintegrated. Light-coloured veins and dykes also penetrate the more central parts of the melteigite body. They are buff to light grey in colour, equigranular, with grain size varying in different examples from 2 to 6 mm., and essentially of aplosyenitic composition and appearance. Some carry considerable percentages of nepheline, although the nepheline is always subordinate to felspar. The only dark minerals in these rocks are sparsely distributed needles of aegirine.

The leucocratic minerals and veins occur in the following three ways:—

(1) permeated through certain parts of the basic rocks giving them a speckled intermediate appearance;

(2) as distinct veins from 1 to 5 mm. wide with sharp boundaries and parallel sides;

(3) as diffuse anastomosing and ramifying hybrid syenitic veins, replacing the basic rocks.

Specimen 69/309, taken from the stream section referred to previously, is interesting in that it presents evidence of the replacement of the basic rock by syenite. In the hand-specimen, which consists of melteigite with part of a felsic vein, the contact of the vein with the melteigite adjacent to the vein have been replaced by vein material. The melteigite has clearly been replaced rather than displaced and none of the basic fragments enclosed by the syenite mesh were forced from the walls by the injection of magma. Though many parts of the basic rocks are homogeneous, others contain small idiomorphic crystals of nepheline and felspar growing in a basic matrix. Many of the basic blocks adjacent to each other do not show matching of the walls and it can only be assumed that they have been partly replaced by syenite. Yet the leucocratic veins often have sharp boundaries against the basic blocks and many exposures do not show any hybridization of host or exotic rock.

The thin section of 69/309 was taken from a "permeated" part of the specimen. The dark minerals are relics from the basic rock and consist of somewhat altered titan-augite mantled by aegirine-augite. The titan-augite has in two cases been altered centripetally to aggregates of granular diopside bordered by intergrowths of biotite and aegirine-augite. Strongly pleochroic green hornblende containing biotite and apatite is also seen to replace the augite. The felsic minerals consist of hypidiomorphic untwinned orthoclase set in a sparse matrix of equigranular nepheline.

A thin section (69/309 (*e*)) of the leucocratic vein consists almost entirely of inequigranular anhedral orthoclase as ragged grains varying from 0.25 to 5 mm. in diameter. Some albite is present but no nepheline was identified.

The corona structure previously mentioned occurs in slice 69/306 (Fig. 4A). A nest of small granules of diopside is surrounded by radially arranged plates of biotite and barkevikite in about equal proportions. The nest of diopside is 1.5 mm. wide while the corona of biotite and barkevikite is 4 mm. in width. Only two structures of this kind were seen in the basic rocks. It is considered that they may have arisen from the breakdown of titan-augite as a result of the introduction of alkali-rich fluids into the rock during the period of veining. The widespread development of biotite and to a lesser extent barkevikite may be attributed to the alkali (Na, K, Al) enrichment of the basic rocks during the last stages of their crystallization. The *modus operandi* of his enrichment appears to be akin to that of metasomatism by a liquid medium, or it may be likened to autometamorphism, depending on whether the alkali fluids are considered to be exotic or of local derivation. The leucocratic vein material in general may represent apophyses of a syenitic body not at present exposed but, more likely, is due to diaschism of the melteigite magma at a late stage of crystallization.

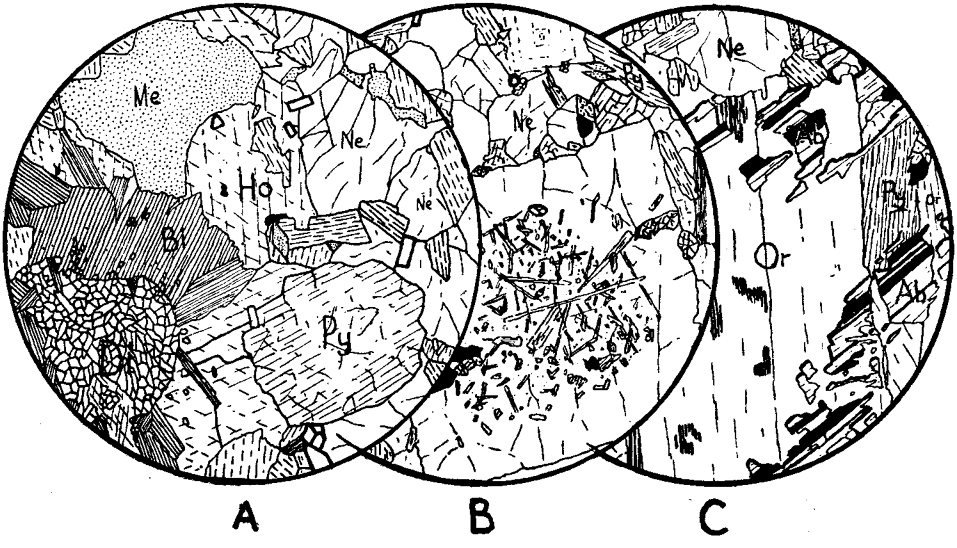

Fig. 4.—Drawing of thin sections of Jombo rocks.

A.—Melteigite. Slide 69/306. X 14. Ordinary light. The drawing shows a part of a "corona" structure consisting of a granular mass of diopside (Di) surrounded by biotite (Bi) and barkevikite (Ho). Pyroxene (Py). nepheline (Ne) and melanite (Me) with accessory apatite are also present.

B.—Malignite. Slide 69/302. X 14. Ordinary light. A phenocryst of nepheline has a central mass of aegirine needles replacing the host nepheline.

C.—Foyaite. Slide 69/290. X 14. Crossed nicols. The slide shows a phenocryst of orthoclase partially replaced by twinned albite. Small areas of albite also appear in the interior of the orthoclase crystal.

(*e*) *The Nepheline Syenite*

The nepheline syenites forming the summits of the hill and the greater part of the summit ridge represent the last plutonic phase in the activity of the Jombo intrusion. The last phase took place in the centre of the intrusion, that is, with the same centre as that prevailing during the intrusion of the foyaites. In the intervening phase the centre of intrusion was shifted to the south, during the emplacement of the melteigites. This shifting of the intrusion centres explains the eccentricity of the outcrops of the main rock bodies.

The summit syenites appear to be appreciably harder and more resistant to weathering than the others, and often a sharp rise or even a cliff marks their outer boundary. In the field the rocks are considerably weathered on the surface but exposures are abundant. They are medium- to coarse-grained, occasionally with an equigranular texture, but more often contain felspar phenocrysts which are smaller and not so plentiful as in the foyaites. The grain size as a whole is appreciably less than that usually seen among the foyaites, the felspars rarely exceeding 10 mm. in length, and having no preferred orientation. Nepheline is easily visible as pale reddish-brown crystals. Small black pyroxenes outline the felspars and nephelines. Some specimens have a tendency to develop more abundant nepheline and pyroxene and are malignitic in appearance. Fine-grained black basic xenoliths, usually less than 30 mm. in size, are often seen.

A thin section of specimen 69/260 shows orthoclase as more or less idiomorphic crystals with parallel extinction. Traces of a myrmekitic structure on a small scale are seen. Nepheline is clear, free of inclusions, and usually subhedral although one individual is very well-formed and zoned. Idiomorphic aegirine-augite occupies an interstitial position. A few are zoned with a less sodic core while some are more augitic in composition.

Specimen 69/254 shows very similar features, though the felspars have been more conspicuously resorbed by nepheline and locally have developed perthite structures. The pyroxene is mostly aegirine in small acicular crystals scattered in nepheline and along intercrystalline boundaries. Sphene is a common accessory in both the above slides as wedges and prisms.

(2) *Syenite Veins and Fenites of Kikonde*

A long low ridge, Kikonde by name, extends from Mrima hill in a north-northwesterly direction, and has several exposures along its crest of altered and veined sandstones of the Middle Duruma Series. They are buff, well-bedded felspathic sandstones with occasional partings of silty shale. Traversing these rocks are many small syenitic veins only rarely exceeding 40 mm. in width. Immediately adjacent to the veins the sandstone assumes a green colour. The veins themselves are numerous, there being as many as three or four parallel veins within a distance of one or two feet. They are vertical in attitude and invariably strike in the direction of Jombo Hill.

The smaller veins, which are from 1 to 2 mm. in width, are dark green in colour and are composed entirely of fibrous aegirine. Larger veins of a width of 20 to 30 mm. have margins composed of fibrous aegirine, and cores of medium-grained potash felspars. The pyroxene needles project into the felspathic centres of the veins, which also carry clusters of green aegirine. The irregular shape of the veins and the fact that linear sedimentary patterns in the rocks are not offset by them proves that they are metasomatic in origin, i.e., they have not been formed from a syenitic fluid (magma) injected into fissures in the sandstones.

The composition and microscopic characteristics of the veins indicate that they have originated by a process of "fenitization". The terms "fenite" and "fenitization" were first introduced by Brögger (1920, p. 171) to describe various rocks and the metasomatic process leading to their formation, around alkaline intrusions in the Fen district of Norway. Brögger originally applied the name fenite to rocks formed by the fenitization of biotite granites or gneisses of similar compostion. Since then, however. the scope of the term has widened to include any rocks that have suffered alkali metasomatism around alkaline intrusions, irrespective of composition, but excluding mobilized (rheomorphic) and transported hybrid mixed rocks. The composition of fenites is the same as those of the common alkaline intrusive rocks. Thus there are fenitic syenites, nepheline syenites, malignites, etc. The development of alkaline pseudo-igneous rocks by fenitization (metasomatism) has been described from several areas, but the concept of a metasomatic origin of some alkaline plutonic bodies has only recently found favour and may still not be generally accepted.

Briefly, the process of fenitization* is said to take place by the abstraction of silica from the solid country rocks and by the addition of calcium and potassium. The transfer of these elements is thought to take place in a fluid pore medium or by ionic migration through crystal lattices. The chemical and thermal gradient necessary for the initiation of the fenitization process is assumed to be established by the intrusion of calcium and magnesium carbonates (carbonatites). The silication of the hot carbonatitic liquid is achieved by the desilication of the surrounding solid rocks, with the result that undersaturated alkaline rocks are produced. It is considered that fully liquified (rheomorphic) alkaline magmas are often generated by the fenitization process; the magma thus produced gives rise to intrusive alkaline plutonic bodies on solidification.

The alkaline syenitic veins found on the Kikonde ridge must therefore be termed fenites and although it has operated on a restricted scale, every step of the fenitization process can be traced. The gradation from sandstone to fenitic syenite takes place over a distance of only a few centimetres.

Slice 69/346b shows a fine-grained partly fenitized sandstone. In part of the section the rock has a characteristic sedimentary texture, but it contains orthoclase and subordinate twinned albite as subangular grains mimicking the clastic quartz grains they have replaced. It is considered that the quartz has been converted into orthoclase *in situ* apparently without the presence of any fluid medium. Small round relic grains of quartz remain in the felspar. Green aegirine is common as laths and needles growing in intergranular spaces and replacing quartz. Towards one edge of the thin section fenitization has been more intense. Here the orthoclase is in larger plates and the clastic texture is destroyed, but the felspars are still anhedral and sub-angular. The felspar is mostly perthitic and occasionally shows Carlsbad twinning. It envelops early-formed aegirine, and occasional relic quartz inclusions remain even in the large plates of orthoclase. Sphene appears to have developed simultaneously with the pyroxene. Chemically this more fenitized portion of the rock corresponds to quartz-syenite.

