THE GEOMORPHOLOGY OF SOUTHEAST KENYA

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STELLINGEN

1. Bij de vorming van de uitgestrekte planatievlakken in Oost-Kenia heeft marine en lacustrine abrasie een belangrijke rol gespeeld.

   Dit proefschrift.

2. De schaarste aan fossielen van hominiden in Oost-Afrika over de periode van ongeveer 500 000 tot 50 000 jaar BP is schijnbaar.

3. Voor de toepassing van geografische informatiesystemen op bedrijfsniveau in reliefrijke gebieden is het essentieel om programmatuur te ontwikkelen die identificatie van de geologische en geomorfologische positie van een gekozen punt mogelijk maakt.

4. De klink van het Basis- en het Hollandveen is er medeverantwoordelijk voor dat er in Nederland geen aanwijzingen worden gevonden voor hoge holocene zeestanden.

5. De geringschatting van het belang van onderwijs en onderzoek in de geologie en geomorfologie aan de Landbouwuniversiteit te Wageningen is een uiting van onwetenschappelijk doe-het-zelf-denken.

6. Zolang de programmatuur voor het opnemen, opslaan en opvragen van karteringsgegevens minder flexibel is dan een veldboekje staat het gebruik van handterminals en veldcomputers vernieuwing in de weg.

7. De betrouwbaarheidsgrens van 25 000 jaar voor de datering van organische carbonaten met behulp van de 14C-methode is te hoog.

   Dit proefschrift.

8. Het woord automatisering wekt onjuiste verwachtingen als het gaat om de invoering en het gebruik van computers.

9. Kerkelijke liedboeken behoren losbladig te zijn.

10. De stelligheid waarmee waarheden worden verdedigd is eerder een maat voor onkunde dan voor inzicht.

Stellingen behorende bij het proefschrift: The Geomorphology of Southeast Kenya.

A.P. Oosterom
Wageningen, 20 april 1988

A.P.Oosterom

THE GEOMORPHOLOGY OF SOUTHEAST KENYA

Proefschrift

ter verkrijging van de graad van
doctor in de landbouwwetenschappen
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
in het openbaar te verdedigen
op woensdag 20 april 1988
des namiddags te vier uur in de aula
van de Landbouwuniversiteit te Wageningen

ABSTRACT

Oosterom, A.P., 1988. The Geomorphology of Southeast Kenya. Doctoral Thesis, Agricultural University, Wageningen. 227 pp., 34 tbs, 32 figs, 160 refs, English and Dutch summaries, 1 map (1: 500 000).

A geomorphological map of an area of 66 500 km^2 in the southeastern part of Kenya has been prepared.
In the littoral zone eight major terrace levels occurring between the present shore and approximately 160 m +MSL have been described.
Analysis of radiometric datings and uplift rates of the coastal succession suggested that the formation of the terraces extends over the last 1.4 my of the Pleistocene. Soil development indicate a climatic change from humid to savannah conditions at approximately 800 ky BP.
Three sedimentary levels occurring in the landward part of the coastal region have been linked with the three highest littoral terraces.
In the interior region, the denudation of the vast plains east of the $38^{o}15'$ meridian was correlated with the deposition of Plio-Pleistocene deposits in the Lamu embayment and the coast.

To Heleen, Lonneke, Leen, Wimke and Han

CURRICULUM VITAE

Arie Pieter Oosterom was born on the 3rd October 1952 at Stolwijk, The Netherlands. After obtaining his HBS-b certificate at the Christelijk Lyceum at Gouda, he started his studies in 1970 at the Agricultural University of Wageningen. In 1978 the Ingenieur's degree was obtained with specialization in tropical soil science and geology with soil fertility as additional subject.
From 1978 to 1982, he was employed by the Netherlands Organization for Scientific Research (ZWO). During this period he carried out geomorphological fieldwork in southeast Kenya in co-operation with the Department of Geography at the University of Nairobi.
From 1982 to 1983 he was associated with the Department of Soil Science and Geology at the University of Wageningen. As a guest researcher, he obtained facilities to prepare a thesis on the geomorphology of southeast Kenya.
Since 1983 he has been employed by the Agricultural University of Wageningen as a university lecturer in the Department of Soil Science and Geology.

CONTENTS

PREFACE

The study of the origin and development of landforms is the work of a geomorphologist. He classifies and describes the nature of the Earth's surface and tries to interpret its genesis.

It was my present promotor Professor J.D. de Jong who, through his lectures, attracted my attention to this field of science. He was able to convey to me part of his knowledge and enthusiasm during my study at the Agricultural University of Wageningen. The request to conduct geomorphological research in southeast Kenya meant an unexpected opportunity for further graduation under his supervision.
Having come to the end of the study, I wish to express my sincere thanks for his contribution. I look back with pleasure on his yearly field visits and the lively discussions we had. The large number of letters which he wrote from Wageningen witness his continuing interest in the work. The time taken in molding the ideas and field data into a readable account was a strain on both our scientific and personal relationships but it is with honour and respect that I remember his patience and forbearance.

I am also grateful to my co-promotor Professor H. Th. Verstappen for his interest, critical remarks and guidance especially during the preparation of this thesis.

Among the many others, to whom I am indebted are in the Kenyan authorities in the guise of the Office of the President who permitted the research and gave their full cooperation during the fieldwork. I am grateful to the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) which provided the research funds. I wish particularly to thank Messrs. Schenk, Toet and Vontsteen for their pleasant and accurate handling of the administrative, financial and technical matters.

During the fieldwork many people helped and encouraged me. In particular I wish to mention:
- Professor F.F. Ojany, head of the Department of Geography at the University of Nairobi, for the important role he played in the research in the form of advice, interest and practical support;
- Dr. F.N. Muchena, former head of the Kenya Soil Survey and present director of the National Agricultural Laboratories, for his cooperation in many ways and his personal interest in the completion of the work;
- Dr. W.G. Sombroek, who as former team leader of the Kenya Soil Survey Project made the first proposals for this study, for the time he took to

follow the progress of the work and to discuss the preliminary results;
- Dr. R.F. Van der Weg for his support and advice in Kenya and later in Wageningen;
- my field and laboratory assistants Joseph Lilumbi Machinji, Newton Nguzo, Kahasso Ngombao and Mohammed Salim for their indispensable contribution and personal friendship.
- Dr. J. Gowlett of the Research Laboratory for Archaeology and the History of Art, Oxford University, who identified and classified the artefacts handed in to the National Museum in Nairobi, for his kind assistance.
- Messrs. J.W.Chr. Doppert, G.F.W. Herngreen and G. Spaink of the Geological Survey of the Netherlands, for their paleontological analysis.
- Mr. G. Kortenbout van der Sluijs of the National Museum of Geology and Mineralogy for his identification of the found skeletal fragments

For the final reporting in Wageningen I am indebted to the board of the Department of Soil Science and Geology for their provision of facilities. I wish especially to thank especially Mr. F.A.H.M. Schelbergen, who as administrator gave his full support to the work. Many other colleagues showed their keen interest or were involved in the preparation of this thesis. In particular I wish to mention:
- Mr. O.D. Jeronimus, who as an artist completed the cartography and lithography of the geomorphological map, for his accurate work and what he taught me of his fine craftmenship.
- Mr. J.P. Heerema, former head of the drawing-office of the Stiboka, for the facilities he provided for the preparation of the geomorphological map and his valuable advice.
- Messrs. G. Buurman and P. Versteeg for their contribution to the remaining art work in this publication.
- Messrs. J.D.J van Doesburg and A. Engelsma for their assistance in the clay and heavy mineral analysis.
- Dr. and Mrs. Bound for helping in proof reading the text.

A special word of thanks goes to Professor dr. S.B. Kroonenberg. His personal encouragement have been of great value for the preparation of this thesis.

I wish to write a word of remembrance to two persons who passed away during the completion of this study and have been of great importance to me:
- my beloved father, who till a few weeks before his death showed his interest in the work and longed to see the day of my promotion;
- my dear colleague and Kilifi neighbour Willem Boxem, whose practical advice and personal friendship I miss even to this day.

Finally, I wish to express my gratefulness to the people who are most near to me. I mention my mother and parents-in-law for their love, care and support they gave to me. I especially thank my wife and children for their contribution, patience and tolerance. Without their backing this study would not have been completed.

1 INTRODUCTION

In the period between 1973 and 1977 fieldwork was carried out for the preparation of a 1 : 1 000 000 exploratory soil map of Kenya (Sombroek et al., 1982, p. 9). It revealed extensive saline and alkaline soils in the eastern part of the country. The parent material in which the soils developed was indicated as Plio-Pleistocene bay sediments (Marafa beds). The deposits were believed to have been derived from local reworking of Pliocene bay sediments (Sombroek et al., 1976, p. 8). Saggerson and Baker (1965, p. 64) originally described these deposits as Plio-Pleistocene sediments of the Tana basin. They connected their distribution with an incursion of a shallow sea over the end-Tertiary surface after a downflexing of the Tana region in northeast Kenya. This crustal movement permitted the accumulation of marine sediments near the coast and extensive continental and probably lagoonal deposits further inland. Regional geological mapping in the Tana basin (Rix, 1964; Wright, 1964, 1973) confirmed the presence of Plio-Pleistocene sediments as far as 350 km inland. A firm age setting however was still lacking.
During the fieldwork for a reconnaissance soil survey of the Voi area Plio-Pleistocene bay deposits were found south of the Tana basin (Van Wijngaarden, 1978, p. 47, Appendix 1b). This renewed the idea of a far reaching inland incursion of the sea at the transition of the Pliocene and Pleistocene periods. However it seemed to have involved a much wider area than just the Tana basin. A striking correspondence with the geological history of the eastern coast of South Africa, as described by King (1972a, b), was suggested (J.D. de Jong, pers. comm.).

The work of the Kenyan Soil Survey did not only yield new data on soils and their parent materials. Using landform and geology at the first two levels of the legends to the soil maps, it gave also a fresh impulse to the study of the present configuration of the land surface. A new subdivision of the rocks was made and definitions of land forms in relation to soil mapping were proposed (Van de Weg, 1978). This classification included the use of several geomorphological levels with relative position (lower, middle, upper etc.) as a criterion for further subdivision. In northeast Kenya three sedimentary levels were recognized. They were indicated by the names Red-sand plain, Sealing-loam plain and Grey-clay plain (Sombroek et al. 1976). In the Voi and Mtito Andei area four different levels were distinguished (Van Wijngaarden, 1978, p. 53). They were indicated by topographical names partly after the erosion surfaces described by Ojany

(1978). Herewith also the question on the denudation chronology of eastern Kenya was raised again.

The practical scope of the soil-mapping programme however caused many ideas to remain in the stage of the field notes and campfire debates. Therefore further scientific investigations were recommended by the staff of the Kenyan Soil Survey. This resulted in a proposal for a research project on the geomorphology of Southeast Kenya, which was passed to the Department of Soil Science and Geology of the Agricultural University in Wageningen, the Department of Geography at the University of Nairobi and the International Institute for Aerospace Survey and Earth Sciences (ITC) at Enschede. Agreement was reached on a research programme to investigate the combined geomorphological, sedimentological and pedological history of southeast Kenya. The Kenyan Government authorised the research and financial support was obtained from the Netherlands Foundation for the Advancement of Tropical Research (WOTRO) at The Hague.
In October 1978 the field work started in the most southeastern corner of the study area where, due to the dissected nature of the land, most exposures could be expected. With the aid of aerial-photo interpretation and field work a geomorphological map was produced. In a later stage of the research the more remote northern and western parts were mapped with the aid of satellite images, aerial photographs and exploratory field-trips. The field work came to an end in August 1981 and the data analysis and reporting were continued at the Agricultural University of Wageningen.

This publication presents the results of the research. A coloured map on a scale of 1 : 500 000 (Appendix I) is included. It gives an overview of the main geomorphological divisions of the area. A map in black and white (Appendix II) has been added to help the reader to find the location of geographical features named in the report. The written text has been divided into four chapters. After this introduction to the occasion and scope of the research more general information is given in chapter 2. It deals mainly with the physiography of the area. In chapter 3 an analysis is presented of the landscapes in Southeast Kenya. Emphasis is laid on the geomorphological features and their correlative deposits. In the concluding chapter 4 the geomorphological history is discussed and potential areas for future research are mentioned.

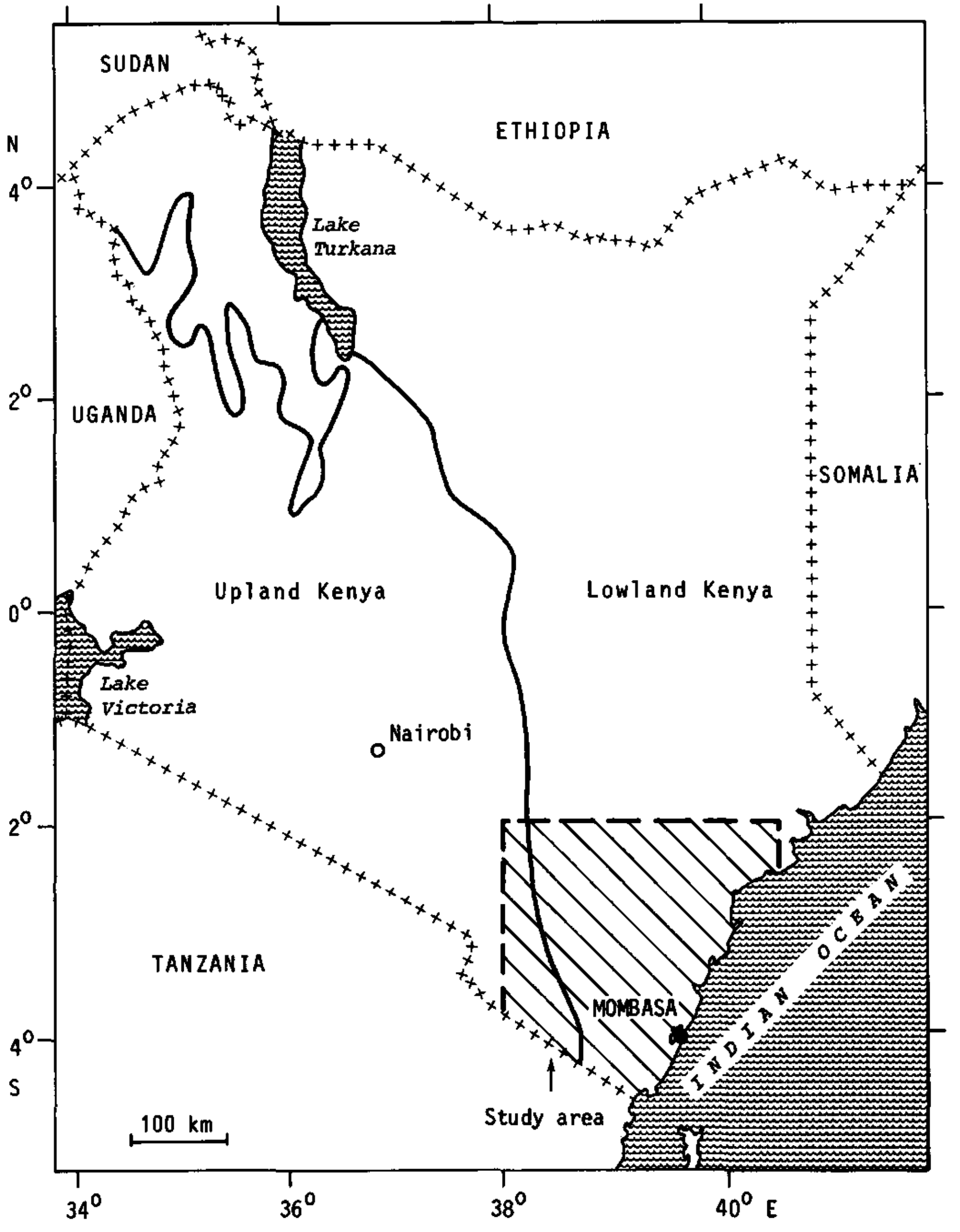


Fig. 1 Location of the study area

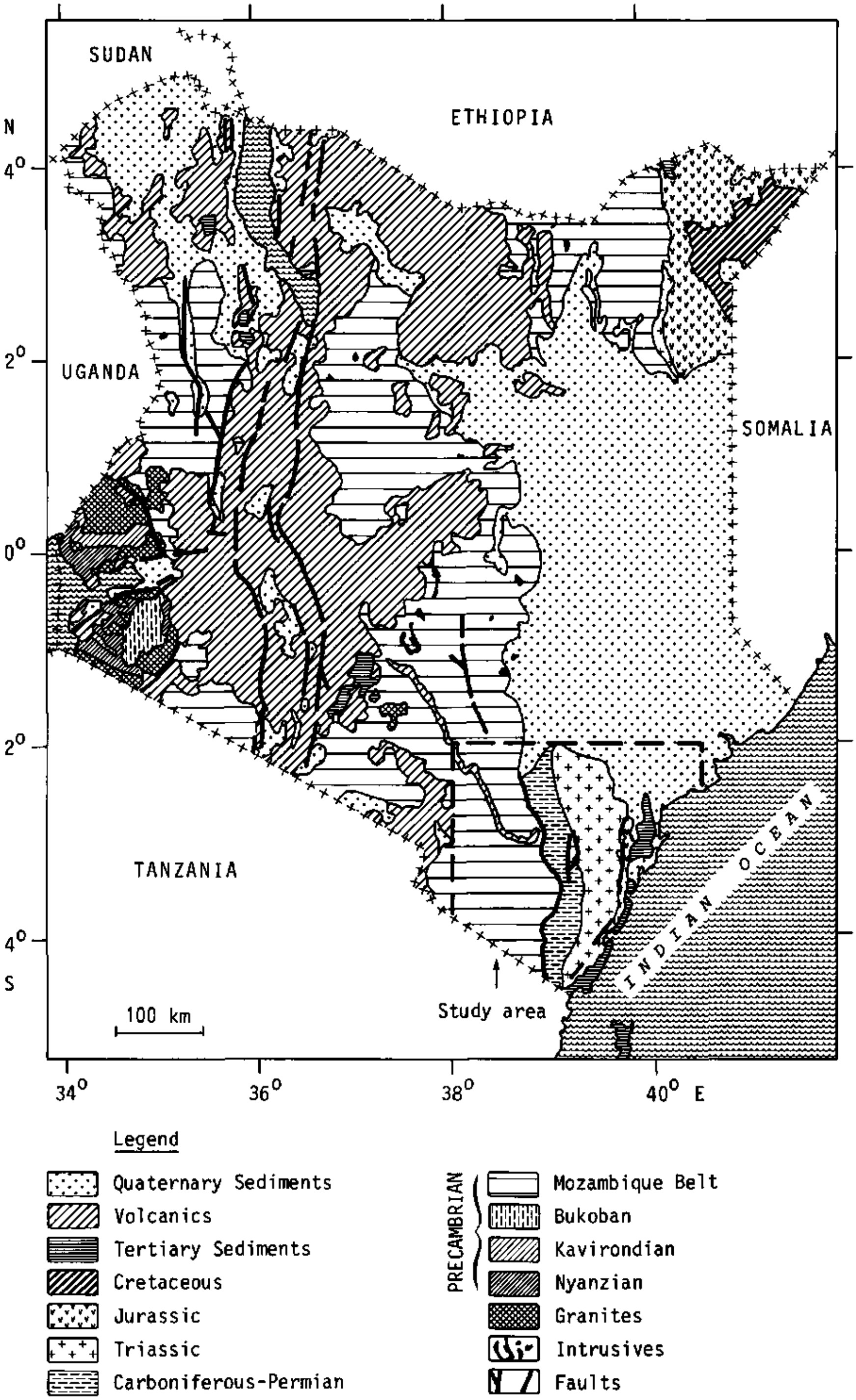


Fig. 2 Geology of Kenya (after Walsh, 1970)

2 GENERAL INFORMATION

The area of southeast Kenya, covered by the present study, is bounded in the north by the parallel of latitude 2^{o} S and in the west by the meridian of longitude 38^{o} E. The southern and eastern limits are determined by the Kenyan-Tanzanian border, the shoreline of the Indian Ocean and the meridian of longitude 40^{o} 30' E. respectively. In total it comprises a surface of about 66 500 square kilometers. The altitude varies from 0 m at the shore to about 2200 m in the Taita Hills. The two major upland and lowland regions into which Kenya geographically can be divided (Ojany & Ogendo, 1973, p. 38) are both represented in the area (Fig. 1). More information on the physical environment is given in the following sections.

