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GEOLOGY OF THE HADU-FUNDI ISA AREA, NORTH OF MALINDI

DEGREE SHEETS 61, S.E. QUARTER AND 62, S.W. QUARTER

(with coloured maps)

by

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FOREWORD

The report continues the account of the geological survey of the coastal belt of Kenya. A strip some 40 miles in width, between the Tanganyika border and the River Sabaki, has already been described in earlier publications (Reports Nos. 20, 24, 34 and 36), and the present account extends the survey to the latitude of the mouth of the River Tana. The area is one of considerable difficulty for the geologist in view of the general lack of relief, the fewness of outcrops, and the scarcity of roads and tracks. Mr. Williams is to be congratulated on the amount of valuable information he has extracted from such unpromising material.

The mapping has shown that Miocene sediments, which for a long time have been thought to occur in scattered localities in the area, in fact cover a considerable extent. Mr. Williams has collected numerous fossils from them, and gives a useful summary of the Miocene fossils that have so far been collected in the area. The survey has also shown that the Miocene beds extend up to an elevation of 550 ft. above sea-level on the Rogge ridge, west of Fundi Isa, an altitude that is greatly in excess of those of other deposits of similar age along the East African coast. There is as yet, however, insufficient evidence to indicate whether the height of the Miocene beds indicates a previously unexpected height for the Miocene Sea, or whether it is a result of post-Miocene earth movements.

An account is given of the sands along the coast and of the interest that has been taken in recent years in connexion with the possibility of the extraction of the titanium mineral, ilmenite, from them. The ilmenite contains a small amount of vanadium which, if extractable, would be a valuable by-product.

The report has been delayed in publication because, shortly after Mr. Williams began his field-work, he was seconded for emergency duties, and was unable to resume the survey for a period of two years.

Nairobi,
3rd July, 1958.

WILLIAM PULFREY,
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ABSTRACT

The report describes an area of about 1,800 square miles, situated in the north-central part of the Kenya Coast Province and bounded by the latitudes 2° 30′ and 3° 00′ S., longitude 39° 30′ E. and the coastline.

With the exception of two small occurrences of basic igneous rocks, the geological succession embraces only poorly exposed sediments, which range in age from Triassic to Recent. The oldest beds, comprising continental and lacustrine deposits, are correlated with middle and upper members of the Duruma Formation of the southern part of the coast, while later formations include marine upper Jurassic rocks, richly fossiliferous lower Miocene littoral deposits and a variety of Quaternary sediments. The possible existence of Pliocene deposits is discussed, and a chapter deals briefly with postulated structures in the sedimentary rocks.

The entire area is at present (1958) covered by an Oil Exploration Licence and occurrences of ilmenite-bearing sands are held under an Exclusive Prospecting Licence.

GEOLOGY OF THE HADU-FUNDI ISA AREA, NORTH OF MALINDI

I—INTRODUCTION

During the periods January to May, 1953, and July, 1955 to January, 1956, a geological reconnaissance was carried out of an area in the north-central part of the Coast Province of Kenya, covering some 1,800 square miles and bounded by the meridian 39° 30′ E., parallels 2° 30′ and 3° 00′ S., and the coastline of Formosa Bay. It comprises the south-east quarter of degree sheet 61 (Kenya) and the south-west quarter of degree sheet 62 (Directorate of Colonial Surveys Sheets Nos. 186 and 187 respectively), embracing the northern portion of the Kilifi District together with two sections of the Tana River District. A coastal belt, ten miles in width, constitutes part of the Protectorate of Kenya which is rented from the Sultan of Zanzibar.

Survey and Maps.—No reliable maps of the area were available and geological information was plotted on air photographs in the field. Tracings were subsequently reduced photographically to the scale of the map, control being provided from a plane-table survey. The meagre ground control in and around the area, coupled with the flat terrain, considerably curtailed the use of a plane-table and the reliability of the survey probably decreases from south to north. To provide additional control in the south-central portion of the area, the Hadu (Adu)-Marafa road was surveyed by plane-table and checked by a compass-cyclometer traverse.

Approximate form-lines were inserted from aneroid spot-heights, a correction being made for diurnal variation. Place-names were obtained largely from local information, and district boundaries have been plotted as accurately as possible from the latest available records.

For convenience in printing the map has been divided into two along the meridian 40° E., and is issued as two sheets, the Hadu sheet and the Fundi Isa sheet. For purposes of description in the following pages the area is, however, treated as a whole.

Communications.—The main Malindi-Garsen road traverses the eastern half of the area with motorable tracks branching off to Karawa and towards Odda on the Tana river. In addition, a dry-weather road links Hadu with Marafa, and another passes south-eastwards through the villages of Ramada and Fundi Isa to join the Garsen road.

A number of vehicle tracks, cut during the survey to provide access to starting points for foot traverses in the uninhabited hinterland, are shown on the geological map. The rough track from Dakatcha, a village south of the present area, to the Dererisa district was subsequently slightly improved by the Administration to provide access to outlying African settlements. A track encountered at the foot of the Dakawachu hills, and said to originate further south-west near Lali, was cleared as far as the western boundary of the area.

In the north-east corner of the area the Tana river provides a useful line of communication, being navigable by dhows and shallow-draught launches.

Population.—African settlement is confined largely to the districts bordering the two roads to Hadu, a few scattered villages further west in the neighbourhood of Dakatcha, and a thinly populated belt along the Tana. With the exception of a small settlement at the Karawa wells and a single European house on Ngomeni headland, the remainder of the area is completely uninhabited, although local stories tell of isolated villages in the neighbourhood of Dakawachu more than 50 years ago.

The majority of the Africans belong to the *Giriama* tribe, with a mingling of the more adventurous *Wasania* invariably living on the outskirts of the settled area. Along the Tana are to be found the *Wapokomo*, normally grouped in neat villages carefully sited on natural mounds on the river-banks. The nomadic *Waorma* (*Wagalla*) are also attracted to the Tana as it offers a watering-place for their cattle.

Natural Vegetation and Cultivation.—Striking contrasts in vegetation are often apparent. Calcareous soils and clays derived from Jurassic and Tertiary marine sediments in the area characteristically support impenetrable bush, with a wide variety of succulent plants, including *Sansevieria.* A similar type of vegetation is frequently found over the partly calcareous Mariakani Sandstone outcrop, although drier bush with occasional small grassy glades is more typical.

Clayey sands which occur both as a result of weathering *in situ* of the Mazeras Sandstones and also on the Pleistocene Marafa Beds, bear a more open cover of light forest. In contrast, dense dry bush is often encountered where Pleistocene superficial red-brown sands attain any appreciable thickness.

Mangroves invariably fringe the coastal salt-water creeks and the lower reaches of the Ozi (Tana) river, while doum palms are ubiquitous on small hillocks of Pleistocene deposits that are scattered along the edge of the Tana flood-plain.

Cultivation is restricted mainly to calcareous soils, particularly where they have been derived from Jurassic and Miocene limestones, maize being the dominant crop. Cotton is cultivated on Pleistocene clayey sands in the Midadoni district a few miles inland from Ngomeni, and the alluvial silts of the Tana provide fertile maize and banana plantations along the river-banks.

Rock Exposures.—Reliable rock exposures are rare throughout the area and over wide tracts of country the nature of the underlying formations can only be inferred from "float", with additional indications from the type of vegetation. Geological boundaries are inevitably vague and the structure can frequently only be suggested after reference to air photographs.

Climate.—The area experiences a normal coastal climate with two wet seasons, the south-east monsoon bringing the heaviest rain between April and June, with lighter falls expected from October to December. Table I shows the average rainfall figures in and around the Hadu-Fundi Isa area, demonstrating the general decrease in rainfall both southwards and westwards.

Acknowledgments.—The writer is indebted to the following members of the staff of the British Museum (Natural History) for their work on the fossil collections submitted:—Mr. L. Bairstow for the identification of echinoidea; Dr. L. R. Cox and Messrs. C. P. Nuttall and D. L. F. Sealy for the identification of mollusca; Dr. C. G. Adams and the late Mr. A. G. Davis for the identification of foraminifera; Dr. H. Dighton Thomas for the identification of corals, hydrozoa and polyzoa; the late Mr. W. N. Edwards for examining the fossil plant remains; Dr. M. K. Howarth for his work on the ammonites and Dr. E. I. White for his identification of the fish teeth.

TABLE I—AVERAGE MONTHLY AND ANNUAL RAINFALL FIGURES IN AND AROUND THE HADU–FUNDI ISA AREA

(from the Summary of Rainfall in East Africa for the year 1956, *E.A. Meteorological Department)*

NAME OF STATION	Rainfall in Inches												Average Annual Rainfall	Number of years Recorded
	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sep.	Oct.	Nov.	Dec.		
Belazoni Estate	1·21	0·36	1·40	4·66	10·17	6·89	3·11	2·42	2·20	2·60	1·52	3·46	40·00	20
Kipini District Office* ..	0·88	0·28	1·68	5·11	14·41	5·35	3·18	1·66	2·07	1·97	2·47	3·36	42·42	40
Gongoni†	0·05	0·04	1·31	4·72	12·57	4·01	3·15	2·17	1·37	2·87	1·80	1·39	35·45	17
Marafa‡	0·26	0·33	2·03	3·35	8·66	2·76	2·31	2·36	2·11	3·56	2·35	3·18	33·26	19
Baricho§	0·06	0·66	1·68	2·69	5·00	0·71	1·12	0·79	0·86	5·77	3·04	2·67	25·05	4

*At the mouth of the Tana.

†2½ miles south of the present area, on the Malindi road.

‡2 miles south of the present area.

§5½ miles south of Dakatcha.

II—PREVIOUS GEOLOGICAL WORK

It is understandable that a river the size of the Tana should have been a source of attraction to several of the early East African explorers. While the separate Ozi and Tana mouths had previously been observed from the sea, the true relationship between the two waterways was first recognized by Baron von der Decken during a journey up the Ozi in 1865 and through the man-made Belazoni (Beledzoni) canal into the Tana river (E. G. Ravenstein in discussion of Gedge, 1892, p. 530*).

In 1891 an expedition, led by Capt. F. G. Dundas, ascended a stretch of the Tana by steamer in the first stages of a journey to Mount Kenya, C. W. Hobley being attached to the party as geologist (Gedge, 1892). The Ozi and Tana mouths were regarded as outlets in the alluvial delta of a single large river (Gedge, 1892, p. 514), and it is of interest to note that the existing salt-water creek known as Mto Tana in those days was the main estuary. Hobley (1894, p. 99) also gave an account of the lower Tana and of the canal, its construction and state at the time of the expedition.

J. A. G. Elliot aroused further interest in the area by collecting a few fossils about six miles inland from Fundi Isa, in those days a village on the coast (Gregory, 1921, p. 73). This discovery led Hobley to visit the same district, where he made small collections of fossils from two localities, the first five to seven miles west of the original Fundi Isa settlement and the second about 16 miles from the coast and to the south-south-east of Hadu. R. B. Newton examined the specimens and suggested the presence of Miocene sediments at the eastern locality, with Eocene beds further inland (Gregory, 1921, Appendix II, Section II, p. 383).

Gregory travelled along the Tana river in 1892 and across the coastal plain in the following year during a journey from the Tana to Malindi (Gregory, 1896, pp. 26, 44). He revisited Kenya in 1919 and subsequently published a volume on the geology of East Africa (Gregory, 1921) in which he discussed the details of Hobley's fossil collections. Gregory recognized a belt of bright red sandhills behind the coast, extending from the Tana to the Mombasa area, and noted a general increase in width and height as traced southwards across the present area. These sediments he called the Magarini Sands (Gregory, 1896, p. 229) and assigned them to the Trias, but later referred them to the Pliocene in view of Hobley's evidence that they overlie Eocene and Miocene limestones (Gregory, 1921, p. 77). He quoted the following succession based on his own observations in the coastal belt (*op. cit.*, pp. 47, 49, 72) and on those of Maufe (Muff, 1908, p. 4):—

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)	
Permian and Trias	Shimba Grit		Duruma sandstone.
	Mazeras Sandstone		
	Mariakani Sandstone		
	Maji ya Chumvi Beds		
	Taru Grit		
Eozoic	Gneiss.		

* References are quoted on pp. 61-62.

E. Parsons published a paper in 1928 in which he included a summary of the geology of coastal Kenya between the Tanganyika border and the mouth of the Tana river, proposing a succession which differed from Gregory's in four respects:—

(i) Parsons claimed that the Mazeras sandstones and shales overlie the Shimba Grits, and included both divisions in his "Shimba Grit Group".

(ii) He preferred a simplified Jurassic-Cretaceous sequence, divided into a lower Miritini Series and an upper Changamwe Series.

(iii) He considered that coral limestones, calcareous sediments and pebble beds are interbedded with Gregory's Magarini Sands and, in view of the fact that the limestones had yielded fossils ranging in age from Eocene to Pliocene, he grouped together all these deposits to constitute a "Magarini Series".

(iv) He suggested that the raised coral reefs are of Recent age.

In 1928-29 and again in 1930 Miss M. McKinnon Wood made two expeditions to the Kenya coastlands and, in the course of her travels, she examined the Fundi Isa limestones in the neighbourhood of Hobley's localities. The details of her fossil collections from "Mkwajuni", west of Fundi Isa, and from "Lafihi" (a locality in the district now known as Lafiti, some eight miles south of Hadu) were subsequently published in two monographs* which remain standard reference works on the palaeontology of the Colony's coastal sediments. The stratigraphical succession proposed by Miss McKinnon Wood (1930, p. 218) was essentially similar to that postulated by Gregory:—

Pleistocene	Fossil Coral Reef	
	Kilindini Sands	
	Oyster Beds	
Pliocene	North Mombasa Crag	
Pliocene to Miocene (?)	Magarini Sands	
Miocene	Fundi Isa Limestones	
Cretaceous (?)	Igneous Intrusions	
Cretaceous	Freretown Limestone	
Jurassic	Changamwe Shales	Kimmeridgian
	Coroa Mombasa and other Limestones	Kimmeridgian to Corallian
	Rabai Shales	Corallian to Oxfordian
	Miritini Shales	Callovian
	Kibiongoni Beds	Callovian (?)
	Kambe Limestone and Mwachi Shales†	Bajocian and Bathonian
Duruma Sandstone	Shimba Grit	Rhaetic or Triassic (?)
	Mazeras Sandstone	Rhaetic or Triassic (?)
	Mariakani Sandstone	Triassic (?)
	Maji ya Chumvi Beds	Lower Triassic
	Taru Grits	Upper Permian

†McKinnon Wood, 1938, p. 5.

* Monographs IV (1930) and V (1938) of the Geological Department of the Hunterian Museum, Glasgow University.

In 1938 H. G. Busk and J. P. de Verteuil compiled a confidential report on the oil prospects of the Colony but, in a summary of the geology of the coastal belt, only vague reference was made to the inaccessible country north of the Sabaki river. The authors recognized the continuation of the Duruma Sandstones, mentioning a "distant scarp of Shimba Grits"—apparently referring to the Dakabuko hills—and they also suggested that the Coast Jurassic sediments thin out to the north of the Malindi area. The Magarini Sands were regarded as Pliocene and bands of shelly and coral limestones were included in the formation.

III—PHYSIOGRAPHY

Gregory (1894, p. 295; 1896, p. 222) suggested a three-fold physiographic division of the coastal belt into:—

(1) The Coast Plain

(2) The Foot Plateau

(3) The Nyika.

In the Mombasa area these units coincide roughly with the distribution of Pleistocene, Jurassic and Permo-Trias sediments respectively, and for the same region Caswell (1953, p. 5) reintroduced a fourth term, the "Coastal Range" (originally used by Thornton, 1862, p. 449 in the form "coast-range"), to include the Shimba hills which form a prominent scarp behind the Foot Plateau.

In the present area the Coast Plain is well defined (Fig. 1) and includes a series of Pleistocene raised beaches up to the 200-ft. contour at the foot of the Rogge escarpment. The Malindi-Garsen road runs along the edge of the 30-ft. platform near the site of the abandoned Posts and Telegraph camp, while a few miles further inland a higher and less obvious platform stands at 100 to 120 ft. above the present-day sea-level. The plain widens from a mere six miles in the south to over 30 miles along the parallel 2° 30′ S., where it includes the broad expanse of alluvial silt constituting the delta of the River Tana. High Recent sand-dunes flank the seaward margin of the Coast Plain, being particularly well developed at Adara and Ngomeni where they reach altitudes of 164 and 168 ft. respectively.

Behind the Coast Plain the ground rises steeply to form an escarpment, with the Rogge plateau beyond, apparently representing an extension of the Nyika bevel. Caswell (1953, p. 5) quotes an altitude of from 200 to 450 ft. for the Foot Plateau near Mombasa whereas the crest of the Rogge escarpment stands at over 550 ft. O.D. north-east of Hadu. The plateau has been largely obliterated by stream dissection south of Hadu and by blankets of Pleistocene sands elsewhere, so that the western limit is not easily defined. The Rogge plateau has as its immediate foundation the lower Miocene Fundi Isa Limestones confirming that the bevel is at most mid-Miocene in age, but Caswell (1956, p. 6) has produced evidence further south showing the surface to be the end-Tertiary bevel of upper Pliocene age.

The Nyika plain, underlain by sediments of the Duruma Formation, can be distinguished in the western parts of the present area, where it lies at an altitude of a little over 500 ft. Erosion during and since Pleistocene times has dissected the Nyika bevel between Rogge and the western margin of the area.

The term "Coastal Range" is not strictly applicable to any hills in the present area, although the fault-blocks of Mazeras Sandstone at Dakabuko, Dakawachu and Gaabo are residual hills and are the structural and stratigraphic equivalents of the Shimba hills, which form the coastal range south of Mombasa. Dakabuko, a flat-topped horst, is the highest feature in the area and rises some 500 ft. above the surrounding Nyika surface. Wachu (Plate I, Fig. 1), the most prominent member of

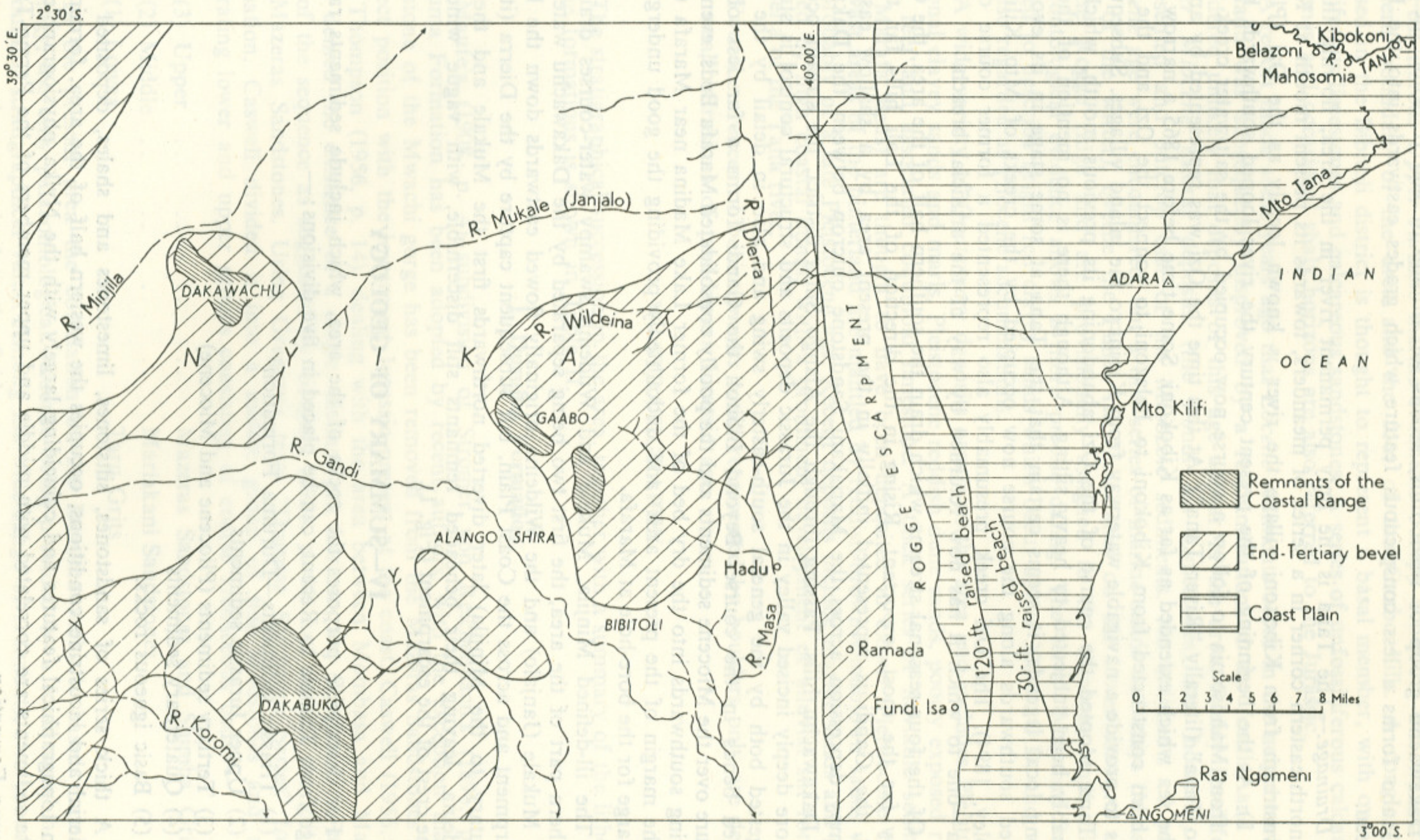


Fig. 1.—Physiographical Map of the Hadu-Fundi Isa area

the Dakawachu group of small hills, attains an altitude of 800 ft. while the scarp at Gaabo forms a less conspicuous feature which grades eastwards into the Rogge plateau.

Drainage.—The Tana is the only permanent river in the area, flowing through the north-eastern corner in a series of meanders, towards its present mouth at Kipini. Downstream from Kibokoni village the river is known locally as the Ozi (Plate I, Fig. 2). At the beginning of the present century the river looped southwards half a mile from Mahosomia to follow a course now occupied by the salt-water creek called "Mto Tana" (literally "River Tana"). At this time the Ozi was represented by an inlet of the sea which extended as far as Kibokoni. Some time before 1865 a narrow canal had been constructed from Kibokoni to Belazoni to connect the Ozi and the Tana so as to provide a navigable waterway from Kipini to the inland villages. Subsequently the Tana adopted the course of the Ozi abandoning its previous mouth, which had probably been subjected to heavy silting. Although there is no mention of the fact among local legends, it seems certain that the Tana at some stage in its evolution flowed southwards along the course now occupied by the creeks of Mto Kilifi (cf. Hobley, 1894). The Ozi creek presumably also represented a former course of the Tana—one to which it has now returned by way of the artificial breach.