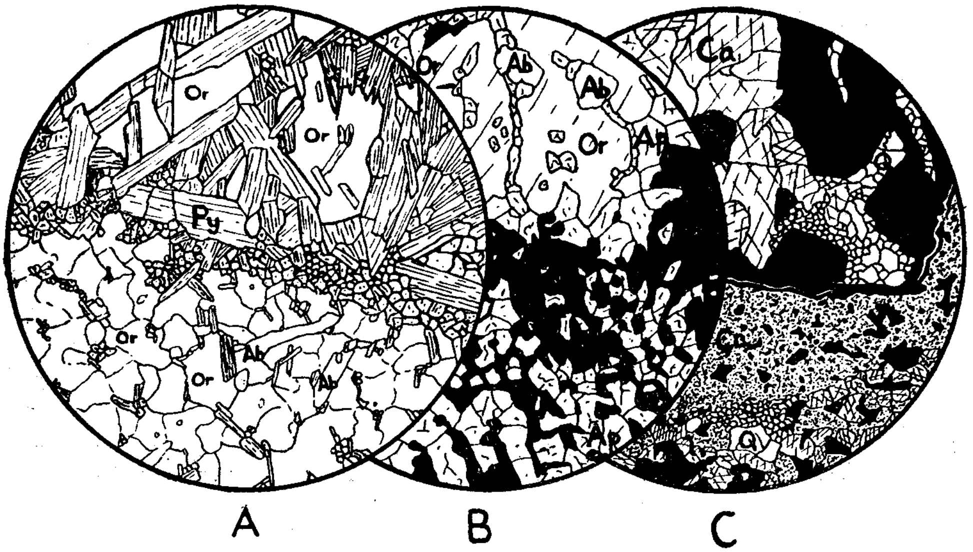

Fig. 5.—Drawings of thin sections of rocks from the Jombo district.

A.—Fenite vein, Kikonde. Slide 69/354c. X 20. Ordinary light. The lower half of the drawing shows fenitized sandstone where almost all the quartz grains have been replaced by orthoclase (Or), albite (Ab) and aegirine. The upper half illustrates the fenite proper where complete recrystallization has taken place and the aegirine (Py) is in coarse bladed crystals replacing orthoclase.

B.—Fenite vein, Kikonde. Slide 69/352b. X 20. Ordinary light. The dark mineral is deeply coloured aegirine that has been partly replaced by apatite (Ap). Apatite also penetrates and replaces orthoclase (Or) but not albite (Ab).

C.—Agglomerate, Ngululu. Slide 69/333a. X 20. Ordinary light. A partly silicified limonite-carbonate fragment occupies the upper part of the drawing and is surrounded by fine-grained carbonate with irregular limonite grains. Larger clastic quartz and calcite grains and some limonite occupy the lower part, where some of the carbonate has been replaced by granular silica.

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* For detail *see* von Eckermann, 1948, pp. 27–43

A sequence of three thin sections taken at intervals of two inches at right angles to the margin of a large vein shows the same stages of replacement as in the slide described above. The three sections are 69/352a, b and c, 69/352c being the fully fenitized rock. The slices b (Fig. 5B) and c are distinctive in having apatite replacing felspar, and pyroxene to a lesser extent. Green aegirine, in these last slides, is in large, idiomorphic crystals although small needles of aegirine still penetrate the felspars.

Slice 69/354c (Fig. 5A) shows the margin of one of the veins. The sandstone adjacent to the vein is considerably fenitized, having about 20 per cent of aegirine and almost all the quartz replaced by subangular orthoclase and twinned albite. The margin of the vein is distinct but ragged in outline. At the margin fibrous and needly green aegirine forms a dense felted mass of closely-packed stellate aggregates varying from 2 to 6 mm. in thickness. The needles of these aggregates terminate abruptly on entering the fenitized sandstone where the aegirine is smaller and more granular. The needles project well into the felspathic centre of the vein, which consists of orthoclase and subsidiary albite in the form of hypidiomorphic grains. No quartz remains. Smaller and stouter aegirine crystals, about a millimeter in length are common as inclusions in the felspar. They are distinct from the long aegirine needles and are later than the felspathization of the quartz. The following table illustrates the stages of the fenitization of the sandstone:—

(1) Conversion of quartz to potash felspar and albite.
(2) Introduction of aegirine and sphene.
(3) Increase of grain size—final destruction of all quartz—growth of larger crystals of felspar.
(4) Introduction of aegirine, which crystallized on the margins of the main channels of metasomatism as needles replacing felspar in part.
(5) Introductions of apatite replacing felspar and to a lesser extent aegirine (Fig. 5B).

The changes involve the addition of K, Na, Al, Fe, Ti and P to the standstones and the removal of SiO_2.

The fenitic veins of Kikonde do not show the development of nepheline, a fact that is certainly due to the small scale on which fenitization took place. So much silica is available in the sandstones adjacent to the veins in this restricted state of fenitization that the nephelinization of felspar could not be initiated. Were the fenitic syenite bodies of larger size it is possible that nephelnization of felspar could have begun in their central parts.

In alkaline complexes such as those in the Norwegian Fen district, at Alnö, and at Spitzkop (Straus and Truter, 1951), where marginal fenitization is well-known, the fenites are usually large ring-like bodies. In the present case the fenitic veins on Kikonde are at a distance of some five miles from the main intrusion at Jombo. The intervening ground has no exposures but evidence of float fragments and morphology suggests that sedimentary sandstones occupy this space. It is possible to explain the eccentricity of the Jombo intrusive bodies and the vein system on Kikonde by drawing a fault along the southern base of Jombo hill, through the southern extremity of the Kikonde ridge, and on through the Kiruku explosion vent. There is no positive or negative evidence for such a fault in the sedimentary geology of the area due to the extremely poor exposures. The fault has been included on the maps but must be regarded as very tentative.

(3) *The Silicified Agglomerates of Kiruku*

The small conical hill Kiruku rises beside the road between Mrima and Kikoneni village. It is roughly ovoid in plan with a greatest dimension of 500 yards at the base. Exposures on the summit and higher slopes are numerous the rest of the hill being masked by deep red-brown loam. The rocks consist entirely of reddish-brown to brownish-black chert containing numerous scattered angular and brecciated fragments of partly silicified sandstone. The colour variations are caused by the presence in variable amounts of the iron oxides, limonite and hematite.

In thin section (69/349) the sandstone is seen to contain small (¼-½ mm.) angular quartz and felspar fragments in a crypto-crystalline matrix of quartz. The fragments of sandstone are enclosed by chert in the form of fine to medium-grained chalcedonic silica. Considerable iron-staining in patches and veins is present, but the chert is most strongly iron-stained with the result that parts of some slices (e.g. 69/350) are almost opaque.

The rock is regarded as a strongly iron-stained and silicified agglomerate consisting entirely of sandstone fragments. The hill is composed of these agglomerates and forms the infilling of an explosion vent.

Kiruku has similarities to the vents described by Dixey, Campbell Smith and Bisset in the Chilwa Series of Nyasaland (Dixey *et. al.* 1937, pp. 16-17), where the fragments of the agglomerate are primarily felsitic volcanic rocks and the matrix is commonly composed of felsitic tuff and carbonates. In two of the vents hydrothermal silicification is described.

(4) *Agglomerate of Nguluku.*

Another small vent similar to Kiruku occurs at Nguluku, which is a hill, rather smaller than Kiruku, situated about five miles north-east of Jombo. The hill is approximately 400 yards across and is circular in plan. The exposures on the hill are excellent, there being large rounded outcrops on the summit and upper slopes. The rocks exposed are uniform in appearance and composition, and consist of light brown agglomerates to which the included fragments give a spotted appearance. It is estimated that the agglomerates have the following general composition:—

	per cent
Shale fragments	15
Sandstone fragments	20
Siliceous and calcareous matrix	65

Specimen 69/333 has a fine-grained light-brown matrix in which are sub-angular shale and sandstone fragments. The sedimentary fragments vary in size from 1 to 2 mm. up to 10 cm., the largest fragments being of more or less sub-rounded sandstone and grit. Some of the sandstone fragments carry pyrite and have indurated margins, while some of the smaller sandstone fragments appear to have been partially silicified previous to being included in the agglomerate. The shale inclusions are jet black while the sandstone fragments vary both in grain size and colour, some being buff, others reddish-brown or grey. A thin section was cut across one of the shale fragments (69/333a). The shale is well-laminated on a microscopic scale and completely unaltered, with small angular fragments of quartz and acid plagioclase in an almost cryptocrystalline quartzose carbonaceous matrix. A thin slice of specimen 69/333a (Fig. 5C) reveals a fragment of medium-grained limestone which has been partly replaced by chalcedonic quartz. The limestone has apatite intergrown with the calcite, and contains a garnet of reddish-brown colour with the appearance of andradite. A higher proportion of the matrix is occupied by limonite as ragged grains and patches than in the previous thin section.

The matrix of the agglomerate consists almost entirely of quartz, felspars and calcite. Angular inequigranular quartz and felspar grains, usually optically strained, lie in a matrix composed of anhedal calcite and groups of particles of comminuted quartz. Much of the felspar is twinned sodic plagioclase. Rounded calcite particles are also present, but most of the calcite is distributed at random through the matrix in small groups of ill-defined crystals. There is evidence of secondary silicification of the agglomerate in the presence of patches of micro-crystalline chalcedony. Apatite is common as small grains associated with the calcite.

The process of silicification and replacement of the calcite by chalcedony is illustrated in slice 69/333b. Mantles of chalcedony surround isolated calcite grains and considerable areas of the matrix have been converted to chalcedony, leaving only a few angular felspar and quartz grains. Limonite also is replaced showing that the silicification is a late hydrothermal alteration and that the limonite was originally associated with the primary carbonates. Idiomorphic apatite is common in the groundmass, and small rounded grains of zircon are present. Limonite forms up to 25 per cent of the rock.

The Nguluku agglomerate vent corresponds to those that occur in the Chilwa series of Nyasaland. The same minerals are developed but the Nguluku vent shows more silicification than is found in the Nyasaland occurrences.

It is very likely that Kiruku represents an agglomerate vent where the process of silicification has gone to an extreme stage and all the carbonate has been replaced.

The origin of explosion vents of this type is generally attributed to the explosive qualities of hot carbonatitic liquid at a temperature above the dissociation point. With relapse of confining pressure, perhaps caused by penetration to a level where the cover of sediments was thin, such a fluid would dissociate and explode, drilling a vent filled with sedimentary fragments. Carbonate fluid would follow and form the matrix of the resulting agglomerate. The carbonatitic fluid carried a considerable amount of iron and possibly already crystallized apatite. Rather coarser-grained fragments of limestone enclosed in the agglomerate appear to represent fragments of pre-existing solid carbonatite.

(5) *Manganese deposits of Mrima*

Since the discovery of manganese ores* on Mrima hill about 1919 sporadic prospecting has been done by various private organizations and officials of the Mines and Geological Department. No detailed geological survey of the hill has been attempted, nor in fact is such a survey likely to produce new information on account of the dense vegetation and poor exposures.

Numerous pits and trenches have been dug on the slopes of the hill, and have revealed boulders of mixed iron and manganese oxides embedded in ferruginous earth or decomposed sandstone. None of the pits have exposed unweathered rock *in situ*, but the extent of float fragments or ore and of the chocolate-brown soil, together with such evidence as is revealed in the pits, suggests that the greater part of the hill is composed of buff or yellow sandstone capped by an iron-manganese laterite.

An unpublished report by Norstrom of the Swedish Mines Syndicate refers to brecciated rocks at the summit of the hill. The writer also found boulders of sandstone agglomerate at the northern extremity of the hill. The occurrence of such rocks suggests that the summit may consist of an agglomerate-filled vent similar to that of Kiruku. If this is the case then Mrima is definitely part of the alkaline complex as a whole. This view is supported by the occurrence of a carbonatite vein on the northern slope of the hill.