2.1 Geology

The tectonic structure of the African continent is characterised by the occurrence of several cratons and mobile belts (Choubert & Fauret-Muet, 1976). Their formation took place during Precambrian times as a result of repeated orogenic cycles. These large structural units of stability and mobility are represented in East Africa by the East African Craton and the Mozambique Mobile Belt respectively.

- The East African Craton occurs in west Kenya and consists of Precambrian, slightly metamorphosed volcanic and sedimentary deposits belonging to the Nyanzian and Kavirondian Systems (Fig. 2). The area where these rocks are exposed is structurally known as the Tanzanian Shield. The rocks of the Bukoban System constitute a platform cover on the East African Craton. In west Kenya the rocks consist of Precambrian, volcanic and sedimentary deposits of the Kisii Series.
- The Mozambique Mobile Belt occurs mainly in central and eastern Kenya. It consists of Late Precambrian metamorphic rocks of the Mozambique Belt System, formerly known as the Basement System (Sanders, 1965). The Precambrian rocks are exposed in most of the western half of the study area.

A mainly Paleozoic-Mesozoic platform cover occurs farther east. The older part of it consist of fluviatile, lacustrine and deltaic sandstones and shales. The rocks belong to the Karroo System of Kenya and form a lithostratigraphical unit known as the Duruma Group (Cannon et al., 1981a, p. 421). These mainly Permian and Triassic deposits are overlain by marine

Mesozoic sedimentary rocks. Lithological and paleontological evidence shows that the sea in which the material deposited had an epicontinental character. It was in fact an arm of Tethys transgressing in a depression on the Gondwana continent (Cannon et al., 1981a, p. 423). In the study area the exposures of these Mesozoic sediments form a narrow strip of land down-faulted against the rocks of the Karroo System (Fig. 2).

The break-up of Gondwana during the Late Cretaceous Epoch made southeast Kenya a coast bounded by the Indian Ocean. The date of this event is set by the age of the oceanic crust east of the Kenyan coast (Unesco & Commission for the Geological Map of the World, 1976). The igneous Jombo Complex in the southeastern part of the study area dates from the Late Cretaceous (Pulfrey, 1969 p. 10) and might well be related to this continental rupture. Considerable physiographical changes followed this major tectonic event. A new cycle of erosion was initiated which resulted in a rejuvenation of the Jurassic and Early Cretaceous landscapes. Unfortunately no sedimentary succession reflecting these events is exposed in the study area. However, in the Lamu Embayment over 2000 m of Late Cretaceous deposits are known (Walters & Linton, 1973, p. 153). They serve as an important additional source of information on the geological and geomorphological events of this period. Remnants of the Late Jurassic land surface are thought to be present west of the study area in the Mua and Iveti Hills (Ojany, 1978, p. 466). Parts of the Taita Hills have also been considered as residuals of this Jurassic landscape (Van Wijngaarden, 1978, p. 56). A proper characterization and dating of these remnants is often impossible. In Section 3.2.1.2.2 attention is paid to this problem.

The Tertiary domal-uplift in central Kenya and Ethiopia had an even stronger influence on the geological development of the area. In the depressions between the two updoming areas sediments were laid down during Early Miocene times. The deposits were partly overlain by Middle and Late Miocene volcanites (Brotzu et al., 1984, p. 82). In the study area this episode is represented by the phonolitic lavas of the Yatta Plateau. The uplift culminated in the formation of the East African Rifts with the Western Rift in Uganda and the Eastern Rift in Kenya and Ethiopia. They are part of the Afro-Arabian Rift System and their formation took place mainly during Pliocene and Early Pleistocene times (Baker & Wohlenberg, 1971, p. 538). The Eastern Rift divides the crust of Kenya and Ethiopia into two large tectonic blocks. The western block has uplifted margins and a central depression in which the Lake Victoria basin developed. The study area is situated on the eastern or East Kenya - Somalia block. This main tectonic unit is characterised by NNW-SSE tending faults and a seaward tilt (Baker et al., 1972, p. 9). The influence of the Tertiary and Quaternary tectonic events on the development of the landscapes of southeast Kenya gets further attention in Chapter 3.

Widespread volcanism went hand in hand with the formation of the rift system

in central Kenya (Baker et al., 1971, p. 191). Large amounts of lavas and tuffs from Early Pliocene fissure and multi-centre eruptions accumulated in the Kenyan Rift valley and on its shoulders. The Aberdare Range and in part the Nyambeni Range are the representatives of these events in eastern Kenya. During Late Pliocene times, at about 3.1 to 2.6 my BP (my BP = million years before present), the lavas and volcanoclastic materials around the central volcano Mt. Kenya accumulated to an height of more than 6000 m (Baker, 1967, p. 8). During Early and Middle Pleistocene times, between about 1.1 and 0.36 my BP, an even greater volcanic body was formed around the central vent of Mt. Kilimanjaro (Baker, 1971, p. 207). Its lower slopes, which consist of olivine basalts, extend into in the study area. The volcanism on the eastern tectonic block continued up to historical times. In the study area this recent activity is represented by the olivine basalts and abundant pyroclastics of the Chyulu Hills.
During the development of these volcanic landscapes on the eastern block, Mt. Kenya together with the Aberdare and Nyambeni Ranges became the source area of Tana and Athi/Galana rivers. They are the two major streams in the study area which transport erosion products from central Kenya to the coast. The northern slopes of Mt. Kilimanjaro were connected to the drainage system of southeast Kenya by the Tsavo river which forms a major branch of the Galana. As a result the sedimentary history at the coast can be expected to reflect in one or more ways the volcanic and erosional history of the eastern rift-shoulder. Moreover it might provide a means of dating for the events in the study area.

In addition to these tectonic and volcanic events, the morphogenesis of the study area has been influenced by climatological changes. This is evidenced by for example the presence of ferralitic soils (Sombroek et al., 1976, p. 9) or large fossil termite mounts (Muchena, 1987, p. 39) in the present arid and semi-arid regions of eastern Kenya. Sea level changes played an important role in the development of the coast, which for example is evidenced by the marine succession and the presence of marine terraces west of the present-day shore (Walters & Linton, 1973; Toya et al., 1973, Crame, 1980, 1981; Braithwaite, 1984). The character and stratigraphy of these mainly Quaternary deposits and terraces are analysed and discussed in Chapter 3.

2.2 Relief

The general configuration of Kenya has long been subject of interest to workers of various disciplines (Gregory, 1896, 1921; Pritchard, 1962; Saggerson, 1962a; Pulfrey, 1960a; Baker, 1963). In a comprehensive study Ojany (1966) reviewed the previous work and defined fourteen physiographical regions. The distinctions are mainly based on difference in relief and geology. Seven of these regions are found in the study area (Fig. 3).

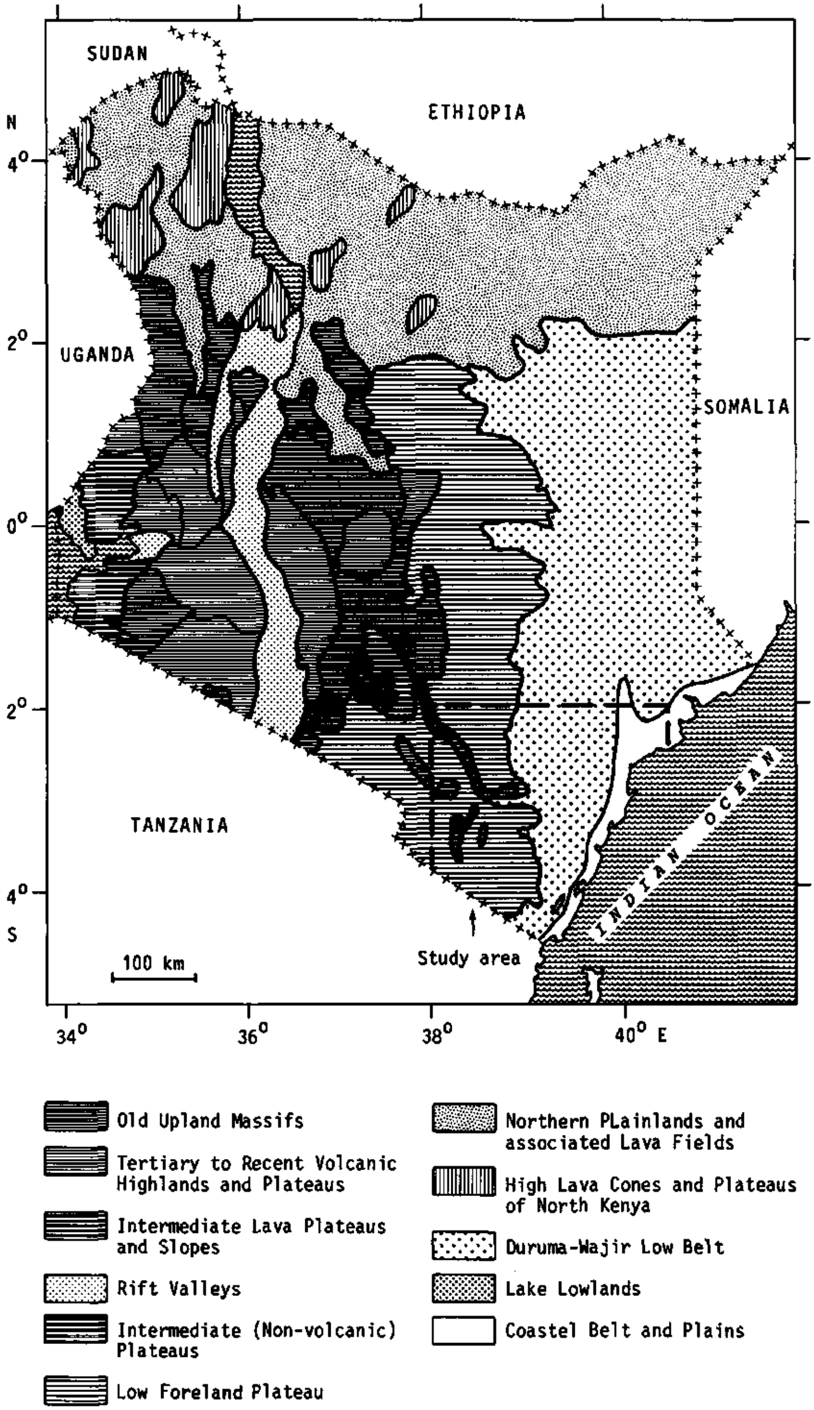


Fig. 3 Physiography of Kenya (after Ojany, 1966)

Their names and further subdivisions as reported by Ojany (1966, p. 188-196) are summarised below.

Old Upland Massifs
The Old Upland Massifs embrace the oldest land surfaces in Kenya, occurring above 1500 m. Two summit levels have been recognized in these areas and thought to be correlated with the Gondwana and the post-Gondwana planation surfaces of King (1962). In the study area one of the eight sub-regions is found. It is known as the Taita Hills and consists of a group of upland residuals with a maximum altitude of about 2200 m. The subsurface of this unit is formed by metamorphic rocks of the Mozambique Belt System.

Tertiary to Recent Volcanic Highlands and Plateaus
The Tertiary to Recent Volcanic Highlands and Plateaus comprise the volcanic upland areas above 1500 m. One of the five sub-regions is found in the study area and is known as the Chyulu Range or Hills. The area consists of lava flows and scoria cones with a maximum altitude of about 2175 m.

Intermediate Lava Plateaus and Slopes
The Intermediate Lava Plateaus and Slopes comprise the volcanic areas with an intermediate position between the upland and lowland plateaus. The parent rocks consist of Tertiary to Recent volcanites. In the study area one of the five sub-regions is present. It is known as the Yatta Plateau, formed by a narrow belt of phonolites with a length of about 300 km and a width of 10 to 15 km. Its altitude increases from 380 m in the east to 940 m at the western boundary of the study area. Its origin is widely debated and gets further attention in Section 3.2.2.2.2.

Intermediate (non-volcanic) Plateaus
The Intermediate (non-volcanic) Plateaus comprise the areas which have been produced by sub-aerial erosion and within which extensive remnants of the African planation surface (or sub-Miocene surface) have been preserved. In the study area one of the four sub-regions is found, known as the Taita Intermediate Plateau. It is represented by three groups of residual hills.
- The Ngulia and associated residuals, with a maximum altitude of approximately 1820 m.
- The Sagala Hills and associated residuals, with a maximum altitude of approximately 1520 m.
- The Mbulia and associated residuals, with a maximum altitude of around 1060 m.

The subsurface of the Taita Intermediate Plateau consists of metamorphic rocks of the Mozambique Belt System.

Low Foreland Plateau
The Low Foreland Plateau comprises the areas situated between about 300 and 900 m and characterised by the occurrence of metamorphic rocks of the Mozambique Belt System. The surface is regarded as representing the latest

planation surface of Tertiary time. The summits of numerous isolated residual hills are believed to rise to the sub-Miocene planation bevel (Ojany, 1966, p. 193). Four of the six sub-regions are represented in the study area.

- The Amboseli Plains, situated west of the Tsavo river and southwest of the Chyulu Range. In the south they are bounded by the volcanic cones of Mt. Kilimanjaro and Mt. Meru, both occurring in the Tanzanian territory.
- The Kibwezi Corridor, situated northwest of the Tsavo River, between the Galana river and the Chyulu Range.
- The Serengeti Plains and Aruba Plains, situated south of the Galana and east of the Tsavo rivers. In the south they are bounded by the Pare and Usambara Mountains of Tanzania.
- East Kitui Low Plateau, situated between the Galana and Tana rivers.

The region as a whole correlates broadly with the western part of the Nyika area distinguished by Gregory (1896, p. 222-3).

Duruma-Wajir Low Belt

The Duruma-Wajir Low Belt consists of an extensive plain area occurring at an altitude between 150 and 350 m. The subsurface is formed mainly by Paleozoic sedimentary rocks of the Duruma Group (Karroo System). The plain level is thought to record a lower Late Tertiary cycle of erosion and an Early Pleistocene cycle. Isolated hills rising above the general plain level are included. Their summits are believed to reach the level of the upper of the Late Tertiary planation cycles (Ojany, 1966, p. 195). Two of its four sub-regions are present in the study area.

- The Kwale Low Belt, situated west of the Coastal Belt between the Tanzanian border and the Sabaki river. It includes the southeastern part of the Nyika, the Coastal Range and the Giriama Hill Lands distinguished by Gregory (1896, p. 222-3).
- The Galana-Tana River Low Belt, situated between the Galana and Tana Rivers, west of the Coastal Belt. It correlates broadly with the northeastern part of the Nyika area of Gregory (1896, p. 222-3).

Coastal Belt and Plains

The Coastal Belt and Plains are situated along the shore of the Indian Ocean. This physiographical unit comprises two sub-regions both present in the study area.

- The Coastal Plain, composed of a true coastal plain country with a maximum altitude of about 60 m. It embraces the Pleistocene deposits with three wave-cut platforms and correlates with what Gregory (1896, p. 222) originally called Temborari or Coastal Plains.
- The Coastal Belt, composed of a narrow zone of dissected country with an altitude of about 60 to 150 m. It is underlain mainly by the Mesozoic sedimentary rocks and further characterised by a planed-off surface. The Foot Plateau distinguished by Gregory (1986, p. 222) is part of this area.

In Chapter 3 the above mentioned physiographical regions are correlated with the geomorphological units defined for the purpose of the present study. Where needed the existing physiographical subdivision is treated and discussed in more detail.

2.3 Drainage

A third aspect of the landscape which results in a natural division of the terrain is the drainage. In Kenya the major drainage systems are related to the large tectonic units of East Africa. A distinction of three groups can be made:

- The drainage systems on the western rift shoulder, being part of the continental Nile basin;
- The drainage systems in the Eastern Rift Valley, consisting of a complex of internally drained basins without a continental outlet;
- The drainage systems on the eastern rift shoulder, forming individual epicontinental basins with their outlets to the Indian Ocean.

In the study area seven of the twelve major drainage basins on the eastern rift shoulder are present (Fig. 4). They are briefly described below.

Tana basin

The Tana basin is found in the northern part of the study area. The main stream of this catchment area is the Tana river rising on Mt. Kenya and the Aberdare and Nyambeni Ranges. It is a perennial stream with a mean annual discharge of about 4700 million m^3 (Ojany & Ogendo, 1973, p. 71-72). The Tana river has a well developed alluvial valley in it lower course with an attached delta plain. They are known as the Tana alluvial plain and the Tana delta respectively.
The Tiva is the second important stream with its head waters on the Kitui Intermediate (non-volcanic) Plateau. It is a perennial river in its upper reaches, but east of the Hidilathi Wells it loses its waters for most of the year. The intermittent lower course is known as Laga Kokani. The total catchment of the Tana basin comprises an area of 132 000 km^2. It is geologically characterised by the occurrence of volcanic, metamorphic and sedimentary rocks. Only the southeastern part of it is present in the study area.