Of the four seasonal streams which drain the southern half of the area, the Gandi is by far the most important. Rising in the direction of the Lali hills far to the west, the Gandi is represented initially in the present area by a shallow east-west swampy depression across the Mariakani Sandstone outcrop between the Dakabuko and Dakawachu hills. Passing through the Alango Shira district, the stream occupies a more deeply incised valley in the Jurassic deposits and structural control is strongly suggested both by the general south-easterly swing and also in detail by the right-angled bends in the course. Beyond Bibitoli the Gandi forms a far less obvious feature over the Miocene sediments and the poorly consolidated Marafa Beds, eventually flowing southwards into the dry bed of the former Lake Madina near Marafa (south of the margin of the present area) and undoubtedly providing the good underground recharge for the bore-hole at Marafa.

The ill-defined Minjila, Mukale and Wildeina swampy water-courses drain the northern part of the area, the first two being separated by the Dakawachu watershed. The Mukale (Janjalo) and the Wildeina originally flowed eastwards down the Rogge escarpment and across the Coast Plain, but subsequent capture by the Dierra (itself a tributary to the Minjila) later diverted northwards first the Mukale and then the Wildeina, leaving their beheaded remnants still discernible, with vague wind-gaps at the crest of the escarpment (Fig. 1).

IV—SUMMARY OF GEOLOGY

For descriptive purposes the rocks of the area, which include sediments ranging in age from Triassic to Recent, can be placed in five divisions:—

(1) Triassic sediments—Duruma Formation
(2) Upper Jurassic sediments
(3) Tertiary sediments (Pliocene and Miocene)
(4) Quaternary sediments
(5) Basic igneous rocks.

A thick series of sandstones, siltstones, limestones and shales, deposited under subaerial and lacustrine conditions, occupies the western half of the area, forming the main topographical features and coinciding largely with the Nyika physiographic unit. These sediments are correlated with middle and upper members of the Permo-Triassic *Duruma Formation.*

Fossiliferous *Upper Jurassic* marine sediments occupy a narrow belt between the southern boundary of the area and the foot of the Gaabo hills. A conglomerate exposed in the Bibitoli district is thought to represent a basal member, with overlying fossiliferous limestones and calcareous sandstones. A series of unfossiliferous calcareous siltstones and occasional shaly horizons are also referred to the Jurassic.

A report made some years ago that *Eocene* sediments occur in the neighbourhood of Hadu was subsequently disproved by a re-examination of the fossils, and it is considered unlikely that deposits of this age appear in the area. Richly fossiliferous *Lower Miocene* littoral deposits (the Fundi Isa Limestones) are, however, well represented and outcrop east of the Mesozoic sediments. No sediments of proved *Pliocene* age were encountered, but a thin series of marine sands and clays (Midadoni Beds of the writer), overlie the Fundi Isa Limestones on the lower seaward slopes of the Rogge ridge and are provisionally assigned to the Pliocene until further palaeontological evidence allows a more precise dating. The term "Magarini Sands" is used to describe bright red clayey sands which occur above 300 ft. O.D. and which are also regarded as Pliocene accumulations.

A wide variety of *Quaternary* deposits occurs in the area and includes Pleistocene lagoonal clayey sands and marls, Pleistocene reddish dune sands, poorly exposed raised coral reef and associated coquinoid limestone. A thick series of fluviatile sediments (the Marafa Beds) are thought to have been deposited in Lower Pleistocene times, and vast areas of the hinterland are mantled by reddish-brown windblown sands which are probably of a late Pleistocene age. Recent deposits include marine sands and muds flanked by high coastal dunes, with a prominent development of alluvial silt forming the delta of the Tana river.

Two occurrences of *basic igneous rocks* represented by boulders only are derived from small intrusions of post-Upper Jurassic age.

V—STRATIGRAPHY

The stratigraphical succession in the area, together with a summary of the lithology of the formations is shown in Table II.

1. Duruma Formation

Maufe's (1908, p. 4) subdivision of Stromer von Reichenbach's (1896, p. 22) Duruma Formation has been adopted by recent authors, with the exception that the limestone of the Mwachi gorge has been removed from the Mazeras Sandstones to its correct position with the lowermost Jurassic present at the coast. Caswell (1956, p. 7) and Thompson (1956, p. 14), dealing with the area between Mombasa and Malindi, have denied the existence of a single, distinct grit horizon, the Shimba Grit, at the top of the sequence as suggested by Gregory (1921, p. 46) and include the grit with the Mazeras Sandstones. Using Gregory's term "Duruma Sandstone Series" for the formation, Caswell divided it into a middle group of fine sandstones and shales separating lower and upper groups consisting of coarse arenaceous beds:—

(3) Upper .. .. Mazeras Sandstones and Shimba Grits
(2) Middle .. .. Mariakani Sandstones
(1) Lower .. .. Taru Grits

In the present area the correlation of the Duruma rocks is based mainly on lithology, the only palaeontological evidence being provided by a fossil wood horizon of doubtful stratigraphical value. Among the wide range of sediments, two broad subdivisions can be recognized in the field:—

TABLE II—THE STRATIGRAPHICAL SUCCESSION IN THE HADU–FUNDI ISA AREA

Era	Period		Environment of Deposition: Continental		Environment of Deposition: Lacustrine and Fluviatile	Environment of Deposition: Marine and Lagoonal		Earth Movements and igneous action
CAINOZOIC	Recent		White dune sands (160 ft.)	Reddish brown wind-blown sands	Alluvia	Sands and clays		
	Pleistocene	Upper	Reddish brown dune sands (<200 ft.)					
		Middle						
		Lower			Marafa Beds: Non-calcareous sands and sandstones with pebble-beds (300 ft.)	Lagoonal clayey sands and marls (<500 ft.)	Coral Reef	
	Pliocene		Magarini Sands: Reddish-brown sandy soils (200 ft.)			Midadoni Beds: Yellow-brown marls and calcareous sandstones (400 ft.?)		
	Miocene	Upper						Faulting and igneous intrusion (?)
		Lower				Fundi Isa Limestones: Detrital limestones, calcareous sandstones and marls (<800 ft.)		
	Oligocene							
	Eocene							
MESOZOIC	Cretaceous							Faulting
	Jurassic	Upper				Calcareous sandstones, limestones and shales with (?) basal conglomerates (<400 ft.)		
		Middle						
		Lower	Duruma Formation	Mazeras Sandstones: Coarse kaolinitic sandstones (600 ft.)				
	Triassic	Upper	Duruma Formation	Mazeras Sandstones: Coarse kaolinitic sandstones (600 ft.)				
		Lower	Duruma Formation	Mariakani Sandstones: Siltstones, flaggy sandstones, thin limestones and shales (>5,000 ft.)				

(2) The Mazeras Sandstones—non-calcareous, kaolinitic coarse sandstones and grits.

(1) The Mariakani Sandstones—fine- or medium-grained sandstones and siltstones with intercalated shales and thin limestones.

The nature of the junction between the two groups is not clear owing to widespread faulting and the paucity of exposures.

Miller (1952, p. 6) has shown that the Mariakani Sandstones in the type area conformably overlie the Upper Permian to Lower Triassic Maji ya Chumvi Beds. In the Mombasa area Caswell (1953, pp. 7, 17) referred the lower part of the Mazeras Sandstones to the Upper Triassic, suggesting a possible upward extension into the lower Jurassic since they are overlain (unconformably) by middle Jurassic sediments (Kambe Limestone; Bajocian-Bathonian). A pre-Upper Jurassic age for the Duruma Formation is demonstrated by the present survey, but unfortunately the straight lithological correlation with areas to the south and south-west, unsupported by palaeontological evidence, fails to distinguish possible diachronism or lateral facies variation.

(1) Mariakani Sandstones

Virtually unexposed sediments occupy a large part of the area west of the Gaabo hills, but sufficient evidence is provided by float to suggest a correlation with the Mariakani Sandstones described in the Malindi and Kilifi areas (Thompson, 1956, p. 11; Caswell, 1956, p. 7). They include a wide variety of types, but consist dominantly of thin-bedded siltstones and fine-grained, flaggy, micaceous sandstones, varying in colour from pale pinkish brown to brick red depending on the iron content.

Thin sections of these arenaceous rocks show small subangular quartz grains with less obvious fragments of plagioclase felspar, often having a composition close to oligoclase, and lesser amounts of microcline. The felspar is typically altered to kaolinitic material or small aggregates of sericitic mica. Finely disseminated opaque ore, including ilmenite, limonite and magnetite, is ubiquitous, while shreds of muscovite are common and occasionally accompanied by flakes of brown biotite. Small rounded grains of zircon and yellow-brown or reddish brown rutile are often present. The cementing medium is frequently limonite, but the majority of the specimens collected display varying degrees of silicification, so that in extreme cases the rocks become quartzitic. More rarely calcite forms part of the cement.

During a survey of the Kilifi-Mazeras area, Caswell (1956, p. 7) recognized a two-fold subdivision of the Mariakani Sandstones:—

2. Greenish brown or yellowish brown fine sandstones with local quartzitic or quartzo-felspathic horizons, with silty sandstones and shales at the base.

1. Pale greenish grey sandstones containing small greyish white blotches.

It is impossible to attempt any subdivision of the Mariakani Sandstones in the present area because of the limited field evidence but the restricted occurrence of fine-grained arenaceous and calcareous float to broad belts surrounding the main outcrops of the Mazeras Sandstones may be indicative of an increase in grade towards the top of the middle Duruma succession, accompanied by the intercalation of thin limestones.

Only occasional quartz pebbles were encountered in the grey clayey soils that form an unbroken veneer in the extreme western parts of the area, and it is possible that the underlying sediments are dominantly shaly. South of the Koromi drainage system, however, small boulders of fine-grained yellow sandstone are probably of local origin, while further north near Debassadella the surface float comprises fine, ferruginous, partly silicified sandstones. Similar sediments are apparently capped by coarser Mazeras Sandstones on the north-western slopes of Dakabuko.

A mile and a half north of Haluabagalla, close to the boundary between the Mazeras and Mariakani Sandstones, which was inferred from changes in vegetation and soil, a variety of float specimens was collected across a shallow valley occupied by a tributary of the Gandi water-course. The specimens include medium-grained ferruginous sandstones, fine-grained quartzitic calcareous sandstones, detrital limestones and a few fragments of fossil wood, with coarser ferruginous sandstones on the higher ground. Specimen 61/114A,* collected from this valley, is a green flaggy silicified siltstone, becoming chocolate brown on weathered surfaces. Cleanly fractured edges that truncate the bedding planes indicate jointing in at least two directions at an angle of 60 degrees, an observation in concordance with regional trends of faults, which were plotted largely from air photographs. The rock consists dominantly of small subangular quartz grains, fragments of plagioclase felspar having a composition near oligoclase-andesine and possibly some potash felspar. Subordinate allogenes include scattered flakes of muscovite and biotite, rounded zircons, rarer prismatic crystals of rutile, garnet and opaque grains of ilmenite and limonite. The cement is dominantly siliceous, but calcite is not uncommon.

Around Dakawachu there is further evidence to indicate the presence of calcareous beds towards the top of the Middle Duruma succession. To the south and south-west of the hills kunkar limestone was encountered in a belt about three and a half miles wide on the Mariakani sediments and extending as far as the junction with the overlying Mazeras Sandstones. Float here includes medium- and fine-grained ferruginous sandstones with rare fragments of detrital limestone.

Sediments similar to those described above reappear east of the Mazeras Sandstone outcrops which form the Dakabuko and Dakawachu hills. In the water-hole near Kazakini village there is a poor exposure of flaggy pink siltstones with interbedded shales dipping gently to the east, and the continuation of the Mariakani Sandstones outcrop to the north-west of Kazakini is probably justified by the calcareous clayey soils and the sporadic occurrence of kunkar between Dererisa and Haluabagalla, on the slopes of the Gandi river, and east of Boragi. Between Dakawachu and the Gaabo hills float includes a variety of partly silicified fine-grained sandstones and siltstones.

A large N.N.E.-S.S.W. fault, inferred from a striking change of vegetation, limits the eastward extent of the Mariakani Sandstones, both Mazeras Sandstones and Jurassic sediments being apparently downthrown against them, suggesting a total movement of more than 300 ft.

With the angle of regional dip unknown and the effect of strike faulting not obvious, any estimate of thickness is necessarily conjectural, but the Mariakani succession in the present area probably exceeds 5,000 ft.

(2) Mazeras Sandstones

Outcrops of the Mazeras Sandstones are confined to the western half of the area, where they overlie the Mariakani Sandstones and form the Dakabuko, Gerujo, Dakawachu and Gaabo hills. Further south Caswell (1956, p. 12) and Thompson (1956, p. 15) have demonstrated an unconformity between the middle and upper parts of the Duruma Formation but evidence in the present area is inconclusive.

* Numbers prefixed by 61/ and 62/ refer to specimens in the regional collection of the Geological Survey, Nairobi.

The Mazeras Sandstones are essentially coarse kaolinitic deposits, probably with more flaggy horizons intercalated low in the succession. Typical examples are white, pink or yellowish brown, friable, coarse-grained sandstones, displaying varying degrees of silicification. Bedding is normally only apparent when the sandstones are of finer grade but small-scale faulting which is almost certainly related to original joint directions, is frequently seen. On weathering, the Mazeras Sandstones first break up into massive blocks, which subsequently disintegrate to form coarse quartz sands, so that reliable exposures are rare.

Thin sections show that the sandstones are composed dominantly of subangular quartz grains up to 1 mm. in diameter frequently welded into clusters by silica, with sericitized felspar relics and rarely a few grains of undetermined plagioclase. Flakes of muscovite and grains of zircon and rutile are often present, particularly in the flaggy horizons. The cement includes varying proportions of silica, kaolin and sericite.

The Dakabuko hills, which rise to a little over 1,000 ft. in the south-western corner of the area, consist of an upfaulted block of medium- and coarse-grained ferruginous, kaolinitic sandstones.

Exposures at the top of the three-miles-long scarp on the northern flank of the hills reveal pale brown, coarse, micaceous sandstones dipping to the west-north-west at about 20 degrees, a variation from the probable regional dip that may be partly explained by the proximity of the faults. The constituent quartz grains are commonly welded together by silica into small clusters so that the rock assumes an open porous texture following the rapid weathering out of the original kaolinite and limonite cement. This partial silicification tends to check the rate of disintegration of the sandstone.

There are no exposures on the steep north-western scarps of Dakabuko and the slopes are littered with large fallen blocks and scree composed of typical coarse Mazeras Sandstone, with fragments of finer, flaggy, pale brown micaceous sandstones at lower levels, possibly indicating the presence of the Mariakani Sandstones. On top of the north-western hill which forms the highest point of the Dakabuko group occasional flat exposures show minor faulting in massive ferruginous sandstone devoid of bedding.

On Gerujo hill near the southern boundary of the area deeply weathered, coarse, yellow-brown kaolinitic sandstones also display minor fractures. In thin section the Gerujo sandstones (specimen 61/107) show untwinned felspar grains in which alteration has not proceeded to the extremes noted in the majority of specimens collected elsewhere, as well as occasional grains of fresh microcline.

At Barkisuu, between Dakabuko and Kazakini village, a number of silicified tree stumps (61/103) project from brown sandy soil. The largest has a diameter of 18 ins., stands up to 2 ft. above the surface and is inclined towards the W.N.W. at 10 degrees from the vertical, while less perfect examples nearby have a random orientation. Silicification is complete, no trace of carbonaceous material being left. Although the structure of the wood is moderately well preserved, a specimen (61/103) proved quite indeterminable. Float fragments of silicified wood (e.g. specimen 61/99/1, collected beside the bush-track midway between Dererisa and Haluabagalla—Plate II, Fig. 1), were encountered at many other localities across the inferred Duruma outcrop. It is not known whether the wood is restricted to a single horizon, but the distribution of the localities from which specimens were recorded strongly suggests that the material is confined to strata near the base of the Mazeras Sandstones.

Specimens of silicified wood collected in the southern parts of the Coast Province have generally defied specific identification but several fragments in the McKinnon Wood collection were referred to the form *Dadoxylon sclerosum* Walton (McKinnon Wood, 1930, p. 124), previously recorded from the Upper Triassic Molteno Beds of South Africa. *Cedroxylon* has also been identified from the Mombasa district (Maufe, 1908, p. 9).

Some 15 miles north of Dakabuko the Mazeras Sandstones form a group of low hills that stand as conspicuous landmarks above the surrounding featureless Nyika plain. The sediments exposed on the small fault-block known as Wachu (Plate I, Fig. 1) are pale grey-brown, coarse well-bedded sandstones in which flakes of muscovite are not uncommon, being particularly obvious along the bedding planes. In general the rocks (61/135 and 61/136) contain less kaolinite than the Dakabuko specimens and silicification has proceeded further, yielding more resistant horizons. Sericitized relics seen in thin sections of the Wachu sandstones probably represent altered fragments of felspar, while subordinate allogenes include small euhedral and rounded grains of zircon and dark brown to amber-coloured rutile. Northerly dips of up to 20 degrees confirm the local tilting that is suggested by the general outline of the hill. A few low reverse dips were observed at the foot of the north scarp.

Similar sediments are exposed on Hoshingo Mdogo, a small steep-sided hill some three miles north-west of Wachu. Here silicified flaggy sandstones display very shallow north-north-westerly dips, which are often exaggerated by local slumping. On Dabasso, another conical isolated mass, there are rather more friable brown kaolinitic sandstones, and a float fragment from the foot of the north flank yielded a few poorly preserved plant impressions.

At Eggelali, north-east of Wachu, exposures of reddish "speckled" porous sandstones show north-easterly and north-westerly dips of 5 to 10 degrees, but the observations are of doubtful regional value in view of nearby faults. Three miles south-east of Wachu kaolinitic sandstones are exposed along the low scarp at Konodibaa.

Near Boragi large boulders of dark weathering grey-brown and yellow-brown coarse sandstones presumably indicate an outcrop of Mazeras sediments beneath the sand cover. The texture of the rocks is partly quartzitic and the cementing material consists largely of silica with subordinate limonite. Incorporated in the sandstone are small pellets of clay.

At Gaabo (*Mlima ya Kalama*) the Mazeras Sandstones form a long arcuate scarp along part of which the Jurassic beds are downfaulted some 400 ft. The Duruma sediments are not exposed but the steep slopes are strewn with massive blocks of white and pink coarse kaolinitic sandstones. The ridge is probably truncated to the west by a continuation of the Kazakini fault.

Thompson (1956, p. 14) states that the Mazeras Sandstones are at least 1,000 ft. thick in the Malindi area, but it is thought that appreciable thinning has occurred further north so that within the Hadu area the same formation probably rarely exceeds a thickness of 600 ft.

(3) Conditions of Deposition of the Duruma Sandstones

The change in lithology from the fine sandstones, siltstones and shales of the Mariakani Sandstones to the massive, kaolinitic Mazeras Sandstones is a reflection of the succession of a period of subaqueous sedimentation by a phase of more intense erosion under arid conditions, which resulted in the rapid accumulation of a great quantity of coarse material.

The fossil tree trunks exposed at Barkisuu, and other fossil wood in the Mazeras Sandstones, as would be expected, apparently represent trees that thrived immediately prior to the ultimate desiccation of the lakes, only to be subsequently buried beneath the ensuing accumulation of deposits that form the bulk of the sandstones.

2. Upper Jurassic Sediments

Poorly exposed fossiliferous beds of Upper Jurassic age are restricted to a narrow belt extending from the Dakatcha and Denisa districts to the Gaabo hills, where faulting apparently terminates the outcrop. The sediments include detrital limestones, calcareous sandstones, calcareous siltstones and shales, and possibly basal conglomerate exposed at Bibitoli.

Upper Jurassic marine sediments near the Sabaki river, some seven to ten miles south of the present area, were described originally by Miss McKinnon Wood (1930, p. 224, and 1938, p. 7) and more recently by Thompson (1956, p. 18). On the evidence provided by molluscs and brachiopods collected from the Baricho and Merikano districts J. Weir (in McKinnon Wood, 1930, p. 93) assigned the beds to the Kimmeridgian stage, with the possibility of a downward extension into the Argovian (i.e. Upper Oxfordian). The same author later revised this opinion following an examination of further material from the same districts, suggesting a possible post-Kimmeridgian Jurassic age for the Sabaki limestones. He quoted the following fauna (in McKinnon Wood, 1938, p. 25):—

Rhynchonellids

Belemnites

Pseudomonotis lieberti (Müller) (? = *P. tendaguruensis*, Hennig)

Exogyra solea, Müller

Entolium sp.

? *Spondylus* sp.

Plicatula sp.

? *Plicatula* sp.

Lima (*Pseudolimea* ?) sp.

Placunopsis aff, *tatrica*, Zittel.

The *Pseudomonotis-Lima-Exogyra* assemblage suggested to Weir a correlation with the *Trigonia smeei* stage of the Tendaguru Series of Tanganyika, the age of which had been the subject of much discussion, but which Spath referred to the Portlandian on the strength of the ammonite fauna.

Thompson traced the Upper Jurassic beds northwards from the Sabaki river to the Dakatcha district and postulated a faulted contact with the Mazeras Sandstones, based on the section exposed in the Sabaki (1956, p. 18).

In the present area, sediments that possibly represent the basal Upper Jurassic horizon are exposed in the Bibitoli district. One and three-quarter miles north-west of Bibitoli village coarse conglomerates dipping gently eastwards outcrop in a small tributary of the Gandi while, three-quarters of a mile to the south, coarse ferruginous sandstones and grits (thought to underlie the conglomerates and to belong to the Mazeras Sandstones) are exposed in the same water-course. A mile and a quarter south-west of Bibitoli village Upper Jurassic (?) conglomerates with interbedded coarse sandstones and grits outcrop on the north side of the Gandi valley along the down-throw side of a small inferred fault that trends N.N.W.-S.S.E. and locally controls the direction of the main water-course. The conglomerates at this locality contain pebbles up to 4 in. in diameter of silicified ferruginous sandstones, set in a matrix of coarse friable kaolinitic sandstone. The sediments are non-calcareous and dip at between 5 and 20 degrees to the north and east. A little over half a mile to the west another N.N.W.-S.S.E. fault (recognizable on the ground by a prominent scarp littered with boulders of Mazeras Sandstones) apparently downthrows Upper Jurassic beds against the Duruma sediments.