The boulders and fragments of iron-manganese ore are chocolate-brown on weathered surfaces but when broken show metallic grey minerals with botryoidal form. The ore forms homogeneous masses reaching 3 or 4 cm. in size, penetrated by numerous vug-like cavities filled with red-brown limonitic earth and barytes. Analyses of composite samples of the laterite have given the following calculated modes, according to C. S. Hitchen:—

	I	II
	%	%
psilomelane	63·65	69·74
limonite	17·37	9·39
barytes	14·24	17·00
Al_2O_3, SiO_2, etc.	6·22	4·22

A recent, more complete, analysis of the acid soluble portion of material taken from "Hobley trench" on the south-west flank of Mrima, is given below:—

	%
MnO_2	30·51
Fe_2O_3	42·20
Al_2O_3	8·62
CaO	—
MgO	Trace
Zn	0·21
Pb	0·04
Cu	0·02
Ag	Trace
Insol.	3·36
Loss on ignition	12·18
Total	100·14

Anal. W. P. Horne, 16/10/51

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* *See "Manganese", p. 55.*

The insoluble residue probably represents barytes while the high loss on ignition is probably due to loss of CO_2 from iron and manganese carbonate. The significance of the small quantities of base metals in the laterite is difficult to decide. Small amounts of lead and zinc often accompany manganese lateritic ores of this kind, and may be derived from sediments containing traces of these elements. On the other hand the metals may have been derived from an underlying lode.

That the iron and manganese were derived from as yet unexposed carbonities is suggested by comparison with the Chilwa carbonatite vents (Dixey, Campbell Smith and Bisset, 1937, p. 20) and the Fen area of Norway (Brogger, 1921, pp. 271-275) where iron and manganese concentrations occur in such rocks. At Chilwa they are present as carbonates and for one part of the limestone body at Kangankunde hill, values of 17.31 per cent MnO_2 and 57.39 per cent Fe_2O_3 were recorded. The *rodberg* or iron-bearing carbonatite of the Fen area in Norway, in one case carries 31.9 per cent Fe_2O_3 and 5.40 per cent. MnO. Brogger (*op. cit.*) considers the iron to have been introduced at a late stage. Iron ores associated with alkaline intrusives are known from a number of places such as the Kaokofeld, South-west Africa; Lokupoi hill, Karamoja, Uganda; and Okorusu, South-west Africa.

(6) *Dykes* (*P.V.C.*)

Minor intrusives, in the form of dykes, are present in the southern part of the area and are found cutting the igneous rocks of Jombo Hill and the sedimentary Duruma Sandstones, within a radius of some ten to fifteen miles of the hill. They rarely exceed six feet in width and are often much less. The contacts are generally clean-cut and no alteration of the country rock has taken place.

The dykes occurring on Jombo Hill are porphyritic nephelinites that become microcrystalline, or almost vitrophyric towards their margins. A thin section of specimen 69/283b, taken from the centre of a dyke, shows that it is composed largely of phenocrysts of pale green or brownish-green diopsidic augite, and idiomorphs of nepheline which often contain pyroxene inclusions. The nephelines are partially altered to pale yellow zeolite. The pyroxene is of tabular habit, zoned, and frequently mantled by aegirine-augite. The phenocrysts are set in a groundmass of extremely fine grain that consists essentially of small acicular needles of aegirine-augite. Accessory minerals include sphene, apatite and magnetite. Other specimens of the dyke rocks from Jombo Hill were taken from, or very near to, their contacts with the country rocks with the result that they are microcrystalline, or even cryptocrystalline. One or two specimens, such as 69/305 and 69/310, contain idiomorphic crystals of nepheline, some of which poikilitically include minute acicular crystals of augite or aegirine-augite.

The dykes cutting the Duruma Sandstones are mostly of lamprophyric composition. Exposures, except in stream sections, are poor and it is seldom possible to trace any dyke over a distance of more than a few yards. Five small dykes are exposed in the Mwena River, immediately east of the Kinango-Tanga road, the largest of which is between three and four feet wide and is a monchiquite. In hand-specimen (69/324) it is a compact, dark-grey to black rock of very fine grain containing phenocrysts of olivine and pyroxene, and amygdales of calcite. In thin section the olivines are seen to be largely replaced by antigorite with occasional patches of calcite and chlorite; they are margined by irregular plates of biotite. Other crystals of biotite occur independently in the groundmass. The pyroxene is augite and occurs as almost colourless prismatic crystals. The groundmass is composed largely of secondary calcite with some patches of analcite, and the accessory minerals include apatite and iron ores. No felspar is present.

Cutting across this dyke are four smaller dykes, each less than twelve inches wide, that appear to be of similar constitution. The olivines have been completely replaced by antigorite, chlorite, and calcite, and the biotites are badly corroded. Pseudomorphs after pyroxene are composed of calcite, which also makes up the bulk of the groundmass. A thin section of specimen 69/141 shows the contact between one of these dykes and the country rock, a poorly sorted, quartzo-felspathic sandstone. The contact is sharp and there is no indication of any alteration of the sandstone having taken place. The manner in which many of the grains of the sandstone are sheared at the contact shows that the dyke was emplaced along a fracture plane.

Rolled boulders of another monchiquitic rock were obtained from a dam site near Mwangulu but the dyke from which they were derived was not found. The rock (69/93, 69/94 and 69/329) is of a similar texture and appearance to specimen 69/324 but brown hornblende is largely present in place of biotite. The hornblende phenocrysts are often zoned and the majority exhibit dark borders. The pyroxenes, which are pale green to colourless diopsidic augites, occur in two generations; the phenocrysts of the first generation are of large size and much corroded, whilst the crystals of the second generation are small and usually idiomorphic. Biotite is rare and felspar is apparently absent. Magnetite and apatite are the principal accessory minerals.

Five dykes, represented by specimens 69/330, 69/331 and 69/332 are exposed in the Ramisi River, north-east of Jombo Hill. Two of these (69/330 and 69/331) are in juxtaposition at one point, their plane of contact being marked by a glassy grey zone of from 10 to 15 mm. width. The zone appears to be an integral part of one of the dykes (69/331), which is also slightly intrusive into the other and is, therefore, the younger of the two. It is a dense, greyish-green microcrystalline rock containing a few phenocrysts of mafic minerals and felspars. In thin section the rock is seen to be a typical aegirine tinguaite. The aegirine occurs as phenocrysts and as minute, acicular crystals that make up the bulk of the groundmass. The felsic minerals are anorthoclase, microperthite, and nepheline, the foremost being predominant. The accessory minerals include apatite and flecks of iron ores, the latter tending to form clusters that are surrounded by dark green halos.

Specimen 69/331 is similar to specimen 69/329 but contains a lesser proportion of brown hornblende. In a thin section (69/331b) of the contact of the dyke with a thin lenticle of indurated sandstone that separates it from dyke 69/330, the dyke is seen to consist of a few small idiomorphic crystals of aegirine and pools of calcite set in a greenish-brown cryptocrystalline matrix that becomes increasingly dense towards the contact. The contact is irregular and small-scale infiltration of the sandstone by the igneous material has occurred.

Specimen 39/332 was taken from one of three similar parallel dykes, each roughly one foot in thickness. They are exposed in close proximity to the other Ramisi Valley dykes but the inter-relationship of the two sets is obscured. The dykes are biotite-monchiquites of similar constitution to 69/324.

Four hundred yards to the east of Gandini is another dyke (69/334) that is from four to six feet in width. In the hand-specimen it is light to medium grey with a somewhat saccharoidal appearance, and contains phenocrysts of felspar and ferromagnesian minerals. A thin section shows that it is highly altered and shot through with patches of calcite. The porphyritic felspar is andesine in prisms up to 5 mm. in length, and short prisms of orthoclase make up most of the groundmass. The ferromagnesian minerals are hornblende and pyroxene, both of which have undergone considerable alteration to chlorite and are often replaced by secondary calcite. Iron ores and apatite occur as accessory minerals. The rock appears to be allied to the vogesites.

Specimens 69/335 and 69/336 were obtained from two dykes that outcrop between Gandini and Mwangulu. The first, from a dyke about ten feet wide, is an olivine-free camptonite. It contains large prisms of andesine with smaller laths of the same mineral in the groundmass. The larger crystals are often grouped together. Small subhedral phenocrysts of titanium-rich augite that are often chloritized around their margins, and columns of brown hornblende that frequently exhibit dark borders, comprise the ferromagnesian minerals. Secondary calcite and chlorite are present and the accessory minerals include apatite and magnetite. The second dyke is narrower and appears to be a vogesite of similar composition to 69/334, though alteration has proceeded to a much greater degree.

Another monchiquite dyke (69/18) is exposed at the more southern of the two Ramisi hot springs. Like those described above, it contains two generations of ferromagnesian minerals, those of the first generation attaining comparatively large dimensions (up to 4 mm.). The pyroxenes are augites, usually titaniferous, whose margins are corroded and altered to chlorite. Zonal and hour-glass structures are common. The amphiboles are brown hornblendes which are often replaced by secondary calcite.

3. PETROGENESIS AND CONCLUSIONS (B.H.B.)

The igneous rocks of Jombo are emplaced in the Middle Duruma Sandstones of late Triassic age, but do not pentrate the Magarini sands. Dykes situated in the Galana valley, which are probably associated with the complex, are reported by McKinnon Wood (1930, p. 3) as cutting Jurassic shales. It would appear therefore, that intrusion occurred during the late Jurassic—mid-Pliocene interval. It has been suggested (Gregory, 1921, p. 192) that the Jombo intrusion can be correlated with similar complexes that are known in Madagascar and India and other parts of Africa that are of late Cretaceous age. The alkaline intrusions of central East Africa, such as Homa Mountain (Saggerson, 1951 and Pulfrey, 1946, p. 426), Mount Kenya and Kilimanjaro, appear to be of Tertiary age and possibly younger than Jombo.

The mechanism of intrusion of the main mass of alkaline rocks at Jombo is difficult to decipher on account of the complete absence of exposures of the the wall rocks. Backlund (1932, pp. 14-18) favours a quiet mode of intrusion for alkaline bodies in general suggesting that when volcanic eruption does occur it is nearly always accompanied by strong shattering of the roof of the magma chamber and the injection of dykes in large numbers in concentric and radial swarms.

The elliptical plan and ring structure of the intrusion correspond closely with those of other similar rock bodies and such features have been interpreted (Backlund, *op. cit.*) as being due to a vertical "funnel" form of intrusion where convection currents keep the magma active and hot. But such a concept does not fit the genetic picture drawn below.

The walls of the intrusion probably consist of relatively unaltered sandstones since indurated or metasomatically altered rocks would be expected to give rise to some feature on the ground. Moreover all the sandstone fragments seen near the margin of the intrusions are completely unaltered.

Within the intrusion itself the sequence of rock types has been established as follows:—

foyaite .... melteigite .... nepheline syenite.

The foyaites, which exhibit no extraordinary chemical or textural features, were emplaced about an axis passing through the present summit of the hill. The basic rocks were emplaced along different axis, situated about 500 yards south of the first. During the intrusion of the nepheline-syenite the intrusion centre reverted to that of the foyaite.

Perhaps the only unusual phenomenon of the Jombo intrusive is the character and veining of the melteigites. At a late stage in the crystallization of these rocks the residual magma is considered to have become enriched in silicon, aluminium, potassium and, to a lesser extent, sodium ions. Most of these elements must have been introduced from a hypothetical syenite body not at present exposed. Such portions of the rock as were solid were brecciated and intimately veined by leucrocratic material of syenitic composition. In some localities felspathization appears to have taken place and was accompanied by a partial breakdown of the native pyroxene into micas and sodic amphiboles. This process has given rise to small bodies of rock of an unusual composition that can be termed pyroxene-rich or orthoclase-biotite malignites (69/297).

Basic lamprophyre dykes cut all the members of the plutonic rock series and are also found in the neighbouring country rocks. The injection of these dykes brought to a close the intrusive activity at Jombo hill.

The progressive solidification and cooling of the main magma column may well have led to violent disassociation of gases from magmas in the intrusion chamber. Since carbonate material comprises a considerable part of at least one of the explosion vents resulting from this gas formation, it is reasonable to assume that the diatremes resulted from the dissociation of carbonates in depth. It is probable that all the diatremes contained calcium carbonate as a matrix for the agglomerate fragments but the carbonate has been replaced to a variable extent by hydrothermal silica. This late-stage silicification appears to be a characteristic of explosion vents of this type and has been described by Dixey (Dixey, Campbell Smith and Bisset, 1937, p. 20) in the Chilwa vents of Nyasaland. The hydrothermal silica was also accompanied by oxides of iron and manganese as in the case of Kiruku, Nguluku and Mrima. At Mrima the concentration of oxides has been brought about by lateritization of the surface sandstones. The origin of the iron and manganese is considered to be a hypothetical underlying carbonate rock rich in siderite and rhodochrosite.