Athi-Galana/Sabaki basin

The Athi-Galana/Sabaki basin has as its main stream the Athi river rising in the Aberdare Range and on the Athi and Kapiti Plains. The Tsavo river is the main branch with its head water on the northern slopes of Mt. Kilimanjaro. Both streams are perennial and the total average annual discharge at the mouth near Malindi amounts to approximately 1295 million m^3 (Ojany & Ogendo, 1973, p. 71-72). The lower course of the Athi river is called Galana (Giriama name) or Sabaki (Swahili name). It has a well defined alluvial

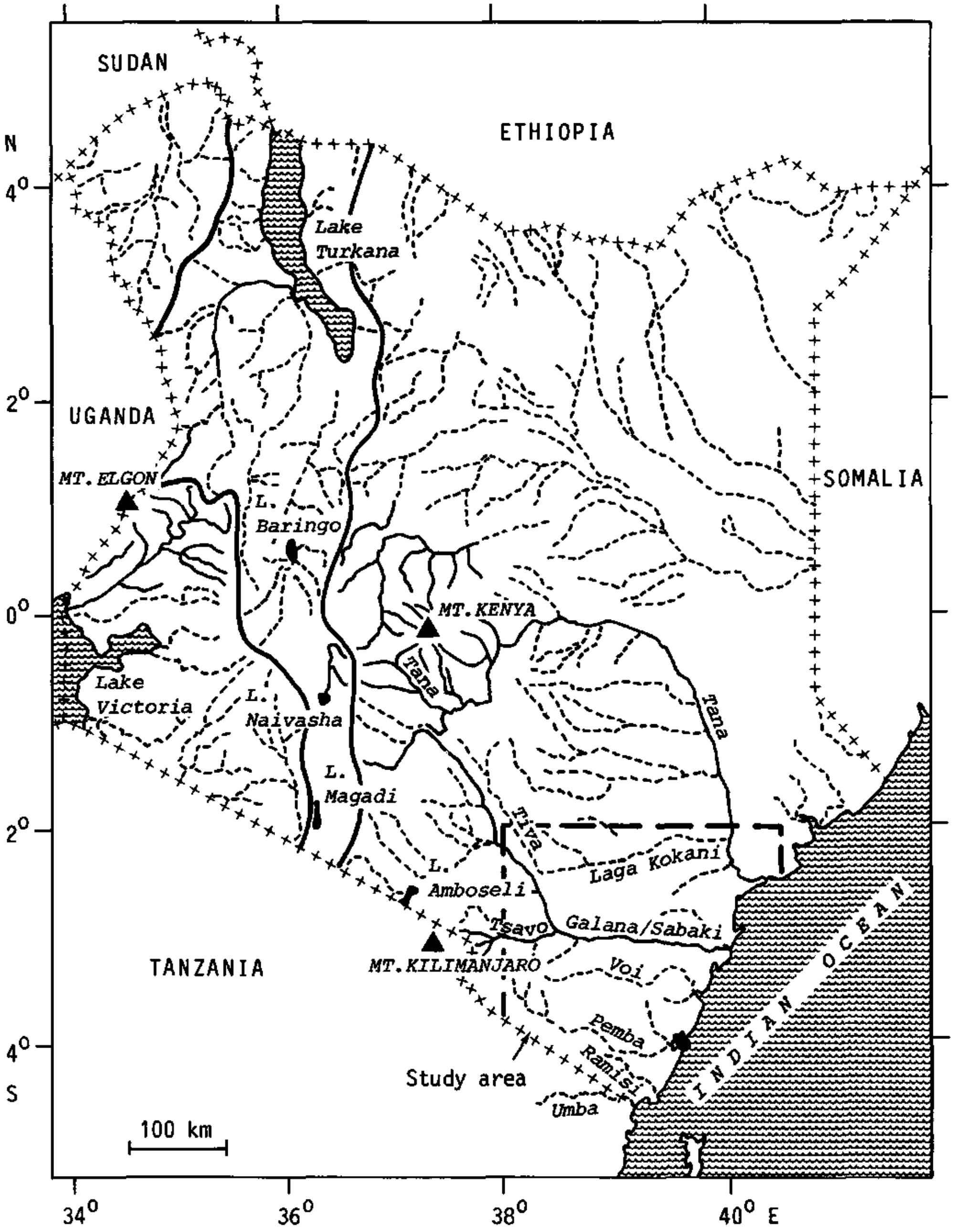


Fig. 4 Drainage basins of the study area

plain, but lacks a delta. Instead its seaward termination seems to consists of a filled in estuary (Appendix I). The total drainage area comprises approximately 70 000 km^2. The subsurface of the Athi basin consists of volcanic, metamorphic and sedimentary rocks. Only its eastern half occurs in the study area.

Voi-Goshi/Vitengeni-Rare basin

The Voi-Goshi/Vitengeni-Rare basin has as its main stream the Voi river rising in the Taita Hills. It is a perennial river only in its upper course. It looses its water east of Ndolo for most of the year. The lower course is known as the Goshi or Vitengeni and Rare rivers. The Ndzovuni is a second important river of the Voi basin. It is an intermittent stream which discharges only in the rainy season. The mouth of both streams is situated in a branching bay known as the Kilifi Creek or Bandari ya Wali. The total surface of the drainage area amounts to approximately 7400 km^2. It is geologically characterised by the occurrence of metamorphic and sedimentary rocks. The whole catchment is part of the study area.

Mwatate-Puma-Pemba basin

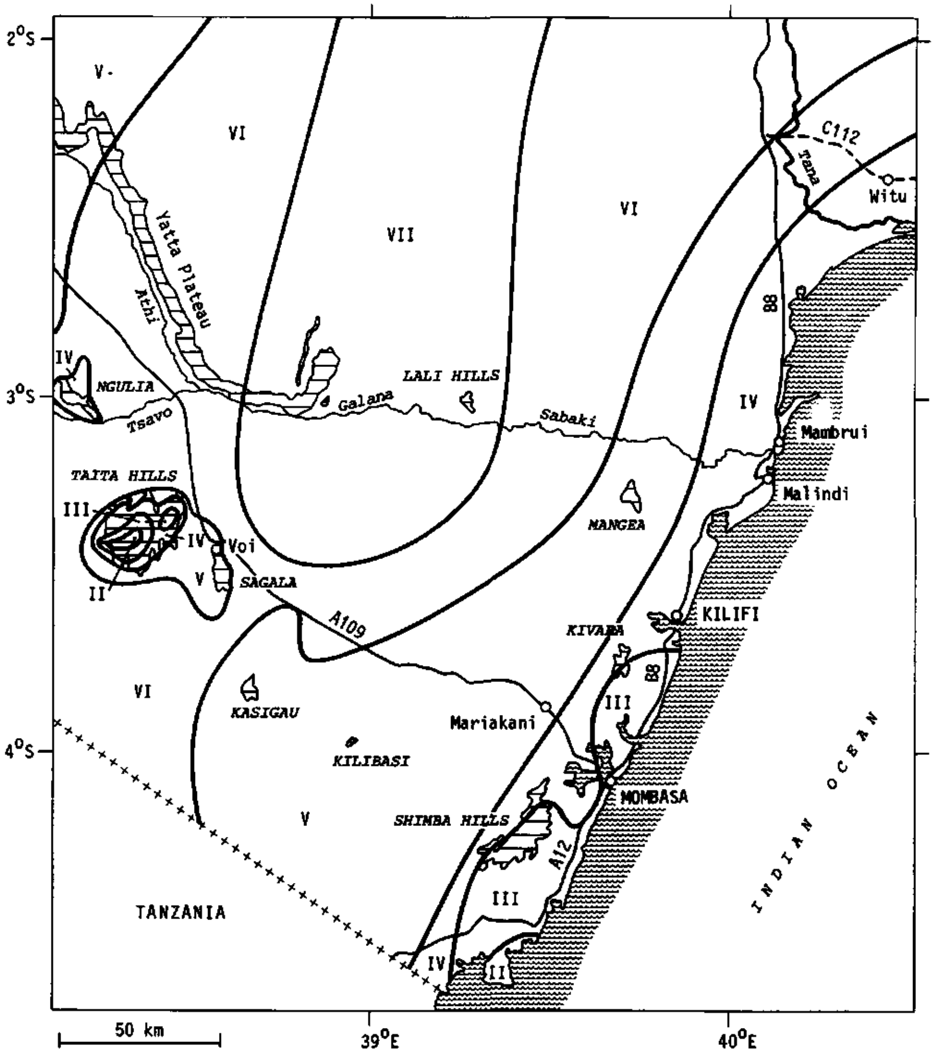
The Mwatate-Puma-Pemba basin has as its main stream the Mwatate river rising in the Taita Hills. Its lower course is known as Puma and Cha Shimba or Pemba river. The river mouth is situated in the southern arm of the branched bay near Mombasa, known as Port Reitz. The Mwachi and Manjera rivers also discharge into Port Reitz. They rise in the Kwale Low Belt and their catchment areas are considered to be parts of the Mwatate basin. The same applies for the Kombeni and Tsalu rivers which have their outlets in the northern arm of the branched embayment near Mombasa, known as Port Tudor. All streams belonging to the Mwatate drainage system are intermittent. The total surface of the catchment areas amounts to around 9200 km^2. Its subsurface is characterised by metamorphic and sedimentary rocks. The whole Mwatate-Puma-Pemba basin is part of the study area.

Ramisi basin

The Ramisi basin has as its main stream the Ramisi river rising on the Low Foreland Plateau. Its discharge is intermittent. The total surface of the drainage area amounts around 1300 km^2. The subsurface is mainly composed of sedimentary rocks of the Karroo System. The complete drainage basin occurs in the study area.

Umba basin

The Umba basin is the most southerly catchment area. It has as its main stream the Umba river rising in the Pare and Usambara Mountains of Tanzania. Like the other rivers of the central part of the study area it has an intermittent discharge. The catchment of the Mwena river has been included to the Umba basin as it discharges in the same embayment. The Mwena river rises on the Low Foreland Plateau and also has an intermittent character. The total surface of the Umba basin amounts to approximately 8200 km^2 of which



zone	r/Eo (%)	classification	r average annual rainfall (mm)	Eo average annual potential evaporation (mm)	vegetation
II	65-80	sub-humid	1000-1600	1300-2100	moist and dry forest
III	50-65	semi-humid	800-1400	1450-2200	dry forest and moist woodland
IV	40-50	semi-humid to semi-arid	600-1100	1550-2200	dry woodland and bushland
V	25-40	semi-arid	450- 900	1650-2300	bushland
VI	15-25	arid	300- 550	1900-2400	bushland and scrubland
VII	< 15	very arid	150- 350	2100-2500	desert scrub

Fig. 5 Moisture availability zones (after Sombroek et al., 1982)

approximately one quarter makes part of the study area. Both metamorphic and sedimentary rocks are found in the subsurface.

A narrow strip of the extreme southwestern part of the study area drains its surface water towards Lake Jipe which belongs to the Ruvu basin of Tanzania. As this catchment has no direct connection with the coast of southeast Kenya it is not further taken into account in this study.
Near the coast the topographic divides between these main drainage areas diverge and delineate independent interfluves (Fig. 4). They are either internally drained or have minor surface drainage systems with a direct outlet to the Indian Ocean. They are provisionally indicated as interoutlet areas in the present study.

2.4 Climate and vegetation

The prevailing climatic conditions in southeastern Kenya are of the savanna type with two dry seasons (Köppen, 1923, Table 1, symbol Aw"). The seasonal pattern is dominated by three airstreams (Ojany & Ogendo, 1973, p. 56):
- The Arabian (or Indian) northeast trade winds, forming the northeast monsoon. They prevail during the period of November to March and give rise to a short wet season, which is followed by a relatively long dry season.
- The southeast trade winds, forming the southeast monsoon. They start to influence the weather by about the month of April and give rise to the main wet season. It is followed by a dry or transitional season starting during July.
- The Congo airstream, connected with the prevailing trade winds at the West African coast. The associated high winds penetrate through Equatorial Africa and cause the change of weather conditions in July. In western Kenya it gives rise to convectional storms, while in eastern Kenya its influence is felt by a decrease in strength of the southeast trade winds.

The annual average precipitation in the study area varies from about 200 mm to over 1200 mm. The average annual potential evapotranspiration increases from less then 2000 mm at the coast to more than 2200 mm in the interior. In the areas with an altitude of more than 1000 m +MSL (+MSL = above mean sea level) the potential evapotranspiration decreases again to less than 2200 mm. The monthly mean maximum temperature varies between 30^{o} C at the coast to about 35^{o} C in the interior. The monthly mean minimum temperature ranges from 22^{o} C along the coast to around 16^{o} C inland. The combination of precipitation, potential evapotranspiration and temperature data makes it possible to distinguish five moisture availability zones. They are characterised by specific vegetations and agriculture potentials (Fig. 5).

The general circulation of the Indian Ocean currents is also related to the pattern of the seasonal winds. In the period of the southeast monsoon coastal currents are predominantly northward. Less strong southward directed currents occur during the season of the northeast monsoon (Barry & Chorley, 1971, p. 159).

3 GEOMORPHOLOGICAL ANALYSIS

The separation of the distinct associations of landforms into the constituent parts is essential for the study of morphology of the Earth. It opens the way to investigate the nature, origin and development of the individual landforms in relationship with the underlying rocks and the geological changes as recorded by them. The geomorphological analysis of the present study started with interpretation and delineation of terrain units on aerial photographs. This was followed by further description and characterization with the aid of fieldwork.
In an early stage of the research the need arose for the development of a regional landform classification system, which would preferably emphasise such aspects as process and chronology as well as relief, geology and topographical position. The current physiographical divisions of Ojany (1966) and the pragmatic or physiognomical definitions of the Kenyan Soil Survey (Van de Weg, 1978) were neither meant nor suited for such an approach. Therefore a new geomorphological division was outlined and used in the present study. It distinguishes two main regions:

- The coastland, defined as the landmass region which morphologically developed to its present configuration in alternating terrestrial and marine environments.
- The inland, defined as the landmass region which morphologically developed to its present configuration in terrestrial environments.

The presence or absence of coastal landforms and deposits is the criterion on which the boundary between the two main units is defined. In practice this enables to distinguish those landscapes which still have direct evidence of the influence of former sea-levels from those which have not. In a tectonic active area with important lithological differences this classification keeps together those parts of the terrain which initially were formed under comparable conditions.
In the following sections these main units and their further subdivisions are described and discussed.

3.1 Coastal region

The coastland of southeast Kenya is represented by a strip of flat to rolling terrain bordering the Indian Ocean. Its width increases from approximately 50 km in the south to approximately 175 km in the north. It loosely correlates with the Duruma-Wajir Low Belt and the Coastal Belt and Plains of Ojany (1966). It also embraces the Coastal Plains, the Coastal Uplands and parts of the Erosional and Sedimentary Plains distinguished on the exploratory soil map of Kenya (Sombroek et al. 1982).

The coastland can be further divided into two subregions with regard to the character of their superficial deposits. In the present study they have been indicated (Appendix I) and defined as:
- The littoral zone, occurring at the seaward part of the coastland and characterised by the presence of intertidal deposits. In practice this unit comprises landscapes with remnants of former marine plains.
- The paralic zone, occurring at the landward part of the coastland and characterised by the presence of paralic deposits. In practice the unit includes the terrains where the Plio-Pleistocene bay sediments occur. The proposed use of the adjective paralic for these transitional areas of the coastland towards the inland is further explained and discussed in Section 3.1.2.

Depending on whether certain parts of these zones have been elevated above their surroundings or not they have been called hills and plateaus or plains respectively. Both units are characterised by the occurrence of several plain or summit levels. They represent stripped structural surfaces and true erosional and sedimentary levels. In the present study they have been given the geographical name of the area where they were first described. The erosional and sedimentary levels reflect a relative chronology, the highest levels being the oldest. Dating of the levels has been attempted by correlation with the chronology of the coastal sedimentary succession (Sections 3.1.1.3 and 3.1.2.3). The local degree of dissection of these surfaces made it possible to distinguish areas with different topographic relief. This resulted in terms as e.g. undulating or rolling plains etc. in accordance with the definitions given by FAO/UNESCO (1977, p. 8) for the description of the topography.

3.1.1 Littoral zone

The seaward part of the coastland is the best studied area of southeast Kenya. Geological surveys by Caswell (1953, 1956), Thompson (1956) and Williams (1962) cover the area except for its extreme northern sector. They also summarised the work of early investigators such as Muff (1908), Gregory (1921) and Parson (1928). Although they paid relatively little attention to the Quaternary geology, they provided the stratigraphies which are still widely used. A recent remapping programme of the Geological Survey of Kenya has resulted in a proposal for a revised stratigraphy (Cannon et al. 1981a, b), which gives a workable division of the Paleozoic and Mesozoic deposits. As the work was less concerned with the Cainozoic succession its

stratigraphy remained essentially unchanged.
Special attention was given to the littoral deposits of southeast Kenya by Battistini (1969). However the result was a gross simplification of the stratigraphical details. Rossi (1981) attempted to correlate the Quaternary history of the Kenyan coast with that of Madagascar. His work resulted in a more detailed stratigraphy which will be further discussed in Section 3.1.1.1. In a recent publication Braithwaite (1984) gave a valuable contribution to the stratigraphy of the reef limestones.

Most of the above mentioned authors paid some attention to the geomorphology of the area. Specific geomorphological studies however were carried out by Hori (1970), Toya et al. (1973) and Åse (1978; 1981). Their work concentrated mainly on the coastal section between Mombasa and Malindi and resulted in the distinction of seven terrace levels.
Reconnaissance soil surveys (Michieka et al., 1978; Boxem et al. 1987) provided more information on the character of the superficial deposits of the coastal plains. Unfortunately the detail of the soil maps does not allow a straightforward correlation with the terrace levels distinguished in geomorphological studies.

In the following sections an attempt is made to incorporate all existing data in a new geomorphological framework for the entire littoral zone. First the geological data are correlated and summarised in a preliminary stratigraphy. Thereafter the morphological structure of the landscapes is treated in detail. Finally the developmental history of the littoral areas is discussed.

3.1.1.1 Stratigraphical record

The subsurface rocks of the littoral areas consist mainly of the Mesozoic limestones and shales of the Kambe and Mtomkuu Formation. Towards the east they are succeeded by mainly unconsolidated Cainozoic sediments. A preliminary stratigraphical framework for the entire littoral zone has been compiled by correlating the geological work done so far (Table 1). Its structure mainly follows the proposed stratigraphy of Cannon et al. (1981a). The frame work and its correlation is commented on below.

Kambe Formation
The Kambe Formation comprises Middle Jurassic marine limestones with subordinate shales and siltstones deposited in a shallow water environment. The rocks correlate with the Jurassic or Kambe Limestones described by Caswell (1953, 1956), Thompson (1956) and Williams (1962). The date of Middle Jurassic is set by fossil corals and ammonites belonging to the Late Bajonian to Bathonian stages.

Table 1 Preliminary Mesozoic/Cainozoic stratigraphy of the littoral zone

Period	Epoch	Formation/member	Predominant lithology
Quaternary	Holocene	Recent alluvium	silts/clays
		Recent beach deposits	sands
		Recent tidal-flat deposits	sands/muds
		Recent dune deposits	sands
	Pleistocene	Younger Pleistocene sands	sands
		Older Pleistocene sands	sands
		Pleistocene reef complex	limestones/sands
		Changamwe deposits	sands/silts/clays
		Magarini F. - Upper member	sands
		- Lower member	sands/gravel
Tertiary	Pliocene	Marafa F.	clays/sands
	Miocene	Baratumu F.	sandstones
	Oligocene	(not exposed)	sandstones/limestones
	Eocene	(not exposed)	sandstones
	Paleocene	(not exposed)	limestones
Cretaceous	Upper	(not exposed)	shales/mudstones
	Lower	Mtomkuu F. - Upper member	shales
		- Middle member	shales
Jurassic	Upper	- Lower member	shales
	Middle	Kambe F.	limestones

Mtomkuu Formation

The Mtomkuu Formation is composed of marine rocks. It is subdivided into three formal lithostratigraphical members.

- The Lower Member comprises a complex of probably Upper Jurassic shales, siltstones sandstones and limestones deposited in a shallow water environment. It roughly correlates with the Kibiongoni Beds of Caswell (1953, p. 22; 1956, p. 21). The date of Upper Jurassic is uncertain. It is inferred from the position of the deposits in between definite Middle and Upper Jurassic sediments.
- The Middle Member comprise Upper Jurassic shales with subordinate limestones and sandstones deposited in a shallow water environment. It correlates with the Upper Jurassic shales of Caswell (1953, p. 22; 1956, p. 22), Thompson (1956, p. 17) and Williams (1962, p. 16). The unit includes the former Miritimi shales, the Coroa Mombasa limestone and Changamwe shales. Their date of Upper Jurassic is set by fossil ammonites.
- The Upper Member comprise Lower Cretaceous limestones with shale partings. It correlates with the Freretown Limestone of Caswell (1953, p. 24). Its date is set by fossil Exogyra species.

Upper Cretaceous

The Upper Cretaceous sedimentary rocks are made up of mudstones and shales with thin bands of fine sandstones and limestones. The deposits are known to occur in the Lamu embayment (Walters & Linton, 1973, p. 141). They have been deposited in an undisturbed, relatively deep, marine environment. In the study area no Upper Cretaceous rocks are exposed at the surface.

Paleocene

The Paleocene sedimentary rocks are mainly made up of limestones with interbedded shales and fine sandstones. The rocks are found in the subsurface of the most southeastern part of the Lamu embayment. They have been laid down in a variable, shallow marine environment and their deposition continued into the Lower Eocene (Walters & Linton 1973, p. 141). The deposits are present in the deeper subsurface of the northeastern part of the study area.