There are no exposures on the higher ground in the immediate vicinity of Bibitoli village, but float specimens of grey fossiliferous limestone were collected from the cultivated calcareous soil half a mile west of the small settlement. The limestone shows numerous sections of lamellibranch valves, but is unfortunately too compact to permit extraction of the fossils and identification of the fauna. Lithologically, however, the rock is related to the Jurassic sediments encountered to the west rather than to the buff and yellow limestones of Miocene age.

Some three miles north by west of Bibitoli fossiliferous blocks of sandy limestone (specimen 61/80) were collected on the eastern slope of a north-south section of the Gandi valley. None of the fragmentary shell remains were identifiable.

Further float on the small hill includes grey calcareous sandstones and siltstones, while on the southern slopes buff and green barren shales dip at 10° to E.S.E. A mile to the north-west an outcrop of coarse ferruginous Mazeras Sandstone is indicated by numerous large blocks scattered throughout reddish brown sands, and the contact between the Jurassic and Duruma sediments is probably marked by a small N.E.-S.W. fault, as can be inferred from the air photographs.

No exposures were found at Alango Shira but the occurrence of Jurassic beds was inferred from fossiliferous float. A block of buff shelly limestone (specimen 61/70) containing a few poorly preserved ammonites (Plate II, Fig. 4) was found a quarter of a mile north-west of the semi-permanent water-holes in the Gandi valley.

Dr. M. K. Howarth kindly examined the material at the British Museum, but was able to expose only a small fragment of ammonite surface, from which he reports that the form is strongly and regularly ribbed on both the inner and outer whorls and, being obviously evolute, the specimens are thought to be perisphinctids of the Upper Jurassic (probably of Oxfordian-Kimmeridgian age). A specimen of the lamellibranch *Meleagrinella* was also extracted during this examination.

The sediments at Alango Shira also include a series of pale grey and brown unfossiliferous partly silicified calcareous sandstones (61/69A) and siltstones (61/90). Specimen 61/69A is composed dominantly of subangular quartz grains with a few fragments of plagioclase and subordinate zircon, rutile and muscovite, the cement being partly calcareous, partly siliceous. In striking contrast to the Duruma Sandstones, the felspar is typically unaltered.

On the higher ground to the south of the Gandi valley the Jurassic beds are evidently represented by pale grey massive oolitic limestones of which abundant loose boulders are to be seen scattered throughout the soil. Nearby, the superficial sands bear blocks of Mazeras Sandstone in such close proximity as to suggest a faulted contact. Further south, between Alango Shira and Dakatcha the Jurassic sediments probably rest with unconformable succession on the Mazeras Sandstones but if a basal conglomerate exists, it is not unlikely that it has been mapped with the Duruma beds since the weathered products would be identical. The plantations at Dererisa yielded fossiliferous float (specimen 61/68) of hard shelly limestone containing a small specimen of *Entolium briconense* (Cossman). A few belemnites were found at the same locality. Specimen 61/68/2 (Plate II, Fig. 3) is referred to the family Belemnopsidae by Bairstow, who states that it is probably of middle or upper Jurassic age, and specimen 61/68/1 (Plate II, Fig. 2) is also believed to be of the family Belemnopsidae.

At two localities near Dakatcha and about a mile beyond the boundary of the present area, fragments of limestone and calcareous sandstone (specimens 66/337 and 338) have been turned up during cultivation. The following lamellibranchs were identified by L. R. Cox:—

Specimen 66/337—

Meleagrinella cf. *lieberti* (Müller)

Ostrea sp.

Chlamys ? sp.

Isocyprina ? sp.

Specimen 66/338—

Meleagrinella lieberti (Müller)

Quenstedtia ? sp.

About a mile and a half to the south-east of the previous localities near the small shop at Dakatcha a bore-hole, drilled in 1955 to a depth of 400 ft. from the surface, apparently pierced only Jurassic calcareous sandstones and shales beneath the superficial sands. The venture was unsuccessful in that no water was struck, but it provided the following geological information (inferred from a study of the driller's samples):—

DAKATCHA BORE-HOLE (C. 2399)

Feet	Metres	Lithology
0–10	0·3·0	Reddish brown wind-blown sand.
10–20	3·0–6·1	Reddish brown sand with poorly consolidated sandstone.
20–40	6·1–12·2	Yellow-brown coarse sandstone. Partly silicified with inclusions of grey-green clay.
40–80	12·2–24·4	White and pale brown calcareous sandstones with grey-green shale.
80–120	24·4–36·6	Brown, grey-green and grey calcareous shales.
120–180	36·6–54·9	Grey-brown limestone, calcareous sandstones, siltstones and grey-green shales.
180–240	54·9–73·2	Brown calcareous sandstones and calcareous siltstones with grey shale.
240–260	73·2–79·3	Grey shale with white and brown calcareous sandstones.
260–400	79·3–121·0	Yellow-brown and grey calcareous shales with calcareous sandstones and siltstones.

East of Denisa surface float suggests that the Jurassic beds include yellow-brown limestones and coarse calcareous sandstones, and at one locality rock fragments (specimen 61/94) lying in the soil yielded the following fauna:—

Ostrea sp.

Chlamys ? sp.

Crinoid remains

while at Ilibabu a few fossils (specimen 61/93) were collected, also from float, and identified by Cox as follows:—

Entolium sp.

Lopha sp. [? *L. marshi* (J. Sowerby)]

Ostrea sp.

While the Dakatcha bore-hole suggests that the Upper Jurassic sediments attain a thickness of over 380 ft. immediately to the south of the present area, the beds probably thin considerably when traced northwards to the foot of the Mazeras Sandstone scarp at Gaabo (*Mlima ya Kalama*) and it is unlikely that the Jurassic succession exceeds 200 ft. at the terminating fault.

3. Tertiary Sediments

(1) Reported Occurrence of Eocene Sediments Near Hadu

Gregory (1921, pp. 73-4 and 383-4) published details of a small fossil collection made by C. W. Hobley from a locality about 16 miles west of the coast, south-south-east of Hadu and at an elevation of about 250 ft. The specimens were identified as follows by R. B. Newton:—

Foraminifera	*Alveolina*
	Miliolina
Coral	*Favia somaliensis*
Mollusca	*Campanile* sp.
	Volutilithes cf. *sanurensis* (Oppenheim)
Marine alga	*Lithothamnium.*

On this evidence an Eocene age was assigned to the beds. L. R. Cox (in McKinnon Wood, 1930, p. 104) subsequently examined the material, however, and redetermined the *Campanile* as a large species of the Cerithiidae, suggesting that the specimens might perhaps represent casts of the form *Telescopium charpentieri* (Lower Miocene). The gastropod cast, identified by Newton as *Volutilithes* cf. *sanurensis,* Cox related to the genus *Strombus* and noted the similarity to specimens collected by McKinnon Wood from Miocene beds not far from Hobley's locality. Of the foraminifera the *Alveolina* was probably correctly identified since Alveolinids (specimen 61/3) were in fact collected by the writer two miles north of Mizijini (presumably very near Hobley's site) and a small species of *Alveolina* (specimen 61/16) was collected two miles south-east of Hadu. The *Miliolina* might well have been *Miliola,* since that genus has also been identified from the locality two miles north of Mizijini. The coral *Favia somaliensis* has not since been reported from material collected in Kenya.

It is of interest to note that sediments believed to be Eocene in age were also found a few years ago at Chui Beacon, near Malindi. These beds have now been assigned to the Pliocene by Eames and Kent on the evidence provided by foraminifera (Thompson, 1956, p. 28).

The fossils collected by Miss McKinnon Wood and by the writer have provided no further suggestion of the existence of Eocene sediments and the oldest beds in the Tertiary succession of this part of East Africa are apparently of Lower Miocene age.

(2) Fundi Isa Limestones (Lower Miocene)

Miss McKinnon Wood (1930, p. 225) referred to the Kenya marine Miocene beds as the "Fundi Isa Limestones", an unfortunate term in view of the fact that younger sediments may occupy the lower seaward slopes of the Rogge ridge and possibly underlie the small dune on which the present village of Fundi Isa is situated. Since, however, Lower Miocene beds outcrop only a few miles to the west, the writer has retained the name in order to obviate any confusion.

The rocks of the formation are calcareous throughout ranging from yellowish limestones which are frequently foraminiferal to calcareous sandstones and fine-grained calcareous conglomerates, and the available evidence suggests deposition in shallow water, subject to flooding of detrital material from the adjacent coastline at times. The dominant allogenic minerals are quartz and felspar, the latter showing little alteration and including both oligoclase and microcline. Small rounded grains of zircon are frequently present, with rutile less common.

Exposures of the Fundi Isa Limestones are restricted to small water-courses near the Hadu-Marafa and Hadu-Fundi Isa roads but elsewhere Miocene sediments are inferred both from abundant fossiliferous float and also from the distribution of typical yellow and brown fertile soils, frequently bearing numerous fossil echinoid spines and calcareous fragments containing a rich micro-fauna.

Hobley collected a few fossils at a locality 120 ft. above sea-level and five to seven miles west of the since-abandoned coast town of Fundi Isa (the site apparently being not far from the present village of the same name). The specimens, which had probably been washed down on to the 120 ft. Pleistocene platform, were subsequently identified by Newton (Gregory, 1921, p. 383) as follows:—

Ostrea gingensis (Schlotheim)

*Ostrea grypheoides** (?) (Schlotheim) (= *O. orassissima,* Lam.).

Lopha virleti (?) Deshayes

Amussium cristatum Bronn.

Aequipecten cf. *malvinae* (Dubois).

The assemblage was thought to indicate the presence of Miocene (Vindobonian) sediments.

L. R. Cox (1927, p. 16) re-examined the specimens and, while confirming the identity of the two species of *Ostrea,* he added that *O. gryphoides* is still living in the Indian Ocean. Furthermore, he considered the *Lopha virleti* (?) to be an immature representative of the *hyotis* group of oysters, and the *Amussium* too poorly preserved to permit reliable specific identification but related to either *A. cristatum* (Miocene) or *A. pleuronectes* (a living form found in the Indian Ocean). The specimens identified by Newton as *Aequipecten* cf. *malvinae,* Cox considered to be *Chlamys senatoria* (Miocene to Recent). Thus Hobley's collection alone by no means provided conclusive proof of the presence of Miocene sediments.

Miss McKinnon Wood (1930, p. 225) collected a more comprehensive fauna from the neighbourhood of Hobley's locality west of Fundi Isa. Her locality 9 (*a*) was a dry stream-bed immediately west of the village of Mkwajuni, the site of which could not be traced by the writer, but which was presumably situated close to the existing

* i.e. *O. gryphoides.*

Fundi Isa village on the Hadu road. The fossils were found weathered out in the bed of the water-course and the following were subsequently identified*: —

		Known range at time of identification
Foraminifer	*Lepidocyclina gallienii*, Lemoine and Douvillé	L. Miocene
Coral	*Cycloseris radifera*, Gregory	
Echinoidea	cf. *Temnechinus rousseaui* (d'Archiac)	Miocene
Polyzoa	*Retepora* sp. a, Dighton Thomas	
	Retepora sp. b, Dighton Thomas	
	Cellepora sp.	
Mollusca	*Pecten* (*Amussiopecten*) cf. *burdigalensis*, Lamark.	Lower Miocene
	Chlamys pusio (Linné)	Oligocene–Recent
	Chlamys senatoria (Gmelin)	Miocene–Recent
	Ostrea sublingua, d'Orbigny	L. Miocene–Pliocene
	Ostrea gryphoides (Schlotheim)	Miocene–Recent
	Ostrea hyotis (Linné) (= *O. virleti*, Deshayes)	L. Miocene–Recent
	Teredo (*Kuphus*) aff. *polythalamia* (Linné)	Eocene–Recent

Although it is impossible to pinpoint Miss McKinnon Wood's locality 9 (*a*), it probably lies in the water-course a mile and a quarter W.N.W. of Fundi Isa village close to the locality of specimen 62/33. Blocks of yellow limestone and calcareous sandstone found there were, however, practically unfossiliferous and yielded only a few poorly preserved lamellibranchs including *Spondylus* cf. *ornatissimus* Böhm (specimen 62/33/1).

In another stream-bed a mile to the north-west of her locality 9 (*a*), Miss McKinnon Wood (1930, p. 6; p. 225) encountered exposures of limestone capped by reddish sand. Some of the specimens collected from this site were found *in situ* while others were lying loose in the water-course. The fauna identified from locality 9 (*a*) is listed below: —

		Known range at time of identification
Corals	*Isis obliquus*, Gregory	
	Stylophora nodosa, Gregory	
	Actinacis sabakiensis, Gregory	
Echinoidea	*Echinocyamus woodi*, Currie	
	Breynia cf. *carinata* (d'Arch. and Haime)	Miocene
	Schizaster cf. *uhligi*, Scholz	Miocene
	? *Opissaster* sp.	
Polyzoa	*Retepora* sp. c, Dighton Thomas	
Mollusca	"*Cerithium*" (? *Ptychocerithium*) *pseudocorrugatum*, d'Orbigny	Miocene
	Telescopium charpentieri (Basterot)	Oligocene–L. Miocene
	Strombus sp. A, Cox	
	Cernina callosa (J. de C. Sowerby)	L. Miocene
	Pecten (*Amussiopecten*) cf. *burdigalensis*, Lamark	L. Miocene
	Chlamys pusio (Linné)	Oligocene–Recent
	Chlamys senatoria (Gmelin)	Miocene–Recent
	Spondylus ornatissimus, A. Böhm	L. Miocene
	Ostrea folium, Linné	L. Miocene–Recent
	Cardita sp.	
	Antigona granosa (J. de C. Sowerby)	Miocene
	Corbula socialis, Martin	L. Miocene–Pliocene

* The full synonymy for each form, together with a detailed description, is given in the monograph.

During the present survey fossils (62/35) were collected from poor exposures of limestones and calcareous sandstones in a dry water-course $2\frac{3}{4}$ miles north-west of Fundi Isa village. The sediments are overlain by reddish sandy soil and the outcrop probably corresponds to Miss McKinnon Wood's locality 9 (*b*). Further down-stream the Miocene beds are overlain by poorly consolidated clays and sands of the presumed Pliocene Midadoni Beds (*see* p. 40). The fauna collected from the Miocene beds comprises:—

Foraminifera	*Miliola* sp.
	Austrotrillina howchini (Schlumberger)
	Archaias sp.
	Miogypsina (?) sp.
	Peneroplid
Corals	*Isis obliquus,* Gregory
	Isis sp. (Plate V, Fig. 6). Specimen 62/35/9
	Dendracis bifaria, Gregory
	Goniopora sp. Specimen 62/35/14
	Favites diversiformis (Michelin). Specimen 62/35/13.
	Favites irregularis (Defrance). Specimen 62/35/10
	Petrophylliella ? sp. Specimen 62/35/11
	Alcyonarian coral (Plate V, Fig. 5). Specimen 62/35/8
	Indeterminate compound coral. Specimen 62/35/12
Echinoidea	Cidarid spines
Polyzoa	*Cellepora* sp.
Mollusca	*Globularia* cf. *callosa* (J. de C. Sowerby)
	Strombus sp. A, Cox
	Strombus sp. C, Cox. Specimen 62/35/2
	Strombus sp. Specimen 62/35/5
	? Buccinid. Specimen 62/35/3
	Chlamys cf. *senatoria* (Gmelin)
	Chlamys (*Amussiopecten*) ? sp. Specimen 62/35/6
	Pectinid. Specimen 62/35/15.
	Ostrea hyotis (Linné). Specimen 62/35/7
	Ostrea cucullata, Born
	Ostrea sp.

It is of interest to note that, although the foraminifer *Miogypsina* is a common form in the Miocene Baratumu Beds of the Malindi area (Thompson, 1956, pp. 24, 26 and 27), this was the only recorded occurrence of the fossil during the present survey.

Bedding is not well defined, but the deeply weathered sediments are nearly horizontal and are invariably stained red near the junction with the overlying Magarini Sands. The lower beds are typically pale grey calcareous sandstones (62/35) in which the allogenic constituents comprise subangular quartz grains, small fragments of plagioclase having a composition near andesine, and rare small grains of garnet.

Miss McKinnon Wood made a further fossil collection from Miocene sediments at her locality 66, in "a dry stream bed near the little village of Lafihi, about six miles north-west of Marafa" (1930, p. 225). The following fauna was subsequently identified: —

Corals	*Pocillopora retusa*, Gregory	
	Thecosmilia pusilla, Gregory	
	Brachyphillia lafihensis, Gregory	
	Dendracis bifaria, Gregory	
	Isis obliquus, Gregory	
	Latimaeandra mackinnonwoodae, Gregory	
	Prionastraea diversiformis (Michelin)*	Miocene
	? *Diploastraea*	
	? *Goniastraea*	
Echinoidea	*Echinocyamus woodi*, Currie	
	? *Opissaster* sp.	
Polyzoa	*Cellepora* sp.	
Mollusca	*Trochus* sp.	
	Nerita ? cf. *teilhardi*, Collignon and Cottreau	L. Miocene
	"*Cerithium*" (? *Ptychocerithium*) *pseudocorrugatum*, d'Orbigny	Miocene
	Terebralia bidentata (Defrance)	Oligocene–Miocene
	? *Telescopium charpentieri* (Basterot)	Oligocene–L. Miocene
	Strombus sp. A, Cox	
	Strombus sp. B, Cox	
	Strombus sp. C, Cox	
	Pecten (*Amussiopecten*) cf. *burdigalensis*, Lamark	L. Miocene
	Chlamys pusio (Linné)	Oligocene–Recent
	Chlamys senatoria (Gmelin)	Miocene–Recent
	Ostrea sublingua, d'Orbigny	L. Miocene–Pliocene
	Ostrea folium, Linné	L. Miocene–Recent
	Ostrea subangulata, d'Orbigny	L. Miocene
	Cardita sp.	
	Crassatellites cf. *sulcatus* (Solander)	U. Eocene–L. Miocene
	Ostrea latimarginata (Vredenburg)	L. Miocene
	Ostrea gryphoides (Schlotheim)	Miocene–Recent
	Spondylus ornatissimus, Böhm	L. Miocene
	Lucina (*Miltha*) sp.	

* Now referred to the genus *Favites*.

There is now no trace of "Lafihi" (Lafiki) village, but a small district some five miles north of Marafa is known locally as Lafiti. Miss McKinnon Wood's locality 66 was probably very close to a locality where, during the present survey, fossils (61/3) were collected from a dry water-course, which is crossed by the Hadu-Marafa road $1\frac{3}{4}$ miles north of Mizijini and which yielded the following typical Lower Miocene assemblage:—

Foraminifera	*Miliola* sp.
	Alveolinids, Lenticulinids and a Peneroplid
Corals	*Pocillopora* sp.
	Dendracis bifaria, Gregory (Plate V, Figs. 4 (*a*) and (*b*))
	Cycloseris radifera, Gregory
	Favites diversiformis (Michelin)
	Montastraea sp. 1, Dighton Thomas
	Montastraea sp. 2, Dighton Thomas
	Montastraea guettardi (Defrance)
	Alcyonarian coral ?
Echinoidea	*Fibularia* (?) cf. *woodi* (Currie) [= *Echinocyamus woodi,* Currie]
	Cidarid plates and radioles
Polyzoa	*Acanthodesia nelliiformis,* Harmer
	Steganoporella sp.
	Nellia oculata (Busk)
	Nellia ? sp.
	Retepora sp.
	Margaretta sp.
	Cellepora sp. (Plate V, Fig. 3). Specimen 61/3/8
Mollusca	*Natica* sp. (Plate III, Fig. 8). Specimen 61/3/2
	Cerithium sp.
	Xenophora sp.
	Architectonica affinis (J. de C. Sowerby)
	Strombus sp. C, Cox
	Strombus sp.
	Cypraea sp. (Plate III, Fig. 7). Specimen 61/3/1
	Cymatium sp. (Plate III, Fig. 6). Specimen 61/3/3
	Conus sp.
	Arca (*Trisidos*) *semitorta,* Lamarck
	Pecten (*Amussiopecten*) cf. *burdigalensis,* Lamarck

Anomia sp.

Ostrea gryphoides (Schlotheim) (Plate IV, Figs. 1 (*a*) and 1 (*b*)). Specimen 61/3/4

Ostrea cf. *gryphoides* (Schlotheim) (Plate IV, Figs. 2 (*a*) and 2 (*b*)). Specimen 61/3/7

Ostrea subangulata, d'Orbigny

Ostrea folium (Linné). Specimen 61/3/9

Venericardia ? sp.

Lucina (*Anadontia*) *globulosa,* Deshayes.

Less than a mile north-west from the locality of specimen 61/3 poor exposures of white and yellow-brown calcareous sandstones and limestones were encountered in a small tributary to the main water-course. In one section about 15 ft. of the sediments, probably dipping at a shallow angle to the west, are exposed. The fauna listed below (61/12), was collected at this locality, the specimens being found *in situ* or lying loose in the stream bed:—

Foraminifera	A Peneroplid
	Archaias cf. *aduncus* (Fichtel and Moll)
Corals	*Favites irregularis* (Defrance)
	Porites sp. cf. *gajensis,* Duncan
	Petrophylliella ? sp.
Echinoidea	Cidarid radioles
Polyzoa	*Cellepora* sp.
Mollusca	*Globularia callosa* (J. de C. Sowerby)
	Strombus sp. C, Cox (Plate III, Figs 4 and 5). Specimens 61/12/3 and 61/12/4
	Conus sp. (Plate III, Fig. 2). Specimen 61/12/1
	Terebra neglecta, Michelotti
	Lucina (*Anadontia*) *globulosa,* Deshayes (Plate V, Figs. 2 (*a*) and 2 (*b*)). Specimen 61/12/2
	Teredo (*Kuphus*) *polythalamia* (Linné)
Fish	*Carcharinus* sp. (tooth)

A quarter of a mile further west similar fossiliferous sandstones and pale limestones dipping up to 5° to north-west outcrop in another small water-course. The following fossils (61/13) collected from them have been identified:—

Foraminifer	*Archaias* sp.
Coral	*Cladocora* sp. cf. *cespitosa* (Linn.)
Mollusca	*Ostrea* sp.

Further small collections of fossils were made from poorly exposed Miocene beds between the Lafiti and Ramada districts. Buff-coloured calcareous sandstones and limestones outcrop in a water-course 2½ miles N.N.W. of Mizijini village where the sediments yielded the following fauna (61/14):—

Echinoidea	Portion of test (order Spatangoida-Amphisternata)
Mollusca	? Muricid. Specimen 61/14/1
	Meretrix sp. Specimen 61/14/2

A mile to the north-east pale limestones are exposed in a dry stream-bed immediately north of a small village called Ramada (not to be confused with the settlement of the same name on the Hadu-Fundi Isa road). The fauna collected (61/28) comprises:—

Foraminifer	*Archaias* sp. cf. *aduncus* (Fichtel and Moll)
Coral	*Dendracis bifaria,* Gregory
Echinoidea	Cidarid spines
Polyzoa	*Cellepora* sp.
Mollusca	*Strombus* sp. C, Cox (Plate III, Fig. 3). Specimen 61/28/1
	Conus sp.