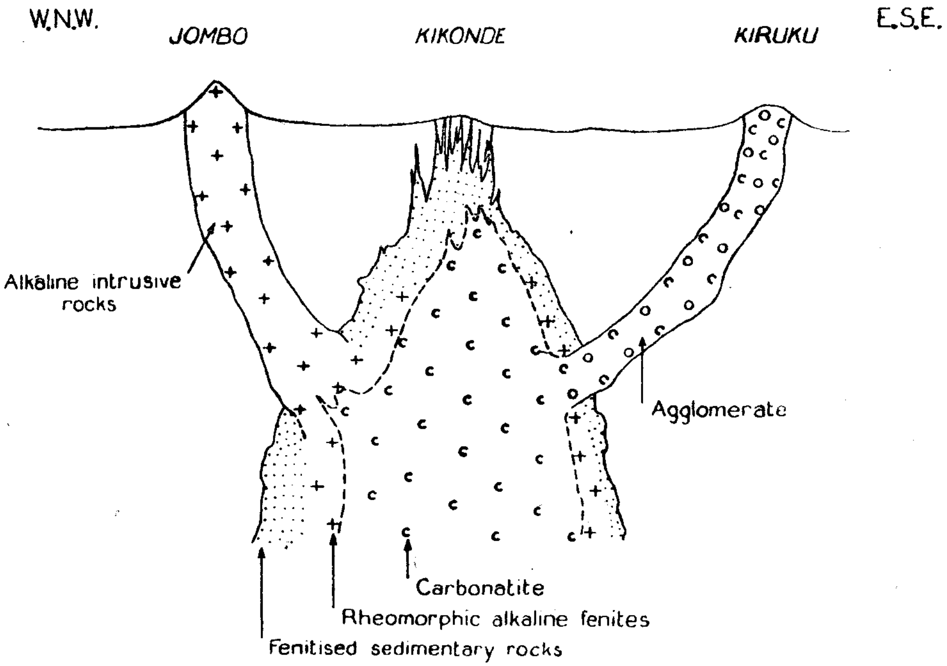

Fig. 6.—Hypothetical section through the Jombo igneous complex.

It is considered that the small-scale fenitization exhibited on the Kikonde ridge is the surface manifestation of a much larger fenite complex below. This would be of the type figured by von Eckermann (1948, p. 148) consisting of a central carbonate core at an elevated temperature, surrounded by fenites corresponding in composition and texture to the various alkaline igneous rocks. The fenites, which may under extreme conditions become fluid, would be arranged in shell-like concentric zones grading outwards into unaltered sandstone. It is therefore suggested that the upper extremity of the sub-surface fenite is represented at Kikonde. Taking the vertical axis of this fenite complex to be situated a little to the north of Kikonde hill itself, it is seen that the main intrusion at Jombo and the explosion vents at Nguluku and Kiruku are situated approximately on a circle of a radius of four and a half miles. The circular arrangement of these centres may be due to their being situated on a cone fracture with its apex in the presumed central carbonate body probably several thousand feet below Kikonde. The pipe or stock at Jombo may well have been initiated by explosion which may have built an ash cone on the surface, but the pipe was subsequently infilled by rheomorphic magmas derived from the central fenite complex. The vents at Nguluku and Kiruku on the other hand, were not injected by magma, possibly due to their small size, but remained as agglomerate pipes. The hypothesis outlined above is diagrammatically illustrated in Fig. 6.

VI—STRUCTURE

The structure of the area (Fig. 14) is generally simple and references to some of its aspects have already been given in previous chapters. The Palaeozoic and Mesozoic rocks have a regional dip of from five to ten degrees in an east-south-easterly direction. This is subject, in the Lower and Middle Duruma Sandstone Series, to local modifications that have produced a gentle rolling of the beds along more or less east-west trends. The degree of rolling is small and does not produce a "marked dome and basin structure" as stated by Parsons (1928, p. 70). In fact it is probably not a tectonic feature but rather a superficial phenomenon caused by the sagging of more resistant beds following the partial weathering out of the softer underlying strata along the valley sides. It is often to be noticed that the surface dips conform, to a modified degree, to the topography. Alternatively, the rolling might be a reflection of the sub-Duruma Sandstone floor although the principal trends of the Basement System immediately to the west of the area would not appear to support this view. A slight increase in the angle of dips is to be observed near the junction of the Mariakani Sandstones and reversed dips have been noted in the Ramisi River to the north of Jombo Hill, along the eastern flanks of the Shimba Hills, and in the topmost horizons of the Jurassic and Cretaceous rocks. In each case the reversed dips appear to be accompanied by minor faulting immediately to the east, and it is possible that the relief of stress caused a slight marginal tilting of the strata on the upthrow side. In the Shimba Hills, this has produced a broad syncline with a N.N.E.-S.S.W. trend (p. 14). The hills have the typical appearance of a horst, as was stated by Busk (1939, p. 222), but faulting seems to be confined to the eastern and northern sides only. The Cainozoic rocks are all more or less flat-lying and undisturbed by faulting.

The faulting is all of a normal type and follows two dominant trends:—

(*a*) N.N.E.-S.S.W.
(*b*) W.N.W.-E.S.E.

The first trend is most clearly exemplified by the faulted relationship of the marine Jurassic rocks and the Mazeras Sandstone. It is paralleled by the boundary fault of the Duruma Sandstone against the Basement System that lies beyond the western limit of the present area (*see* Miller, 1952), and also by the Ruvu-Mombasa fault of Bailey Willis (1936, Plate III). The postulated Freretown and Mkanda faults are also referred to this trend. The faults of the second trend occurred at a later date and their effects are seen in the stepping of outcrops; the Rabai fault is also stepped.

The age of the faulting is not known with any certainty. The Freretown Limestone is apparently affected but not the Magarini Sands, so that it would seem that the faulting took place between Middle Cretaceous and Middle Pliocene times. Stockley (1928, p. 52) has shown that faulting occurred in Zanzibar during late Miocene times and it is reasonable to assume that the same was true in coastal Kenya. It is of interest to note that the faulting of the Gregory Rift Valley is presumed to have reached its maximum intensity at about the same period, and, in the same way as the earth movements that led to its formation are believed to have been initiated in Mesozoic times, it is considered that the coastal faulting may also have originated during the same era. This would be compatible with the theoretical break-up of Gondwanaland.

The results of the present survey are in general agreement with the views expounded by Gregory in 1921 but the scale of faulting is regarded as being larger than he admitted. The main point of difference concerns the relationship of the Jurassic rocks to the Duruma Sandstones; this was discussed on page 19. In referring to the thickness of the Jurassic beds, Gregory (1921, p. 72) mentions a series of N.E.-S.W. faults that throw the beds down to the S.E. and so repeat them. No evidence to indicate such faults was seen but if they do exist their effect will be the opposite to that stated by Gregory.

The antithesis of Gregory's hypothesis was put forward by Parsons in 1928. He regarded the coastal belt as having been subjected to compressional forces acting from the north and east that caused overthrusting and the development of shear-planes. The earth movements are claimed to have begun in late Triassic or early Jurassic times and to have continued intermittently until the close of the Tertiary Period. The writer could find no evidence of thrusting in the coastal succession, and in company with Gregory, Maufe, and Wayland is unable to accept such a hypothesis. Not least among its difficulties is the cause of the thrusting, that from the east in particular. Parsons unfortunately devoted little attention to the mechanics of the thrusting, but in a reference to his paper Du Toit (1937, p. 123) suggested that it may have been caused by a slight anti-clockwise twist of Madagascar whilst it was still attached to Africa. Yet if, as Du Toit claims, Madagascar and Africa were separated during Cretaceous times, the subsequent Tertiary thrusting is left unexplained.

Writing of the Ruvu-Mombasa fault, Bailey Willis (1936, p. 32) states that it is a normal fault, with a downthrow to the east-south-east, that runs north-north-eastwards for more than 1,200 miles defining the continental edge throughout most of its length. It crosses the coastline at its southern end between Tanga and Dar-es-Salaam where it is paralleled to the west by a series of three step-faults—the Fall line, the Morogoro line, and the Kilosa line. These faults are spaced at intervals of from fifteen to thirty miles and are considered to be normal upthrusts with a total vertical displacement of about 3,500 ft. It is possible that the Fall and Morogoro lines represent the southward extensions of the Rabai and Duruma Sandstone boundary faults but, as was stated on page 49, the Kenya representatives are regarded as normal gravity faults rather than upthrusts.

VII—GEOLOGICAL HISTORY

In this chapter an attempt is made to reconstruct the geological history of the area. The evidence is often slender, particularly that concerning pre-Tertiary events so that the reconstruction is largely conjectural. Moreover, there are two schools of thought concerning pre-Tertiary geographies as a whole and one must inevitably subscribe to one or the other. The first postulates that the continents were originally grouped together into two unified land masses, Laurasia in the northern hemisphere and Gondwanaland in the southern. Gondwanaland included South America, Africa, peninsular India, Australia and Antarctica. The segments of Gondwanaland are supposed to have remained in close proximity to each other until late Mesozoic times when the land masses split up into the various continents, more or less as they are at present, and then began to drift apart. This theory of continental drift is championed by Du Toit (1937) who amasses abundant evidence—tectonic, stratigraphic, palaeontological and climatic—in its support. The other school postulates that the continents have always maintained their present spacial relationships and that any tectonic and stratigraphic similarities are largely coincidental. To account for faunal and floral migrations they envisage "land bridges" that arose from the ocean floors at the required times. Of these two hypotheses, the evidence from the present area favours the first.

Towards the end of the Palaeozoic era it seems that a gentle down-warping was initiated along what is now the margin of the East African continent. It may be hinted that this down-warping was indirectly due to the weight of the ice sheet that had covered the greater part of southern Gondwanaland during Carboniferous times. The effect of the warping was to form a broad trough that trended roughly N.N.E.-S.S.W., into which the drainage systems found their way. Sediments carried by the rivers, and to a lesser extent by winds, were deposited in the trough to form the Duruma Sandstone Series. The succession in East Africa represents only the sediments that were deposited on the western margin of the trough; those deposited on the eastern margin are to be seen in Madagascar which, if one is to accept Du Toit's view, was adjacent to East Africa at that time.

It appears that, in its early stages, the downwarping was fairly rapid for the oldest sediments exposed, the Taru Grits, are of coarse grain and poorly sorted. Moreover, the freshness of the felspars and the general sub-angular nature of the individual grains show that the grits were deposited at no great distance from their provenance. The inter-bedded shales have yielded the fresh-water bivalve, *Palæanodonta fischeri* Amal. (Gregory, 1921, p. 53) from which it is concluded that the depositional environment was lacustrine rather than marine.

The rate of sedimentation became slower towards the top of the Taru Grits and quieter conditions persisted throughout Middle Duruma times resulting in the accumulation of a thick series of shales and fine-grained silty sandstones. These beds are typically ripple-marked showing that deposition took place under shallow water. The lowest division of the Maji-ya-Chumvi Beds yields plant remains and carbonaceous material whilst the beds themselves are often rain-pitted and sun-cracked; they also contain a high proportion of precipitated salts (*see* p. 62). These last features are characteristic of an arid climate and the postulated lake must sometimes have partly dried up to expose the freshly deposited sediments as mud flats upon which plants began to grow. It is likely that, of the entire coastal sedimentary series, the Maji-ya-Chumvi beds accumulated in an environment most closely approaching that necessary for the formation of coal seams.

In middle Maji-ya-Chumvi times there occurred a marine invasion that led to the introduction of fish into the lake, and some 70 ft. of fish-bearing sediments were deposited. Thereafter the sea appears to have receded for the Upper Maji-ya-Chumvi Beds contain *Estheria,* a fresh or brackish water genus.