Eocene
The Eocene sedimentary rocks are made up of mainly sandstones with bands of limestones and mudstones. The rocks are present in the subsurface of the Lamu embayment. Deposition is thought to have taken place in a fluviomarine or deltaic environment with periodic marine incursions (Walters & Linton, 1973, p. 141).

Oligocene
The Oligocene sedimentary rocks are made up of sandstones and limestones. The rocks are a continuation of the Eocene beds. Towards the end of the Oligocene the depositional environment changed and shallow marine limestones were deposited. They form the base of approximately 1500 m of Miocene beds consisting of mainly limestones (Walters & Linton, 1973, p. 141).

Baratumu Formation
The Baratumu Formation comprises Lower to Middle Miocene sandstones with subordinate shales and limestones. In southeast Kenya the formation correlates with the Baratumu Beds distinguished by Thompson (1956) in the Malindi area. He considered the sediments to have been deposited in a littoral or neritic environment and described them as mainly sandy marls, marly limestones and sands with uncommon calcareous sandstones. The lower Miocene age (Aquitanian-Burdigalian stage) accepted by Thompson is based on the determination of fossil corals, gastropods, foraminifera and marine algae.
The Fundi Isa Limestones described in the area north of Malindi have been included in the Baratumu Formation. It is a tentative correlation, based mainly on correspondence in age and position. According to Williams (1962) the Fundi Isa Limestones comprise calcareous sediments. They range from limestones to sandstones with fine- grained conglomerates deposited in shallow water near an adjacent coastline. Thompson based his description primarily on exposures at the eastern edge of the occurrence of the Baratumu Formation and Williams more at the western edge. It might well be possible that the difference in lithology is caused by a sedimentary facies change from more sandy in the northwest to more clayey in the east. The occurrence of limestone intercalations especially towards the top of the sequence has already been reported by Thompson (1956, p. 27). Walters & Linton (1973, p. 146) suggested a Middle Miocene age after a revision of the fauna of the Baratumu Beds and the Fundi Isa Limestones. More stratigraphical work is required to unravel the complete sedimentary history of the deposits assigned to the Baratumu Formation.

In the Lamu embayment about 1500 m of shallow marine Miocene limestones and mudstones are present. They represent an important marine transgression which had already started in the Upper Oligocene (Walters & Linton, 1973, p. 143). The sediments of the Baratumu Formation of southeast Kenya were probably deposited during this same event.

Marafa Formation

The Marafa Formation comprises Pliocene sandstones and sands with subordinate shales and marls. It correlates loosely with the Marafa Beds which were described by Thompson (1956, p. 28-9) as sub-aqueous (marine-deltaic) deposits, essentially consisting of non-calcareous sands, clays and pebble beds. His dating of Pliocene to Early Pleistocene is based on the determination of fossil foraminifera. The inclusion of younger sands and gravels which previously had been assigned to the fluvial facies of the Magarini sands by Caswell (1953; 1956) makes a straightforward correlation impossible. In the present stratigraphy these younger deposits have been excluded from the Marafa Formation.
In the north of the area Williams (1962) defined the Midadoni Beds. He described them as Pliocene (?) clayey sandstones, sandy clays and calcareous sandstones with local quartz pebble beds. He considered his dating based on paleontological evidence as inconclusive. With the same reservation the Midadoni Beds have been tentatively correlated with the Marafa Formation in the preliminary stratigraphy. However the deposits which Williams called Marafa Beds are definitely not to be correlated with the Marafa Formation. Their occurrence, as deposits in previously deeply incised valleys and their fluviatile nature, points much more to a correlation with the lower member of the Magarini Formation.
In the stratigraphy proposed by Walters & Linton (1973, p. 144) the deposits of the Marafa Formation are again correlated with those of the Magarini Formation. Of interest is their description, from a borehole near Shimanzi, of Upper Miocene to Lower Pliocene beds of minimal 73 m thick under around 30 m of Magarini Sands. However the proposed correlation with the North Mombasa Crag of Caswell (1953, p. 27) is confusing. The name originally has been given to only the calcareous beds exposed in the cliffs of the embayments around Mombasa Island (Gregory, 1921, p. 67). A correlation of the beds described by Walters & Linton with those of the Marafa Formation is more likely.

From the above it will be clear that the differentiation between the deposits of the Marafa Formation proper and younger fluviatile deposits in the field is often uncertain. In the present study the ferricrete layer at the top of the Marafa Formation (Thompson, 1956, p. 29) proved to be a useful marker horizon. In places where the top of the profile has been truncated, the progressed state of weathering of the Marafa deposits is characteristic. It is reflected in a high content of kaolinitic clay and a low content of recognizable feldspar minerals.

Magarini Formation

The Magarini Formation consists of two different stratigraphical members.

- The Lower Member is formed by Plio-Pleistocene fluviatile sands and gravels and correlates with the fluviatile part of the Magarini Sands described by Caswell (1953, p. 26; 1956, p. 27). The unit further includes the fluviatile part of the Marafa Beds as defined by Williams (1962, p. 46). The age of the deposits is uncertain. Caswell considered them to be Upper Pliocene and correlated the beds with the Mikindini Beds in Tanzania. It was Stockly (1928, Table 4) who originally dated these last beds as Upper Pliocene by fossil evidence. Williams (1962, p. 47) suggested a Lower Pleistocene age. His dating is based on the fact that the deposits occur in channels which he considered too deep to be due to downcutting by Pliocene streams.
- The Upper Member consists of Pleistocene (?) sands of mainly eolian origin. They correlate more or less with of the eolian part of the Magarini Sands of Caswell (1953, p. 26; 1956, p. 29) and with the Magarini Sands of Thompson (1956, p. 30). The Magarini Sands, mapped and described by Williams (1962, p. 43), prove to be of a total different character. Therefore they have not been included in the Magarini Formation. Thompson (1956, p. 31) proposed an upper Middle Pleistocene age on evidence of apparent Levalloisian artefacts at the base of the sands. Caswell advocated a Lower Pleistocene age by correlating the deposition of the sands with supposed dry conditions during the first interpluvial, a period which at that time was considered to be contemporaneous with the Günz-Mindel Glaciation in Alpine Europe.

Changamwe deposits

The Changamwe deposits comprise flat-bedded, probably Pleistocene, marine yellowish sands and clays. They were described by Caswell (1953, p. 26) who included them in the Magarini Sands on his map. The marine character is indicated by numerous fossil oysters. The deposits were provisionally dated as uppermost Pliocene or Lower Pleistocene (Caswell, 1953, p. 26). A more detailed description was given by Hori (1970, p. 32). He distinguished strong reddish brown sands on top of the succession and considered them Upper Pleistocene. This dating is based on the occurrence of artefacts at the transition from the brown sands to the flat-bedded, yellowish or whitish grey sands and clays below. These last deposits contain calcareous nodules and quartz gravels. Bluish grey clays occur as the lowermost deposits . They have been deposited on a rolling surface cut into the rocks of the Jurassic shales of the Mtomkuu Formation. No further dates are assigned to these two lower beds by Hori. Walters & Linton (1973, p. 143) called the deposits Kipevu Beds, after the name of site where they described their type section. The suggested age of Middle Miocene for these beds on base of a single *Austrotrillina howchini* specimen will shown to be incorrect by new data described in Section 3.1.1.2.4. In a still later study Rossi (1981, p. 50) deduced a Lower to Middle Pleistocene age by connecting the Changamwe deposits with the first post-Pliocene transgression. Kajita (1982, p. 11) established a detailed stratigraphy of Pleistocene deposits at the Mtongwe site. They are in the present study considered to be part of the Changamwe deposits.

Pleistocene reef complex

The Pleistocene reef complex comprises a collection of coral breccias, coral limestones and intercalated sands and silts. It correlates with the Fossil Coral Reef and Raised Coral Reef of Caswell (1953, p. 27; 1956, p. 27), the Fossil Coral Reef and Coral Breccia of Thompson (1956, p. 35) and the Raised Coral Reef of Williams (1962, p. 47). A Middle Pleistocene age was originally assigned to the rocks by Caswell (1953, p. 25 and 30). The age is based on the consideration that the reef must have been built up during the second interpluvial. This conclusion was reached by estimating the time needed for the building-up of the reef body. In a recent study of the coastal limestones of Kenya, Braithwaite (1984) was able to distinguish five sedimentary units in the reef deposits between 0 and 25 m +MSL. The various lithological units are shortly described below. Informal names have been added where they have not been previously given.

- The Mombasa sands, corresponding with the basal sands of unit 1 mentioned by Braithwaite (1984, p. 687), consist of friable, pale grey sands with quartz gravels. The deposits probably correlate with the lower part of the North Mombasa Crag described by Caswell (1953, p. 27) and are exposed in the cliffs around Mombasa island.
- The Msambweni limestones, described by Braithwaite (1984, unit 1, p. 687), consist of dense, hard limestones with scattered coral heads. The upper surface of the deposit is irregular but shows no signs of either marine or subaerial erosion. At Msambweni the deposits form the base of a sea cliff and extend under the present waterline.
- The Shimoni limestones, corresponding with the limestones of unit 2 described by Braithwaite (1984, p. 687). They consist of hard and tightly cemented rocks varying from calcarenites to carbonate muds with generally calcitized coral colonies. The calcarenites occur at the top as well as on the bottom of the unit and are locally cross-bedded. More to the west they appear to change into pale friable sands, which may correlate with the Kilindini Sands described by Caswell (1953, p. 29). The unit can be up to 6 m thick and its top is characterised by a deeply eroded surface with locally preserved solution pits. The pits are filled in with red-brown sands with a laminated crust. They clearly represent a phase of sub-aerial conditions during the built-up of the Pleistocene reef complex. In places the solution surface is covered by a red sandy sediment with corals included. It has been interpreted as redeposited soil material related with the deposition of the next marine limestones (Braithwaite, 1984, p. 689).
- The Watamu calcarenites, corresponding to the shallow shelf calcarenites in unit 3 of Braithwaite (1984, p. 689), consist of cross-bedded, quartz-bearing calcarenites. From structural evidence both a barrier-beach and an eolian origin has been deduced. The deposits have been found at

Watamu, Bamburi, Nyali and Tiwi Beaches. Those described near Watamu are identical to the Coquinas of Thompson (1956, p. 36). The deposits are in places more than 6 m thick and have at the top an erosion surface with deep solution pits filled with hard red sediment.

- The Nyali sands, corresponding to the quartz sands in unit 3 of Braithwaite (1984, p. 691), consist of locally burrowed sands with a pale grey colour. They are believed to have been deposited in a subtidal or intertidal shallow water environment. The base of the sands consists of bright red sands filling solution pits. More to the south, the pale grey sands are absent and instead red sandy sediments with large corals are found. They are most likely correlated with the Nyali sands.
- The Mtwapa limestones, corresponding to the marine limestones in unit 4 of Braithwaite (1984, p. 691), consist of coral-bearing limestones with characteristic large calcite crystals indicating a solid state transformation of aragonite. The unit reaches a maximum thickness of about 12 m at Mtwapa. East-west channels filled with cross-bedded Halimeda sands and calcarenites are locally found at Ras Mwachema, Kilindini and Mombasa Harbours and the Kilifi Creek. They grade westward in thin cross-bedded, quartz sands which are presumed to be continuous with the Kilindini Sands of Caswell (1953). The surface of the marine limestones is again characterised by deep solution pits filled in with brown and red sediments with coral fragments and molluscs.
- The Tiwi calcarenites, corresponding to the marine margin deposit in unit 5 of Braithwaite (1984, p. 695), consist mainly of dense calcarenites occurring on top of the Mtwapa limestones at Tiwi. The contact is marked by deep solution pits filled with red sands, laminated crusts or coral rubble in a red sandy matrix. The calcarenites are probably comparable to the calcarenites found at Kilimanjaro Hill.
- The Tiwi sandstones correspond to the sandstone rich in fragments of the barnacle *Tetraclita*, *Turbo operculi* and coral fragments of unit 5 (Braithwaite, 1984, p. 695). The contact with the underling deposits is marked by a buff-coloured soil with root traces and burrows. The overlying fine grained quartz sands (Braithwaite, 1984, p. 696) correlate with the Pleistocene sands distinguished by Siambi (1977).

Pleistocene sands

The Pleistocene sands comprise mainly quartz sands with subordinate silts and clays. An older and a younger unit have been be distinguished (Siambi, 1977).

- The older Pleistocene sands correlate broadly with the uppermost part of the Kilindini sands of Caswell (1953, p. 29; 1956, p. 33), the Pleistocene Sands of Thompson (1956, p. 32) and the Pleistocene Lagoonal Sands and Clays of Williams (1962, p. 44). They further correspond to the red sandy laterite of Braithwaite (1984, p. 696). Both Caswell and Thompson considered the sands to be contemporaneous with the deposits of the reef complex. Williams (1962, p. 45) suggested a lower Upper Pleistocene age, based on the supposed age of the so called '30 ft raised beach'.

- The younger Pleistocene sands correlate loosely with the Red Wind-blown Sands of Caswell (1953, p. 30, 1956, p. 35). Thompson (1956, p. 36) distinguished them as the Upper Pleistocene Sands and Gedi Beacon Sands (unit Qt3). The first sands he regards as ridge sands, accumulated on the sea floor during the retreat of the sea from the so called '120 ft terrace'. Redeposition of the sand by wind activity led to the formation of dune ridges of which the materials have been called Gedi Beacon Sands. Thompson considered the sands as Upper Pleistocene assuming that the retreat of the sea took place during that time. In the Fundi Isa area, Williams (1962, p. 45) called them Pleistocene Dune Sands and differentiated three dune generations. The oldest is thought to represent Lower Pleistocene accumulations between approximately 60 and 90 m +MSL and has been connected with a high sea-level at approximately 60 m. A second dune generation was recorded on the so called 120 ft platform and was assumed to have been formed in late Middle Pleistocene times. The deposits of the youngest Pleistocene dunes are thought to have been accumulated after the cutting of the so called lower Upper Pleistocene beaches. Although the distinction of different dune generations is correct, the age setting is doubtful and based on assumptions only. Therefore the Pleistocene Dune Sands of the Fundi Isa area have all been correlated with the Younger Pleistocene sands in Table 1.

Recent dune sands
The Recent dune sands comprise grey to white eolian sands and correlate with the Recent Terrestrial Deposits distinguished by Thompson (1956, p. 37). He attributes a Holocene age to the deposits on evidence of their position. In the Fundi Isa area comparable dune sands have been described by Williams (1962, p.48) under the heading Recent deposits.

Recent beach sands and tidal-flat deposits
The Recent beach sands and tidal-flat deposits correlate with the Recent Marine Sediments of Thompson (1956, p. 36). In his description the partly consolidated beach sands occur on the present beach and on at least one former one at about 4 m +MSL (6 ft above high tide mark). The younger coquinas (unit Qt4) can probably also be correlated with the Recent beach sands. Muds of the coastal creeks have been mapped by Thompson, but were not described in his report. In the Fundi Isa area the same deposits have been described under the heading Recent Deposits (Williams, 1962, p. 48). He pays some more attention to the muds of the creeks and describes them as dark clays and muds with only a gradational boundary between them and the older Pleistocene deposits.

Recent alluvium
The Recent alluvium embraces mainly the younger alluvial deposits of the Galana and Tana rivers. The deposits of the Galana have been recently mapped as Alluvium and partly as Colluvium and Residual Soils (Siambi, 1979). Thompson (1956) also mapped the Galana alluvial deposits but gave no

description. Williams (1962, p. 48) mapped the deposits of the Tana river in the Fundi Isa area and described them as the Silts of the Tana delta.

The above outlined stratigraphy must be seen as a preliminary skeletal structure into which the current geological data from various parts of the coast fit. It will be used in Section 3.1.1.2 for the description of the morphological structure of the landscape. At the same time it is subject to discussion and modification.

3.1.1.2 Morphological structure

The general configuration of the present-day shoreline of southeast Kenya gives rise to a threefold division of the most seaward part of the coast.
- The southern section, consisting of wide sheltered bays behind a broken chain of coral reef patches, has the general appearance of an embayed coral reef and mangrove coast. This configuration is largely typical for both retreating and advancing coasts (Valentin, 1952, plate I) and indicates a complex history for this part of the shore.
- The central section is characterised by a straight fringing coral reef of about 250 m to 2.5 km wide. The reef is divided into several segments by narrow tidal outlets of branching bays or estuaries. At the landward side they are bounded by steep cliffs. Consequently, the central section has the outward appearance of a cliffed coral reef coast. This indicates that both sea level fluctuations and tectonic uplift may have played an important role in its development.
- The northern section is characterised by wide open bays in front of the Tana delta and near the mouth of the Sabaki river. The bays are bordered by long beaches and high dune complexes. Reef patches and sheltered lagoons occur in between the open bays. They form part of what can be roughly classified as a lagoon-barrier and dune-ridge coast. This seems to illustrate the predominantly advancing character of the coast in this part of the study area. The continuous sediment supply to the shore by the two perennial rivers of southeast Kenya (Tana and Sabaki) is one of the main differences with the other sections of the coast and is partly accountable for the difference in general outlook. The presence of abandoned barrier and dune ridges far from the present shore also show that eustatic sea-level movement and tectonic uplift played a role.

The elevated part of the littoral zone is shown to be characterised by landform associations comparable to those at the present-day shore. As a consequence a similar subdivision into three sections can be made:
- The southern section, characterised by former bay or lagoon plains with isolated raised reef-patches;
- The central section, characterised by raised reef-flats and abandoned abrasion-platforms;

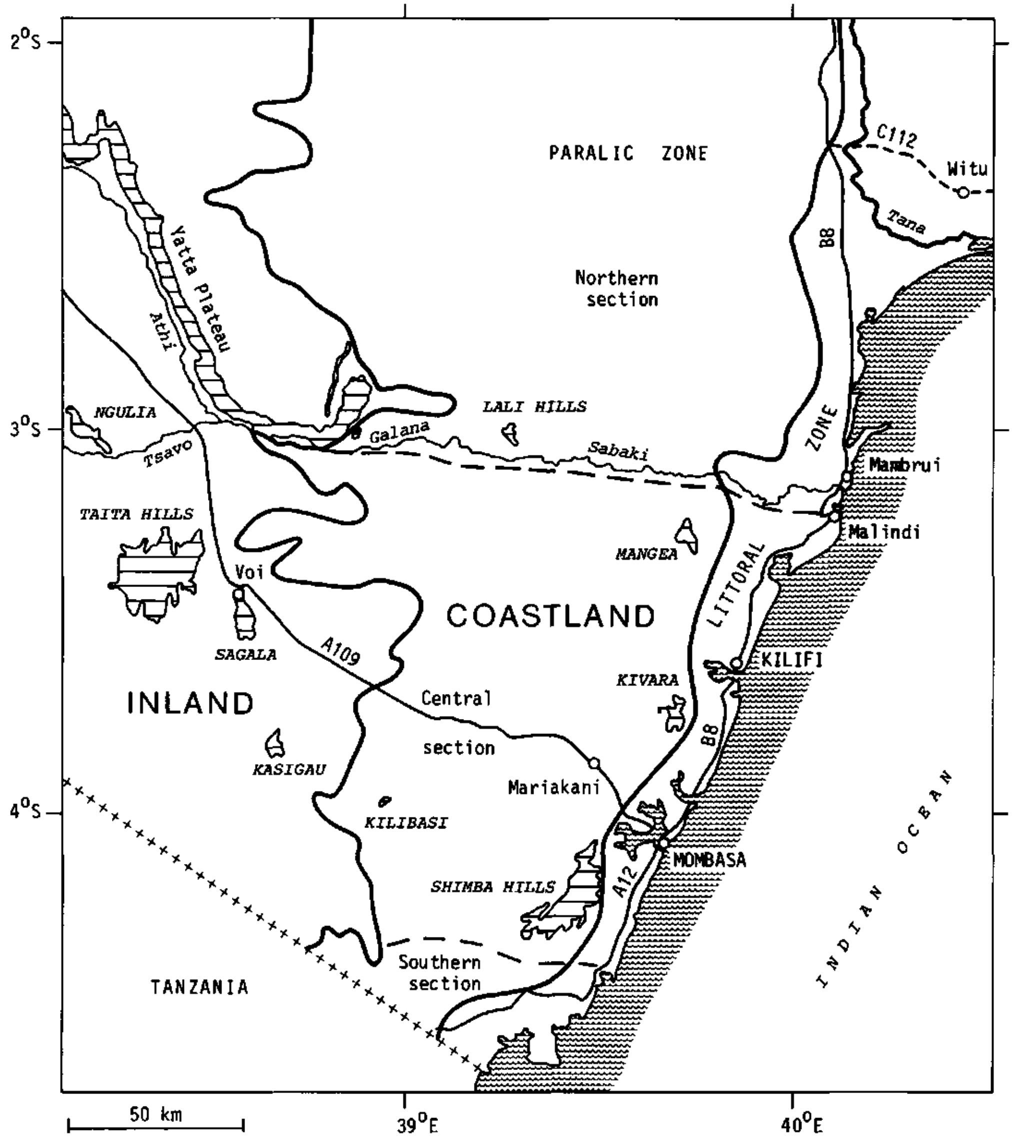


Fig. 6 General division of the coastal region

- The northern section, characterised by ancient dune and beach ridge complexes together with former lagoon-plains with ancient barriers and raised reef-patches.