The last two localities described may be close to the site where Hobley collected his "Eocene" fauna.

A mile south-west of the small roadside shops at Ramada, limestones are exposed in a stream-bed and yielded a few eroded internal gastropod casts (62/39) which have been referred to the following genera:—

Cerithium sp. (Plate III, Fig. 1). Specimen 62/39/1

Strombus sp. C, Cox

Strombus sp.

Along the Marafa-Hadu road a number of fossils were collected from float blocks of limestone or from the soil. The following specimens (61/45) were recovered from a dam-site, three-quarters of a mile north of Mizijini settlement:—

Foraminifer	*Archaias* cf. *aduncus* (Fichtel and Moll)
Echinoidea	Spatangoid
Mollusca	*Globularia* cf. *callosa* (J. de C. Sowerby)
	Terebralia cf. *charpentieri* (Basterot). Specimen 61/45/1
	Conus sp.
	Chlamys pusio (Linné)
	Pectinid
	Ostrea sp. Specimen 61/45/3
	? Tellinid. Specimen 61/45/2

Fragments of limestone, found at the roadside $3\frac{1}{2}$ miles south of Hadu, yielded the following fauna (61/7):—

Foraminifera	*Austrotrillina howchini* (Schlumberger)
	Archaias cf. *aduncus* (Fichtel and Moll)
	Archaias sp.
	Miliola sp.
	Rotalia sp.
	Amphistegina sp. or *Operculinella* sp.
	Peneroplid fragments
Polyzoa	Fragments
Fish	*Notidanus* sp. (tooth)

The following foraminifera have also been identified by A. G. Davis from material collected at other localities beside the Hadu-Marafa road:—

$2\frac{1}{2}$ miles south of the village of Dzitsuhe (Specimen 61/6):

Rotalia sp.

$1\frac{1}{4}$ miles south of Hadu (Specimen 61/8):

Archaias sp.
Borelis sp.
Austrotrillina sp.
Miliola spp.

$1\frac{3}{4}$ miles south of Hadu (Specimen 61/9):

Austrotrillina sp.
Miliola spp.

By the roadside at the village of Dzitsuhe (Specimen 61/10):

Archaias sp.
Miliola spp.

About 1 mile south-east of Hadu on the Fundi Isa road (Specimen 61/17):

Borelis sp.
Miliola spp.

No exposures of Miocene sediments were encountered in the Hadu district, but the road to Fundi Isa traverses a number of deep valleys which are occupied by dry water-courses containing float blocks of yellowish limestones and calcareous sandstones. The following foraminifera were identified in a fragment of limestone (Specimen 61/16) collected two miles south-east of Hadu:—

Alveolina (a small species)
Miliola (two or more species represented)
Textularia sp.
Lenticulina sp.
? *Dendritina* sp.
Austrotrillina sp.
Peneroplid.

KEY TO PLATES II-VIII

The specimen localities are marked on the maps.

Plate II—Triassic and Jurassic Fossils from the Hadu Area

Fig. 1—Silicified wood from the Mazeras Sandstones (Specimen No. 61/99/1).

Fig. 2—Belemnite (family Belemnopsidae (?)) from Upper Jurassic limestones (Specimen No. 61/68/1).

Fig. 3—Belemnite (family Belemnopsidae) (Specimen No. 61/68/2).

Fig. 4—Ammonite (perisphinctid) from Upper Jurassic limestone (Specimen No. 61/70).

Plate III—Lower Miocene Gastropods from the Hadu-Fundi Isa Area

Fig. 1—*Cerithium* sp. (Specimen No. 62/39/1).

Fig. 2—*Conus* sp. (Specimen No. 61/12/1).

Fig. 3—*Strombus* sp. C, Cox (Specimen No. 61/28/1).

Fig. 4—*Strombus* sp. C, Cox (Specimen No. 61/12/3).

Fig. 5—*Strombus* sp. C, Cox (Specimen No. 61/12/4).

Fig. 6—*Cymatium* sp. (Specimen No. 61/3/3).

Fig. 7—*Cypraea* sp. Specimen No. 61/3/1).

Fig. 8—*Natica* sp. (Specimen No. 61/3/2).

Fig. 9—*Strombus* sp. C, Cox (Specimen No. 62/35/2).

Fig. 10—Buccinid ? (Specimen No. 62/35/3).

Plate IV—Lower Miocene Lamellibranchs from the Hadu Area

Figs. 1 (*a*) and 1 (*b*)—*Ostrea gryphoides* (Schlotheim)
(*a*) internal and (*b*) external view of the same valve (Specimen No. 61/3/4).

Figs. 2 (*a*) and 2 (*b*)—*Ostrea* cf. *gryphoides* (Schlotheim)
(*a*) internal and (*b*) external view of the same valve (Specimen No. 61/3/7).

Plate V—Lower Miocene Lamellibranchs, Corals and Polyzoa from the Hadu-Fundi Isa Area

Figs. 1 (*a*) and 1 (*b*)—*Ostrea hyotis* (Linné) (Specimen No. 62/35/7).

Figs. 2 (*a*) and 2 (*b*)—*Lucina* (*Anadontia*) *globulosa,* Deshayes (Specimen No. 61/12/2).

Fig. 3—*Cellepora* sp. (Specimen No. 61/3/8).

Figs. 4 (*a*) and 4 (*b*)—*Dendracis bifaria,* Gregory (Specimen No. 61/3/6).

Fig. 5—Alcyonarian coral (Specimen No. 62/35/8).

Fig. 6—*Isis* sp. (Specimen No. 62/35/9).

Plate VI—Lamellibranchs from the Midadoni Beds of the Fundi Isa Area

Figs. 1 (*a*) and (*b*)—External and internal views of a valve of *Amusium pembaense,* Eames and Cox (Specimen No. 62/23/3).

Fig. 2—*Chlamys senatoria* (Gmelin) (Specimen No. 62/23/8).

Fig. 3—*Chlamys senatoria* (Gmelin) (Specimen No. 62/23/9).

Fig. 4—*Chlamys senatoria* (Gmelin) (Specimen No. 62/23/10).

Figs. 5 (*a*) and 5 (*b*)—External and internal views of a valve of *Ostrea* sp. (Specimen No. 62/23/6).

Figs. 6 (*a*) and 6 (*b*)—External and internal views of a valve of *Ostrea hyotis* (Linné) (Specimen No. 62/23/1).

Plate VII—Lamellibranchs, Echinoids and Gastropods from the Midadoni Beds of the Fundi Isa Area

Figs. 1 (*a*) and 1 (*b*)—External and internal views of *Ostrea hyotis* (Linné) (Specimen No. 62/37/10).

Figs. 2 (*a*) and 2 (*b*)—External and internal views of a valve of *Ostrea hyotis* (Linné) (Specimen No. 62/23/7).

Figs. 3 (*a*) and 3 (*b*)—Apical and lateral views of *Opechinus* cf. *rousseaui* (d'Archiac and Haime) (Specimen No. 62/23/16).

Fig. 4—Interambulacral plate (Ciderid) (Specimen No. 62/23/17).

Fig. 5—Cidarid spine (Specimen No. 62/23/18).

Fig. 6—Cidarid spine (Specimen No. 62/23/21).

Fig. 7—Cidarid spine (Specimen No. 62/23/19).

Fig. 8—Cidarid spine (Specimen No. 62/23/20).

Fig. 9—Tube of *Teredo* (*Kuphus*) aff. *polythalamia* (Linné) (Specimen No. 62/23/4).

Fig. 10—*Ostrea hyotis* (Linné) (Specimen No. 62/23/5).

Fig. 11—*Strombus* sp. C, Cox (Specimen No. 62/37/2).

Fig. 12—*Terebralia bidentata* (Defrance) (Specimen No. 62/37/1).

Fig. 13—Strombid (? *Hippochrenes* sp.) (Specimen No. 62/37/4).

Plate VIII—Pleistocene Fossils from the Fundi Isa Area

Fig. 1—*Terebralia* (Terebralia) *palustris* (Linné) (Specimen No. 62/38/1).

Fig. 2—*Terebralia* (Terebralia) aff. *palustris* (Linné) (Specimen No. 62/4/1).

Fig. 3—*Terebralia* (Terebralia) *palustris* (Linné) (Specimen No. 62/13/1).

Fig. 4—*Terebralia* (Terebralia) *palustris* (Linné) (Specimen No. 62/13/4).

Fig. 5—*Goniastraea retiformis* (Lamark) (Specimen 63/7/1).

Fig. 6—*Chlamys* (*Aequipecten*) cf. *flabelloides* (Reeve) (Specimen No. 62/12/3).

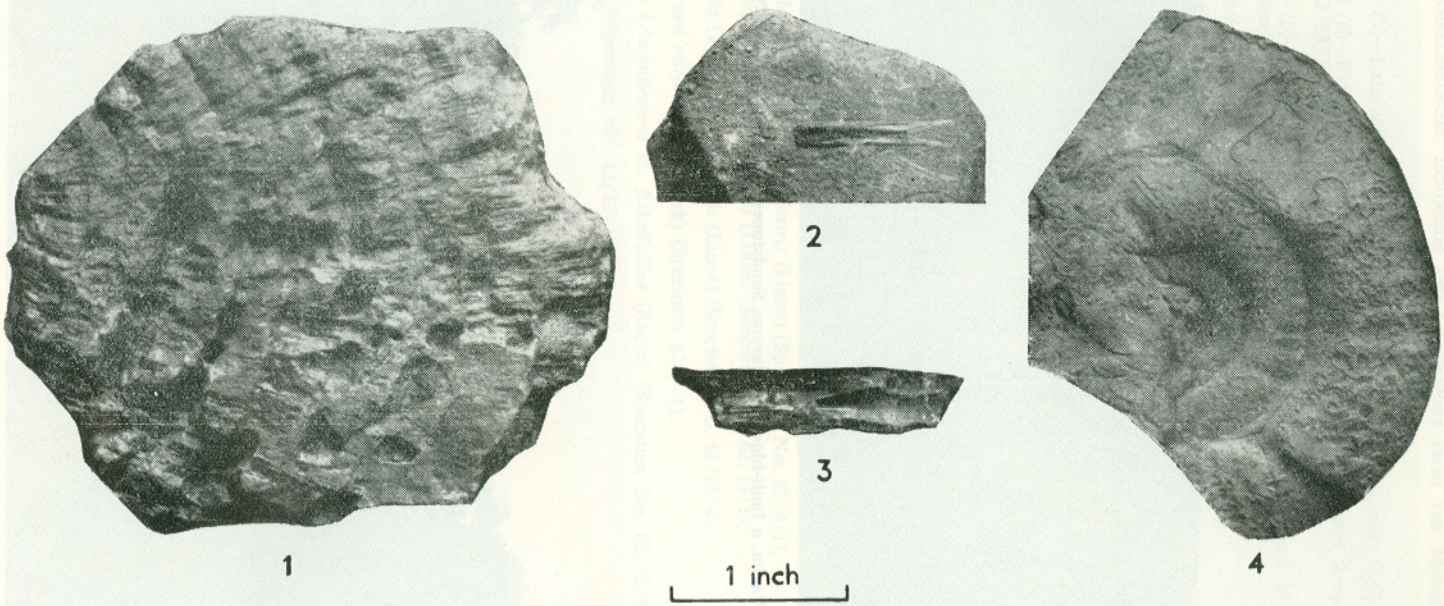
Fig. 7—Cassidid (Specimen No. 62/12/1).

Plate I

Fig. 1—Wachu, a fault-block of Mazeras Sandstones, surrounded by the Nyika plain

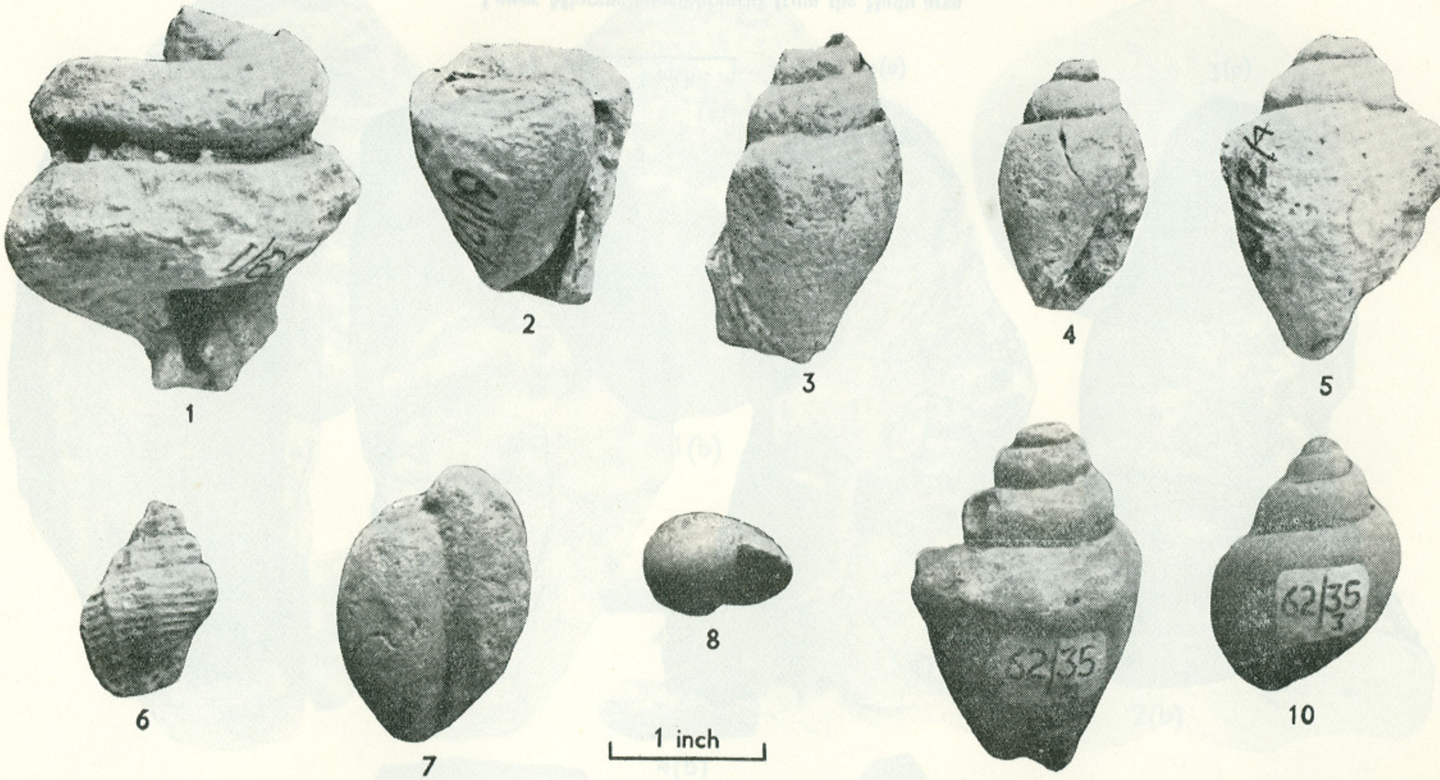
Fig. 2—The Ozi (Tana) River, several miles downstream from Kibokoni

Plate II



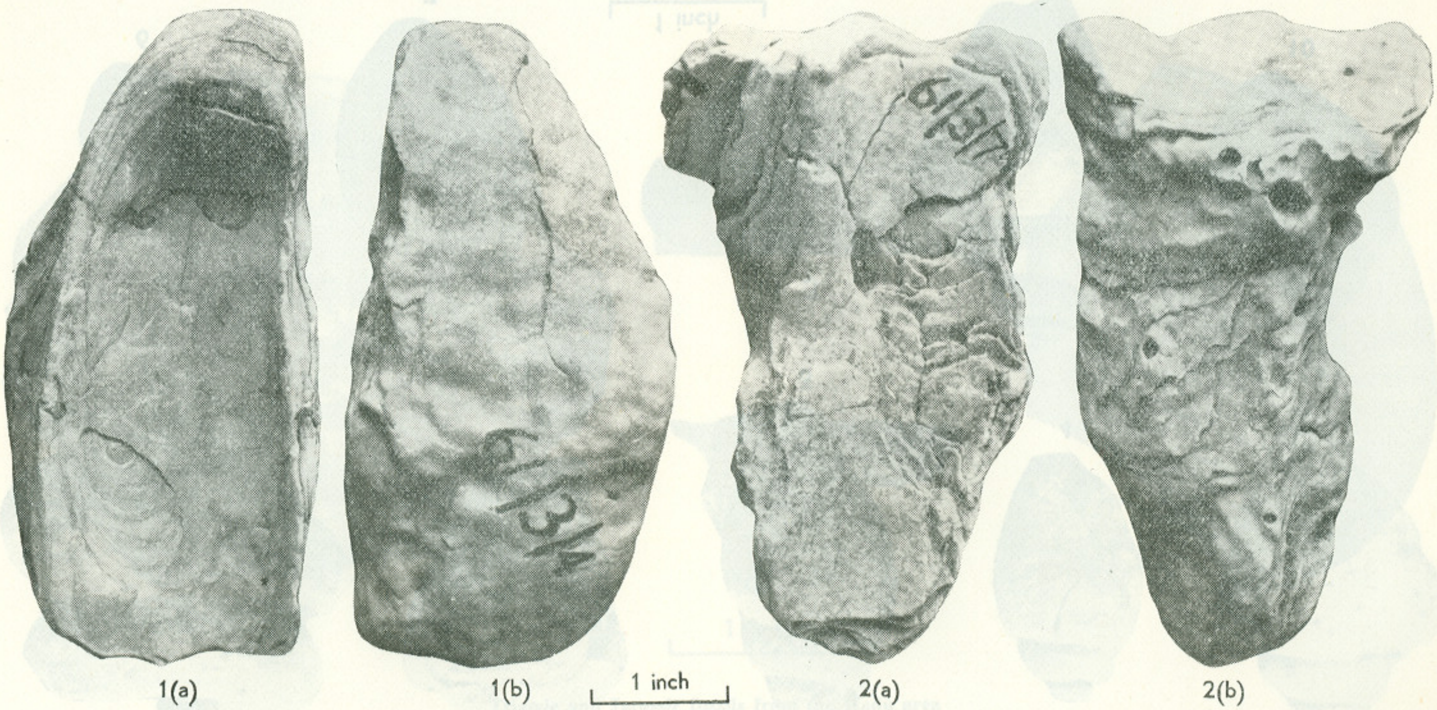
Triassic and Jurassic fossils from the Hadu area

Plate III



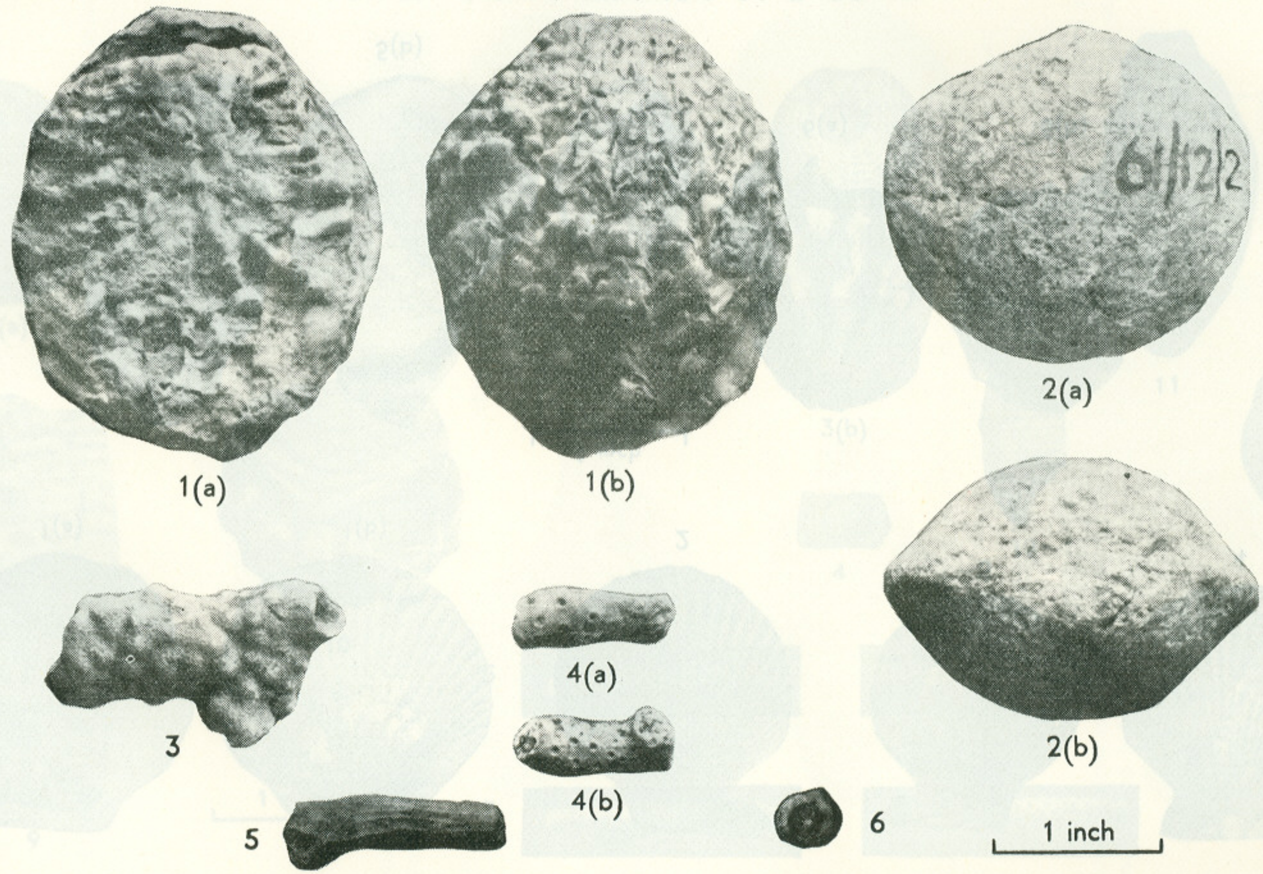
Lower Miocene gastropods from the Hadu-Fundi Isa area