Towards the end of Middle Duruma times there seems to have been a more active phase of erosion, for the Mariakani Sandstones exhibit a rhythmic succession of finer- and coarser-grained beds. The lower Mazeras Sandstones demonstrate a continuation of the same phenomenon on a more pronounced scale. The coarser grain of these sandstones led to their being accumulated more rapidly than the Middle Duruma Beds and they soon outpaced the rate of subsidence. Deltas were built up on which the *Dadoxylon* forests grew. The next stage, when the lake was unable to accommodate all the material that was being brought into the trough, saw the formation of alluvial fans and small coastal dunes. From this point onwards the Mazeras Sandstone was largely of terrestrial origin. Infrequent subaqueous horizons mark periods when the lake waters extended westwards once more; one such horizon can be seen in the waterfall in the Kitanzi River, another is exposed in the road-section about half a mile to the east of Kwale.

The general increase in grain size of the upper Duruma Sandstones from bottom to top indicates that the cycle of erosion was speeded up during these times. Several reasons may be suggested to account for this. The first involves a purely climatic change, possibly to conditions of greater aridity with increased wind erosion. Other reasons are more complex and involve flexures of the trough margin. By Upper Duruma times at least some 6,000 to 7,000 ft. of sediments had been accumulated and the weight of this material must have increased the rate of the downwarping. This would be counterbalanced by the isostatic rise of the continent due to the sub-crustal transfer of simatic material. As the trough sank, so would the continent rise, although not through quite the same extent. The overall relief, however, was probably more or less maintained. Recent work by Vening Meinesz, Umbgrove and others on continental margins has shown that, whereas the down-sinking of the margin may be a fairly steady process, the isostatic rise of the continent is periodic. It is possible, therefore, that such a rise occurred during Upper Duruma times and that the consequent accentuation of relief led to the increased erosion and deposition. A similar accentuation of relief might have been brought about by a partial collapse of the trough. On Du Toit's hypothesis, Gondwanaland began to break up during late Jurassic or early Cretaceous times. Obviously this process could not have taken place suddenly and one might assume that structural weaknesses began to develop in lower Jurassic times, or even earlier. Such weaknesses, aided by the incumbent weight of the great thickness of the overlying sediments, might conceivably have caused a partial collapse of the trough. In the light of the marine invasion that followed, this explanation is perhaps the most tenable. It leads one, however, to considerations as to how far up the stratigraphic table the Duruma Sandstones extend. The evidence from the present area is inconclusive but from that of Madagascar it would seem probable that they include representatives of the Lower Jurassic. The hiatus, then, between the deposition of the Duruma Sandstones and the succeeding marine Jurassic rocks was probably not great.

In Bajocian times the sea invaded the trough and a series of limestones, shales and sandstones was deposited. These rest with slight unconformity upon the Mazeras Sandstone, a point significant in itself, for in the normal course of events they would have been expected to rest on the Shimba Grit. The evidence obtained from the Kambe Limestone points to their having been deposited in a warm shallow sea in which the water was kept in fairly active circulation, such conditions being necessary for the formation of reef and oolitic limestones. During Bathonian times the deposits were gradually being built up to sea level, for the succeeding beds, the Kibiongoni Beds, show traces of aqueous ripple-markings and rain-pittings, the latter demonstrating that, at some stage, they emerged above sea-level. As was suggested in the stratigraphic section (page 22), the Kibiongoni Beds are considered to be of lenticular development and to represent estuarine deposits. Overlying them is a thick series of calcareous shales and mudstones that has yielded numerous fossils. Among them, in the lower part of the series, is the Bajocian-Callovian pelecypod *Posidonia ornati.* This genus is characteristic of muddy, deep-water deposits so that it would appear that the water rapidly deepened after the deposition of the Kibiongoni Beds, perhaps due to a further collapse of the trough. This state of affairs did not persist, however, for by Argovian times there was a further occurrence of shallow-water oolitic limestones as is seen in the Public Works Department quarry at Mwamtsola. Sedimentation continued, apparently without a break, until Middle Kimmeridgian times and probably into the Lower Cretaceous, although no beds of from Upper Kimmeridgian to Purbeckian ages are exposed. Neocomian rocks outcrop near Freretown but the exposures are insufficient to decide whether these rocks represent a marine transgression that over-lapped the Jurassic rocks, or whether the succession is complete but that subsequent faulting dropped the Cretaceous rocks down against the Jurassics. The dips of the two formations suggest that their contact is faulted and it is possible that the succession is complete, as it is in both Madagascar and Cutch.

The extent to which the Jurassic rocks over-lapped the Duruma Sandstone Series is unknown. Fraas's report of a belemnite and an indistinct impression of a Lower Jurassic ammonite from grits near Samburu (*see* page 2) would indicate that the Jurassic rocks extended over the greater part of the sandstones, but the report was emphatically refuted by Maufe. It certainly seems improbable, for the lithology of the Lower Jurassic rocks is characteristic of a near-shore, neritic environment. Moreover their petrology shows them to be composed largely of material derived from the Duruma Sandstones which must, therefore, have been undergoing erosion at that time. Fragments of silicified wood are sometimes found in the lower shale horizons, and if the conclusion that these sediments were deposited in deep water is correct, the fragments could not represent trees that grew near to the place where the shales were deposited, but were probably derived from the Mazeras Sandstone. It appears from these considerations that the marine Jurassic rocks did not over-step the Middle Duruma Sandstones, and the assumption that a partial collapse of the trough took place in Mazeras times is strengthened. One might go further and suggest that the rift faulting was initiated at this stage. An interesting point in this connexion is made by Jessen (*see* Umbgrove 1947, p. 111) who states that the thickening of the continental margin may be classified according to three types:—(1) warping accompanied by faults, (2) updoming accompanied by faults and slight folding, (3) folding and overthrusting, accompanied by underthrusting of the ocean floor, giving rise to a deep-sea trough.

During early Tertiary times, the coastlands underwent extensive erosion that continued until the end of the Miocene period when there was a phase of rift faulting, the effects of which are present throughout much of East Africa. The major faulting of the area, together with the up-tilting of the Upper Duruma Sandstone margin that produced the Shimba Hills syncline, is provisionally referred to this phase (*see* p. 49). As a result of the rifting, the base-level of erosion was lowered and the river systems began to cut into the Miocene erosion surface. The relatively soft Middle Duruma Sandstones were easily removed but the Upper Duruma Sandstones, with their capping of Shimba Grit, proved more resistant and it is possible that the Shimba Hills represent a remnant of the Miocene surface.

The next known event was the deposition of the Magarini Sands during the late Pliocene Period. The sands rest upon an eroded surface of Jurassic rocks and are apparently confined to the seaward side of the Shimba Hills. It is suggested that their deposition was preceded by renewed movement along the Rabai fault accompanied, perhaps, by a retreat of the sea. The effect would be to increase the topographic gradient on the seaward side of the Shimba Hills and so produce the conditions necessary for the deposition of the Magarini Sands. Moreover, it is then possible to correlate the Pliocene erosion surface of the coastal strip with the erosion surface of the Nvika and so explain the anomalous termination of the latter at Mazeras. An examination of these two surfaces shows that they can be fitted together with little difficulty and their displacement indicates that the throw of the Pliocene fault was of the order of 300 ft. Furthermore, the profile of the surface shows that it had reached a state approaching maturity and that it was graded to a base-level of erosion that stood at approximately 400 ft. O.D. The evidence afforded by the Mwachi River is of interest in this connexion. The thalweg shows a knick-point at about the 600-ft. level some 14 miles to the west of the fault and, assuming that the river had reached a more or less mature state with a gradient of from seven to ten feet per mile, it would originally have crossed the fault at about the 450-500 ft. contour, a height that corresponds closely with that of the erosion surface (about 520 ft.) at this locality (*see* Fig. 15). This would indicate that the base-level of erosion was practically reached and suggests that the Mwachi River was formerly graded to about 400 ft. O.D. That the river had reached a state of old age is suggested by the sinuosity of its course immediately to the west of the fault.

Nothing is known of the early Pleistocene history of the area but it might be assumed that the 300 ft. knick-point in the Mwachi was caused by the drop in sea-level during the first pluvial period. The remaining three knick-points that occur at the 250 ft., 200 ft., and 120 ft. levels are possibly to be correlated with the drops in sea-level following the three interpluvial periods. By producing the thalwegs beyond the knick-points (*see* Fig. 15) the approximate levels of the sea can be deduced, and it is of interest to note the similarities between the figures obtained and the better known levels of Europe (*see* Table VII). During the Kamasian Pluvial, the sea-level would appear to have fallen to approximately −200 ft. O.D. and a marine platform was cut that formed the base upon which the coral-reef subsequently grew. It is assumed that the coral-reef grew during the second interpluvial period, firstly because this was the longest of the three interpluvial periods and secondly because the apparent maximum height of the reef is most closely matched by the 2nd interglacial sea-level of Europe. In the succeeding Kanjeran Pluvial, the sea-level dropped considerably, possibly to as much as −150 ft. O.D., and the river systems were rejuvenated. Borings in the Mwachi estuary have shown that the river bed lies at about −70 ft. at the head of Port Reitz, −130 ft. opposite to the Makupa Causeway, and −150 ft. at Kilindini (*see* Sikes, 1930, p. 4). The Kombeni River which flows into Port Tudor, will doubtless show similar figures. In excavating their channels, these two rivers cut deeply into the freshly formed coral-reef and so determined the north and south shorelines of what was later to become Mombasa Island. During the third interpluvial period the sea-level rose again to a probable maximum of between 30 and 40 ft. O.D. and drowned the river estuaries. In advancing, the sea cut a platform on the seaward margin of the reef, a remnant of which forms the site of the Mombasa Golf Links. At the same time marine erosion in Port Reitz and Port Tudor was removing the soft, unconsolidated Kilindini Sands until the land strip at Makupa was finally breached and the island of Mombasa was formed. In the south of the area, the irregular coastline with its groups, or chains, of coral islands is also to be attributed to this transgression.

The onset of the Gamblian Pluvial caused a further retreat of the sea with a possible pause at about the 15 ft. level, for caves and beaches are occasionally to be seen at this height (Sikes 1930, p. 7),

TABLE VII—PLEISTOCENE CHRONOLOGY AND CORRELATION

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

E.Gl.=early glacial period; Ap.IGl.=antepenultimate interglacial period; Ap.Gl.=antepenultimate glacial period; P.IGl.=penultimate interglacial period; P.Gl.=penultimate glacial period; L.IGl.=Last interglacial period; L.Gl.=last glacial period; P.Gl.=post-glacial period.

The final phase has been a rise of the sea to its present level with a silting-up of the heads of Port Reitz and Port Tudor. Thus the present picture, as is typified by the Mwachi River, exhibits the paradoxical combination of knick-points and drowned valleys corresponding with coastlines of emergence and submergence respectively.

VIII—ECONOMIC GEOLOGY

Manganese.—For many years it has been known that manganese deposits occur on Mrima Hill, in the southern part of the area, and from time to time they have been investigated. A description of the hill and its geology is given in Chapter V of this report. It was probably through the work of C. W. Hobley that the deposit was first known and his sampling trenches are still open for inspection, although now partly overgrown.

In 1934, applications were made by the East African Portland Cement Company and the East African Rock Product Company for Exclusive Prospecting Licences covering an area of roughly eight square miles centred on Mrima Hill. Both applications were refused pending a report by the Government Geologist and Mining Engineer, and the area was closed by the Governor by Government Notice No. 398 of the 1st June, 1934. Subsequently Government Notice No. 522 of the 25th July, 1934 invited applications for Exclusive Prospecting Licences over the area after sampling. Four applications were received; from the Anglo-Continental Mining Company, the E. A. Portland Cement Company, the S.M. Syndicate, Ltd., and the East African Rock Product Company. Sampling was carried out, and programmes of work submitted by all except the first-named company, but no further developments took place.