This threefold division of the littoral zone of the coast (Fig 6.) is shown to be closely related to the topography of the areas west of it. In the central section the transition of the littoral to the paralic zone is marked by the broken chain of prominent hills of the Coastal Range. Directly behind lies the dissected country of the Giriama Hill-lands. More to the west the relief intensity decreases again and gives way to the almost flat to undulating plains of the Nyika. The elevated areas of the Coastal Range and the Giriama Hill-lands with their cuesta ridges apparently have protected the littoral zone against strong fluvial erosion and sedimentation. The Coastal Range is absent in the two other sections. In the south the transition towards the paralic zone is marked by a narrow strip of dissected land with low relief intensity. However, just south of the Kenya-Tanzania border, this dissected part disappears and the littoral plains grade into the paralic plains of the Coastal Plateau mentioned by Alexander (1968, p. 133; 1969, p. 104). The transition between the two coastal zones south of the Tana delta in the northern section is marked by the Rogge Plateau. Its country consists of slightly to moderately dissected plain, elevated in the east and bounded by a scarp, known as the Rogge escarpment. Towards the west, the terrain grades into the extremely flat Nyika plains. East of the Tana delta the littoral plains give way to the plains of the paralic zone without topographic transition .

Apart from the topography of the areas towards the west, the present natural division of the shore is also related to the character of the main drainage systems. In the northern section the Tana and Sabaki rivers connect the coast with the interior. They have a considerably greater discharge and sediment load then the seasonal Umba river which connects the southern section with the Para and Usambara Mountains of Tanzania. This partly explains the different configuration of the southern and northern sections of the modern shore.

In conclusion, it seems that the protected position behind the Coastal Range and the absence of perennial rivers played an important role in the development of the continuous reef complex of the central section of the littoral zone. A comparable conclusion was reached earlier by Werth (1952, p. 448). Perennial rivers are shown to have dominated the development of the seaward part of the coast in at least the northern sections. Comparable landform associations in the elevated areas of the littoral zone indicate that this has also been the case during a considerable part of the Pleistocene period.

Previous studies on the geomorphology and littoral stratigraphy of southeast Kenya (Battistini, 1969; Hori, 1970; Toya et al., 1973; Åse, 1978, 1981;

Table 2 Classification of the littoral levels

category	name	elevation (m +MSL)	category	name	elevation (m +MSL)
shore	Bofa	-10 to 2	middle	Mtondia	10 to 25
				Majaoni	25 to 40
lower	Uhuru-II	2 to 3			
	Uhuru-I	3 to 5		Tezo	40 to 85
	Mackenzie-II	5 to 8	higher	Cambini	85 to 130
	Mackenzie-I	8 to 10		Sokoke	130 to 175

Rossi, 1981 and Braithwaite, 1984) mainly deal with the central section. In order to incorporate the morphological and sedimentological data of the southern and northern section a wider geomorphological framework has been set up. The system distinguishes various land-surface levels of which the origin and development is believed to be connected with the sequent Pleistocene climatic and tectonic/eustatic episodes. Using topographic position and predominant lithology as criteria, the levels can be divided in four categories (Table 2):

- The active level of littoral zone, characterised by the landforms of the modern shore and the related coastal deposits. Older submerged shore levels are also believed to occur along the present shore (Thompson, 1953, p. 47). They form in fact a fifth category. However, as their study requires special equipment not available during the present research, they are not given further attention.
- The lower levels of the littoral zone, characterised by coastal landforms of former shores apparently related to mainly Holocene deposits.
- The middle levels of the littoral zone, characterised by coastal landforms of former shores apparently related to the Pleistocene sands and the underlying reef complex.
- The higher levels of the littoral zone, characterised by coastal landforms of former shores apparently related to the Changamwe and Magarini deposits.

The levels are constituted by the surfaces of different marine plains. When their width is small compared to their length they are referred to as marine terraces. Delta and lagoon plains have been included although strictly they take an intermediate position between the fluviatile and paralic areas respectively. In Table 2 the field names of the levels used in the present study are given. The elevation indicates the approximate height range of the terraces and plains, measured from the base of their front slopes to the upper boundary of their treads.
The land units of which the levels consist have been hierarchically arranged into two classes:

- land types, embracing the major morphological units of the landscape;
- land components, forming the minor morphological units which constitute the land types.

They are described and classified in the following sections of Chapter 3.

Table 3 Land units of the present-day shore

southern section		central section		northern section	
land types	land components	land types	land components	land types	land components
reef patches and minor reef-segments	reef fronts reef flats reef lagoons erosion ramps small beaches mangrove swamps	major reef-segments	reef fronts reef flats reef lagoons erosion ramps small beaches foredune ridges	reef patches and minor reef-segments	reef fronts reef flats reef lagoons erosion ramps small beaches mangrove swamps
sheltered bays	tidal channel mangrove swamps tidal flats tidal creeks bay deltas	branching bays and estuaries	bay/river mouths mangrove swamps tidal flats tidal creeks bay deltas	open bays and sheltered lagoons	barrier islands barrier beaches tidal inlets mangrove swamps tidal marshes tidal flats tidal creeks foredune ridges

3.1.1.2.1 Present-day shore

A narrow strip of land alternately being exposed and covered by tides or waves of the Indian Ocean constitutes the present-day shore of southeast Kenya. Its upper edge is formed by the landward limit of effective wave-action, often marked by a cliff base. Its lower edge is less easy to demarcate. In the central part of the coast it is formed by the outer edge of the fringing reef. On aerial photographs its position is indicated by the surf. However from a morphological point of view the outward reef slope also belongs to the shore. Therefore the transition towards the scree slope of the reef front at a depth of about 10 m has been taken as the seaward limit of the shore. It can be recognized on aerial photographs by a change in the grey tone of the ocean water. In the northern and southern sections this depth zone is rather arbitrary. More information on the submarine topography is needed to define the shore more precisely.
In Table 3 a synopsis is given of the land units on the level of the present-day shore. As the central part is the best studied this has been taken as a reference. The geomorphological characteristics of the southern and northern sections are compared with it.

Central section

The fringing coral reef of the central section of the present-day shore exists in seven segments. They are situated between the bay or river mouths of the Mwachema river, the Kilindini and Mombasa Harbours and the Mtwapa, Kilifi and Mida Creeks. In the first six cases deep channels are present. A maximum depth of about 65 m is recorded on marine charts of the Kilindini Harbour. The depth decreases to about 12 m near the present-day outer reef edge. This reduction in depth is supposedly due to recent coral growth (Sikes, 1930, p. 5). It indicates that the dissection of the reef body is not an active process. A connection with one of the low sea-level stages in the Pleistocene is obvious. This is confirmed by configuration of the Mida Creek which differs from the other bays by the lack of a river or stream discharging into it. The absence of a deep channel across the reef in front of the Mida Creek likewise shows that the channel formation is not related to present-day tidal scour.

Major reef-segments

The major reef-segments are composed of at least six characteristic components (Table 3).

- The reef fronts are constituted by the edges and upper parts of the outer slopes of the present-day coral reef. They are characterised by living corals and an irregular surface dissected by surf channels.
- The reef flats are constituted by stony platforms of dead reef-rock (Fig. 7). They are situated at the inner or outer zone of the fringing reef and are generally dry at low tide. Little or nothing is known of the stratigraphy of the underlying reef rock. The outer and inner reef flats possibly represent reef bodies of different ages. However no datings of

Fig. 7 Reef segment at the present-day shore near Kilifi

the coral rocks are known which confirm this. The reef flats are overlain by an irregular and thin cover of coral fragments and coral sands. Abundant shallow vegetated pools occur as minor landforms on the reef flats.

- The reef lagoons are constituted by elongated stretches of water of 1 to 2 m deep, 50 m to over 200 m wide and kilometers long. They are commonly found between the outer and inner reef flats. They are further characterised by a cover of coral fragments and coral sand with regular knolls of dead and living coral rock.
- The erosion ramps are constituted by the sloping belt of reef limestones or calcarenites immediately above the reef flats (Fig. 7).
  Stratigraphically the rocks belong mainly to the Msambweni and Shimoni limestones in unit 1 and 2 of Braithwaite (1984, p. 687, Fig. 3). They are characterised by bare rock surfaces with numerous circular and oval rock pools with depths of 10 cm to over 150 cm, while their diameter is between 10 and 70 cm. Composite forms also occur. Some rock pools are filled with loose coral and beachrock fragments. Others are filled with consolidated reddish or yellowish beachrock. An influx of water from the bottom can be observed when they are emptied, indicating a mutual subsurface connection. The existence of comparable cylindrical holes at the surface of the raised reef body has been reported by Thompson (1956, p. 36). He classified them as sink-holes formed by solution. Braithwaite (1984, p. 697) described them as (coalescing) pits on the present reef platform. He attributes them to possible subaerial erosion at a time of lower sea-level after the formation of the reef platform. This view is supported by the finding, during the present study, of pits filled in with consolidated sands and rock and shell fragments (e.g. on the reef ramp in front of the Bofa area). However the presence of well rounded coral rubble and beachrock fragments indicate that surf action on the ramp is another factor in the formation of these potholes. The various stages of this process and the scouring mill-stones can be observed in many places. Probably the filled in solution pipes are preferential sites where the drilling takes place due to the softer character of the fill as compared to the surrounding beachrock.
- The beaches are constituted by local discontinuous accumulations of loose water-borne materials on the erosion ramps or reef flats. They are present mainly in small coves and at positions north of the bay mouths. This shows that their position is connected by factors like protection against wave action and the predominant direction of along-shore currents of the ocean water. The beaches are characterised by well sorted medium fine sands, composed mainly of quartz near the major river outlets and of shell and coral fragments on other places. The sands form part of the Recent beach sands.
- The foredune ridges are constituted by coastal dunes of 1 to 5 m high orientated parallel to the shoreline. They are being formed especially at places where cliff formation takes place in unconsolidated materials of the first raised terrace. During the normal tides the eroded material at

the upper part of the beach dries out and is blown in ridges against or even over the cliff face The dune ridges are characterised by very well sorted, very fine to fine sands, mainly composed of shell fragments and quartz grains. The ratio between these two components depends on that of the material on the beach. The deposits form part of the Recent dune sands.

In summary, it can be concluded from the land units described above, that at least the inner half of the reef segments is likely to be part of a Pleistocene abrasion platform. It underwent subaerial erosion during at least one period of low sea-level. This is evidenced by the deep-cut channels and the filled in solution pipes of the reef flat and its erosion ramp. The outer reef-flat was possibly formed after the reef became again submerged during the Holocene. The decrease in depth of the channels near the present-day reef front is thought to be related to this.

An age of about 30 ky (1 ky=1000 years) has been attributed tentatively to the original platform by Braithwaite (1984, p. 698). It implies a subsequent average coastal uplift rate of about 1.4 m/ky, accepting a paleosea-level of -42 m at around 30 ky BP (Bloom et al. 1974, p. 202; Aharon & Chappell, 1986, p. 337). This would mean that since the end of the Late Pleistocene the coast of Kenya has been subject to relatively rapid uplift. More information on the elevation of other raised terraces and their ages is needed to check this dating and uplift rate of the reef segments of the modern shore. A recent and still active phase of submergence seems to be evidenced by the fresh cliffs seen in many places.

Branching bays and estuaries

The branching bays and estuaries are constituted by the water bodies connected with the Indian Ocean by the tidal channels through the present reef-platform. Those near Mombasa, Mtwapa and Kilifi are the most prominent. Åse (1981, Fig. 3) referred to them as rias. They are characterised by a wide enclosed water body with narrow passage towards the Indian Ocean. The broad parts are known as Port Reitz and Port Tudor, the Mtwapa Creek and the Bandari ya Wali, respectively. The narrow channels are indicated as the Kilindini and Mombasa Harbours and the Mtwapa and Kilifi Creeks, respectively. In this study the land unit assemblage has been classified as branching bays judging their form and the generally accepted origin as drowned river valleys (Muff, 1908; Sikes, 1930; Penck, 1937, Werth, 1952, p. 529). The typical configuration is related to the type of the surrounding rocks. The broad water bodies are found at places where the Jurassic shales of the Mtomkuu Formation and the clays of the Changamwe deposits occur. The narrow channels are found at places where the more resistant rocks of the Pleistocene reef complex are present. The shape of the branching bays suggests that these former river valleys have been blocked by the deposits of the Pleistocene Coral reef complex. This would mean a low discharge of the rivers in the central section during periods of rising sea-level and reef growth. In other words the climate was not wetter or may be even drier than that of today. The classical subdivision of the Quaternary in East Africa (Leakey, 1952) distinguishes pluvials and interpluvials. In the classification scheme they correlate with the glacials and interglacials of the temperate areas respectively. Despite decisive criticism by Flint (1959), Bishop (1962) and others the concept is still in use (e.g. Rossi, 1981, p. 51). The evidence given above for relatively dry conditions during periods of rising sea-level is an example that at the coast of southeast Kenya the classical model is invalid.

The outlets of the Mwachema and Sinawe rivers are different in plan. They are smaller, lack a broad water body and have only a narrow tidal river with a vaguely funnel shaped outfall. They have been classified as estuaries. The difference in shape is related to the size of the drainage areas connected with them. Relatively large drainage areas of the Voi and Mwatate rivers are connected with the branching bays whereas the small drainage areas of the Mwachema and Sinawe rivers are connected with the estuaries. These last streams apparently had no potential energy to erode broad valleys in the shales and marls behind the Pleistocene reef complex.
The Mida Creek is an exception. It lacks a discharging river and can probably best be described as a cove. Why it developed at that particular site is not well understood. As it is situated in the centre of a slight bend of the coastline it may be due to a concentration of eroding wave energy. The presence of abundant calcarenites instead of reef limestone (Braithwaite, 1984, Fig. 3) may also have affected the formation of the Mida Creek. There are no indications for a possible tectonic cause. Although different in size, plan and origin all three types of embayments have a number of the minor land units in common (Table 3).

- The tidal channels are constituted by the major inlets extending from the offshore zone into the embayments. They are bordered by a narrow platform of 5 to 10 m wide. Near the ocean it consist of coral limestone and is connected with the inner reef-flat. Further inland the platform merges into the tidal flats described below. As pointed out before the formation of the inlets is believed to be connected with low Pleistocene sea-levels. Down cutting of rivers through the reef complex is most likely to have played an important role. However subsurface solution following the lowering of sea level may also have been involved. It could have been brought about by percolating water from the blocked-off bays behind the reef body with calcarenite bodies as preferential zones. As these calcarenites form the fills of former reef channels the process results in the formation of narrow tunnels or subsurface gorges in front of streams finding their way to the lowered sea level. Although such features are not known in Kenya, they have been found in the Pleistocene raised-reef of the Tanzania coast (Cooke, 1974, p. 531).
- The mangrove swamps are represented by mud flats vegetated by mangrove forests commonly at the edges of the bays and estuaries (Fig. 8). They are characterised by slightly ripened sandy clays and clays belonging to the

Recent tidal-flat deposits. A weak soil formation has resulted in the development of dark or greenish grey to dark olive A-C profiles. They have been classified as Thionic Fluvisols with a saline and sodic phase. (Michieka et al., 1978, p. 155; Boxem et al., 1987, p. 97).

- The tidal flats are constituted by the barren tracts of land covered by water only at high tides. They are commonly situated between the mainland and the mangrove swamps. The tidal flats consist mainly of sandy clays and clays which stratigraphically belong to the Recent tidal-flat deposits. A weak soil formation has resulted in the development of dark or olive grey to olive A-C profiles. They have been classified as Gleyic Solonchacks and Eutric Fluvisols with a sodic phase (Michieka et al. 1978, p. 157; Boxem et al. 1987, p. 97).
- The tidal creeks are constituted by the relatively small inlets in the mangrove swamps. They are characterised by layered clays and medium to fine sands and are also included in to the Recent tidal-flat deposits.
- The bay deltas are constituted by fan shaped accumulations of alluvium at places where rivers debouch in the bays. The deposits belong stratigraphically to the Recent alluvium.

Fig. 8 Mangrove swamp near Gazi Bay

In conclusion,it can be said that the land units in the embayments are connected with a recent phase of deposition. This is evidenced by the unripened character of the deposits and the weak soil formation.

Southern section

The configuration of the southern part of the shore is dominated by the presence of three bays sheltered behind a discontinuous coral reef. They are known as the Gazi, Funzi and the unnamed bay between Vanga and Shimoni (in this report further referred to as the Vanga Bay). The bays are separated from each other by the Funzi Island and the Shimoni peninsula respectively. In contrast to the embayments of the central section, the connection with the ocean is not formed by a narrow tidal channel but a wide bay-mouth. The landward limit of the shore is mostly formed by a low bluff developed in unconsolidated clays. However cliffed shorelines are also found where coral limestone is present. The seaward margin is again the reef front, which is vaguely visible on aerial photographs. Instead of major reef segments only isolated reef patches occur. On the topographic maps they are commonly referred to as 'Mwamba' followed by a geographical name. They form a kind of discontinuous barrier protecting the embayments from the direct influence of the ocean swell. Whether they represent a dissected former fringing reef or have been formed as reef patches is not clear. The presence of the outfall of the Umba river probably resulted in a less favourable environment for coral reef growth during the Pleistocene. But this does not give an explanation for the presence of the Funzi and Gazi Bay where a comparable river is absent. It is clear, however, that in the south the shore has been subjected to a more intense dissection than the central section. This is mainly due to the absence of the protecting Coastal Range. To what extent tectonic factors may have played a role is not clear.
The main land units at the southern section of the present-day shore are described and discussed below.

Reef patches and minor reef segments
The reef patches and minor reef segments are characterised by minor land units which are essentially the same as those of the central coast. The most important difference is a thicker cover of muddy sediments on the reef flats in the south. It can give rise to the presence of mangrove swamps in the centre of the reef patches and on the inner reef flats of the minor reef segments as on Sii and Wasini Island respectively. A further difference is that foredunes are lacking, probably as a result of the apparent absence of sandy raised beaches at the ocean side of the shore-zone.