Plate IV



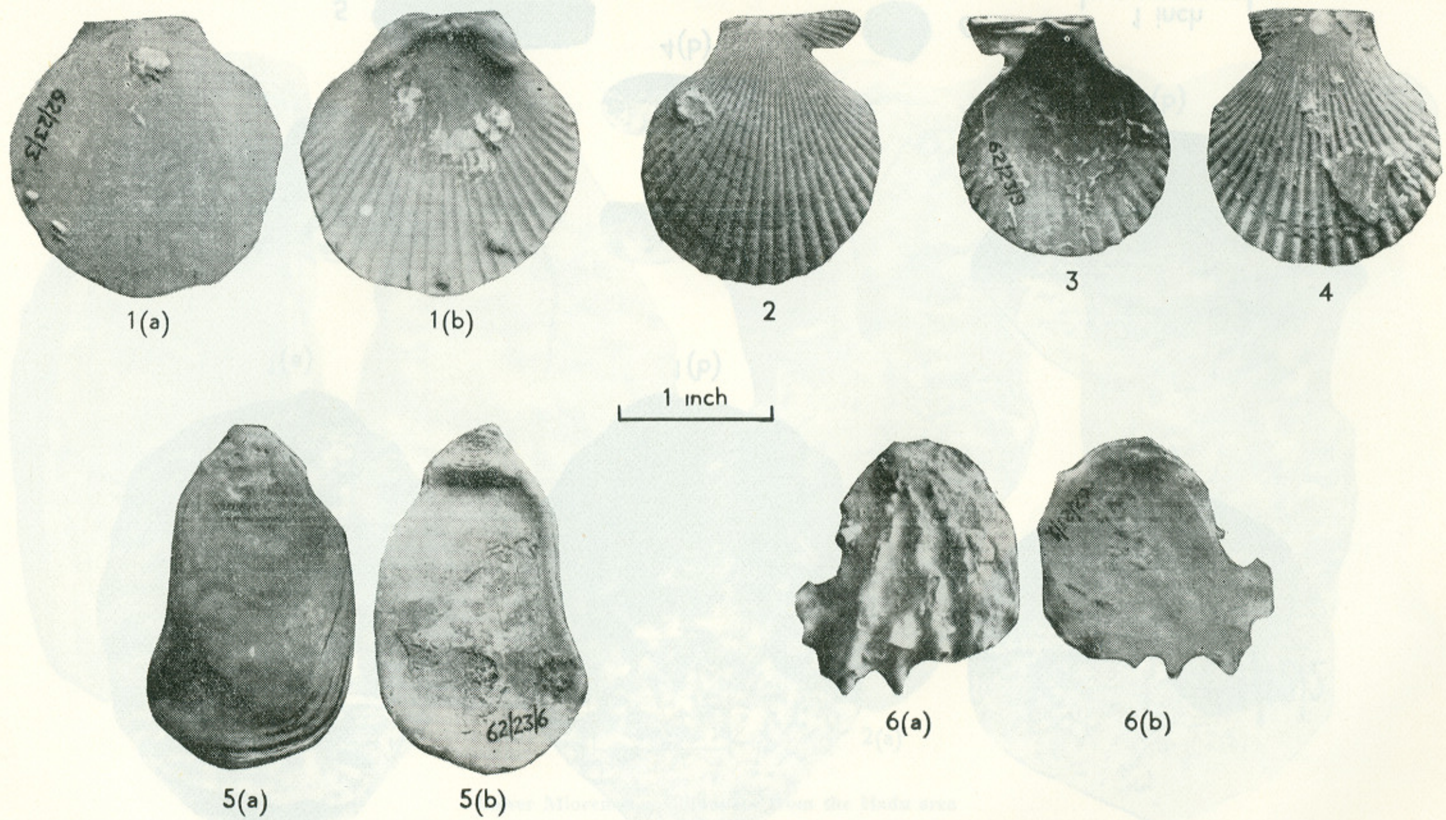
Lower Miocene lamellibranchs from the Hadu area

Plate V



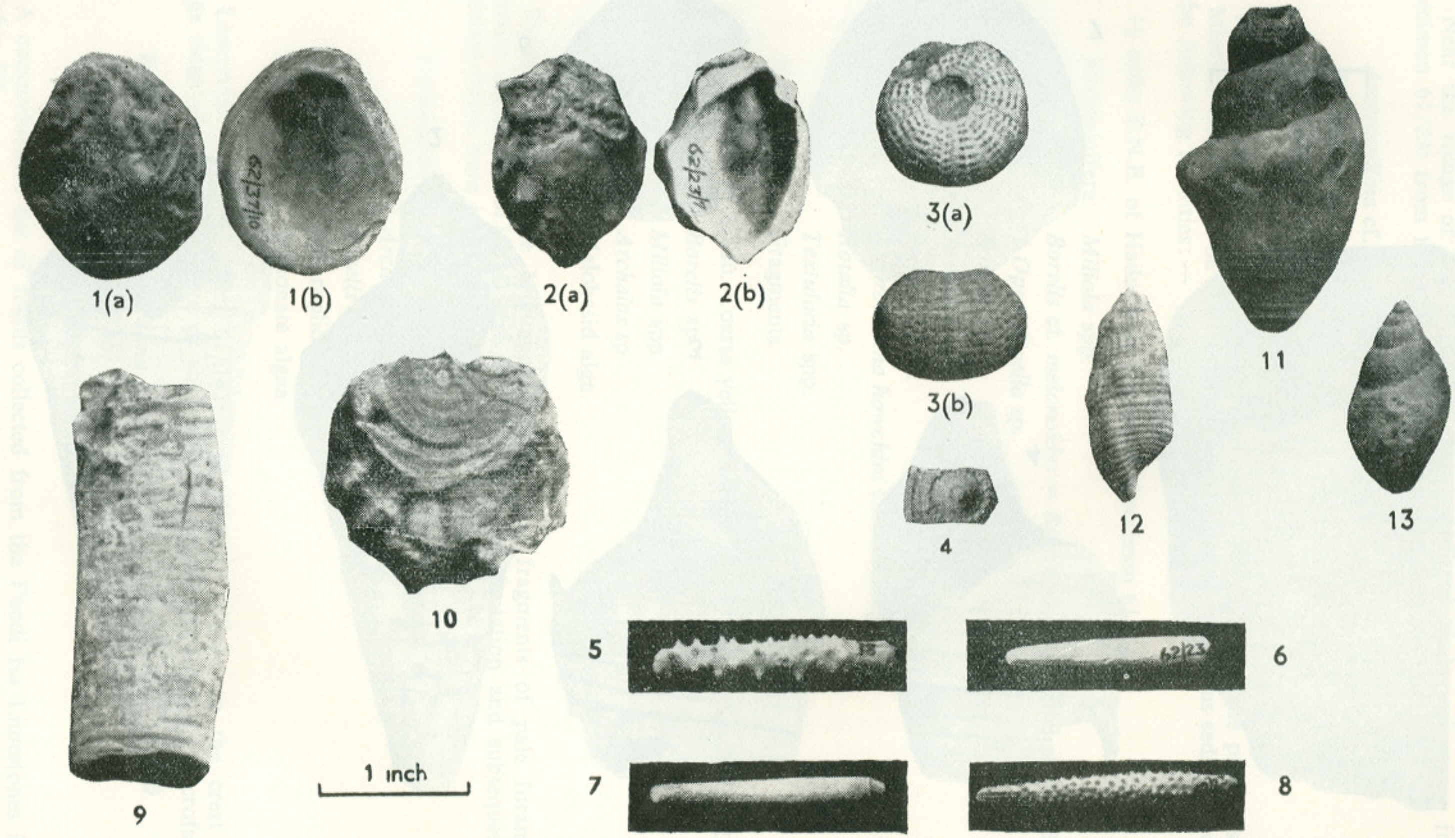
Lower Miocene lamellibranchs, corals and polyzoa from the Hadu-Fundi Isa area

Plate VI



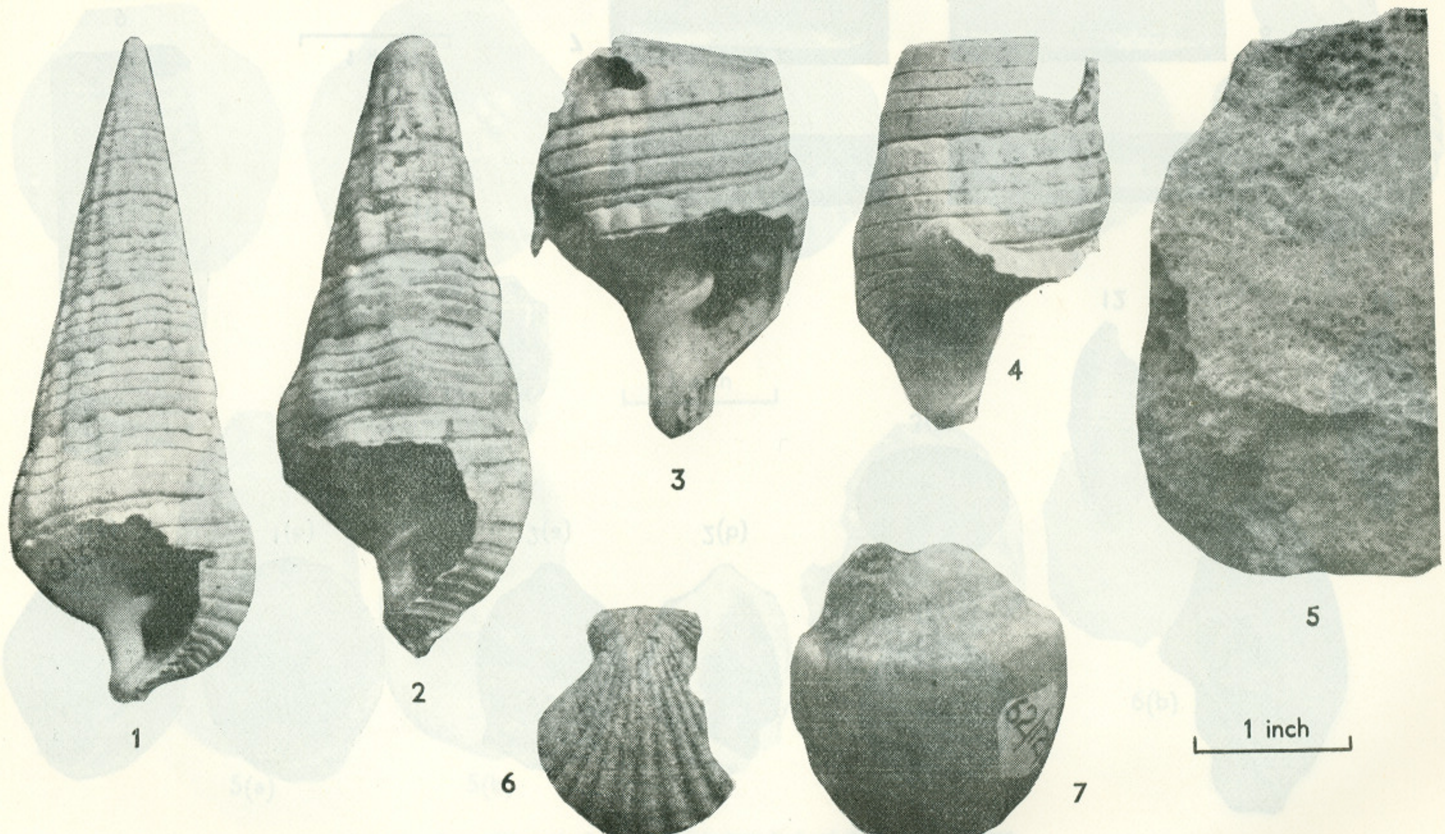
Lamellibranchs from the Midadoni Beds of the Fundi Isa area

Plate VII



Lamellibranchs, echinoids and gastropods from the Midadoni Beds of the Fundi Isa area

Plate VIII



Pleistocene fossils from the Fundi Isa area

Near the village of Bukatwavi, $1\frac{1}{2}$ miles N.N.E. of Hadu, calcareous fragments (Specimen 61/23) from the soil yielded the following microfauna:—

Austrotrillina cf. *howchini* (Schlumberger)
Archaias sp.
Amphistegina sp.

North-east of Hadu, at an elevation of about 400 ft. above the present sea-level, the Miocene outcrop can be inferred from float blocks of calcareous sediments collected at the following localities:—

$1\frac{3}{4}$ miles E.N.E. of Hadu. Pale limestone (Specimen 61/148):

Foraminifera	*Miliola* spp.
	Borelis cf. *melonoides* = *Borelis melo* (Fichtel and Moll)
	? *Operculinella* sp.
	Borelis sp.
	Archaias sp.
	Peneroplis sp.
	Austrotrillina howchini (Schlumberger)
	Rotalia sp.
	Textularia spp.
Polyzoa	Fragments.

2 miles E.N.E. of Hadu. Coarse yellow calcareous sandstone (Specimen 62/40):

Foraminifera	*Borelis* sp.
	Miliola spp.
	Archaias sp.
Alga	Melobesid alga.

Further north in the Mulunguni district float fragments of pale foraminiferal limestone (Specimen 61/142) were encountered in a plantation and subsequently the following forms were identified: —

Foraminifera	*Austrotrillina howchini* (Schlumberger)
	Archaias sp.
	Borelis sp.
	Peneroplid fragments.
Algae	Siphonate algae.

Limestone float (Specimen 61/143) near Waressa village on the crest of the Rogge ridge and at an elevation of about 550 ft., yielded the following microfauna:—

Foraminifera	*Austrotrillina howchini* (Schlumberger)
	Archaias sp.
	Peneroplid fragments.

A comprehensive list of fossils collected from the Fundi Isa Limestones is given in Table III.

Table III—Fossils Collected from the Fundi Isa Limestones

Fossil	Locality (Definitions are given in an appendix to the table)																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Foraminifera																								
Textularia spp.												×							×					
Miliola spp.				×		×	×	×	×			×	×						×		×	×		
Austrotrillina howchini (Schlumberger) ..						×								?			×	×	×			×		
Austrotrillina sp.							×	×				?												
Lenticulina sp.												×												
Lenticulinids				×																				
Operculinella sp.						?													?					
Peneroplis sp.																			×					
Peneroplids				×		×				×		×					×	×	×		×	×		
Dendritina sp.												?												
Archaias cf. *aduncus* (Fichtel and Moll) ..						×				×					×	×								
Archaias sp.						×	×		×		×			×			×	×	×		×	×		
Alveolina sp.												×												
Alveolinids				×																				
Borelis cf. *melonoides*																			×					

TABLE III—(*Contd.*)

FOSSIL	LOCALITY (Definitions are given in an appendix to the table)																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Borelis sp.							×						×				×		×		×			
Rotalia sp.					×	×													×					
Amphistegina sp.						?								×										
Lepidocyclina gallienii, Lemoine & Douvillé	×																							
Miogypsina ? sp.																						×		
CORALS																								
Isis obliquus, Gregory		×	×																			×		
Isis sp.																						×		
Stylophora nodosa		×																						
Pocillopora retusa, Gregory			×																					
Pocillopora sp.				×																				
Dendracis bifaria, Gregory			×	×											×							×		
Latimaeandra mackinnonwoodae, Gregory ..			×																					
Brachyphyllia lafihensis, Gregory			×																					
Cycloseris radifera, Gregory	×			×																				
Goniopora sp.										×												×		

TABLE III—(*Contd.*)

FOSSIL	LOCALITY (Definitions are given in an appendix to the table)																							
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Actinacis sabakiensis, Gregory		×																						
Porites sp. cf. *gajensis*, Duncan										×														
Thecosmilia pusilla, Gregory			×																					
Favites diversiformis (Michelin)			×	×																		×		
Favites irregularis (Defrance)										×												×		
Goniastraea ?			×																					
Cladocora sp. cf. *cespitosa* (Linn.)											×													
Montastraea guettardi (Defrance)				×																				
Montastraea sp. 1, Dighton Thomas ..				×																				
Montastraea sp. 2, Dighton Thomas ..				×																				
Diploastraea ?			×																					
Petrophylliella ? sp.										×												×		
ECHINOIDEA																								
cf. *Temnechinus rousseaui* (d'Archiac) ..	×																							
Fibularia (?) cf. *woodi* (Currie) [= *Echinocyamus woodi*, Currie] ..		×	×	×																				

TABLE III—(*Contd.*)

Fossil	Locality (Definitions are given in an appendix to the table)																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
? *Opissaster* sp.		×	×																					
Schizaster cf. *uhligi*, Scholz		×																						
Breynia cf. *carinata* (d'Arch. and Haime) ..		×																						
Spatangoids																×							×	
POLYZOA																								
Acanthodesia nelliiformis, Harmer				×																				
Steganoporella sp.				×																				
Nellia oculata (Busk)				×																				
Nellia ? sp.				×																				
Retepora sp. a, Dighton Thomas	×																							
Retepora sp. b, Dighton Thomas	×																							
Retepora sp. c, Dighton Thomas		×																						
Retepora sp.				×																				
Margaretta sp...				×																				
Cellepora sp.	×		×	×						×					×	×						×		

Table III—(*Contd.*)

Fossil	Locality (Definitions are given in an appendix to the table)																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Gastropoda																								
Architectonica affinis (J. de C. Sowerby) ..				×																				
Nerita ? *teilhardi*, Collignon & Cottreau			×																					
Natica sp.				×																				
Globularia callosa (J. de C. Sowerby) ..										×						×						×		
Trochus sp.			×																					
Cernina callosa (J. de C. Sowerby)		×																						
Xenophora sp.				×																				
Terebralia bidentata (Defrance)			×																					
Terebralia cf. *charpentieri* (Basterot) ..																×								
"*Cerithium*" (? *Ptychocerithium*) *pseudocorrugatum*, d'Orbigny		×	×																					
Cerithium sp.				×																×				
Telescopium charpentieri (Basterot)		×	?																					
Strombus sp. A, Cox		×	×																			×		
Strombus sp. B, Cox			×																					

TABLE III—(*Contd.*)

Fossil	Locality (Definitions are given in an appendix to the table) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Strombus sp. C, Cox ..			×	×							×				×					×		×		
Strombus sp.				×																×		×		
Cymatium sp.				×																				
Cypraea sp.				×																				
Terebra neglecta, Michelotti										×														
Conus sp.				×						×					×	×								
LAMELLIBRANCHIA																								
Arca (Trisidos) semitorta, Lamark				×																				
Pecten (Amussiopecten) cf. *burdigalensis*, Lamark	×	×	×	×																				
Chlamys pusio (Linné)	×	×														×								
Chlamys senatoria (Gmelin)	×	×	×																			?		
Chlamys (Amussiopecten) ? sp.																						×		
Spondylus ornatissimus, A. Böhm		×	×																					?
Anomia sp.				×																				
Ostrea gryphoides (Schlotheim) ..	×		×	×																				
Ostrea hyotis (Linné)	×																					×		

Table III—(*Contd.*)

Fossil	Locality (Definitions are given in an appendix to the table)																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Ostrea folium, (Linné)		×	×	×																				
Ostrea subangulata, d'Orbigny			×							×														
Ostrea latimarginata (Vredenberg)			×																					
Ostrea cucullata, Born																						×		
Ostrea sp.											×					×						×		
Crassatellites cf. *sulcatus* (Solander)			×																					
Cardita sp.		×	×																					
Venericardia ? sp.				×																				
Lucina (*Miltha*) sp.			×																					
Lucina (*Anadontia*) *globulosa*, Deshayes ..				×						×														
Antigona granosa (J. de C. Sowerby) ..		×																						
Meretrix sp.																							×	
Corbula socialis, Martin		×																						
Teredo (*Kuphus*) aff. *polythalamia* (Linné) ..	×									×														
Fish																								
Notidanus sp.						×																		
Carcharinus sp.										×														

Column

1. Miss McKinnon Wood's locality 9(*a*); near the present village of Fundi Isa.
2. Miss McKinnon Wood's locality 9(*b*); one mile west of locality 9(*a*).
3. Miss McKinnon Wood's locality 66; "about six miles north-west of Marafa".
4. (Specimen No. 61/ 3) 1¾ miles north of Mizijini village and beside the Hadu–Marafa road.
5. (Specimen No. 61/ 6) 2½ miles south of Dzitsuhe village and beside the Hadu–Marafa road.
6. (Specimen No. 61/ 7) 3½ miles south of Hadu and beside the Hadu–Marafa road.
7. (Specimen No. 61/ 8) 1¼ miles south of Hadu and beside the Hadu–Marafa road.
8. (Specimen No. 61/ 9) 1¾ miles south of Hadu and beside the Hadu–Marafa road.
9. (Specimen No. 61/ 10) By the roadside at Dzitsuhe village.
10. (Specimen No. 61/ 12) 2 miles N.N.W. of Mizijini village.
11. (Specimen No. 61/ 13) 2¼ miles N.N.W. of Mizijini village.
12. (Specimen No. 61/ 16) 2 miles south-east of Hadu and beside the Fundi Isa road.
13. (Specimen No. 61/ 17) 1 mile south-east of Hadu and beside the Fundi Isa road.
14. (Specimen No. 61/ 23) 1½ miles N.N.E. of Hadu, near the village of Bukatwavi.
15. (Specimen No. 61/ 28) 3 miles S.S.E. of Dzitsuhe village.
16. (Specimen No. 61/ 45) ¾ mile north of Mizijini village and beside the Hadu–Marafa road.
17. (Specimen No. 61/142) Mulunguni, 2¾ miles N.N.E. of Hadu.
18. (Specimen No. 61/143) Near Waressa village, 5¼ miles N.N.E. of Hadu.
19. (Specimen No. 61/148) 1¾ miles E.N.E. of Hadu.
20. (Specimen No. 62/ 39) 1 mile south-west of the small shops at Ramada.
21. (Specimen No. 62/ 40) 4¾ miles N.N.W. of Ramada shops and 2 miles E.N.E. of Hadu
22. (Specimen No. 62/ 35) 2¾ miles north-west of Fundi Isa village.
23. (Specimen No. 61/ 14) 2½ miles N.N.W. of Mizijini village.
24. (Specimen No. 62/ 33) 1¼ miles W.N.W. of Fundi Isa village.