The manganese occurs on the slopes and along the top of the hill, generally as loose boulders or nodules. It is a residual deposit that appears as a surface veneer and which, for the most part, cannot be expected to exceed a few feet in thickness. On the lower slopes the deposit is thicker and some of the old sampling pits in which bedrock is not exposed show sections of up to twelve feet in thickness.

The ore is inconsistent being composed of the oxides of manganese and iron in widely varying proportions. It occurs as reniform or botryoidal aggregates that, as seen in polished sections, consist largely of alternating bands of psilomelane $(Ba,Mn)_2Mn_8O_{16}(OH)_4$ and pyrolusite (MnO_2) with possibly some hausmannite (Mn_3O_4). Hematite (Fe_2O_3) occurs in small quantities that were apparently co-precipitated at a late stage with the manganese. Larger quantities of limonite ($Fe_2O_3.H_2O$) are present as earths that occupy the vugs, which also contain crystals of barytes ($BaSO_4$). From these observations it is evident that the limonite and barytes were formed at a later stage than the hematite and the manganese oxides. Fig. 7 shows, in diagrammatic form, the apparent order of formation.

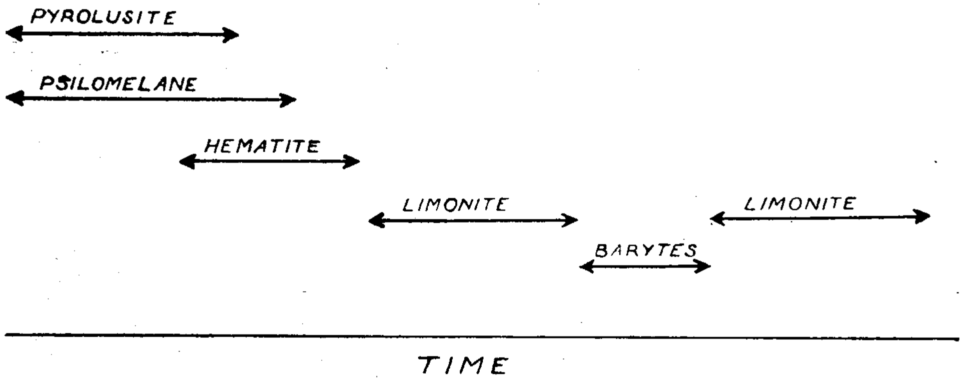

Fig. 7.—Paragenesis of the Mrima manganese ores

In the following table, columns I, II and III give the analyses of individual samples, and column IV the analysis of a composite sample:—

	I	II	III	IV
	%	%	%	%
SiO_2..	0·45	0·41	—	0·64
Al_2O_3	5·17	3·01	8·62	21·82
Fe_2O_3	15·17	8·20	45·20	27·26
MnO_2	58·20	60·80	30·51	31·20
MnO	4·80	6·60	—	4·38
$BaSO_4$	14·24	17·0 0	3·36	—
BaO	—	—	—	8·10
MgO	—	—	Trace	—
CaO	—	—	—	0·82
H_2O+	2·87	3·53	—	2·78
H_2O-	0·60	0·80	—	
Loss on ignition	—	—	12·19 (+CO_2)	—
Zn	—	—	0·21	—
Pb	—	—	0·04	—
Cu	—	—	0·02	—
Ag	—	—	Trace	—
	101·50	100·35	100·14	97·02

Analysts—I, II and IV, Miss A. F. R. Hitchins; III, W. P. Horne

CALCULATED NORMS				
Psilomelane	13·19	18·14	—	11·52
Pyrolusite	52·25	52·60	30·51	25·77
Limonite	10·63	9·09	50·18	8·91
Hematite	5·57	—	—	19·22
Barytes	14·24	17·00	3·36	12·34
SiO_2, etc.	5·62	3·52	16·09	22·28
	101·50	100·36	100·14	100·34

In calculating the norms it was assumed that the total manganese content was derived from psilomelane and pyrolusite, and that the psilomelane is barium-free. No allowance was made for the possible derivation of manganese from hausmannite or manganese carbonates.

In analysis III the MnO content was converted by the analyst to MnO_2 so that no psilomelane content could be calculated in the norm. Moreover, the figure 12.19 was given as being "loss on ignition", this including the CO_2 content, so that the hematite content also could not be reliably calculated.

In addition to these four complete analyses, 58 other samples have been assayed for their manganese (Mn) content alone. Twelve yielded less than 10 per cent Mn but, if these be disregarded, the average manganese content for all samples assayed is 21.78 per cent. Material of such a tenor is too poor to be of economic value—the normal minimum requirements are 40 per cent Mn for low-grade ores and 50 per cent Mn for high-grade ores—but doubtless it could be improved by hand-sorting of the ore boulders and rudimentary separation. For instance, the greater part of the limonite earth might be removed by crushing the ore to a gravel and washing through screens. The removal of the hematite, on the other hand, will probably prove costly. It is not in chemical combination with the manganese, but the two are so intimately associated that separation is likely to be achieved only by flotation. Taking these factors into account, it is considered that the manganese deposits are probably of little present value as an economic proposition except, perhaps, in time of national emergency. Preliminary estimates indicate that the reserves of ore amount to over 600,000 tons.

As to the genesis of the manganese deposits, little can be stated unreservedly. The majority of manganese deposits, and certainly the most important of them, are of residual or sedimentary origin formed by the concentration of decomposed primary manganese minerals, usually silicates. A sedimentary origin might be postulated in the present instance, for manganese staining is a common feature throughout the Duruma Sandstone Series. The frequent association of manganese deposits with alkaline igneous intrusions (*see* Chapter V), however, cannot be overlooked, and since there is reason to suppose that Mrima Hill represents an explosion vent connected with the Jombo complex, it is equally conceivable that the deposit is of residual origin having been derived from the weathering of underlying manganese-bearing carbonates. This mode of origin is favoured by the writer although, of course, until such time as the sub-surface geology of the hill is known, it must remain purely hypothetical.

The interesting feature of Mrima Hill, however, lies not in the manganese laterite but in the possible significance of the other metals present. Of these, barium is the most abundant but, as indicated in analysis III, lead, zinc, copper and silver are also known. Furthermore, of the six analyses submitted by Major Lathbury on behalf of the East African Portland Cement Co. in 1934, four showed silver with an average of four pennyweights per long ton and three showed gold with an average of 0.5 pennyweights per short ton.

These occurrences lead to speculations concerning the possibility of lodes beneath the iron-manganese capping although such speculations must necessarily pre-suppose the origin of the metals. This is not known but the frequent association of the metals in question in other parts of the world is highly suggestive. Systems of lead-zinc-barytes mineralization are a common occurrence and are often associated with chalcopyrite, gold and silver. It is therefore reasonable to suppose that these minerals were co-precipitated in this instance. That the mineralization took place subsequent to the formation of the hematite and the manganese oxides is shown by the relationship of the barytes, so that it appears that there may have been two periods of mineralization. Should a mineralized zone exist beneath Mrima Hill it is anticipated that it will follow the trend of the lead veins discussed in a subsequent paragraph.

It is considered that the sub-surface geology of Mrima Hill is worthy of investigation, preferably by boreholes. If these prove a lode, or lodes, of economic value, the superficial cover of manganese laterite could doutless be profitably exploited at the same time.

Factors concerning the site are as follows:—A road passes around the southern foot of Mrima Hill and connects with the main Mombasa-Shimoni road at Kisiwi, the distance from Mrima to Mombasa being approximately fifty miles. Between Mrima and Kisiwi the road route is poor, and beyond Kisiwi it is handicapped by the necessity of having to cross Likoni Ferry. Southwards from Kisiwi, the main road runs to Shimoni, a small fishing township. The sea, at this locality, is shallow and abounds in mangrove swamps and coral-reefs but it might prove navigable to flat-bottomed barges of shallow draught. Little is known of the water-supply of the area; whilst it is probable that an adequate supply for industrial purposes could be obtained, the water may prove too saline for domestic uses. Most of the rivers are seasonal and many are salty. The recruitment of labour should present little difficulty.

Radioactive Minerals.—During the examination of Mrima and Kiruku a restricted geiger counter survey was carried out, when counts of two to three times background were obtained. The source of the radiation could not be determined at the time, but further and much more extensive work is now being carried out. The area of radiation has been proved to be extensive around Mrima.

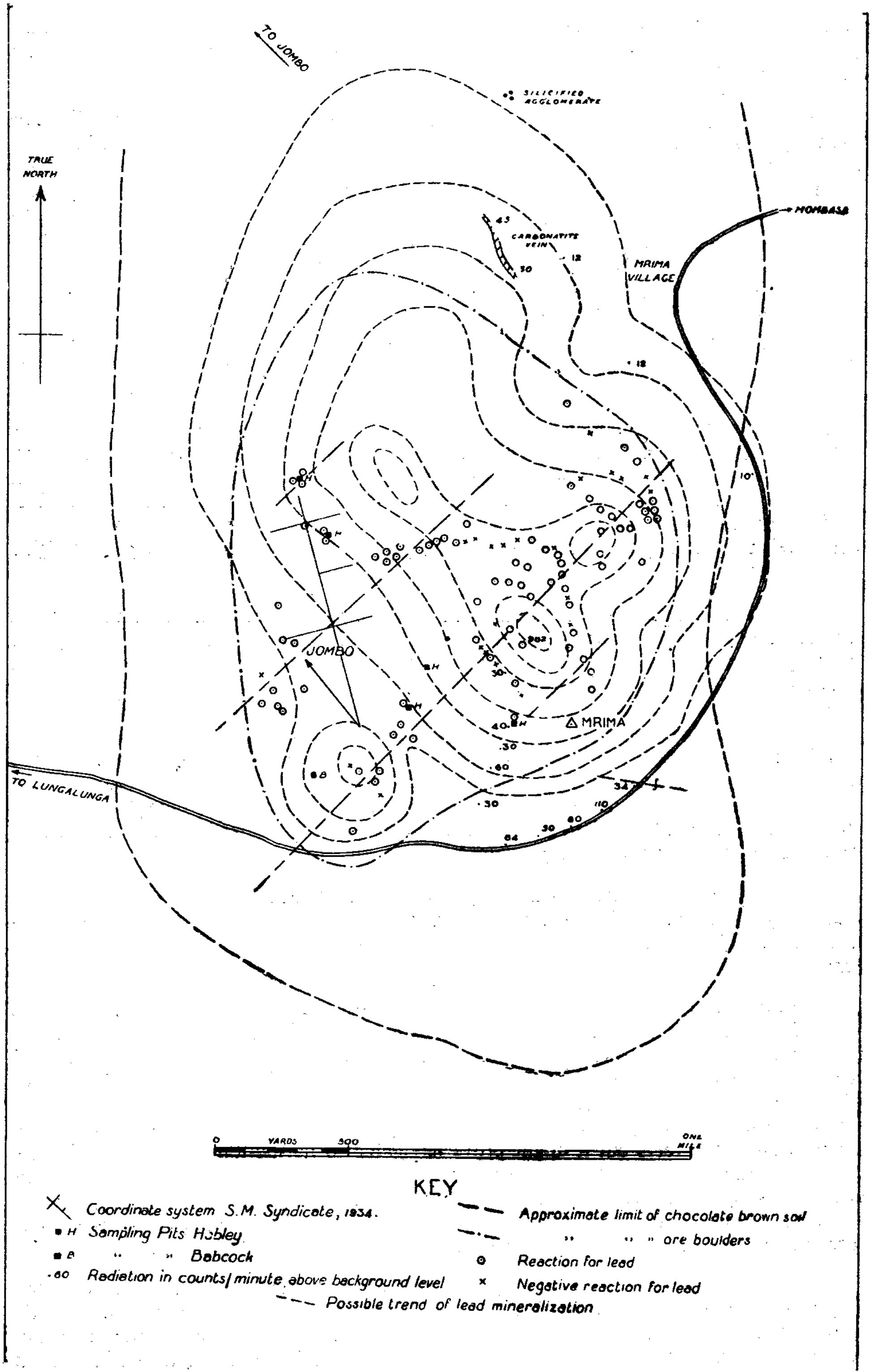

Fig. 8.—Plan of Mrima Hill showing the extent of the manganese deposit and the possible trends of sub-surface mineralization.