The sheltered bays
The sheltered bays likewise have components comparable to those of the central section of the shore. However, the extent of especially the mangrove swamps and the tidal-flats is considerably greater. The fresh cliffs which

can be found at the transition towards the higher ground of the raised terraces indicates active submergence of the south coast at present.

Northern section

The configuration of the northern section of the shore is dominated by wide shallow embayments in front of the Sabaki and Tana rivers. The bay in front of the Sabaki stretches between Malindi and the Ngomeni peninsula. It is composed of a zeta-formed, open bay between Malindi and Mambrui with four minor coves, one of which is known as the Sheshale Bay. Minor reef segments and reef patches occur between them. In this report the whole area is referred to as the Sabaki Bay. The open bay in front of the Tana delta is known as the Ungwana or Formosa Bay. It is characterised by the presence of barrier islands with lagoons near the present and former outfalls of the delta. The open bays of the Sabaki and Tana rivers are separated by two arcs of coral reef patches of the Ngomeni peninsula and the Mwamba Zeboma. In the embayments between them, sheltered bays are enclosed, one of which is known as the Fundi Isa Bay.

Reef patches and minor reef segments

The reef patches and minor reef segments have components comparable to those of the southern section of the shore. However, their presence north of the mouth of the Sabaki river seems contradictory. It is a place of active accumulation of fresh sediments brought into the ocean by the Sabaki river and transported northwards by ocean currents. The muddy water makes actual reef growth impossible at this part of the coast. The stream bed of the Sabaki river cuts deeply through the present-day shore and the raised beaches. Therefore it must be assumed that during the last low sea-level interval the Sabaki was already at its present position. This means that, during the whole Holocene period, reef growth has been impossible or strongly reduced at this location. Therefore it is assumed that, like in the central section, the reef flats are mainly of Pleistocene age. The cutting of the platform could be of recent age as it is rather narrow compared to those of the central section. However, as no rocky cliffs occur at the land-ward side, abrasive tools are absent. It is therefore assumed that also in the north the present shore platform is in fact a Pleistocene abrasion surface which was cut in a previous period of high sea-level. The sand cover which was subsequently deposited is now under attack from the actual wave and tidal action. In some parts it resulted in a complete removal and exposure of the Pleistocene abrasion surface. The consolidated rocks of the reef patches and minor reef segments provisionally have been included in the Pleistocene reef complex.

Sheltered lagoons and open bays

The sheltered lagoons and open bays in the northern section differ in plan from the embayments in the south. The lagoons south and east of the Tana delta lack the influence of a discharging river. Instead small intermittent streamlets find their way towards the embayments, but carry insufficient sediment to form bay deltas. The lagoons have mangrove swamps, tidal-flats and creeks comparable to those in the embayments of the southern section of the shore. However one component not previously mentioned is associated with them:

- The barrier beaches, constituted by sand ridges at the transition of the mangrove swamps and the ocean waters. They are 100 to 200 m wide and interrupted by tidal inlets at various places. They reflect the present meso-tidal regime of the Indian ocean at this part of the coast of East Africa. Their presence also indicates a considerable longshore transport of sediments derived from the Tana and Sabaki rivers. The fact that they are not found in the south can be explained by the smaller amount of sediment brought into the sea by the rivers there.

The open bays differ from the embayments of the other sections of the shore mainly in size and configuration of the composing land units.

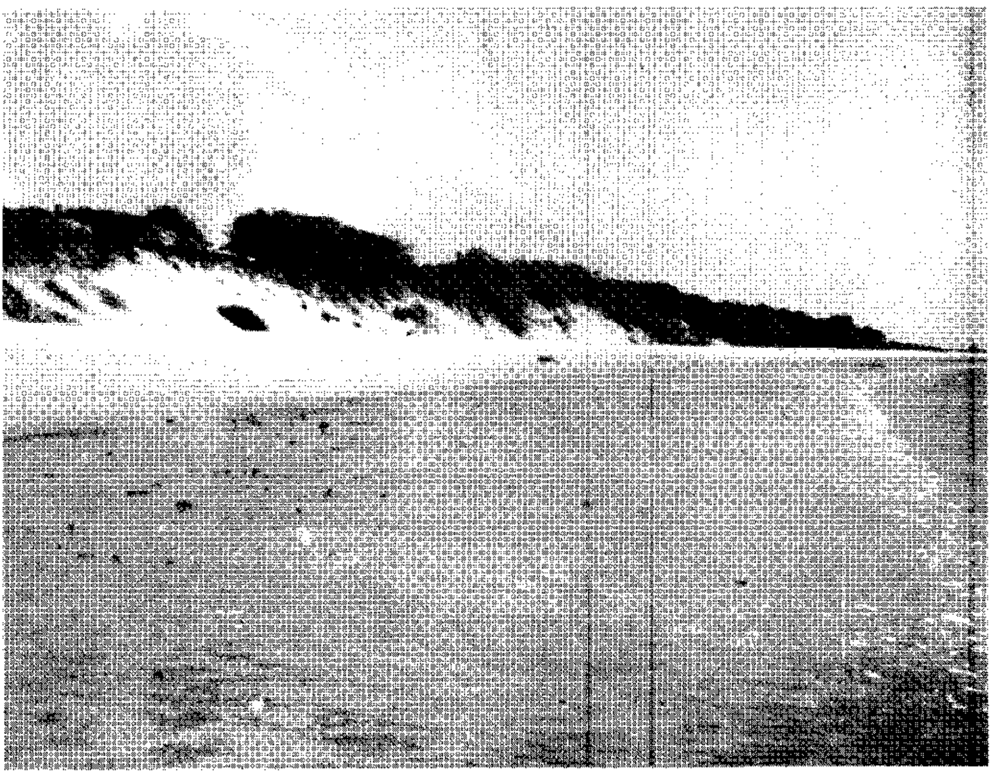


Fig. 9 Beach of the Ungwana Bay near Kipini

- The beaches of the open bays are relatively wide and long. They are limited to the seaside by a gently sloping shoreface. Near the Sabaki river the beach has been deposited over coral limestone, but directly opposite the Tana Delta no signs of any reef remnants are found. Here the beaches are attached to the barrier islands in front of the Tana delta. A sample taken on the lower part of the beach near Kipini (Fig. 9) consists of very fine to medium sand (Md = 147 mu) with very poor sorting (So = 2.08). It has an heavy mineral content of approximately 8 % (weight %) of the sand fraction. In contrast a sample taken from the upper part of the beach near Mambrui consists of fine (Md = 137 mu) and very well sorted sand (So = 1.16). Its heavy mineral content amounts 19.5 %. These data illustrate the wide range of the beach sand characteristics at various positions in the two embayments. The high degree of sorting at the upper beach clearly exemplifies the great influence of wind activity at this part of the unit.
- The tidal inlets are formed by the outfalls of the Galana and Tana rivers and the channels connecting the tidal creeks with the open ocean waters. The inlets in front of the Tana and Sabaki rivers are characterised by the occurrence of spits and bars and an offshore sediment plume. The outfalls of the Tana river are situated in two round and one elongated lagoon. They are partly enclosed by a barrier island at the seaward side. The borders of the small lagoons show evidence of submergence.
- The tidal swamps consist of tidal flats vegetated with grass and reed. The swamps occur at the transition of the lagoons towards the Tana delta plain. They are characterised by heavy clays which stratigraphically are incorporated in the Recent tidal-flat deposits.
- The dune complexes are represented by active sand dunes near the mouth of the Galana river and in front of the Tana delta. They reach a maximum height of around 50 m and have irregular shapes. In general they have a SE-NW direction, oblique to the present shoreline and parallel to the direction of the strong southeast monsoon winds. As in the central section of the shore the dunes are commonly built as foredunes on the surface of raised beaches or on older dunes. Especially near Malindi it is observed that in the older dunes bordering the embayments active wind erosion is also taking place. Consequently the distinction on aerial photographs between the various dune generations is not clear. The dune sands are white in colour and soil formation is virtually lacking. A sample from a foredune ridge near Kipini shows that the sands at this place are fine (Md = 178 mu) and very well sorted (So = 1.23). As in other eolian sands near the outfalls of major rivers, the component of heavy minerals is high (15%).

The mangrove swamps, tidal flats and tidal creeks are comparable to those of the southern section.

In conclusion, it can be said that the structure of the present-day shore in the northern section seems to be closely related to the amount and type of

sediment available for the construction of coastal landforms. The meso-tidal conditions are reflected in areas where the sediment supply is relatively small. This is especially true for the sheltered parts behind the reef patches of the Ngomeni peninsula and Mwamba Zeboma.
The occurrence of coral limestone in this lagoonal environment points to the fossil character of at least a part of the present-day reef flats. The same applies to the minor reef segment and reef patches between Mambrui and the Ngomeni peninsula. It is likely that the reef developed in times when the influx of sediment in the ocean was less than it is today. This conclusion was also drawn from the configuration of the central section of the shore. The drowning of the areas around the major outlets of the Tana river indicates that the area is subjected to submergence, as is the remaining part of the coast. As no differences in intensity at the various sections of the shore could be observed, a tectonic cause is less likely. Consequently, it is assumed that the present submergence is due to a slight rise in the Holocene sea level.

3.1.1.2.2 Lower littoral levels

Between around 2 and 10 m +MSL four elevated shorelines occur which are characterised by relative small height differences. They form the landward boundary of land surfaces with corresponding elevations, which have in the present study been called the Uhuru and Mackenzie levels. They are made up of the treads of marine terraces or benches and their descending front slopes. The Uhuru and Mackenzie levels both appear to have an upper and lower representative. However on the 1:500 000 geomorphological map (Appendix I) this detailed differentiation is not shown. All four levels have been recognized before but mostly in an incomplete sequence. In Table 4 a synopsis is given of references to them in earlier publications.
In the central section the related land units are generally narrow and discontinuous. Åse (1978; 1981) carried out a detailed analysis of their elevation between Jadini Beach and Malindi. His height data are a valuable contribution since the topographical information of the 1:50 000 maps is insufficient for a proper indication of the position of the terraces and benches. In the southern section the lower levels are represented by more continuous but still rather narrow land units. In the northern section of the coast they appear to have a far greater extent as they comprise the Tana delta and the lower parts of its periphery. A synopsis of the various land units is given in Table 5. Their characteristics are described below with the central section of the littoral zone as a reference.

Central section

The lower littoral levels in the central section are represented by various raised surfaces, generally of small extent. On account of their forms and

Table 4 Correlation of the lower littoral levels with surfaces referred to in earlier studies

Earlier publications	Present study: Uhuru II (2-4 m +MSL)	Uhuru-I (4-6 m +MSL)	Mackenzie-II (6-8 m +MSL)	Mackenzie-I (8-10 m +MSL)
Sikes, (1930)		15 ft beach		30 ft old sea beach
Werth (1952)	Vorstufen			
Caswell (1953)		15 ft beaches		30 ft platform
Caswell (1956)				
Thompson (1956)	6 ft level		25 ft level	
Williams (1962)				30 ft raised beach
Battistini (1969)			surface de Récif II	20-30 ft plate-forme
Hori (1970)		Shelly Beach terrace		Lower Mombasa terrace
Toya et al. (1973)		Shelly Beach Terrace		Malindi Terrace
Ase (1978)	Level I	Level II	Level III	Level IV
Rossi (1981)	1.5 m plages	Shelly Beach Terrace		Lower Mombasa

Table 5 Land units of the lower littoral levels

southern section		central section		northern section	
land types	land components	land types	land components	land types	land components
marine terraces	raised platforms raised beaches	marine terraces	raised platforms raised beaches dunes ridges	marine terraces	raised platforms raised beaches dunes ridges
elevated bay or lagoon plains	ancient barriers former tidal flats & marshes	elevated bay plains	former inlets raised platforms former tidal flats	elevated lagoon or delta plains	ancient barriers former tidal flats & tidal marshes interdistributary areas

parent material they have been classified as marine terraces and elevated bay plains. They usually occur in small recesses of the steep cliffs towards the higher terraces of the middle littoral levels. They are present in the form of bay-side terraces around the branching bays.

Marine terraces

The marine terraces are characterised by platforms which are in places covered by raised beaches or dune ridges. As the platforms also may have a cover of unconsolidated residual or eolian deposits, the difference with the raised beaches is not always evident. The occurrence of abandoned beach ridges or sand bars facilitates the identification of raised beaches in the field. However their small size normally precludes their recognition on the 1:50 000 aerial photographs. A more detailed description of their characteristics is given below.

- The raised platforms are formed by relatively small and narrow eroded surfaces of reef rock. They are bound at the landward side by a cliff base and at the seaward side by an often vague transition to the beach or erosion ramp of the present day shore. Those of the lower Uhuru-II level occur between 2 and 4 m +MSL and are mainly developed in Shimoni limestones. The platforms of the Uhuru-I level occur between 4 and 6 m +MSL in both Watamu Calcarenites and Mtwapa Limestones. Those of the Mackenzie-I and Mackenzie-II are found at 6 to 8 m and 8 to 10 m respectively (Fig. 10). When the data of Åse (1978, Fig. 12; 1981, Fig. 9) are compared with those of Braithwaite (1984, Fig. 3) it appears that, as at Shelly Beach and Mackenzie Point, the positions of these platforms often coincide with lithological transitions. More detailed work has to be done to confirm the idea that the position of at least part of the platforms is determined by lithological differences. This might explain why Åse (1981, p. 309) had difficulties in finding consistent elevations in his lower shore elements.

  The surface of the platforms is covered by unconsolidated sediments. On the Uhuru levels well to very well sorted, fine sands consisting mainly of quartz and shell fragments are common. Their white colour is characteristic. Soil formation has resulted in the development of A-C profiles, tentatively classified as Calcaric Regosols with locally a lithic phase.

  A sample of a coral head taken from the surface of the Uhuru-I level near Similani was shown to have an age of 26.5 (+1.3 -1.5) ky (Hori, 1970, p. 38). No lithified platform-deposits are known to occur at that site. The sample must have been derived from the underlying Mtwapa Limestones and bears no direct relationship to the age of the platform. The same applies for the datings of samples taken near Malindi (Toya et al., 1973, p. 101). The two coral head samples with an age of 27.5 (±1.3) and >33.2 ky respectively are likely to have been derived from the Mtwapa Limestone found at that place. The sample described as beach rock (?) with an age of 25.6 (±1.1) probably represents the shell-gravel beds found in the same Mtwapa limestones near Malindi (Braithwaite, 1984, Fig. 3).

– Fig. 10 Raised platform at Mackenzie Point

Battistini (1977) took a coral sample the surface of the Uhuru-II platform along the Kikambala beach. It was shown to have an 230Th/234U age of 240.0 (+70 -40) ky. As there is no known lithified platform deposit related to the Uhuru level at this site, the coral was most likely derived from the Shimoni or Mtwapa limestone into which the platform has been cut.
The surfaces of the Mackenzie platforms are mainly characterised by very well sorted, fine to medium, non-calcareous quartz sands. On the lower level (Mackenzie-II) they are very pale brown. Soil formation has resulted in the development of A-(B)-C profiles, tentatively classified as Dystric Cambisols. On the upper level (Mackenzie-I) soil formation is more advanced. In well drained positions the soils have an A-B-(C) horizon sequence and can also be classified as Dystric Cambisols. The typical strong brown colours of the sands is probably mainly due to this soil development. Near Tiwi Beaches Braithwaite (1984, p. 995) found a dense calcarenite on an eroded surface in the Mtwapa limestones at an elevation of about 6 to 7 m above the present-day reef platform. A paleosol separates these beachrock deposits (Tiwi calcarenites) from the overlying

marine sandstone (Tiwi sandstones) with coral fragments. The surface of the deposits is part of a platform which in the present study has been correlated with the Mackenzie-II level. Therefore it seems likely that the Tiwi sandstones have to be considered as beachrocks related to the Mackenzie-I level. The Tiwi calcarenites then probably date back to the formation of the lower Mtondia level. Hori (1970, p. 38) dated a coral head taken from the surface of the Mackenzie-II platform at Tiwi Beaches and arrived at a 14C age of 21.6 (+2.3 -0.7) ky. The sampled coral must have been derived either from the Tiwi sandstones or from the Mtwapa limestones as they are the only known deposits in which corals occur at that site. Assumed that this dating is reliable it provides a dating for the Tiwi sandstones and the Mackenzie-I level in the first case. In the second case it gives the age of the Mtwapa limestone. Sea levels at around 20 ky BP are estimated as between -120 and -135 m (Bloom et al., 1974 p. 203). If the dating does give an age of the Mackenzie-I level it implies a coastal uplift rate of about 6 m/ky. This is an unusually high figure compared to those found by Bloom et al. (1974, p. 201, Table 3). If the dating is assumed to give an age of the Mtwapa limestones the uplift rate becomes even higher. The preliminary conclusion therefore is that the reliability of the 14C datings is questionable. The problem of the proper age setting of the raised platforms is discussed in Section 3.1.1.3.2.

- The raised beaches are represented by narrow, elevated accumulations of water-borne materials. The ancient beaches occur typically in the more sheltered places and where a rocky cliff is absent. Beach ridges are well developed on the Uhuru levels. The deposits consist mainly of quartz and shell fragments and are included in the Uhuru Beach Sands. The materials have locally changed in beachrock.
  A 14C dating of a beachrock on the Uhuru-II platform gave an age of around 2.8 ky (Hori, 1970, p. 38). It proves the Holocene character of the platform. Shells from the crest of beach ridges on the Uhuru-II level are reported to have a 14C age of around 1.0 to 0.8 ky (Åse, 1981, p. 308).
  The soils of the raised beaches are comparable with those on the platforms but normally lack the lithic phase.
- The dune ridges are formed by low elongated accumulations of eolian sands at the back side of the raised beaches. As along the present shore they often formed at the foot or on top of the cliff or front slope of the higher terraces. The deposits consist of very well sorted, fine quartz and shell sands. The eolian sediments of the Uhuru levels belong to the Recent dune sands since the related platforms and beaches are of Holocene age. If the dating of the Mackenzie-I platform is correct, the related dune sands have to be included with the Pleistocene dune sands. The age of the Mackenzie-II dune sands is uncertain.
  Shells at about 50 cm buried in the dune ridge at the Shelly Beach hotel have been 14C dated by Åse (1978, p. 218) as 2.25 (±0.09) and 2.03 (±0.1) ky. Åse incorrectly tried to use the dating for the age setting of his level III (= Mackenzie-II). He interpreted the ridge as a bar or spit and took the summit as a shoreline feature. However, as the ridge rises more

than 2.5 m above the surrounding raised beach, it is better classified as a low dune ridge which has probably been formed from a former beach ridge by an eolian redeposition. This explains the occurrence of shells under a cover of very well sorted fine sands. Therefore the dating more likely indicates a period of drought during which the vegetation on the beach and dune ridges on the Uhuru-I level deteriorated and eolian redeposition of the dune and beach sands took place.
Soil formation is again comparable with that on the platforms and raised beaches. The dunes of the Uhuru-I level have soils with a vague A-C profile and can be classified as Cambic Arenosols. The C-materials are commonly white. Those belonging to the Uhuru-I level often have a buried A-2A-2C horizon sequence. The buried A-horizon can be more than 40 cm thick. The C-material characteristically has very pale brown colours. The soils are also classified as Cambic Arenosols (Boxem et al., 1987, profile description 198/2-15). They are calcareous and have a strongly alkaline soil reaction. The buried soil profiles are believed to reflect the previously mentioned period of drought in which eolian redeposition of surface materials took place. Typical soils on the dune ridges of the Mackenzie-II level are not precisely known. Deep A-(B)-C profiles with dark brown topsoils and grey subsoils are known to occur north of Kilifi. The soils are tentatively classified as Cambic Arenosols. Soils developed in the dunes on the Mackenzie-I level are typified by deep A-B-C profiles with dark brown topsoils and yellowish brown subsoils. The profiles classify as Cambic Arenosols, have a slightly acid soil reaction and are also slightly leached.