TABLE III, PART 2—FOSSILS COLLECTED FROM THE MIDADONI BEDS

Fossil	Locality (Definitions are given in an appendix to the table) 1	2	3	4	5
FORAMINIFERA					
Miliolids					×
Austrotrillina howchini (Schlumberger) ..				×	?
Taberina sp.					?
Archaias sp.					?
Borelis sp.					?
HYDROZOA					
Millepora sp.	×				
CORALS					
Isid ?		×			
Stylophora nodosa, Gregory ..		×			
Dendracis bifaria, Gregory ..		×			
Desmophyllum sp.		×			
ECHINOIDEA					
Cidarids			×		
Opechinus cf. *rousseaui* (d'Archiac and Haime)			×		
POLYZOA					
Cellepora sp.	×	×			
Celleporaria sp.			×		

TABLE III, PART 2—(*Contd.*)

Fossil	Locality (Definitions are given in an appendix to the table)				
	1	2	3	4	5
GASTROPODA					
Globularia cf. *callosa* (J. de C. Sowerby) ..	×				
Terebralia bidentata (Defrance)	×				
Strombus sp. A, Cox	×				
Strombus sp. C, Cox	×	×			
Strombus sp.	×				
Campanile sp.	×				
Conus sp.	×	×			
LAMELLIBRANCHIA					
Chlamys senatoria (Gmelin)			×		
Amusium pembaense, Eames and Cox ..			×		
Anomia sp.			×		
Ostrea hyotis (Linné)	×		×		
Ostrea cf. *gryphoides* (Schlotheim)		×			
Ostrea sp.			×		
Teredo (*Kuphus*) aff. *polythalamia* (Linné) ..	×	×	×		

Column

1. (Specimen No. 62/37) 3¼ miles N.N.W. of Fundi Isa village.
2. (Specimen No. 62/14) 400 yards south of Fundi Isa village.
3. (Specimen No. 62/23) 1½ miles due east of MK North trigonometrical beacon.
4. (Specimen No. 62/20) 18 miles N.N.W. of Fundi Isa village and 7½ miles west of the Malindi–Garsen road.
5. (Specimen No. 62/21) ¼ mile west of the locality of specimen 62/20.

The Significance of the Lower Miocene Sediments along the Rogge Ridge

Fossiliferous float, which yielded a sparse foraminiferal microfauna including *Austrotrillina howchini* (Schlumberger), *Archaias* sp., and *Borelis* sp., was collected along the top of the Rogge ridge at altitudes up to 550 ft. O.D. These occurrences of presumed Lower Miocene sediments prompt further inquiry into the question of the Miocene sea-level and the possibility of later up-warping of the beds. Marine deposits of this age have been recorded from a number of localities in Kenya, Tanganyika, Pemba, Zanzibar, Madagascar and Somalia and to the south of the present area the Lower Miocene beds generally outcrop at comparatively low levels near the coastline, although at Sing'mgome and Mize Miumbe hills on Pemba Island sediments thought to be of this age occur at over 300 ft. O.D. (Stockley, 1928, p. 14 and map). Along the coast of Somalia, fossiliferous Oligocene and Lower Miocene limestones, marls and sandstones are exposed at a number of localities, for example the section in the cliffs beneath the lighthouse at Ras Hafun displays a conformable Oligocene-Lower Miocene sequence with beds of the latter age at 119 m. (390 ft.) above O.D. (Stefanini, 1937, p. 16). Sketch maps of the same district suggest that Lower Miocene sediments (forming part of the Hafun Series) occur at appreciably higher altitudes further inland.

In the present area it is not unlikely that faulting and folding later than the Lower Miocene have been partly responsible for a local uplift of the Fundi Isa Limestones along the Rogge ridge, although the paucity of exposures precludes any reliable estimate of the magnitude of these structural features.

(3) Midadoni Beds (Pliocene ?)

Three miles north-west of Fundi Isa village the Miocene limestones can be seen to be unconformably overlain by poorly consolidated sediments which are provisionally assigned to the Pliocene. It must be stressed, however, that the palaeontological evidence is at present inconclusive and these deposits, which the writer calls the "Midadoni Beds", may form part of the Miocene sequence or possibly represent Lower Pleistocene accumulations.

Marine Pliocene beds occur near Chui beacon in the Malindi area (Thompson, 1956, p. 28) where they have yielded a number of foraminifera including *Operculinella* and *Heterostegina*. Nearby, between Sabaki village and the Sabaki river, possible Pliocene beds outcrop up to about 100 ft. O.D. The Pliocene sea, however, apparently reached much higher levels along the Kenya coast, for example Caswell (1953, p. 54) suggests a sea-level of about 300 ft. O.D., which is in agreement with figures recorded in Europe.

The Midadoni Beds are inferred between 90 ft. and 280 ft. above present sea-level on the lower eastern slopes of Boyani hill (MK NORTH) and northwards along the foot of the Rogge scarp, and it is therefore considered likely that they represent a phase of Pliocene marine deposition. The limited occurrence of proved Pliocene sediments along the southern part of the Kenya coast may be attributed to erosion, following the rejuvenation of existing drainage systems in response to the rapid fall in sea-level in Lower Pleistocene times. In support of this supposition, it must be remembered that the Miocene beds are also only poorly represented further south (Eames and Kent, 1955, pp. 343-44).

A section of the Midadoni Beds and the upper part of the Fundi Isa Limestones exposed in a water-course three miles north-west of Fundi Isa, and about 195 ft. above sea-level, has the following sequence:—

		Feet	(Metres)
3. Brown soil		2	(0·6)
2. Yellow-brown clayey sands containing pebbles and boulders of limestone with quartz pebble-bed at the base	Midadoni Beds (Pliocene ?)	6	(1·8)
1. Pale grey fossiliferous calcareous sandstones (Base not seen)	Fundi Isa Limestones (Lower Miocene)	4	(1·2)

A quarter of a mile further downstream the following section is exposed, with the base at about 185 ft. O.D.:—

		Feet	(Metres)
3. Reddish sandy soil	Pleistocene (?)	2	(0·6)
2. Yellow-brown sandy clay containing boulders of limestone	Midadoni Beds (Pliocene ?)	9	(2·7)
1. Grey-green unfossiliferous marl (Base not seen)	Fundi Isa Limestones (?) (Lower Miocene)	4	(1·2)

The majority of the fossils collected from this locality were found lying loose in the stream-bed and may well have been derived from the Miocene deposits. Even the specimens seen *in situ* in the Pliocene (?) clays probably represent, in part at least, a reworked Miocene fauna, while any collection from the limestone boulders would similarly be of little value in determining the precise age of the sediments. The following fossils (62/37) were identified from a collection made at this locality:—

Hydrozoa *Millepora* sp.

Polyzoa *Cellepora* sp.

Mollusca *Globularia* cf. *callosa* (J. de C. Sowerby)

Terebralia bidentata (Defrance) (Plate VII, Fig. 12). Specimen 62/37/1

? *Terebralia bidentata* (Defrance). Specimen 62/37/7

Strombus sp. A, Cox

Strombus sp. C, Cox (Plate VII, Fig. 11). Specimen 62/37/2

Strombus sp.

Strombid (? *Hippochrenes* sp.) (Plate VII, Fig. 13). Specimen 62/37/4

Campanile sp.

Conus sp.

Ostrea hyotis (Linné) (Plate VII, Figs. 1 (*a*) and 1 (*b*)). Specimen 62/37/10

Teredo (*Kuphus*) aff. *polythalamia* (Linné). Specimen 62/37/9

A section of the Midadoni Beds and the upper part of the Fundi Isa Limestones exposed in a water-course three miles north-west of Fundi Isa, and about 195 ft. above sea-level, has the following sequence:—

		Feet	(Metres)
3. Brown soil . .		2	(0·6)
2. Yellow-brown clayey sands containing pebbles and boulders of limestone with quartz pebble-bed at the base	Midadoni Beds (Pliocene ?)	6	(1·8)
1. Pale grey fossiliferous calcareous sandstones (Base not seen)	Fundi Isa Limestones (Lower Miocene)	4	(1·2)

A quarter of a mile further downstream the following section is exposed, with the base at about 185 ft. O.D.:—

		Feet	(Metres)
3. Reddish sandy soil	Pleistocene (?) . .	2	(0·6)
2. Yellow-brown sandy clay containing boulders of limestone	Midadoni Beds (Pliocene ?)	9	(2·7)
1. Grey-green unfossiliferous marl (Base not seen)	Fundi Isa Limestones (?) (Lower Miocene)	4	(1·2)

The majority of the fossils collected from this locality were found lying loose in the stream-bed and may well have been derived from the Miocene deposits. Even the specimens seen *in situ* in the Pliocene (?) clays probably represent, in part at least, a reworked Miocene fauna, while any collection from the limestone boulders would similarly be of little value in determining the precise age of the sediments. The following fossils (62/37) were identified from a collection made at this locality:—

Hydrozoa	*Millepora* sp.
Polyzoa	*Cellepora* sp.
Mollusca	*Globularia* cf. *callosa* (J. de C. Sowerby)
	Terebralia bidentata (Defrance) (Plate VII, Fig. 12). Specimen 62/37/1
	? *Terebralia bidentata* (Defrance). Specimen 62/37/7
	Strombus sp. A, Cox
	Strombus sp. C, Cox (Plate VII, Fig. 11). Specimen 62/37/2
	Strombus sp.
	Strombid (? *Hippochrenes* sp.) (Plate VII, Fig. 13). Specimen 62/37/4
	Campanile sp.
	Conus sp.
	Ostrea hyotis (Linné) (Plate VII, Figs. 1 (*a*) and 1 (*b*)). Specimen 62/37/10
	Teredo (*Kuphus*) aff. *polythalamia* (Linné). Specimen 62/37/9

Four hundred yards south of Fundi Isa village, up to 9 ft. of white and pale yellow calcareous sandstones outcrop in a stream-bed and display shallow dips to the east-south-east. The fauna collected from the water-course (Specimen 62/14) comprises:—

Corals	? Isid (Alcyonarian) coral
	Stylophora nodosa, Gregory
	Dendracis bifaria, Gregory
	Desmophyllum sp. Specimen 62/14/2
Echinoidea	Fragments
Polyzoa	*Cellepora* sp.
Mollusca	*Strombus* sp. C, Cox
	Conus sp.
	Ostrea cf. *gryphoides* (Schlotheim). Specimen 62/14/1
	Teredo (*Kuphus*) aff. *polythalamia* (Linné)

In the Midadoni district, a few miles inland from Ras Ngomeni, similar deposits are exposed at the foot of Boyani hill in a small water-course known as "Mto ya Simiti". The sediments comprise white and pale yellow friable calcareous sandstones with intercalated pale yellow and grey marl. The following fossils (62/23) were collected from a locality a mile and a half due east of MK North trigonometrical beacon:—

Coral	Alcyonarian coral
Echinoidea	*Opechinus* cf. *rousseaui* (d'Archiac and Haime) (Plate VII, Figs. 3 (*a*) and 3 (*b*)). Specimen 62/23/16
	Cidarid: interambulacral plate, with contiguous series of ambulacral plates still attached (Plate VII, Fig. 4). Specimen 62/23/17
	Cidarid spines (radioles) (Plate VII, Figs. 5, 6, 7 and 8). Specimens 62/23/18-21
Polyzoa	*Celleporaria* sp.
Mollusca	*Chlamys senatoria* (Gmelin) (Plate VI, Fig. 2) Specimen 62/23/8; (Plate VI, Fig. 3) Specimen 62/23/9; (Plate VI, Fig. 4) Specimen 62/23/10; Specimens 62/23/11-15
	Amusium pembaense, Eames and Cox (Plate VI, Figs. 1 (*a*) and 1 (*b*)). Specimen 62/23/3
	Anomia sp.
	Ostrea hyotis (Linné) (Plate VI, Figs. 6 (*a*) and 6 (*b*)) Specimen 62/23/1; (Plate VII, Fig. 10). Specimen 62/23/5; (Plate VII, Figs. 2 (*a*) and 2 (*b*)) Specimen 62/23/7; Specimen 62/23/2
	Ostrea sp. (Plate VI, Figs. 5 (*a*) and 5 (*b*)). Specimen 62/23/6
	Teredo (*Kuphus*) aff. *polythalamia* (Linné) (Plate VII, Fig. 9). Specimen 62/23/4

Amusium pembaense, Eames and Cox, is considered to be a reliable indicator of a Lower Miocene age.

There are no other exposures between Midadoni and Fundi Isa, but float fragments of yellow-grey poorly consolidated calcareous sandstones and marls are often richly fossiliferous. The specimens are rarely well preserved, but several lamellibranchs (Specimen 62/31) were collected from a locality 2½ miles due south of Fundi Isa village.

The mapped continuation of the Pliocene (?) outcrop northwards beyond the Fundi Isa district is largely conjectural and is based on the existence of a vague dissected platform at about 250 ft. O.D., together with the sporadic occurrence of kunkar and float fragments of limestone which have yielded a poor microfauna. About 18 miles north-north-west of Fundi Isa and 7½ miles west of the Malindi-Garsen road a form related to *Austrotrillina* (*Trillina*) *howchini* was identified by A. G. Davis in a piece of pink limestone (Specimen 62/20) recovered from the soil at about 220 ft. above sea-level. Dr. C. G. Adams subsequently examined further material from the same locality and reported that ". . . All the sections contain specimens of *Austrotrillina howchini* (Schlumberger). These are slightly smaller than the other examples we have from East Africa but are otherwise very similar". The following foraminifera were identified in a float fragment of limestone (Specimen 62/21) collected on the hillside a quarter of a mile west of the previous locality:—

Archaias or *Taberina* sp. indet.
? *Austrotrillina* sp.
? *Borelis* sp.
Miliolids.

(4) MAGARINI SANDS (PLIOCENE)

Gregory (1896, p. 229, and 1921, p. 76) proposed the name "Magarini Sands" to describe deposits that form bright red sandhills behind the Kenya coast. Although at first suggesting a Triassic age, he later revised this view as a result of Hobley's discovery that similar deposits overlie Eocene and Miocene limestones west of Fundi Isa. Gregory accordingly assigned the Magarini Sands to the Lower or Middle Pliocene, suggesting that they are older than the Kilindini Sands and the North Mombasa Crag.

Parsons (1928, p. 66) included in his "Magarini Series" sediments ranging in age from Eocene to Pleistocene and regarded the marine fossiliferous beds as intercalations in the general Magarini sequence. Such a simplification is undesirable and later authors have adopted the earlier succession proposed by Gregory.

Miss McKinnon Wood (1930, p. 225) in a summary of the stratigraphy of coastal Kenya considered that deposits of different ages are probably represented in the Magarini formation and inferred that it ranges from the Miocene to Pliocene in view of fossiliferous beds found near Goshi in the Malindi area (the Miocene Baratumu beds of Thompson, 1956, p. 21) and in the Senawe (Mwakuhenga) river near Kilifi (*see* Caswell, 1956, map).

The term Magarini Sands has been applied to a mixed series of river gravels and dune sands in the southern part of Kenya Coast Province (Caswell, 1953, p. 25, and 1956, p. 27) where a post-Neocomian age has been demonstrated. Similar sediments —the Mikindani Beds—in Tanganyika have been dated as Upper Pliocene on the occurrence of *Pecten vasseli*. Stockley (1928, p. 44) however, states that . . . "As for *Pecten vasseli* Fuchs . . . we cannot say what precisely was its range. Most characteristically it is a Pliocene fossil . . . it is possible, however, that in the Suez district it may occur also in Pleistocene deposits, while in Persia a form differing from the Pliocene specimens only in some slight characters has been discovered in rocks of undoubtedly Miocene age". Teale (in Stockley, 1928, p. 49), commenting on a series of clayey sands and limestones at Tanga, added . . . "The discovery in them of *Pecten vasseli* Fuchs by Koert has been held by most authors to indicate a Pleistocene age". Eames and Kent (1955, p. 343) include "*P. vasseli* Fuchs, of Cox" among a fauna which they maintain is of Lower Miocene age, noting that . . . "There are, however, species of *Operculinella,* in association with *Pecten vasseli* Fuchs and *Ostrea* (*Lopha*) *tridacnaeformis* Cox which are undoubtedly characteristic of the Pliocene". More recently, Eames and Cox (1956, pp. 36 and 49) have described a form *Pecten fasciculatus* that has hitherto been confused with *Pecten vasseli. Pecten vasseli* Fuchs is now regarded as a Pliocene species whilst *Pecten fasciculatus* has so far only been collected from Lower Miocene beds near Mombasa and on Zanzibar island. Neither form has been recorded from the present area.

Thompson (1956, p. 21) found it convenient in the Malindi area to separate fluviatile, deltaic and marine sediments (his "Marafa Beds") from contrasting red wind-blown deposits to which he restricted the term Magarini Sands. He considered the Marafa Beds to be of late Pliocene to early Pleistocene age, with the bulk of the red Magarini Sands representing Middle Pleistocene accumulations. In the Malindi area, Thompson (1956, p. 31) dated the red Magarini Sands on the occasional recognition at the base of a ferricrete layer upon which he collected artefacts provisionally assigned to the middle Upper Pleistocene. As Caswell has pointed out, it is not unlikely that the Magarini Sands have been partly reworked and redeposited, so that the local appearance of artefacts between the Marafa Beds and the red sands does not necessarily demonstrate the age relationship in general.

Thompson's subdivision of the sands is not accepted for the present area, where there is evidence to suggest that the fluviatile Marafa Beds accumulated or were reworked during Lower Pleistocene times. Marine sediments have been excluded from that formation, and the term Magarini Sands is used to describe only red deposits of Pliocene or presumed Pliocene age. Across the surface of the 120 ft. terrace, which is thought to have been cut during the lower Middle Pleistocene, are to be found accumulations of reddish brown dune-sands. It is frequently impossible to distinguish clearly between such Pleistocene red sands and the older Magarini Sands, from which in part they were probably derived. During the survey an attempt was made to separate Pliocene and Pleistocene red deposits by the differences in altitudes of the occurrences and, lithologically, by the lower sand content of the Magarini Sands.

The Hadu-Fundi Isa road crosses reddish brown sandy soil, presumed to be Magarini Sands, in the vicinity of Ramada village, and nearby the soils overlie Lower Miocene beds. A study shows, however, that sand grains form only a small proportion of the deposit and it is possible that locally parts of it are dominantly *terra rosa* decomposition products of the Miocene limestones and may well have been blown into low dunes bordering the Pliocene sea.

Northwards from Ramada, and along the upper slopes of the Rogge ridge, a deep soil cover conceals much of the underlying geology but intimately mixed with the grey and brown soils are patches of reddish sandy soil, probably residual from Magarini Sands.

4. Quaternary Sediments

(1) Pleistocene Lagoonal Sands and Clays

Pleistocene lagoonal deposits occupy much of the Coast plain between the foot of the Rogge escarpment and the overlying Recent deposits east of the Malindi-Garsen road, probably attaining a maximum thickness of over 500 ft. The sediments are essentially sparsely fossiliferous, poorly consolidated grey, yellow-grey and rusty-brown clayey sands and marls with numerous intercalations of reddish brown sands, the formation occupying a belt which widens from three miles near Ngomeni to a maximum of 14 miles in the north, and probably extending beneath the Tana flood-plain. Caswell (1953, p. 27) and Thompson (1956, p. 32) recorded occurrences of similar clayey sands in the Mombasa and Malindi areas, regarding them as lagoonal deposits laid down on the edge of the Pleistocene sea, a view that is shared by the writer.

The following sequence was established from hand-auger samples taken at Msomalini, beside the Malindi-Garsen road:—

	ft.	*in.*
7. White sand	—	5
6. Grey-brown sand	—	7
5. Rusty-grey clayey sand containing fragments of yellow sandstone	—	10
4. Small lens of white sand	—	5
3. Pale brown and grey clayey sand	1	3
2. Yellow-grey clayey sand and sandstone	1	6
1. Rusty-grey clayey sand	5	—

The sands are often poorly cemented by small quantities of gypsum or limonite; mineralogically they consist dominantly of quartz with scattered grains of magnetite, ilmenite and pale pink garnet.

Pale grey sandy and nodular marls are exposed beside the Malindi road, 2½ miles north of the junction with the Hadu road, and yield specimens (62/13) of a gastropod identified as *Terebralia* (Terebralia) *palustris* (Linné) (Plate VIII, Figs. 3 and 4). Rather similar fossiliferous deposits (62/38) occur at the roadside half a mile south of the above locality and there the beds contain small rounded quartz pebbles up to half an inch in diameter and also yield *Terebralia* (Terebralia) *palustris* (Linné) (Plate VIII, Fig. 1—Specimen 62/38/1). Specimens (62/4) picked up from clayey sands, three-quarters of a mile south-west of the junction of the Garsen-Malindi and Hadu roads included a gastropod (62/4/1) *Terebralia* (Terebralia) aff. *palustris* (Linné) that appears to differ from the above specimens in having fewer varices in each of the later whorls (Plate VIII, Fig. 2).

Both the above localities are situated on the 30-ft. raised beach and the sediments are therefore probably of lower Upper Pleistocene age.

(2) Pleistocene Dune Sands

Dune sands, deposited during various stages of the Pleistocene, are found in the area. Reddish brown sands of Upper Pleistocene age often overlie the lagoonal sediments forming still recognizable dune features, and as far as possible these occurrences have been differentiated on the geological map. Near Fundi Isa, however, two small dunes rest on the Pliocene (?) beds between 200 and 300 ft. O.D. and are thought to represent Lower Pleistocene accumulations that bordered a sea which then stood 200 ft. above the present sea-level. Elsewhere the dunes are probably of post-Lower Pleistocene age, becoming progressively younger towards the coastline. East of Fundi Isa, and also near the northern boundary of the area, dunes were recorded on the 120-ft. platform and presumably formed in late Middle Pleistocene times, while lithologically similar deposits along the Malindi-Garsen road apparently accumulated after the cutting of the lower Upper Pleistocene beaches.

It is not unlikely that further, more precise differentiation could be made on a mineralogical basis, but the detailed heavy mineral analyses of large numbers of samples was beyond the scope of the present work.

Pleistocene reddish dune sands have been noted in the Malindi area (Thompson, 1956, p. 36), where they are termed the "Gedi Beacon Sands".

(3) Marafa Beds (Lower Pleistocene ?)

Thompson (1956, pp. 20; 44) proposed the name "Marafa Beds" for a thick series of clays, sands, gravels, pebble beds and conglomerates, dominantly of fluviatile or deltaic origin, but including at least one Pliocene marine horizon near the Sabaki river. He suggested that deposition of the formation took place from late Pliocene to early Pleistocene times and correlated it (*op. cit.*, p. 30) with the fluviatile facies of the Magarini Sands in the Mombasa area (Caswell, 1953, p. 26). During the present survey, marine sediments of presumed Pliocene age were separated from Pleistocene beds and the term Marafa Beds is restricted to a thick series of poorly consolidated river sands and gravels.