Gold.—The occurrence of gold in this area is of historical interest. Professor Gregory noticed a small metallic particle on a specimen of nepheline syenite sent to him in 1893 by Mr. C. W. Hobley from Jombo Hill and had it assayed. It proved to be gold and was the first occurrence of this metal to be recorded from Kenya (*see* McKinnon Wood, 1930, p. 1).

Reference has already been made to the occurrence of gold in Mrima Hill (*see* under manganese).

Both of these occurrences must be regarded as exceptional and not as an incentive to future prospecting.

Lead.—A specimen of Mazeras Sandstone containing small veins of galena, about one centimetre in width, is housed in the Mines and Geological Department. The specimen was obtained from the M.P.L. but the exact locality is not known. It indicates, however, that mineralization has occurred in this area and that there is the possibility of other veins being present. The Upper Maji-ya-Chumvi Beds, west of Mrima, contain sparsely disseminated galena but nowhere was it seen in economic quantities. Lead-barytes mineralization is known elsewhere in the Coast Province. The most important is at Vitengeni, some ten miles north-west of Kilifi; another is near Mazeras where lead veinlets were prospected at the beginning of the century. The Vitengeni mineralization is known to have been emplaced along a fault-zone and it is probable that the same condition obtains in the other localities. It will be noted that the deposits lie parallel to, and at no great disance from the "Rabai Fault".

Barytes.—Barytes occurs in Mrima Hill where, however, it is insufficiently concentrated to be of value. The frequent association of barytes as a gangue mineral in lead veins may be significant should the latter be found.

Zircon.—In 1948, samples of sands from the Ramisi River and the head of Port Reitz were collected by Mr. D. Gill on behalf of the Sierra Leone Development Co. Ltd. and examined for zircon. The percentage recovery from the total samples ranged from 0.0004 to 0.014 at Port Reitz and 0.001 to 0.026 in the Ramisi River.

Coal.—Many years ago a small block of coal was found embedded in carbonaceous shales in a railway cutting near Taru. Since then, the possibility that coal seams might be discovered in the Duruma Sandstone Series has been constantly entertained. Encouragement has been afforded by the presence of plant remains and carbonaceous material at many horizons, the recording of coal from one of the boreholes at Mrere on the western flank of the Shimba Hills, and by the knowledge that seams do occur in beds of the same age in Tanganyika, Madagascar and South Africa. One of the objects of the current survey was to explore the possibility further. The results show that coal does exist but only in minute quantities that are of no economic value, and that the general conditions of deposition of the rocks, as exposed at the surface, were unsuited to the formation of coal seams. There remains the possibility that seams exist at depth beneath the Taru Grit, and not exposed at surface; the balance of evidence renders such a suggestion improbable but not impossible. Of the Duruma Sandstones exposed, the most likely beds to contain coal seams are the Lower Maji-ya-Chumvi shales since the conditions of their deposition most closely approach those necessary for the formation of seams. Plant remains and carbonaceous material are abundant in the beds but the rate of deposition was too great to permit of their being concentrated. The coal reported from the borehole at Mrere obviously resulted from the humification of one of the *Dadoxylon* trees and it must be regarded as pure chance that the borehole happened to pass through it. Doubtless similar coals occur elsewhere at this horizon but it may be stated with certainty that the quantities will nowhere be sufficient to justify development. The possible significance of the coal-measures distribution of Madagascar and Tanganyika was referred to on page 16; it may also be mentioned that in these countries, together with South Africa, the coal-measures are associated with a *Glossopteris* flora which is apparently absent from Kenya.

Lime.—A small limeworks, north of Nyali, produces lime by the calcination of the Pleistocene coral limestone. The coral is well-suited to this purpose for it generally consists almost entirely of calcium carbonate and, since it is wholly fossil, the variable slaking properties often experienced with limes produced from limestones containing scattered calcitic fossils are unlikely to arise. The following analysis is of a sample of coral limestone from Mombasa.

	%
SiO_2	2·62
Al_2O_3 Fe_2O_3 }	2·31
CaO	52·56
Loss on ignition	42·04
Moisture	0·26
	99·79

Analysed by the Industrial Research Board, Nairobi.

In its natural state the coral frequently contains an admixture of sand and clay impurities but these can be removed by washing. The reserves of coral limestones are immense and, if required, the lime industry could be increased enormously.

Analyses of three samples from the Kambe Limestone suggest that this rock is generally unsuited for burning for hydraulic lime although it could be used for plastering or other purposes. The analyses are as follows:—

	I	II	III
	%	%	%
SiO_2 (combined)	2·72	1·86	1·41
SiO_2 (free)	7·18	16·76	7·85
Al_2O_3	2·21	0·13	0·21
Fe_2O_3	1·27	0·66	0·62
MgO	1·29	1·14	0·17
CaO	47·14	44·18	49·97
Loss on ignition	38·20	34·30	38·96
TiO_2	Trace	Trace	Trace
P_2O_5	0·44	,,	,,
SO_3	0·27	0·32	0·20
	100·72	99·35	99·39

I. Locality unknown. Anal. Imperial Institute.
II and III. Mwachi Gorge (Wayland 1927). Anal. Imperial Institute.

Cement.—The British Standard Portland Cement Company has recently projected the setting up of a cement factory near Bamburi, using as raw materials a mixture of Pleistocene coral and Jurassic shale. The company aims at an annual production of 10,000 tons during the first four years with plans for a subsequent increase to over 50,000 tons.

The chemical composition of clean coral might be taken as being more or less constant throughout its entire outcrop but, as will be seen from the following analyses, the same is not true of the shales.

	I	II	III	IV	V	VI
	%	%	%	%	%	%
SiO_2	58·70	56·92	57·25	62·62	80·84	58·51
Al_2O_3	16·91	14·31	13·22	8·02	9·18	13·96
Fe_2O_3	4·74	7·48	5·81	5·86	2·28	6·43
MgO	1·16	2·55	2·32	1·53	1·07	2·28
CaO	0·91	3·14	3·91	9·98	0·30	5·54
Na_2O	2·38	0·98	0·82	—	—	1·32
K_2O	1·30	2/18	3·32	—	1·40	1·06
Loss on ignition	13·38	11·23	10·89	9·47	4·48	9·84
TiO_2	1·07	1·08	1·43	0·40	0·42	0·74
P_2O_5	0·04	0·27	0·30	0·07	0·02	0·01
SO_3	0·77	0·18	0·24	0·10	—	—
BaO	—	—	—	—	—	0·09
MnO	Tr.	0·06	0·74	—	Tr.	0·03
TOTAL	100·64	100·38	100·27	98·05	99·99	99·78

I, II & III	Changamwe. Anal. Imperial Institute.
IV	Kipevu (Wayland, 1927). Anal. Imperial Institute.
V	Mile 11/5 on the railway (Wayland, 1927). Anal. Imperial Institute.
VI	Miritini (Wayland, 1927). Anal. Imperial Institute.

In any cement project, therefore, it is essential that adequate sampling of the shale should be carried out.

Gypsum, a necessary constituent in cement manufacture, occurs as surface deposits in dried-up salinas near Mida Creek south-west of Malindi, and some is extracted accidentally at the salt-works north of Malindi during the evaporation of sea-water (Thompson). The Maji-ya-Chumvi beds were deposited under conditions of sedimentation in which gypsum (or anhydrite) might be expected to occur and the sulphate mineralization of the water obtained from these beds is probably due to this mineral, but it would appear that it is finely disseminated throughout and is nowhere sufficiently concentrated to be workable. Gypsum can be obtained by the evaporation of sea-water at temperatures below 108° F.; above this temperature, the anhydrous form, anhydrite is precipitated. Salinity is also an important factor and it has been shown (Posnjak, 1940) that if sea-water is evaporated at 30° C., the calcium sulphate will be precipitated as gypsum when the salinity is between 3.35 and 4.8 times normal and as anhydrite thereafter. Such conditions must have obtained at the salinas near Mida Creek.

Building Stones.—Few of the coastal rocks are suitable for use as building stones. That most generally used is the Pleistocene coral (or the coral breccia) which is quarried at several localities along the coast. It is cut into large blocks which, when cement-faced, make a satisfactorily resistant material; most of the larger buildings of Mombasa are so constructed. The handiness of the outcrop and the ease with which the coral can be dressed are factors controlling its choice. The Pleistocene sands might be used as a filler and as a constituent in mortar and concrete manufacture. These sands are frequently calcareous so there should be little risk of their containing organic acids; they have been extensively quarried near Makupa Causeway and on the north mainland. The Magarini Sands on the other hand are unlikely to be of much value. They have a large variation in grain size and there is every likelihood that organic impurities will be present that, in the preparation of concrete, would seriously impair the setting properties. The impurities often form transparent coatings around the individual grains and cannot be detected by eye. They can, however, be determined by colorimetric tests and can be removed by washing the material in a three per cent solution of caustic soda. Such a process is costly and would probably render the sands commercially valueless. Of the Duruma Sandstones, the majority are unsuitable as building stone on account of their weak cement. The bonding materials are usually calcite, felspar or mica all of which readily break down on weathering and cause the rock to crumble. Exceptions are the quartzite bands but these are of limited extent and too remotely situated to be of economic value.

Road-metal.—Possibly the most suitable rock in this connexion is the Kambe Limestone. It is compact and tough but it tends to splinter with a high yield of powder. This limestone is being quarried by Markham and Co. on the north bank of the Mwachi River, a few hundred yards above the M.P.L. bridge, and further to the south the outcrop is being worked by the Public Works Department. The Callovian oolite at Mwamtsola was formerly quarried by the Public Works Department but the outcrop was small and is now practically worked out. The Mariakani Sandstone is quarried extensively for road-metal along the railway-line but, in this area, the outcrop is too remotely situated to be of value.

Water-supply.—Water-supply constitutes one of the most important problems in coastal geology, and particularly of this area since Mombasa lies within its bounds. At present, Mombasa obtains the bulk of its two and a half million gallons per day from streams issuing from the Mazeras Sandstone at Mrere, at the western foot of the Shimba Hills below Kwale. This is supplemented to a small extent from boreholes drilled into the same formation at the same locality, and by other surface supplies from streams at the northern end of the Shimba Hills. The Mrere supply is being exploited almost to a maximum and, even now, two successive dry years would be sufficient to cause anxiety, perhaps a partial failure. Yet Mombasa is still expanding and if the expansion continues at its present rate the water requirements may be doubled, or even trebled, within the next decade. Hence it is of vital importance that a second supply should be found and, planning with a long-term policy, the Public Works Department is desirous that it should be capable of supplying twelve million gallons per day. For obvious economic reasons it would be of advantage that this supply should be obtained locally and numerous investigations have been made to test the water potentialities of the neighbourhood. The results have shown that the coastal sedimentary rocks are wholly unsuitable for large-scale water supplies, the reasons being not difficult to appreciate when the rocks and their depositional environments are considered.