Abandoned embayments
The abandoned embayments of the lower levels are of relatively small size and occur at several locations along the central coast. Due to scale limitations only the most prominent ones have been indicated on the geomorphological map (Appendix I). Moreover, further detailed mapping is needed to get a better idea of the upper boundary between the bottom of the embayments of the Mackenzie-I level and that of the reef lagoons of the Mtondia level with which they seem to merge. It might well be that the extent of the Mackenzie-I level around these embayments will prove to be greater than is known at present. The embayments at the Mackenzie-II and the Uhuru levels are clearly visible on aerial photographs. The one found near the Uhuru Farm is relatively large. It has been interpreted as an abandoned tidal inlet because of its shape and deposits. The surface of its bottom correlates with the Uhuru-II level as evidenced by its shell-sand cover and elevation. Of note is the occurrence of a peat deposit below the shell sand cover of the bottom plain. The peat must have started to grow after the embayment was formed and before the deposition of the shell sand. More accurately it must have started to accumulate after the Uhuru embayment was closed and a fresh water environment was created. This closing-off appears to have been caused by the accumulation of a barrier. Later eolian activity remodeled it into the dune ridge on which the office of the Uhuru Farm has

been built. As no tidal channels are found in the present-day reef flat in front of them, the initial formation of the embayments is considered to be due to wave erosion during a period of relatively high sea-level.
The narrow stretches of flat-lying land occurring around the present-day branching bays are also correlated with the Mackenzie and Uhuru levels. Those on the Uhuru levels are mainly sedimentary and are classified as elevated tidal flats. Those of the Mackenzie levels are mainly erosional and consist of platform remnants on the lower part of interfluve spurs. Oyster beds occurring at heights up to about 10 m +MSL in many of the surrounding valleys debouching in the branching bays (Gregory, 1921; McKinnon Wood, 1930; Caswell, 1953, 1956), might also be considered as markers of the Mackenzie levels.

Southern section

Roughly at the same altitude as in the central section of the littoral zone, four elevated shorelines can be distinguished in the south. Mapping of them is, however, in many places hazardous. Due to the dominance of clays the original sea cliffs have been lowered by erosion. Nevertheless the presence of the lower littoral levels can be demonstrated, especially around the outfalls of the Umba, Mwena, Ramisi and Kidogoweni rivers. The landform associations are comparable with those seen at the present-day shore in the south. The main land units are marine terraces and lagoon plains.

Marine terraces
The marine terraces are mainly found in the interfluve areas between the Gazi and Funzi Bays and at the edges of the Shimoni peninsula. The various components are described below.

- The raised platforms are especially present around the Funzi and Vanga bays. The transitions between the levels are marked by low bluffs or cliffs which indicate the position of elevated shorelines. Near the mouth of the Mkurumuji river two platforms can be seen. The higher one occurs at approximately 8 to 10 m. and the lower one at approximately 5 to 8 m. They have been correlated with the surfaces of the Mackenzie-I and Mackenzie-II levels respectively. Another series of terraces can be seen in the Ramisi-Mukurumuji interfluve area near Msambweni. Here the MOW workshop and labour camp are situated on the higher surface, just at the edge towards the lower Mackenzie-II level. The nearby Tumbe leper settlement has been built in a small embayment of the Mackenzie-II level itself. No details about the characteristic sediments are available.
  One profile description (Michieka et al., 1978, profile 200/4-187) is known for the soils on the Mackenzie-I level. It has a dark brown topsoil and a yellowish red to red subsoil of sandy clay loam over coral limestones. At first sight it resembles the soils of the Mtondia level. This may indicate that during the period of high sea-level connected with the Mackenzie-I level, parts of the older Mtondia level became submerged

without a complete stripping of its soils.

- The raised beaches are formed by sand accumulations of small extent occurring on the Uhuru levels. An example of them can seen in front of the Msambweni Hospital. The materials are mainly moderately well sorted quartz sands and stratigraphically can be included in the Recent beach sands. Their soils are characterised by A-C profiles. No clear raised beaches have so far been found on the Mackenzie levels.

Elevated bay or lagoon-plains

The elevated bay or lagoon-plains are mainly found around the present-day Gazi, Funzi and Vanga Bays. Two components are distinguished:

- The ancient barriers occur as broken ridges of sandy deposits. One of them forms the Vanga peninsula and a series of lined up islands of which Kaufumbani, Ngowa and Kuzini are the largest. Another ancient barrier starts at the Jimbo peninsula and continues as a series of islands also in line but of smaller extent than that which starts at Vanga. On the 1 : 50 000 aerial photographs used for the present study the distinction between representatives of the Uhuru and Mackenzie sub-levels is uncertain. Ancient barriers on the higher Mackenzie-I level have not been found so far, but those of the lower Mackenzie-II and the Uhuru levels can be identified in the field. An erosional cliff of 6 m high in a barrier which correlates with the Mackenzie-II level has been reported at approximately 5.5 km northeast of Vanga (Michieka et al., 1978, p. 149). It shows sandy deposits abruptly overlying a clayey subsurface and indicates the transgressive nature of the barriers deposited over a submerged former bay plain. The barriers seem to be confined to the western part of the Vanga Bay and are clearly connected with the sediment transport by the Umba river system. Since at the present shore no clear evidence exists for active barrier formation, except near the Umba river mouth, it must be assumed that the conditions during the formation of the Uhuru and lower Mackenzie levels were different of those of today. A higher discharge and a greater sediment load are likely. The fragmented character of the two barrier ridges indicates that erosion has taken place after their formation. The nature of this erosion has most likely been fluviatile since the gaps in the barriers are all situated in front of the small streams extending from the mainland. Therefore a relatively lower sea-level after the formation of the barriers is assumed.
- Former tidal-flats are formed by the low-lying, flat areas around the present bay-edges. They are characterised by clayey deposits. On the Uhuru levels the sediments consist of sandy clay loams to clays with abrupt textural changes. They are provisionally included in the Recent tidal flat deposits. The stratigraphical classification as Holocene deposits is based on a correlation with dated raised beaches of the Uhuru levels at the central section of the coast. The soils formed in these deposits have a truncated and buried A-2B-2C horizon sequence with very dark grey topsoils and olive grey subsoils. They have a neutral soil reaction and can be classified as Eutric Fluvisols and Gleysols with a sodic and saline phase

(Michieka et al., 1978, profile 202/1-274).
On the Mackenzie levels the deposits of the former tidal-flats consist of montmorillonitic sandy clays to clays. Their stratigraphical position is not yet clear as the ages of the Mackenzie levels are uncertain. They can provisionally be described as Pleistocene tidal flat deposits. The soils on the Mackenzie-I level have an A-B-C horizon sequence with a black topsoil and olive subsoil. They have a neutral to moderately alkaline soil reaction and can be classified as Gleyic Phaeozems with a saline/sodic phase (Michieka et al., 1978, profiles 202/2-283, 284, 285). Data are as yet insufficient to differentiate them from the soils on the Mackenzie-II level. On the soil map of the Lungalunga area (Michieka et al., 1978, Appendix 1b) the soils broadly correlate with those of mapping unit PA6.

- The former tidal-swamps are represented by the low-lying valley plains and backswamp depressions near the shore. They occur in areas where former fluvial sedimentation merged with the marine deposition. The raised swamps are especially known to occur at the Uhuru-I level at the mouth of the Umba river and, to a smaller extent, at that of the Ramisi river. They can be recognized on aerial photographs by the presence of clear bounded, small plots. This is associated with a farming system which preserves the river water, driven up during high tides in the rainy season, by way of numerous low dikes surrounding the fields.
  The deposits consist of heavy clays characterised by a high sulfate content. They are included in the Recent alluvium. The soils consist of cumulative A-C profiles with very dark grey to dark greyish brown colours. They have been classified as very strongly acid Thionic Fluvisols. On the Lungalunga soil map (Michieka et al., 1978, Appendix 1b) they are indicated as unit AA2.

Northern section

Elevated shorelines with a relatively low range of height differences have also been recognized in the northern section of the Kenyan Coast (Fig. 11). In the Sabaki embayment the first two ancient shores are represented by raised mainland beaches. One occurs at around 0.5 to 1 m above the present high-tide mark and the other at 2 to 3 m (2.5 to 3 and 4 to 5 m +MSL respectively). The two surfaces demarcated have been correlated with the Uhuru-II and Uhuru-I level respectively. On the geomorphological map 1:500 000 (Appendix I) they have been indicated as one level because of their small extent. Related dune complexes are well developed between Malindi and Mambrui. At the western periphery of the Tana embayment the elevated shorelines of the Uhuru levels are mainly represented by ancient barriers and lagoon plains. In the Tana delta the levels have been recognized at the delta front in the form of ancient barrier islands. On the delta plain they are represented by former tide-dominated interdistributary areas and marine marshes. At the eastern periphery the present wave attack maintains steep cliffs of about 6 to 8 m and the Uhuru levels are absent.

Fig 11 Elevated shoreline of the Uhuru Level near Gongoni

Two still higher elevated shorelines occur at 6 to 7 and 8 to 10 m +MSL respectively. The surfaces which they demarcate have been correlated with the Mackenzie-II and Mackenzie-I of the central section respectively. Near Malindi and the Sabaki mouth, the Mackenzie levels are present in the form of a marine platform cut into rocks of the Pleistocene reef complex and covered by a thin veneer of unconsolidated deposits. Between Mambrui and Manaheri the level has been interpreted as the surface of a former lagoon plain as evidenced by its silty and clayey superficial deposits. Dune complexes related to the formation of the Mackenzie levels occur between Malindi and Mambrui but are relatively small in extent.
Along the western periphery of the Tana embayment the lower Mackenzie-II level is locally constituted by raised beaches (e.g. near Marereni). It is represented more commonly by ancient estuarine lagoon plains found at the seaward end of relatively short in-filled valleys. The Mackenzie-I level is formed by beach sands overlying a marine platform cut in deposits of the Pleistocene reef complex. At the surface it is characterised by a complex of ridges and enclosed depressions, which have been interpreted as ancient

barriers and barrier or lagoon flats. The spacing of the ridges varies from about 200 to 250 m, measured from crest to crest. Locally they have been reworked into low dune ridges by eolian activity. The whole association of landforms is traversed by a series of low scarps of around 5 to 10 m high running parallel in a roughly NNE-SSE direction.
The scarp slopes affect the elevation of beach ridges without causing any change in their direction. At the foot of the scarps alluvial material can be seen accumulated, in the pools of the ancient barrier flats. This causes a complete or partial burial of the ancient barriers. It is therefore concluded that the low clifflike slopes are fault scarps with their down throw towards the deposition centre of the Tana delta.
In the Tana delta the lower Mackenzie-II level occurs on the delta front as an ancient barrier island. On the delta plain it has been recognized as former marine marshes and tidal-influenced interdistributary areas. The Mackenzie-I level is represented in the delta by ancient barrier complexes. They occur at a distance of 20 to 25 km from the present shore and form a direct continuation of those found along the western periphery of the Ungwana Bay. The sand ridges are partly dissected by the present and several former courses of the Tana river. The Oda and Furaha villages are situated on them. Towards the deposition centre they are overlain by fluvial deposits. The boundaries between the sand ridges and the fluvial areas are often abrupt and straight and occur along parallel lines in a same direction as the fault scarps on the western periphery. From this it is concluded that the tectonic activity influenced or even determined the position of the present Tana delta. This neo-tectonic phase in the northern section of the coast of Southeast Kenya took place after the formation of the Mackenzie-I levels and prior to the formation of the Uhuru levels. On account the preliminary datings of these levels indicates, the tectonic event seem to have occurred at end of the Late Pleistocene.
At the eastern periphery the Mackenzie-I level predominates. Near Kipini it has been identified as an ancient beach-plain with raised beaches and dune ridges. Towards the north it consist of ancient barriers and barrier or lagoon plains as along the western periphery.
The main characteristics of the land units of the northern section are summarised below.

Marine terraces

The marine terraces are mainly found near Malindi and Ngomeni and along the western and eastern periphery of the Tana embayment. They comprise the same components as found at the southern section of the littoral zone of the coast.

- The raised platforms are well developed at both the Uhuru and Mackenzie levels around the embayment in front of the Sabaki river. At the western periphery of the Tana embayment they mainly represent the Mackenzie-levels. Their subsurface is exposed in several road quarries along the B8 between Malindi and Garsen. They show an abraded coral reef-flat overlain by sandy clays. The transition is marked by a layer of

Fig. 12 Exposure of coral rubble in the marine terrace of the Mackenzie-I level along the Malindi-Garsen road

coral rubble of varying thickness (Fig. 12). This indicates that the growth of the coral reef must be of an earlier period than the formation of the marine terraces and plains of the northern section. Williams (1962, p. 47) observed some of these outcrops. In the present study they are included in the Pleistocene reef complex. The raised reef-flats are recognized on aerial photographs by a more open vegetation compared with adjacent areas. The ground surface between the trees and scrubs is often bare resulting in a white-black spotted photo-image. Near the Sabaki river the surfaces of the lower levels are also underlain by coral limestone of the Pleistocene reef complex. The surface is overlain by a rather thin sand cover and is marked by numerous sinkholes, characteristic of the raised platform remnants underlain by coral limestone.

- The raised beaches of the Uhuru levels are especially found along the Sabaki embayment and the barrier island fronting the Tana delta. No details of their sedimentological characteristics are known. They have been included provisionally in the Recent beach sands. A 14C dating of a beach-rock from the Ngomeni peninsula has been published by Toya et al. (1973, p. 101). The sample was taken from the platform on which the unconsolidated beach and dune sands of the Uhuru-II have been deposited. The 14C age obtained (5.25 ±0.13 ky) is therefore more likely to indicate the age of the Uhuru-I level.

- The dune ridges, found in association with the raised reef flats, are especially known to occur between the Sabaki mouth and Mambrui. Four generations of dunes have been distinguished and are connected with the formation of the corresponding Mackenzie and Uhuru levels. The dune ridges of the Mackenzie levels are well vegetated and show up on aerial photographs in light and dark grey tones. The dune sands of the Mackenzie-I level are yellow very well sorted sands, while those of the Mackenzie-II are pinkish grey to white. Both are non calcareous and are provisionally reckoned to the Pleistocene dune sands. The dunes connected with the Uhuru level have a more open vegetation cover and show up as black and white spotted areas on aerial photographs. These younger dunes rise above the older ones and reach a height of about 50 m. Their materials are white, very well sorted and often slightly calcareous sands. They are considered to form part of the Recent dune sands.

Lagoon or delta plains

The lagoon or delta plains of the northern section are found in front of the Tana alluvial valley and along the western periphery of the Tana embayment. They include at least four components which are briefly described and discussed below.

- The ancient barriers are well developed and easily recognizable on aerial photographs by their linear or curvilinear pattern. The sand ridges related to the Uhuru levels resemble in plan and position those described on the Tanzanian coast, where they were classified as beach ridges (Alexander, 1969).
- The former tidal flats occur in association with the ancient barriers situated along the western periphery of the Tana embayment. No details of soils and sediments are known. They are provisionally considered to be comparable with those occurring at the southern section of coast.
- Former tidal swamps occur as wide swampy grass plains just behind the barrier island fronting the Tana delta. They are characterised by heavy clay which is included in the Recent alluvial deposits. Their soils are comparable to those found at the southern section and consist mainly of thionic Fluvisols. In view of their elevation, the swamps are considered to represent the Uhuru levels However more detailed mapping is needed for a further differentiation.
- The interdistributary areas of the lower Tana delta-plain have been included as a unit of the littoral zone. It is a debatable choice as those areas were formed in an environment of alternating marine and fluviatile influence. On considering the materials alone they should have been included in the paralic areas. However from the position of the interdistributary areas it is clear that they developed in a tidal

Table 6 Correlation of the middle littoral levels with surfaces referred to in earlier studies

Earlier publications	Present study: Mtondia-II (10-15 m +MSL)	Mtondia-I (15-25 m +MSL)	Majaoni-II (25-35 m +MSL)	Majaoni-I (35-50 m +MSL)
Sikes, (1930)	40 ft level (?)	80 ft level (?)		
Werth (1952)	<------< Niederterrasse >------>			
Caswell (1953)	<------< 120 ft terrace >------>			
Caswell (1956)	<------< 120 ft Terrace >------>			
Thompson (1956)	<------< 120-ft terrace >------>			
Williams (1962)	<------< 120-ft platform >------>			
Battistini (1969)	<------< Recif-I plate-forme >------>			
Hori (1970)	<------< Upper Mombasa Terrace >------>			
Toya et al. (1973)	<------< Kilifi Terrace >------>		<------< Ganda Terrace >------>	
Åse (1978)	Level V-VII	Level VIII		
Rossi (1981)	Upper Mombasa II	Upper Mombasa I		

Table 7. Land units of the middle littoral levels

southern section		central section		northern section	
land types	land components	land types	land components	land types	land components
marine terraces	raised platforms former reef-lagoons	marine terraces	raised platforms raised reef-lagoons raised beaches ancient beach-dunes	marine terraces	raised platforms raised beaches ancient beach-dunes
bay or lagoon plains	former tidal-flats former tidal-swamps ancient sand-bar complexes	bay terraces	raised platforms interfluve ridges	bay or lagoon plains	ancient barrier-islands ancient sand-bar complexes former tidal-flats ancient beach-dunes
stream valleys	valley slopes valley floors alluvial fans	stream valleys	valley slopes valley floors alluvial fans	stream valleys	valley slopes valley floors alluvial fans
		eolian complexes	sand-drift ridges deflation pans		

environment. Therefore they are included in the littoral areas. In more detailed maps the whole delta complex might be best indicated as a separate unit. The deposits of the interdistributary areas are dark to very dark clays. The soils which developed in them have been classified as Eutric and Thionic Fluvisols (Stolp & Vleeshouwer, 1981, Map 1).

3.1.1.2.3 Middle littoral levels

Two major breaks of slope occur in the coastal plains of the littoral zone at around 25 and 40 m +MSL. They form the landward boundary of the Mtondia and Majaoni levels respectively. The change in slope is abrupt where limestones occur in the subsurface. The relatively hard nature of the rocks gave rise to the preservation of clear terrace front-slopes of about 10 m high. Where clayey deposits form the substratum more gentle transitional slopes occur. Here the delineation of the different terrace levels on aerial photographs is often uncertain. Deposition of alluvium and colluvium at the foot of the terrace slopes can also hamper the recognition of the boundary between the various levels. This is especially the case where minor, intermittent streams have built up alluvial fans on a lower terrace tread. Nevertheless a north-south continuity of the levels parallel to the present-day shore is clear. A tectonic origin could not be proven, although minor fault scarps are found in places. The direction of these latter scarps is however seldom parallel to that of the present shore-line. A marine origin of the larger part of the breaks of slope therefore is assumed. Consequently the transitions have been interpreted as elevated shorelines. This conclusion is confirmed by the presence of raised beach-deposits on both terraces. More advanced soil development on the Majaoni levels as compared to that on the Mtondia levels reflects their difference in age. It indicates that the various levels experienced a sequential development.