The Marafa Beds were traced into the present area from the type locality. They are a formation of clayey quartz sands that conceal the Jurassic-Miocene junction between the Denisa and Lafiti districts, with similar unconsolidated deposits continuing northwards to infill valleys in the Miocene beds north of Hadu. Evidence of the irregularity of the Miocene surface during the accumulation of the Marafa Beds is provided by the Hadu bore-hole which penetrated 284 ft. of non-calcareous sands, sandstones and clays, without revealing any trace of the Fundi Isa Limestones, although the presence of the Miocene beds at the surface nearby can be inferred. The driller recorded the following sequence:—

Hadu Bore-hole—C. 1141 (1950)

Feet	Metres	Lithology
0–15	0–4·5	Yellow-white sand
15–30	4·5–9·1	White sand
30–45	9·1–13·7	White rock
45–70	13·7–21·3	White sand
70–90	21·3–27·4	Sandstone
90–139	27·4–42·1	Yellow sandstone
139–200	42·1–61·0	White sandstone
200–210	61·0–64·0	Hard rock
210–230	64·0–70·1	White sand
230–270	70·1–82·3	Lead-coloured sand and clay
270–280	82·3–85·4	Sand
280–284	85·4–86·6	Hard rock

Mineralogically the sediments in the above succession consist dominantly of coarse quartz and felspar grains with a little opaque ore and abundant clay, the latter often acting as a poor cement. The "hard rock" is probably a more consolidated quartzo-felspathic sandstone.

The bore-hole suggests that the Marafa Beds occupy deep channels or pockets in the Miocene sediments (possibly excavated along a major fault) with bed-rock locally not more than 90 ft. above present sea-level. It is clearly impossible to refer this downcutting to Pliocene streams and the evidence strongly suggests accumulation in Lower Pleistocene times, the bulk of the material having been deposited by rivers graded to the sea which then stood more than 100 ft. below its present level (Caswell, 1953, p. 54).

Further, less conclusive evidence of the steep-walled nature of buried valleys cut in the Fundi Isa Limestones is provided by the occasional erosional hollows displayed by the Marafa Beds close to inferred boundaries between Miocene and Pleistocene sediments. A few miles north-west of Mulunguni a deeply eroded alcove with gullies and earth pillars reminiscent of features at Marafa, shows a series of unconsolidated clayey sands and occasional sandstones, while nearby the soil cover suggests the existence of Miocene beds.

The Marafa Beds frequently include beds of rounded quartz pebbles, and rectangular silicified fragments probably represent pieces of fossil wood derived from the Duruma Sandstones. Parsons (1928, p. 70) found material near Marafa which he regarded as a sinter deposit, suggesting an origin in contemporaneous solfataric action, but it is possible that the specimens may also have been blocks of silicified wood.

(4) Raised Coral Reef

The Pleistocene coral reef deposits, which form an almost unbroken narrow fringe along the southern part of the Kenya coastline, are only poorly represented north of Malindi and there are, in fact, only a few scattered exposures of the reef in the Fundi Isa area.

At Ras Ngomeni an island of coral and coquinoid limestone has become land-tied by a bar of Recent dune-sands, the whole forming a tombolo. Several miles inland weathered coral limestone is exposed in the dry water-course known as "Mto ya Simiti". At neither locality was it possible to extract individual fossils for identification.

Coral limestones (Specimen 62/7) also apparently underlie the superficial reddish brown sands on the Malindi-Garsen road some six miles north of the Karawa turn-off. A specimen (62/7/1) of the coral *Goniastraea retiformis* (Lamark) collected at this locality is shown in Plate VIII (Fig. 5). Three miles further north a small quarry at the roadside exposes up to 6 ft. of cemented coquinoid limestone with intercalated beds of red sand. The exposure, which is capped by 3 ft. of red wind-blown sand, yielded the following fauna (62/12):—

Mollusca   Cassidid (Plate VIII, Fig. 7). Specimen 62/12/1

Cypraeid. Specimen 62/12/2

Chlamys (*Aequipecten*) cf. *flabelloides* (Reeve) (Plate VIII, Fig. 6). Specimen 62/12/3

Cardium. Specimen 62/12/4

Tellinid.

Caswell (1953, p. 30) recorded details of a bore-hole near Bamburi in the Mombasa area, which was still in coral at 194 ft. below the present sea-level. He suggested that the total thickness of the coral must be at least 300 ft. and regarded the reef as a Middle Pleistocene accumulation that grew on a marine platform, cut during the Kamasian Pluvial when the sea-level had fallen to — 200 ft. O.D.

Thompson (1956, p. 35) discussed the variations in level of the coral reef between the Mombasa and Malindi areas, attributing the differences to subsequent erosion. While erosion may be partly responsible for the restricted occurrence of the reefs in the Fundi Isa area, there is also the possibility that a local change of environment (from marine to estuarine) prevented their full development.

It is of interest to note that coral and coquinoid limestones occur beyond the north-eastern limit of the present area. At Ras Shaka, near Kipini, cliff sections display up to 25 ft. of reef limestone with intercalated beds of buff and grey-green nodular clayey sands.

(5) Reddish Brown Superficial Sands of the Hinterland

A veneer of reddish brown wind-blown sand covers large tracts in the Hadu area, being particularly well developed north-east of the Gaabo hills, where it completely masks the underlying geology. Elsewhere the occurrences are not differentiated on the geological maps.

North of Hadu, reddish sands apparently rest on the Lower Pleistocene Marafa Beds, although it is difficult to be certain in a district devoid of natural sections displaying the sequence. Furthermore the Marafa Beds themselves frequently develop a red coloration near the surface. It is equally difficult to demarcate with accuracy any boundaries between the reddish sands and the unexposed Mazeras Sandstones.

(6) Recent Deposits

Recent deposits in the area consist of marine sands and muds, coastal dunes, and the silt of the Tana delta. The mineral composition of the Recent beach sands is discussed in some detail in a later chapter dealing with the economic geology of the area (p. 56).

Dark clays and muds border the intricate network of tidal creeks that spread out behind the coastline, but only a gradational boundary can be drawn between these deposits and the older Pleistocene clayey sands which continue inland up to the 100-ft. platform. Similarly no hard and fast line can be defined between the muds that are at present accumulating in and around the mangrove swamps, and those of the Tana alluvial plain. In years of heavy rainfall the Tana flood-waters carry suspended silt southwards across the low-lying country bordering the Mto Kilifi creeks; conversely, high spring tides result in the alluvials being covered by muds which are, strictly speaking, of marine origin.

High dunes, composed dominantly of white ilmenite-bearing sand, fringe the northern half of the coastline, with sporadic development between Mto Kilifi and Ras Ngomeni, where the headland of raised coral reef is land-tied by a bar of wind-blow sand. These dunes are also considered in more detail in a later section (p. 56).

Melton (1940) has attempted a classification of sand-dunes based on their modes of formation. The bulk of the Formosa Bay accumulations may be regarded as what have variously been termed "source-bordering lee dunes", "lee-source dunes" or "umbrafon dunes", and which typically exist on the lee side of a beach or stream flood-plain. The conditions necessary for the formation of this type of feature are:—

(i) The existence of a constantly replenished sand supply

(ii) Gentle or strong winds, which need not be constant in strength or direction.

Melton adds that such dunes frequently attain a great size. In the present area the high sand-hills at Adara offer a convincing example, being nearly two miles wide and rising to 164 feet at the trigonometrical beacon. To the north-east the dunes form a wider but less imposing feature, comprising a series of parallel ridges such as Melton quotes as typical of source-bordering dunes formed beside sandy river-channels.

Should such an origin be accepted for the sand ridges fringing Mto Tana creek it would suggest that accumulation took place along an estuary that migrated slowly eastwards to the position of the present creek before the Tana abandoned the course in favour of an outlet at Kipini.

Good examples of "blowout" or "parabolic" dune forms (Melton, 1940, p. 126) are to be found in the neighbourhood of Adara, the beacon itself being situated on one such feature. The forms result from the local killing of vegetation by exposure of the root systems and are characterized by the formation of basins and crescent-shaped sand ridges. Stronger winds have occasionally produced chevron-shaped "windrift" dunes (Melton, 1940, p. 129) with the typical gap or "rift" at the apex of the sand rim.

5. Basic Igneous Rocks

In his report on the geology of the Malindi area, Thompson (1956, p. 38) described from the Sabaki valley a number of small igneous intrusions, formed essentially of basanites and olivine nephelinites. Specimens collected from the same district by Miss McKinnon Wood (1930, p. 217 and 1938, p. 112) had previously been identified as nepheline basalt, nepheline basanite, olivine trachy-basalt, ankaramite and tuff (considered by Thompson to be a fault-breccia).

At Alango Shira, about a mile and a quarter south-west of the semi-permanent water-holes in the Gandi stream-bed, abundant small boulders of porphyritic olivine basalt cover an area of about 2,000 square yards. In thin section specimen 61/62 from this locality displays small scattered microphenocrysts of subhedral olivine and pale augite, crystals of the former frequently showing alteration to iddingsite along fractures. The groundmass consists essentially of small prisms of plagioclase having a composition near andesine, grains of pyroxene and small octahedra of magnetite. No felspathoids were detected.

A second occurrence of olivine basalt is also indicated by float lying across the bush-track cut between Dererisa and Haluabagalla. Specimen 61/96 of this rock exhibits a porphyritic texture, the olivine having $-2v = 70°\text{-}80°$. The groundmass is more fine-grained and the contrast of phenocrysts with groundmass is more pronounced in this specimen than in that from Alango Shira.

Thompson has provisionally dated the Sabaki valley intrusions as post-Lower Miocene and pre-Upper Pliocene, although only a post-Upper Jurassic age is convincingly demonstrated in the field. The basalts in the Hadu area are assumed to represent minor intrusions, and a similar post-Upper Jurassic relationship is suggested by the sparse fauna collected from the surrounding sediments at Alango Shira.

VI—STRUCTURE

There are few tectonic features in the Hadu-Fundi Isa area that can be postulated with confidence and most of the structural lines mapped or inferred (Fig. 2) should be treated with caution. The majority of the faults have been inferred entirely from vegetation changes noted on air photographs.

Folds.— The general outcrop distribution, with progressively younger beds appearing towards the coast-line suggests that the structure is comparatively simple, the entire pile of sediments probably being as a whole gently inclined to the east. There is no conclusive evidence of folding in the area and the random strike directions recorded, particularly in the Mazeras Sandstones, are readily explained as a result of proximity to faults if the inferred faults are accepted as a reality. There is, however,

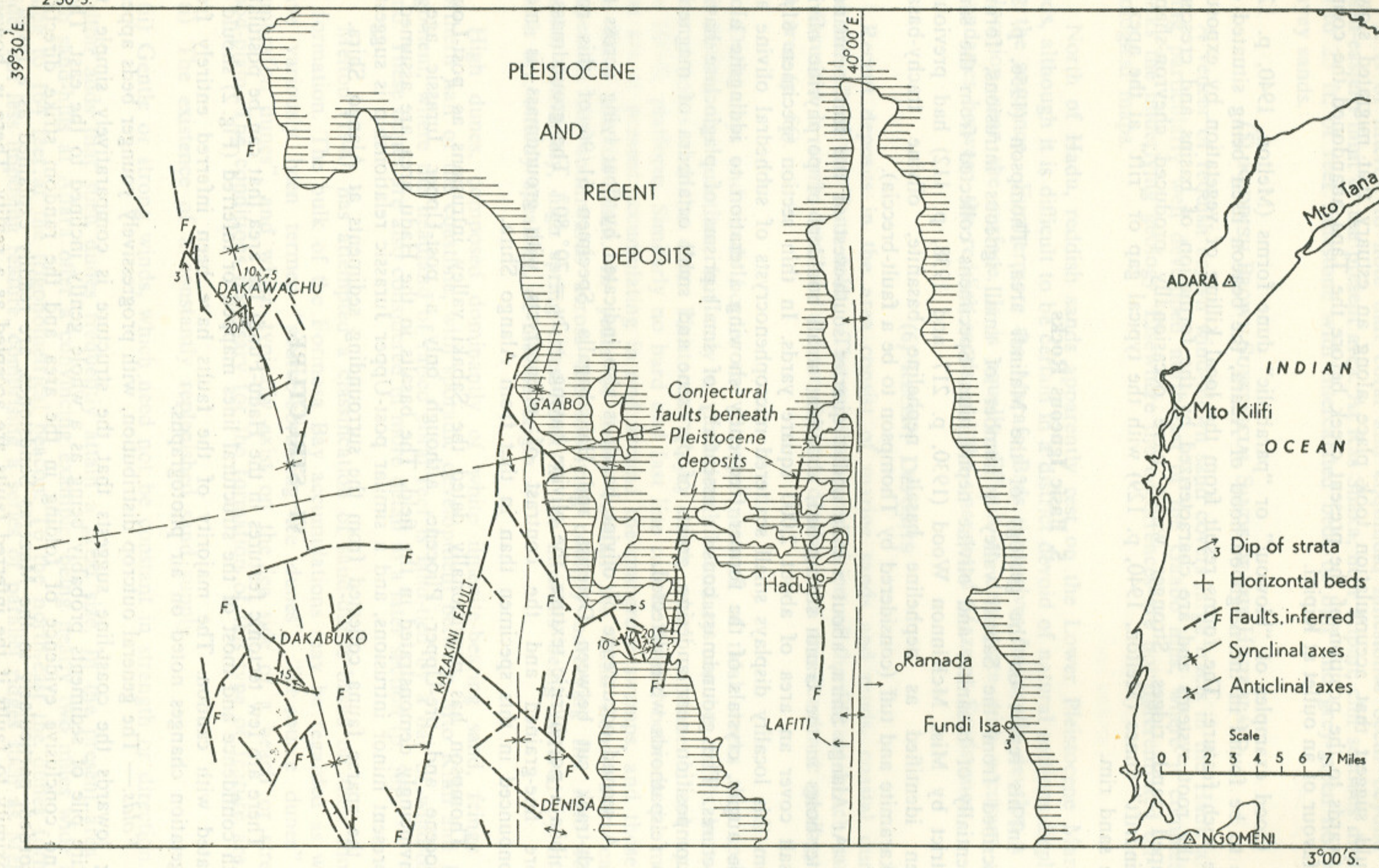


Fig. 2.—Structural Map of the Hadu-Fundi Isa area

a faint suggestion of gentle flexures superimposed on the regional dip at several localities. It is not unlikely that the Duruma sediments between Dakabuko and Dakawachu are folded into a shallow syncline, the reappearance of the Mariakani Sandstones on the east being due partly to faulting, partly to the effect of topography and partly to folding. The fold-axis probably trends roughly N.N.W.-S.S.E. The inliers of Mazeras Sandstone in the Denisa district may also be attributable to shallow folding of the Jurassic and Duruma rocks. The inliers are not obviously explained by faulting alone and it is more likely that the older beds are exposed by the erosion of an anticline having a north-south axis. Immediately east of the Kazakini fault an inferred shallow syncline probably has a similar north-south trend, while dips recorded in the Fundi Isa Limestones between Lafiti and Ramada apparently indicate the existence of a north-south anticlinal axis. Between the Dakabuko and Dakawachu hills an inferred east-west anticlinal cross-fold would explain the narrowing of the Mazeras Sandstone outcrop near the Gandi stream and a complementary widening of the upper Duruma outcrop at Gaabo.

Faults.— The inferred faults in the Hadu area are related to three main trends:—

(i) N.N.E.-S.S.W.

(ii) N.W.-S.E.

(iii) E.-W.

The N.N.E.-S.S.W. trend is exemplified by the Kazakini fault which throws down both the Jurassic sediments and the Mazeras Sandstones against middle Duruma rocks, involving a movement of at least 300 feet. It can be traced for some 14 miles from the southern boundary to the Alango Shira district by a conspicuous vegetation change, thereafter being inferred from a consideration of the field relationships at the foot of the Gaabo hills, where Jurassic beds probably lie adjacent to the Mariakani Sandstones.

A fault with a similar trend, marking the Duruma-Jurassic contact, has been described at Lango Baya in the Galana (Sabaki) valley (Thompson, 1956, pp. 18 and 41). The same trend is represented at Dakawachu where individual faults apparently define the small hills of Mazeras Sandstone. Caswell (1953, p. 49) recorded a similar N.N.E.-S.S.W. fault-trend in the Mombasa-Kwale area and noted that it parallels both the boundary fault between the Duruma Formation and the Basement System as described by Miller (1952, p. 14) and the Ruvu-Mombasa fault postulated by Bailey Willis (1936, p. 32). It is of interest to note that the submarine contours in Formosa Bay, inserted on the geological map from soundings recorded on the Admiralty Chart of the coast, demonstrate an abrupt fall of the sea-floor and may well indicate a continuation of the Ruvu-Mombasa fault (*see* also Thompson, 1956, Fig. 3, p. 47).

The N.W.-S.E. fault-trend is represented by inferred fractures in the Duruma sandstones and the Jurassic beds. Some of the faults, notably those bounding the Dakabuko hills, have a more north-north-westerly direction. The steep south-western scarp of the Dakabuko hills parallels the regional strike of the sediments, but certainly represents a fault along the greater part of its length and is a clearly defined feature as far south as Gerujo. Paucity of exposures prevents any reliable assessment of the throw and the structure is complicated by a number of smaller fractures, which have contributed to the formation of deep embayments into the main scarp. To the north-east the Dakabuko hills are defined by a N.W.-S.E. fault, along which the Mazeras Sandstones have been downthrown some 400 feet. Examples of the east-west trend are also to be found north of the same hills.

The sandstones at Dakabuko display three sets of minor fractures which compare well with scarp directions in the hills (Fig. 3 (*a*)). The dominant N.N.W. trend was apparently locally the earliest, the faults being normal and dipping to the east-north-east at 60 to 80 degrees. Subsequent faulting along E.N.E. and E.S.E. lines shows vertical downthrow to the south. Along the north-western scarps of Dakabuko the joints and small-scale faults are related to two main directions, the dominant trend being N.W.-S.E. (Fig. 3 (*b*)), while on Gerujo hill near the southern boundary of the area the most important set of minor fractures trend N.N.W. (Fig. 3 (*c*)).

A low discontinuous scarp can be traced for several miles between Wachu and Hoshingo and apparently represents a continuation of the fault that defines the south-western face of the former hill. The same fault is probably responsible for the small scarp at Konodibaa, where the sandstones display doubtful dips to the north-east. Postulated north to north-easterly fractures parallel joint and minor fault trends recorded throughout the Dakawachu district (Fig. 3 (*d*)).

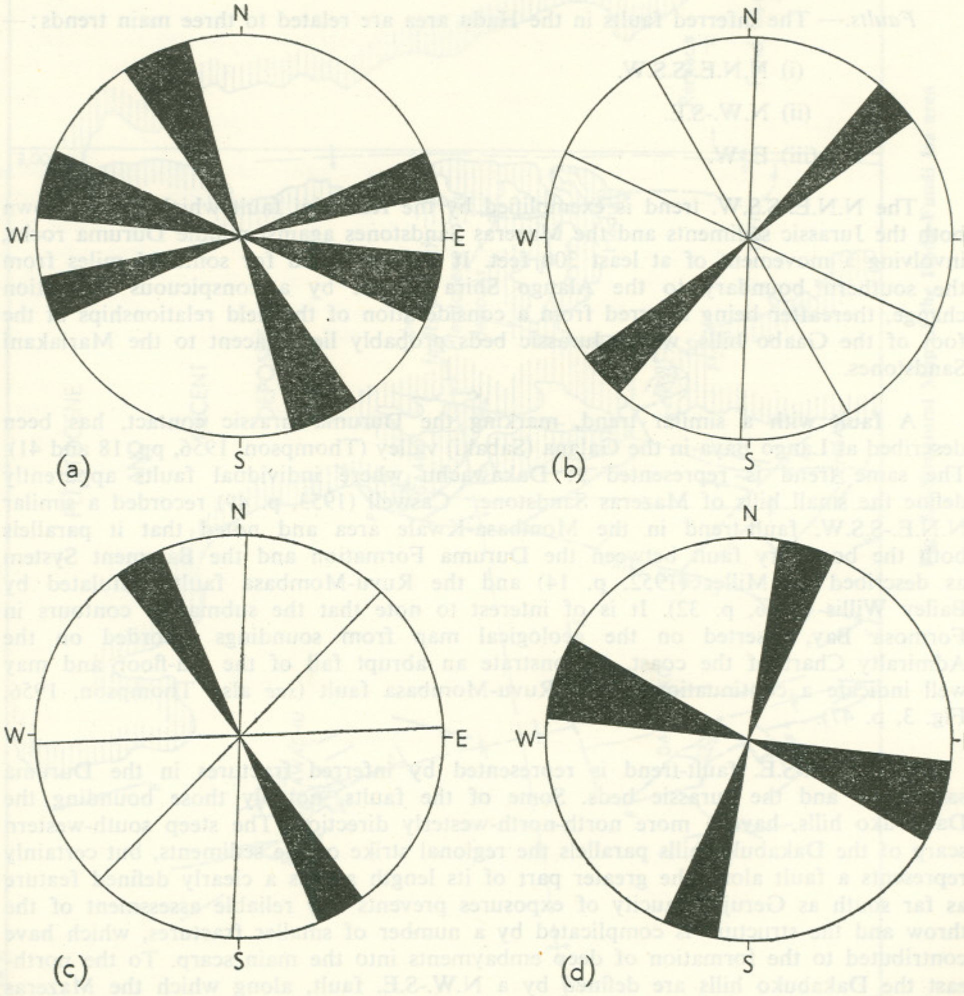


Fig. 3.—Fault and Joint Trends in the Mazeras Sandstones. (a) Dakabuko. (b) Dakabuko, north-western section. (c) Gerujo. (d) Dakawachu

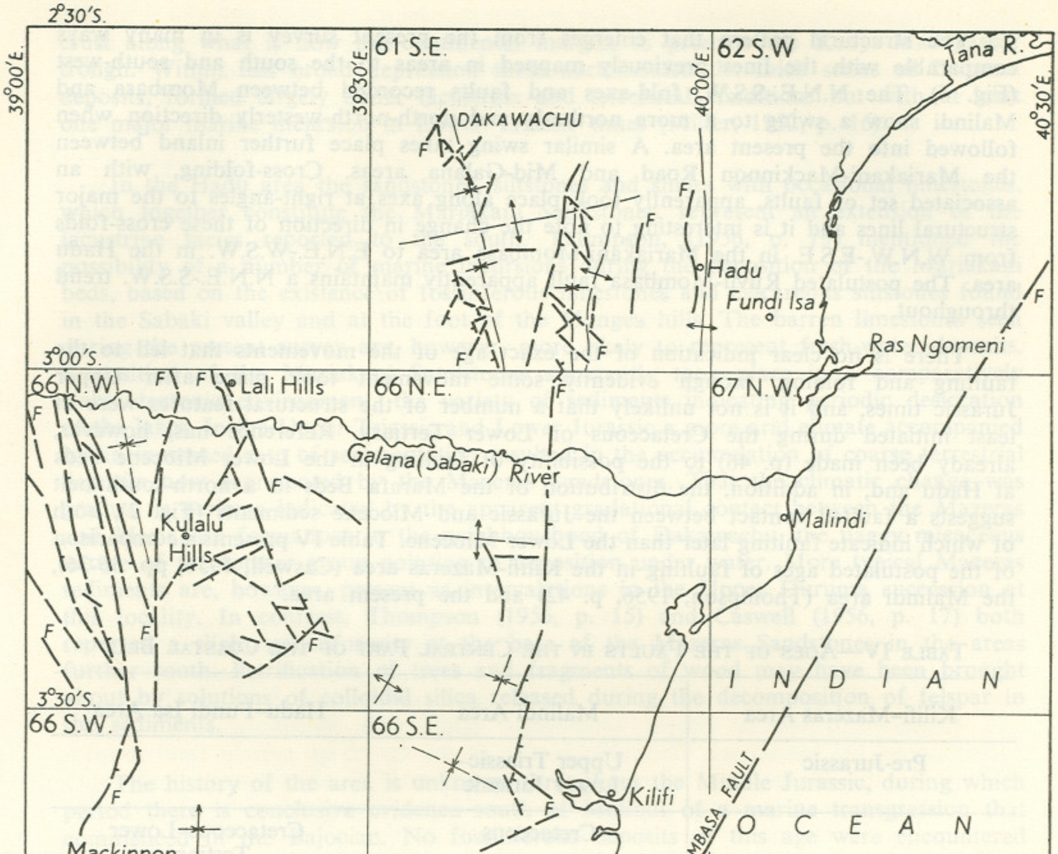


Fig. 4.—Structural Map of the Southern and Central Portions of the Kenya Coastal Belt. Area south of 3°S. based on Sanders (1963, 66 N.W.), Thompson (1956, 66 N.E.), Miller (1952, 66 S.W.), Caswell (1953, 69 N.W. and N.E.; 1956, 66 S.E.)