The bulk of the Duruma Sandstone Series was deposited in a land-locked basin under conditions of semi-aridity. This led to evaporation of the water with the consequent precipitation of mineral salts, mainly carbonates, chlorides and sulphates. These are disseminated throughout the succession with varying degrees of concentration and, being partially soluble, they are readily re-dissolved by ground water; hence the water derived from these beds is liable to be saline. This is particularly true of the water derived from the Maji-ya-Chumvi Beds and, to a lesser extent, from the Taru Grits and Mariakani Sandstones. The following list gives the mineral content of six typical samples:—

Borehole	Locality	Beds tapped	Saline content (parts per million)
(1) C.1107	Kituu	L. Maji-ya-Chumvi beds ..	1,685
(2) C. 934	Kinangoni ..	L. Maji-ya-Chumvi beds ..	5,000
(3) C.1165	Sapo	U. Maji-ya-Chumvi beds ..	1,665
(4) C. 794	Mtaa	U. Maji-ya-Chumvi beds ..	4,921
(5) C. 856	Ndvaya ..	L. Maji-ya-Chumvi beds ..	1,680
(6) C. 766	Kinango ..	U. Maji-ya-Chumvi beds ..	2,237

These figures do not compare favourably with the normally accepted limits:—

0 - 150 p.p.m.	low mineral content.
150 - 500	medium mineral content.
500 - 2,000	high mineral content.
Over 1,000	undesirable for domestic purposes.
Over 3,000	generally unfit for dairy cattle.
Over 7,000	unfit for grazing cattle and sheep.

In one exceptional case (borehole C.1108 at Dungoni) the quantity of sodium chloride alone amounted to 47,100 p.p.m., a salinity that exceeds that of normal sea-water (35,000 p.p.m.).

Yields are variable but generally low. Of the boreholes drilled into the Taru Grit, some of them to a moderate depth, the greatest yield obtained was only 13,000 gallons per day. This is due partly to the poorly sorted, inequigranular nature of the grits, and partly to the filling of most of the inter-granular spaces by secondary calcite. The Middle Duruma Sandstone Series is essentially fine-grained and therefore of low permeability; many of the shale bands are totally impervious. The coarser, inter-bedded horizons make better aquifers, particularly where they are sandwiched between impervious layers but, being of restricted thicknesses, their catchment areas are relatively small. However, the presence or absence of the coarser horizons doubtless accounts for the wide variation in yields from a few hundred to 90,000 gallons per day.

The boreholes seldom exceed 400 to 500 ft. in depth but the nature of the strata is such that there is little or nothing to be gained, either from the point of view of quantity or quality of the water, by drilling deeper.

The Upper Duruma Sandstone Series—The Mazeras Sandstone and the Shimba Grit—presents a different picture. Apart from the lowermost horizons, the beds were deposited under sub-aerial conditions so that evaporites do not occur within them. Even in the lowermost horizons the concentration of salts is much less than in the Lower and Middle Duruma Sandstone Series so that the water obtained from them is only moderately saline. The porosity and permeability of the series are variable but are generally higher at the top of the succession than at the bottom. Some horizons, the quartzites for example, are neither porous nor permeable except along the joints. Yields, therefore, are markedly inconsistent as is shown by the records of the boreholes (Fig. 9) drilled at Mrere (Table VI).

TABLE VIII—MRERE BOREHOLE RECORDS

Borehole No.	Depth	Yield
	ft.	*g.p.d.*
C.243	300	122,400
C.317	178	86,400
C.318	190	74,400
C.319	300	52,500
C.689	250	129,600
C.742	442	50,400
C.749	390	97,200
C.808	600	1,800
C.838	603	82,728
C.857	300	97,200
C.890	500	51,840

Discounting borehole No. 808, which might have penetrated the underlying Mariakani Sandstone, the average yield per borehole is approximately 84,000 gallons per day.

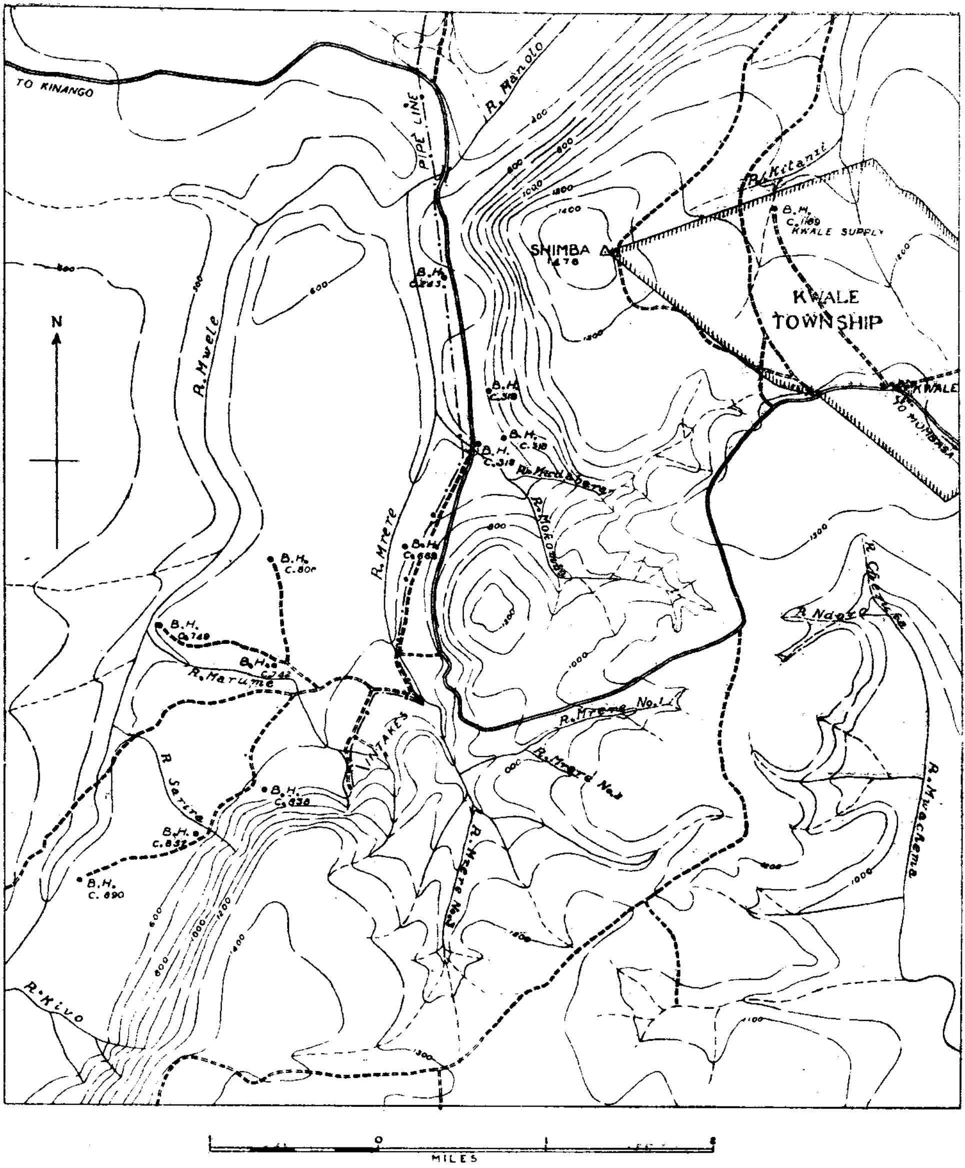

Fig. 9.—Map showing the borehole sites at Mrere.

The Jurassic and Cretaceous rocks, being mostly shales, are of no direct value for water-supplies. Sikes (1934, p. 28) mentions two boreholes sunk into these formations from which the more successful yield was only 21,000 gallons per day. As will be discussed later, these rocks are of indirect value in that they provide an impervious layer beneath the Cainozoic rocks and above the Duruma Sandstones.

The Magarini Sand constitutes a highly pervious formation on account of its lack of consolidation. The sands rest upon a seaward-sloping surface of impervious Jurassic rocks so that sub-surface flowage is directed towards the later Cainozoic deposits. The junction of the Magarini Sands and the Jurassic rocks is frequently marked by springs, the majority of which are seasonal. Water obtained from the sands is generally potable but the ferruginous nature of the sands renders it possible that in places the iron content of the water will be objectionably high.

The coral and coral breccia yield a hard but potable water and the numerous wells sited along the main coast road testify its exploitation. The supply is limited, however, by the close proximity of the sea with the consequent risk of contamination by sea water; it would be totally inadequate for the Mombasa project.

There is evidence to suggest that the Jurassic surface is ruptured along the western margin of the Pleistocene outcrop, the nature and possible cause of this rupture having been given on page 29. The lowering of the impervious Jurassic surface causes a drop in the level of the water-table and this is reflected by the disappearance beneath the surface of several small streams flowing off the Magarini Sand.

Mombasa Water-supply Project.—From the foregoing paragraphs it will be seen that the only formation worthy of consideration in a large-scale water-supply project, either from the point of view of quantity or quality of the water, is the Upper Duruma Sandstone Series. Already these rocks are being exploited for the existing Mombasa and Kwale supplies and numerous investigations to test their further potentialities have been made. A scheme to tap the source of the Mkurumuji River was abandoned when it was found that the maximum supply that could be expected was in the neighbourhood of 1,000,000 gallons per day, and this only during the rainy season. Such a scheme might be of value as a short-term policy, although the difficulties and expense of piping the water to Mombasa would be considerable, but it falls far short of the ultimate requirements and does not fulfil the immediate need of providing a constant supply throughout the year. Similar investigations made to the north of Mombasa were abandoned for the same reason. Consideration has also been given to the sinking of deep boreholes through the Jurassic rocks to penetrate the underlying Mazeras Sandstone but, although this scheme has much to be commended for a small-scale project, it would not be a practical proposition for Mombasa. To judge from the average yield of the Mrere boreholes, the number of successful boreholes required would be over a hundred and since, for the purposes of recharge, it would be necessary to space these boreholes at one-mile intervals they would stretch almost as far north as Kilifi. Moreover, it is not known that the Upper Duruma Sandstones are capable of supplying 12,000,000 gallons per day. It is therefore concluded that the rocks of this area, and possibly the entire coastal sedimentary succession also, must be excluded from any project concerning Mombasa's future water-supply, and that it may be necessary to pipe supplies from a distance.

Small-scale Supplies.—Small-scale supplies are at present obtained from boreholes, wells, streams, dams, and seasonal pools, the choice being dependant upon local conditions. In the Nyika it has often been found necessary to sink boreholes in spite of the fact that the water invariably proves to be saline. An extensive programme of earth-dam construction has been undertaken during the past two or three years which, in general, has proved very successful in view of the natural limitations on the choice of sites. A similar programme is recommended for any development scheme concerning the Jurassic rocks. For information concerning the siting and construction of small earth dams, reference should be made to Dixey's "A Practical Handbook of Water Supply" (second edition, 1950). Coastal supplies are usually obtained from wells sunk into the coral or associated Pleistocene formations, the former being the more successful. Groundwater in the coral is, however, not to be expected to be ubiquitous; rather is it more likely to be confined to solution channels within the rock. Hence it is necessary that preliminary investigations be made before a site is chosen. The fresh-water springs that emerge at the shoreline at some localities may be taken as a guide to the presence of groundwater. Supplies from the coral could be increased by further wells or shallow boreholes preferably sunk as near to the western margin of the outcrop as is practicable, so as to minimize the risk of contamination by sea-water. Fresh-water, having a lower density, floats on top of sea-water and it can be shown that the zone of contamination between fresh and sea water is lowered by about forty feet for every foot at which the water-table exists above sea-level. Hence, if the water-table exists at 10 ft. O.D., fresh water will be encountered to a depth of about 400 ft. The point to be remembered, however, is that as the water-table is lowered, either through pumping or climatic causes, the level of sea-water is raised by forty times as much.

For industrial concerns or coastal development schemes, requiring supplies of over 50,000 gallons per day, a possible source is from boreholes drilled through the Jurassic rocks to penetrate the Mazeras Sandstone. It is known that the Jurassic rocks rest unconformably upon the Mazeras Sandstone and, to judge from the exposed section in the Mwachi River, the unconformity dips to the E.S.E. at roughly 750 ft. per mile. It is not known how deep, nor how far eastwards, the Mazeras Sandstone extends beneath the unconformity although these facts might be ascertained by a geophysical survey. The relative dips suggest that the Mazeras Sandstone will feather out beneath the unconformity although this might be compensated for by the anticipated eastward thickening of the beds. A factor concerning the water-supply is the impervious capping of Jurassic rocks which should produce a sub-artesian effect.

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