The structural pattern that emerges from the present survey is in many ways comparable with the lines previously mapped in areas to the south and south-west (Fig. 4). The N.N.E.-S.S.W. fold-axes and faults recorded between Mombasa and Malindi show a swing to a more northerly and north-north-westerly direction when followed into the present area. A similar swing takes place further inland between the Mariakani-Mackinnon Road and Mid-Galana areas. Cross-folding, with an associated set of faults, apparently took place along axes at right-angles to the major structural lines and it is interesting to note the change in direction of these cross-folds from W.N.W.-E.S.E. in the Mariakani-Mombasa area to E.N.E.-W.S.W. in the Hadu area. The postulated Ruvu-Mombasa fault apparently maintains a N.N.E.-S.S.W. trend throughout.

There is no clear indication of the exact age of the movements that led to the faulting and folding, though evidently some movement took place after Upper Jurassic times, and it is not unlikely that a number of the structural features were at least initiated during the Cretaceous or Lower Tertiary. Reference has, however, already been made (p. 46) to the possibility of faulting in the Lower Miocene beds at Hadu and, in addition, the distribution of the Marafa Beds in a north-south belt suggests a faulted contact between the Jurassic and Miocene sediments (Fig. 2), both of which indicate faulting later than the Lower Miocene. Table IV presents a comparison of the postulated ages of faulting in the Kilifi-Mazeras area (Caswell, 1956, pp. 35-36), the Malindi area (Thompson, 1956, p. 42) and the present area.

TABLE IV—AGES OF THE FAULTS IN THE CENTRAL PART OF THE COASTAL BELT

Kilifi–Mazeras Area	Malindi Area	Hadu–Fundi Isa Area
Pre-Jurassic	Upper Triassic–Lower Jurassic	
	Cretaceous	Cretaceous–Lower Tertiary
Post-Cretaceous (late Miocene ?)		
	Lower Pliocene	
Middle Pliocene		Late Tertiary
	Upper Pliocene–Lower Pleistocene	

Stockley (1928, pp. 9, 10 and 52) related the N.N.E.-S.S.W. "Pemba Trough," which separates the island from the mainland, to late Miocene rift faulting, noting the fact that the structure parallels one of the common East African Rift Valley trends. He also postulated a number of N.W.-S.E. faults bounding Pemba island, so that in general the fault pattern bears a strong resemblance to that suggested in the Hadu-Fundi Isa area.

VII—GEOLOGICAL HISTORY

The palaeogeography of coastal Kenya during Upper Palaeozoic and early Mesozoic times, as evidenced by the lithology and distribution of sediments of the Duruma Formation, has already been discussed by Caswell (1953, p. 50; 1956, p. 37) and Thompson (1956, p. 42), Both authors postulate a gentle down-warping of the crust along what is now the continental margin, to produce the Kenya-Madagascar trough. Within this broad depression there accumulated the thick series of Duruma deposits, formed largely under lacustrine and terrestrial conditions but with at least one major marine incursion in Lower Triassic times (Miller, 1952, p. 16).

In the Hadu area the sandstones, siltstones and shales with occasional limestones, which together constitute the Mariakani Sandstones, represent an extension of the lacustrine facies reported to the south. Thompson, (1956, p. 13) mentioned the possibility of a number of marine incursions during the deposition of the Mariakani beds, based on the existence of fossiliferous limestones and calcareous siltstones found in the Sabaki valley and at the foot of the Mangea hills. The barren limestones seen during the present survey are, however, more likely to represent fresh-water deposits. Deposition of the Mariakani Sandstones apparently took place in a comparatively stable tectonic environment, the variety of sediments indicating periodic desiccation of the lakes. In the Upper Triassic and Lower Jurassic a more arid climate accompanied by an increased rate of sedimentation resulted in the accumulation of coarse terrestrial deposits now represented by the Mazeras Sandstones. That the climatic change was gradual is perhaps indicated by the apparent gradational contact between the Mazeras and Mariakani formations in the neighbourhood of Dakawachu, the flaggy micaceous nature of the former group pointing to deposition under water. More typical Mazeras sediments are, however, present as intercalations in the Upper Duruma succession at this locality. In contrast, Thompson (1956, p. 15) and Caswell (1956, p. 17) both reported a slight unconformity at the base of the Mazeras Sandstones in the areas further south. Petrification of trees and fragments of wood may have been brought about by solutions of colloidal silica released during the decomposition of felspar in the sediments.

The history of the area is unknown throughout the Middle Jurassic, during which period there is conclusive evidence south of Malindi of a marine transgression that commenced in the Bajocian. No fossiliferous deposits of this age were encountered during the present survey and the country north of the Sabaki river might well have remained above sea-level. In post-Kimmeridgian times, however, the Jurassic sea spread beyond its earlier shore-line to flood the northern part of the Malindi area at least as far as the Gaabo hills. Conglomeratic beds resting on the Mazeras Sandstones at Bibitoli represent the original deposits from this more extensive invasion and, as the sea apparently remained shallow, the limit of the transgression is probably to be found within the present area.

In late Cretaceous and early Tertiary times the Hadu-Fundi Isa area probably experienced a phase of erosion which might well have been accompanied by the initiation or rejuvenation of faults, and perhaps the small igneous intrusions were also related to this period of tectonic activity. During the Lower Miocene there occurred a fresh marine transgression and the local, richly fossiliferous deposits — the Fundi Isa Limestones — indicate sedimentation within the littoral zone. Miocene beds were encountered at an elevation of over 550 feet O.D. but it is not known whether this figure in fact represents the contemporary sea-level or whether faulting and folding are locally responsible for the altitude of the occurrence. The junction between the Jurassic and Miocene sediments is obscured by a north-south belt of the Lower Pleistocene Marafa Beds, possibly deposited from a river following a faulted boundary between the Mesozoic and Tertiary formations and suggesting that faulting took place in later Tertiary times. Throughout the Middle and Upper Miocene and possibly part of the Pliocene the area was again subjected to a period of erosion, and there is evidence from areas further south to support the idea that wide-spread faulting along roughly north-south lines took place in the coastal belt about this time. The late Tertiary history of the area is largely conjectural, but it is thought that a further marine invasion occurred in Pliocene times, with the Rogge ridge forming the shoreline of a sea that probably stood some 300 feet above present sea-level. Meanwhile, a chain of reddish sand-hills — the Magarini Sands — was accumulating along the coast.

The Pleistocene period was marked by a series of major fluctuations in sea-level and the distribution of sediments of this age in the present area, together with the existence of a number of poorly defined physiographic features, tend to confirm the sequence of events suggested by Caswell (1953, p. 54). Lack of evidence precludes reconstruction of the palaeography during the Lower Pleistocene, but the fluviatile Marafa Beds were probably deposited or reworked during the Kamasian Pluvial by rivers graded to a sea that had fallen several hundred feet below present sea-level. In early Middle Pleistocene times the sea returned to flood what is now the Coast plain, cutting a platform between 100 and 120 feet O.D. Simultaneously there was forming off-shore a coral reef, now only represented by sporadic occurrences of coral and coquinoid limestone, notably at Ras Ngomeni. The raised coral reef is well developed further south, from the Mombasa area to the mouth of the Sabaki river, and its limited extent along the coast-line of Formosa Bay may be partly explained by the local estuarine environment produced by the Pleistocene Tana river. In addition, the subsequent fall in sea-level during the Kanjeran Pluvial was accompanied by a rejuvenation of drainage, which would result in the destruction of any reef previously formed. The 30-ft. raised beach near the Hadu turn-off from the Malindi-Garsen road demonstrates the rise in sea-level during the Upper Pleistocene. Throughout the entire period reddish coastal dunes were built up behind the Pleistocene beaches but no attempt has been made during the present work to separate deposits of different ages. Meanwhile, reddish brown wind-blown sands were accumulating as a thin veneer across the hinterland. The ultimate rise of the sea to its present level towards the end of the Pleistocene, following an intermediate fall of unknown magnitude, may well have been responsible for the silting of the Mto Kilifi river channel and the subsequent diversion of the Tana into a fresh course.

VIII—ECONOMIC GEOLOGY

1. Ilmenite and Vanadium

The existence of detrital ilmenite in the form of local beach concentrations has been recognised for many years along the Kenya coast, notably in the neighbourhood of Malindi. Similar placer deposits have been exploited elsewhere in the world as a source of titanium ore, the most productive beaches being in Travancore State, India.

No commercial interest was shown in the local occurrences until 1952, when the Kenya Government received an application from Mr. Maxwell McGuinness for authority to begin initial investigations north of Malindi — an area which, together with other large tracts in the Coast Province, is closed to prospecting and mining without special authority. Permission was granted, and Exclusive Prospecting Licence No. 111 was subsequently issued to McGuinness in October, 1955. The licence* was renewed in October, 1956 and again in October, 1957, for a further period of one year. At the time of writing, no application for a Special Mining Lease had been lodged, although the matter has been under discussion.

In the Fundi Isa area, the western boundary of the E.P.L. area is defined by a line following the centre of the Malindi-Garsen road northwards from the parallel 3° 00′ S. to a point where the abandoned telegraph line to Kipini branches away from the main road (i.e. at the Karawa track junction). The boundary then follows the

* The licence was allowed to lapse in October, 1958, the area then again becoming closed to prospecting and mining under Government Notice No. 477 of 15th June, 1938.

old telegraph line to its point of intersection with the Tana (Ozi) River near Kipini, the eastern limit being defined by "a give and take line two miles seawards from the low spring tide mark". The total area covered by the E.P.L. is quoted as 88 square miles.

In 1953, having received authority to prospect pending the issue of an E.P.L., McGuinness carried out an extensive sampling programme along the coast-line of Formosa Bay. The majority of the samples were taken from holes put down with a Banka drill to an average depth of 10 feet, a composite specimen for analysis being taken from a line of holes. The sampling lines near Mto Tana creek are shown in Fig. 5.

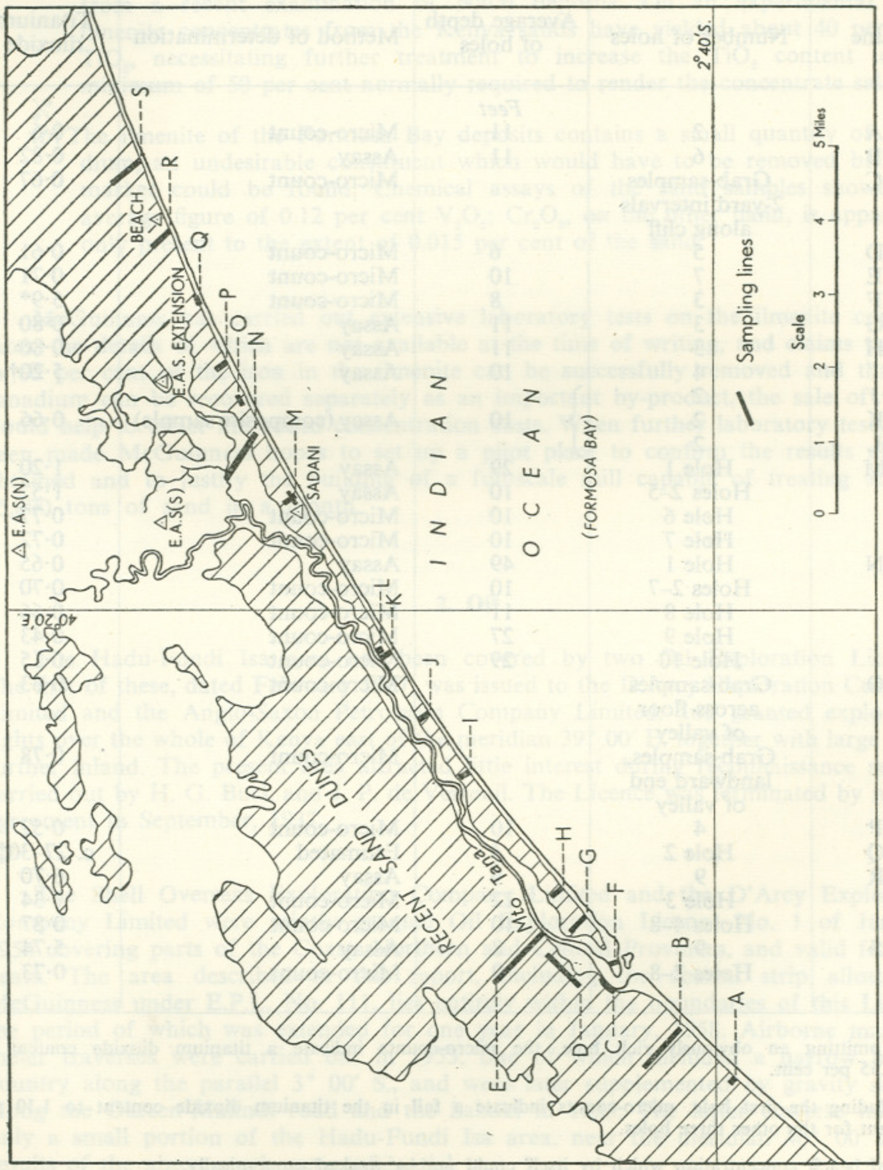


Fig. 5.—Sampling Lines in Ilmenite-bearing Beach Sands, Formosa Bay

The determination of the titanium dioxide percentage in some sand samples was made by chemical assay; in other samples the approximate ilmenite content was first estimated by a "micro-count", a process which involves recording the ratio of opaque and translucent grains seen under a microscope, a subsequent calculation of the titanium dioxide percentage being based on ilmenite analyses previously carried out.

The following table shows the results obtained from the initial sampling:—

Line	Number of holes	Average depth of holes	Method of determination	Titanium dioxide
		Feet		%
A	2	11	Micro-count	0·6
B	6	11	Assay	0·82
C	Grab-samples 2-yard intervals along cliff		Micro-count	0·67
D	5	6	Micro-count	0·61
E	7	10	Micro-count	0·71
F	3	8	Micro-count	5·9*
G	3	11	Assay	0·80
H	3	11	Assay	0·80
I	4	10	Assay	5·20†
J	2			
K	2	10	Assay (composite sample)	0·66
L	2			
M	Hole 1	29	Assay	1·20
	Holes 2–5	10	Assay	1·57
	Hole 6	10	Micro-count	0·77
	Hole 7	10	Micro-count	0·72
N	Hole 1	49	Assay	0·65
	Holes 2–7	10	Micro-count	0·70
	Hole 8	11	Micro-count	0·66
	Hole 9	27	Micro-count	0·43
	Hole 10	29	Micro-count	0·15
O	Grab-samples across floor of valley		Micro-count	0·63
	Grab-samples, landward end of valley		Micro-count	0·78
P	4	10	Micro-count	0·52
Q	Hole 2	4	Estimated	c. 27–30‡
R	9	9	Assay	6·70
	Hole 3	12	Micro-count	1·34
	Holes 4–8	10	Micro-count	0·87
S	9	8	Assay	5·74
	Holes 2–8	9	Micro-count	0·73

* By omitting an obviously rich hole, the micro-counts indicate a titanium dioxide content of 1.55 per cent.

† Excluding the first hole, micro-counts indicate a fall in the titanium dioxide content to 1.10 per cent for the other three holes.

‡ Local beach concentration which by itself could not be worked economically.

Two serious difficulties were revealed as a result of analyses carried out during the early stages of the investigation of the black sands:—

(*a*) Although widespread, the Formosa Bay deposits are of low grade in comparison to workable occurrences elsewhere in the world. Excluding the figures obtained from the analyses of shallow beach concentrations which are not economically important and omitting results from obviously misleading samples, the figures quoted above indicate an average content of less than 1 per cent of titanium dioxide. A low-grade beach deposit worked at Jacksonville, Florida, has a combined rutile, ilmenite, zircon and monazite content of $2\frac{1}{2}$ per cent. On the other hand, over 11 per cent TiO_2 has been reported from a recent examination of Natal deposits. On an experimental scale ilmenite concentrates from the Kenya sands have yielded about 40 per cent TiO_2, necessitating further treatment to increase the TiO_2 content to the minimum of 50 per cent normally required to render the concentrate saleable.

(*b*) The ilmenite of the Formosa Bay deposits contains a small quantity of vanadium, an undesirable constituent which would have to be removed before a market could be found. Chemical assays of the sand samples showed an average figure of 0.12 per cent V_2O_5; Cr_2O_3, on the other hand, is apparently only present to the extent of 0.015 per cent of the sand.

McGuinness has carried out extensive laboratory tests on the ilmenite concentrates, the details of which are not available at the time of writing, and claims that up to 60 per cent of the iron in the ilmenite can be successfully removed and that the vanadium can be recovered separately as an important by-product, the sale of which would help to offset the added concentration costs. When further laboratory tests have been made McGuinness hopes to set up a pilot plant to confirm the results already obtained and to justify the building of a full-scale mill capable of treating at least 15,000 tons of sand in a month.

2. Oil

The Hadu-Fundi Isa area has been covered by two Oil Exploration Licences. The first of these, dated February 1937, was issued to the D'Arcy Exploration Company Limited and the Anglo-Saxon Petroleum Company Limited, and granted exploration rights over the whole of Kenya east of the meridian 39° 00′ E. together with large tracts further inland. The present area attracted little interest during reconnaissance surveys carried out by H. G. Busk and J. P. de Verteuil. The Licence was terminated by mutual agreement in September, 1937.

The Shell Overseas Exploration Company Limited and the D'Arcy Exploration Company Limited were jointly granted Oil Exploration Licence No. 1 of January, 1954 covering parts of the Coast, Northern and Central Provinces, and valid for four years. The area described in this report, including the coastal strip allotted to McGuinness under E.P.L. No. 111, lies entirely within the boundaries of this Licence, the period of which was extended for one year in January, 1958. Airborne magnetometer traverses were carried out in 1953, one of which included a narrow belt of country along the parallel 3° 00′ S., and were later supplemented by gravity surveys along the Garsen-Malindi road and the Sabaki in 1955. The latter traverse included only a small portion of the Hadu-Fundi Isa area, near the meridian 40° 00′ E. All results of the above work are confidential.

Although both the surface and sub-surface geology is highly conjectural, the inferred structures and formations described in this report offer little encouragement for further work within the area in connection with the search for oil, until more hopeful signs are obtained from other areas.

3. Coal

The belief that workable coal seams might exist in the Duruma Formation has been largely discredited in areas to the south and south-west (Caswell, 1953, p. 59; Miller, 1952, p. 22). The writer found no suggestion of widespread humification of plant remains in the Duruma sediments examined during the present survey and, on the contrary, there is every reason to believe that silification precluded the formation of coal.

4. Water-supply

In common with most other parts of the Coast Province, water-supply constitutes a major problem in the inhabited portions of the present area.

The only bore-hole (C. 1141) is situated at Hadu (Adu) where water was struck at a depth of 250-260 feet in the Marafa Beds. Although originally estimated at 5,760 gallons per day, the present yield is probably considerably less and, even supplemented by a few seasonal water-holes, the supply is barely sufficient to meet the needs of the district. In conjunction with the aridity of the climate the collecting area is small, underground recharge being provided by the tributaries to the Masa water-course. Details have already been given (p. 46) of the sediments pierced by the bore-hole, together with the inference that the Marafa Beds occupy deep pockets in the Miocene deposits.

Although no other boring for water has been undertaken in the area, brief surveys were made in 1955 by the African Land Development Board a few miles beyond the southern boundary. A bore-hole, drilled to 400 feet near Dakatcha, failed to strike water and did not encourage further work in the districts to the north.

Shallow wells have been successfully constructed at Karawa, east of the Malindi-Garsen road, where the Pleistocene clays and sands now provide an invaluable supply of water on the main stock route from the Tana river. The Recent coastal dunes have also provided good sites for small wells, perfectly fresh water overlying brackish and saline solutions by reason of its lower density. It is important that there should be no overdrawing from these wells, in view of the danger of admixture of the layers. Prior to the sinking of the Hadu bore-hole, water was obtained from shallow wells excavated to a depth of about 10 feet in the thick sands of the Masa water-course. Several of these wells were in use at the time of the survey, but the supply was very limited.

Seasonal water-holes constitute the only source of water in the districts far removed from the Tana river and from the supplies mentioned above. The majority of these pans dry up shortly after the wet seasons and, if situated on the outskirts of the settled areas, are liable in addition to pollution by game. By careful conservation a number of water-holes in the Dakatcha-Dererisa district remain in use throughout years of normal rainfall and these, together with two deep holes in the Gandi stream-bed at Alango Shira, are marked on the geological map as permanent supplies.

Within recent years a few small earth dams have been constructed in the more easily accessible regions, but results on the whole have been disappointing.

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