The marine terraces of the Mtondia and Majaoni levels compose most of the flat parts of the central section of the coast. They have been mentioned by most workers on the geology and geomorphology of Southeast Kenya. The continuation of these levels in the more dissected areas around the present embayments and their presence in the northern and southern sections of the coast has received less attention. The occurrence of several ancient foredune-ridges, particularly in these little studied parts, shows that the genesis of the terraces of the middle levels was not completed in just two episodes only.
Several sub-levels occur which are not or only poorly preserved in the central section. The division proposed in this study is given in Table 6, together with a synopsis of the references to the levels in earlier studies. In a more detailed morphological subdivision four major units can be distinguished on both the Mtondia and Majaoni levels. Two of them are related to the initial formation of the levels. They have been indicated as

the marine terraces and elevated bay or lagoon plains. Both are differentiated by a characteristic landform association. The two other major units, indicated as stream valleys and eolian complexes, are related to the later development of the levels. The various minor land units which have been distinguished are summarised in Table 7. They are described in more detail below. The central section of the littoral zone is again taken as a reference area.

Central section

The middle littoral levels in the central section of the littoral zone consist mainly of raised abrasion surfaces. They are overlain by unconsolidated sandy deposits. When underlain by the sand and limestones of the Pleistocene reef complex, the surfaces are relatively undissected and form a well recognizable series of marine terraces. Around the branching bays and estuaries the levels are present in the form of elevated bay plains. These are often strongly dissected due to the impervious nature of the underlying shales of the Mtomkuu Formation. As the remnants of these elevated plains occur in a relative narrow strip along the bays and estuaries, they can also be described as bay-edge terraces.

Marine terraces

The marine terraces of the middle levels in the central section consist of four components (Table 7). They are briefly described below.

- The raised platforms are formed by ancient reef-flats or other abrasion surfaces. The stony platforms of abraded reef rock are comparable with those of the present-day reef. They can be recognized by their slightly higher position and relatively dark tones on aerial photographs. On the Mtondia level an outer reef-flat can often be distinguished from one or two ancient inner reef-flats. The outer one is situated at around 12 to 15 m +MSL and appears to be underlain mainly by Mtwapa Limestones. Crame (1980; 1981) has demonstrated the back-reef facies of these rocks. It is thus clear that the terms outer and inner can only be used in the context of the present position. The absence of true reef-front limestones points to the destructive activity of either erosion or tectonic processes. Crame (1980, p. 5) suggested a removal by marine erosion. During the present study, however, evidence for tectonic movements was found in the form of low fault scarps. More details on the structure of the subsurface are needed to prove a tectonic cause for the absence of the remnants of a raised reef-front. The outer reef-flat is covered locally by a veneer of slightly indurated calcarenite. The fresh-looking Halimeda sandstones and other calcarenites found in the quarries near Maweni are an example of this. They lack the signs of prolonged subaerial erosion seen in the Mtwapa limestones such as the presence of solution pipes. The fresh veneer of mainly calcarenites is considered syngenetic with the formation of the Mtondia-II level and is tentatively correlated with the Tiwi calcarenites

described by Braithwaite (1984, p. 695). A radiometric dating of this material may reveal a proper age of the Mtondia-II level.
Where the outer reef-flat directly borders the shore it forms steep rocky cliffs. At these sites the marks of the lower plain-levels are normally absent or at best ill defined. The surface of the outer platforms is overlain by a thin cover of fine sands and silts and is characterised by abundant rock outcrops.
Shallow dark brown soils with an A-R horizon sequence have been formed at places where Tiwi calcarenites occur. When Mtwapa limestones occur at shallow depth, the soils are dark reddish brown and show an A-B-R horizon sequence. They have been classified respectively as Lithosols and Ferralic Cambisols with a lithic phase (Michieka et al., 1978, unit PL4P Appendix 1; Sombroek et al., 1982, unit Pc9 Appendix 1; Boxem et al., 1987, unit P2LI1P Appendix 1, profile 198/4-1). In places the soils have developed in the red sandy sediments filling the solution pits in the Mtwapa limestones. This explains the inclusions of deep soils in the soil units mentioned above. These red sands are derived from paleosols developed before the reef platform was overlain by marine Tiwi calcarenites (Braithwaite, 1984, p. 695). This demonstrates that the outer reef-flat of the Mtondia-II level is an old abrasion platform. The surface underwent intense soil formation before it became submerged during the Mtondia-II transgression. This episode of submergence led to the stripping of most of its soils followed by the deposition of the Tiwi calcarenites. A similar sequence of events has been described in Section 3.1.1.1 for the present-day reef-flat. It demonstrates that the surface of a certain coastal level can be rejuvenated by later transgressions. Consequently there will be less terrace levels left than there have been stages of high sea-level. This is important to keep in mind when materials are chosen to be sampled for dating.
Two higher situated inner reef-flats have been recognized further to the west. One is situated at around 20 to 25 m +MSL and has been correlated with the Mtondia-I level. Its subsurface rocks are exposed in several places along the B8 (e.g.the Mtondia posho mill). The other inner reef-flat occurs at around 30 to 35 m +MSL and has been connected with the Majaoni-II level. A good exposure of its subsurface is found along the A14 near the Gidomal coconut plantation. Evidence of sub-aerial solution in the form of honeycomb weathering and cavities is more marked on the Majaoni level. This indicates that the Majaoni level is older than the Mtondia level. Characteristic of these inner reef-flats is the sediment cover of sandy loams to sandy clay loams. The coarse fraction (> 0.05 mm) of the deposits on the Mtondia levels consists of well sorted fine sands. On the Majaoni levels the sands are also fine but mainly moderately well sorted. The thickness varies from almost nothing near the outer edges to over 2.5 m more land inward. Rock outcrops are common, expressing the irregular contact between the coral rock and the superficial sands. The platform deposits of the Mtondia and Majaoni levels are part of the Older Pleistocene Sands in the preliminary stratigraphy. On the soil maps of the

Kwale and Kilifi area they are indicated as the Kilindini Sands or the medium and coarse grained sandy deposits of the Kilindini Formation respectively (Michieka et al., 1978, Appendix 1b; Boxem et al.,1987, Appendix 1). As a result of the detailed work of Braithwaite (1984) it is clear that these Kilindini sands comprise at least four different sandy deposits related to the formation of the upper part of the Pleistocene reef complex.

Closed semi-circular depressions occur as minor land-forms associated with the reef-flats. They may represent sinkholes or remnants of ancient, small lagoons.

Soil formation on the Mtondia-I platforms is influenced by the nature of the subsurface lithology. When underlain by coral limestones or calcarenites the profiles are characterised by an A-B-R horizon sequence with dark brown topsoils and yellowish red subsoils. They have been included in the unit PL2I2p and classified as Ferric Luvisols during the soil survey of the Kilifi area (Boxem et al., 1987, Appendix 1). In the Kwale-Mombasa-Lungalunga area they correlate with the soils of unit PL2p, classified as Rhodic Ferralsols (Michieka, 1978, Appendix 1a, 1b). The difference in classification is due to the recognition of clay illuviation in the soils of the Kilifi area. Whether its absence in the Kwale area is caused by a deviating interpretation of field evidence and laboratory data or by the slightly greater rainfall is unknown. The deeper subsoil is dark red in places (Boxem et al., 1987, profile 198/2-36). This may indicate the presence of buried paleosols which are known to occur on top of the Mtwapa limestones and the Watamu calcarenites (Braithwaite, 1984, p. 689, 691).

- The raised reef-lagoons are formed by the relative low stretches of land behind or between the raised reef-flats. The interpretation as raised reef-lagoons is based mainly on its correspondence in form and position with present-day reef-lagoons. Those on the Mtondia-II level occur between 10 and 15 m +MSL. Near present and former embayments, they grade into reef platforms of the Mackenzie-I level. The raised reef-lagoons on the Mtondia-II level are filled with deposits largely identical to those of the raised platforms. The thickness of the deposits varies from about 1.5 m to over 3 m. The topography of the contact with the underlying reef rock is irregular but rock outcrops are normally absent. Where the raised reef-lagoons border on the present shoreline a steep, sandy front slope is found instead of the often oversteepened, rocky cliffs. The reef deposits underlying the raised lagoons belong to the Mtwapa limestones or the Watamu calcarenites. The raised reef-lagoons of the Mtondia-I and the Majaoni levels are less easily recognized as outer reef-flats are often absent. They occur behind the outcrop of the Pleistocene reef complex. The superficial deposits vary from sands to clays. The fill of the former lagoons includes alluvial deposits laid down in front of minor valleys formed in higher situated terraces. The numerous well and borehole records show that the subsurface consist of a complex of yellowish brown sands, clays, marls and coral limestones overlying blue clays and sandstones.

Although the stratigraphy of the deposits is not yet established, it is clear that the succession comprises a complex of deposits which parallels, at least in its upper part, the Pleistocene reef complex. It includes the North Mombasa Crag and Kilindini Sands mentioned by Caswell (1953, p. 27). The term Kilindini complex is proposed and used in this study for the total succession. It includes the lagoonal, beach and reworked platform deposits which are contemporaneous with the sediments of the Pleistocene reef complex.

The soils found in the deposits of the raised reef-lagoons of the Mtondia-II level are yellowish red and have an A-B-R horizon sequence. Except for their greater depth, they hardly differ from those on the raised inner reef-flats of the Mtondia-II level. On the transition towards the surface of the Mackenzie-I level however CEC values of the clay and the base saturation of the soil increase. Here the soils classify as Chromic Luvisols or Chromic Cambisols, depending on whether enough evidence for an argillic B-horizon is present or not. The deeper subsoils are locally red or dark red (Boxem et al., 1987, profile 198/2-35; Michieka et al.,1978, profile 201/1-173) and probably represent the truncated remnants of paleosols developed in the underlying rocks.

The soil pattern of the raised reef lagoon of the Mtondia-I varies with the character of the subsurface deposits and depends on the internal drainage. The subsoil colours of the A-B-(C) profiles vary from red to yellowish brown. Signs of clay illuviation are difficult to detect in the sandy soils but evident in the clayey soils. They are both included in the unit P2El1 and P2El3 on the soil map of the Kilifi area (Boxem et al. 1987, Appendix I). The low CEC of the clay of the soils in the well drained areas leads to their classification as Ferric Luvisols (profile 198/3-82, 83). Orthic and Gleyic Luvisols (profile 198/4-1) occur in the less well drained parts .

Raised reef-lagoons constitute the major part of the marine terraces of the Majaoni levels. Their identification can often be based solely on sedimentological evidence because the reef front is absent in most places. A complete sequence, however, can be seen west of the Gidomal coconut plantation. The superficial fill consists for the larger part of sandy alluvial-fan deposits. The deeper subsurface deposits are made up of clays, silts and sands of the Kilindini complex. Characteristic are the deep light grey to white soils with an A-E-(B) horizon sequence. They are evidence of intense leaching which must have taken place under wetter conditions than those of today. These soils have been included in unit PA1 on the soil map of the Kwale area (Michieka, 1978, Appendix I) and are classified as Albic and Luvic Arenosols.

- The raised beaches are formed by thick sand accumulations on the landward parts of the terrace treads. They are recognised on aerial photographs by their lighter tones compared with those of the raised platforms and raised reef-lagoons. On the Mtondia levels the deposits consist of loamy sands. Their sand fraction appears to be slightly better sorted than that of the platform deposits. Deposits of over 3 m thickness have been observed at

Mtondia. They are overlying the sands, silts and clays of the Kilindini complex. Any positive evidence of the water-borne nature of the sands is lacking due to progressed soil formation. The deposits correlate with the younger Pleistocene sands in the preliminary stratigraphy (Section 3.1.1.1). The eolian origin assigned to them by Caswell (1956, p. 35) is clear in places where dunes can indeed be recognized. The deposits in these cases consist of very well-sorted sands with less than 10 % silt and clay. However on the flatter parts sorting is less and the deposits contain a higher amount of the fine earth fraction. Thompson (1956, p. 36) recognized a swell-and-swale topography west of Malindi, in places where the deposits occur. Here their classification as beach sands is sustained by morphological evidence.

Of note is the difference in soil formation compared with that of the raised platforms and reef-lagoons. On the Mtondia-II level the profiles are characterised by a vague A-B horizon sequence and strong brown subsoil colours (Boxem et al., 1987, profile 198/2-34). On the Mtondia-I level yellowish red subsoils occur (Boxem et al., 1987, profile 198/2-14). In both cases the soils classify as Cambic Arenosols. The less advanced stage of soil formation indicates a younger age for the beach deposits compared with the sediments on the raised platforms and reef-lagoons. This is understandable considering the presence of paleosols on a preexisting platform which became reoccupied during the Mtondia transgression. The old soils are likely to have been reworked and taken up in the profiles now found on the raised platforms and reef-lagoons. In the case of the raised beaches, the paleosols seem to have been completely buried under the accumulation of fresh beach material. The differences in texture often found between topsoils and subsoils of the raised platforms and reef-lagoons is probably also connected with the presence of these younger sands. They may have been laid down as a thin cover during the re-emergence of the Mtondia levels. The fact that parts of the old soils survived the period of re-submergence implies a form of lithification before this event. Red sandstones are indeed found on the Mtwapa Limestones (Braithwaite, 1984, Fig. 3). The re-emergence probably took place in two phases. This may be the reason for the presence of a Mtondia-I and a Mtondia-II sub-level with relatively slight mutual differences in height, sediments and soils. A tentative correlation is made between the beach sands of the higher and lower Mtondia sub-level and the Tiwi calcarenites and sandstones respectively. This is based on the fact that both post-date the first emergence of the Mtwapa limestones and the subsequent period of soil formation.

Ancient beaches on the Majaoni level are in general less easy to recognize. An exception is the terrace surface west of Malindi where, as on the Mtondia level, a swell-and-swale topography is found. Its occurrence at that particular place is probably connected with an abundance of sediment supply from the Sabaki river. The grain-size characteristics are comparable to those of the Mtondia levels. This may indicate that the transgression which led to the re-submergence of the

Mtondia platform reached the Majaoni level in this area. More evidence is needed to confirm this idea.

- The ancient foredunes are formed by eolian sand accumulations at former backshores. The dune ridges are aligned in a NNE-SSW direction, parallel to the present shore. They are especially found on the Mtondia-II level near Gede, Kilifi and Takaungu and reach a maximum elevation of about 45 m +MSL. The dune ridge of Kilifi town has a higher southwestern end. The rise from its lower northeastern part coincides with a clear break of slope in the raised platform on which the dune ridge rests. This suggests the presence of a minor fault-scarp with a general NNW trend. Its magnitude and direction is comparable with that of the low scarp found north of Kinangwani. Here it typically coincides with a sudden narrowing of the present reef-flat from about 800 m to less than 100 m. Similar features are found north of Diani Beaches on the raised reef-segment south of Mombasa. Both these examples show that tectonic movement took place not only in the north but also at the central part of the coast.

  The deposits of the dune ridge near Gede beacon consist of very well sorted (So = 1.18) fine sands (Md = 160 mu). In the preliminary stratigraphy they are included in the younger Pleistocene sands. They are clearly distinct from the beach sands as indicated by their smaller fine earth fraction and better sorting. It is now proposed to reuse the name Gede Beacon Sands, originally assigned to them by Thompson (1956, p. 36) in the Malindi area. The unit then includes all foredune sands on the Mtondia levels.

  The soils developed in sands of the foredunes on the Mtondia-II level have a vague A-B-(C) horizon sequence. Their subsoils have strong brown colours, which make them resemble the soils of the raised beaches on the Mtondia level. They have tentatively been classified as Cambic Arenosols.

  Dune ridges apparently related with the Mtondia-I level are found near Vipingo. Not enough details of the area are known to give a proper description of the materials. Solely because of their situation near the transition of the Majaoni level, they have been interpreted as belonging to the Mtondia-I level.

  Low dune ridges on the Majaoni levels are found near the headquarters of the Vipingo sisal estate. Their form however is more irregular and it not possible to differentiate them from secondary sand-drift dunes. Also near Waa south of Mombasa low dunes are found, which are irregular and hard to recognize on aerial photographs. Their deposits are however low in clay and silt content and have a very well sorted sand fraction. This confirms the eolian origin of the sand accumulations. It remains uncertain whether they are real beach dunes or sand-drift features connected with later redeposition of the platform sediments.

Bay terraces

The bay terraces are found around the present embayments near Kilifi and Mombasa. They are mainly underlain by Jurassic shales of the Mtomkuu Formation. As a result of the impervious nature of this material they tend to be strongly dissected. The former bay plains consist of two components (Table 7). They are briefly described and discussed below.

- The platform remnants are represented by flat topped interfluve areas, which are often overlain by a thin sand-cover. The grain-size distribution of the sand fraction is comparable with that of the deposits on the raised platforms of the marine terraces. The clay percentage is mostly higher, which may be due to an admixture of abrasion materials from the underlying shales. Caswell (1953, p. 30) recognised these platform remnants around Port Reitz and described them as small marine terraces at about the 120-ft contour. He assigned a likely eolian origin to the deposits to explain their supposed post-reef-complex age. Grain size analysis of the deposits shows, however, that their clay fraction is unusually high compared with the other wind-blown sediments found on the contemporary marine terraces. It is therefore concluded that the deposits on the platform remnants are littoral deposits. Their supposed young age can be well understood from the evidence for re-submergence found on the corresponding platforms of the marine terraces. The small peninsula in the embayment near Kilifi is a good example of a remnant of the Mtondia-I level developed on Jurassic shales of the Mtomkuu Formation. An important feature is the inland increase in elevation of the remnants. This could reflect the normal platform gradient. However the elevation of the most landward platform remnants of the Majaoni-I level rises in places up to about 50 m +MSL. This is more than the elevation of the most seaward lying platform remnants of the next, Tezo level. A seaward tilt of the land after the formation of the Majaoni-I level is therefore postulated. More details are needed to prove a tilt of the Mtondia levels. However, the presence of the minor fault-scarps does indicate the occurrence of neo-tectonic influences after its formation.
- The interfluve ridges are formed by the rounded and often narrow parts of the surface between the stream valleys. Although lowered by erosion their accordant summit and shoulder levels still indicate the position of the raised shore-lines of the Mtondia and Majaoni levels. The transitions between the levels can be recognized on aerial photographs by the knickpoints in the longitudinal profile of the interfluve ridges. The materials on the ridges consist mainly of residual deposits overlying shales of the Mtomkuu Formation or marls and sands of the Changamwe deposits.

  The soils on the ridges are characterised by an A-(B)-C-(R) horizon sequence. They classify as Vertic Cambisols and Chromic Vertisols. More details are needed for a further differentiation of the soils on the various summit and shoulder levels.

Stream valleys

The stream valleys of the middle plain-levels of the littoral zone are in fact more fluviatile than littoral landforms. However, as they are too small in size to be mapped separately on a 1:500 000 scale, they have been included with the landforms of the littoral levels. Three characteristic components have been distinguished (Table 7).

- The valley slopes consist of the sloping terrains connecting the platform remnants with the valley bottom. Their configuration depends mainly on the character of the subsurface materials and on the height of the level in which they have been formed. The slopes of the valleys in the platforms of the Majaoni levels are 10 to 20 m long. Those of the valleys on the terraces of the Mtondia level are not longer then 3 to 5 m. This indicates a different valley age on the two main levels and shows again that the Mtondia and Majaoni are features connected with separated events at the coast. The slopes of the valleys eroded into the surface of the elevated bay-plains around the present embayments are considerably longer. Near the present-day shore their lower parts are buried by valley floor deposits. This indicates that the valley formation here took place or at least continued during a previous period of low sea-level.
- The valley floors are formed by the flat parts of the terrain enclosed between the slopes of the valleys in the raised platforms. On marine terraces of the Majaoni levels they are narrow, having widths of about 10 to 20 m. Their materials consist of alluvium of varying texture. The soils are characterised by hydromorphic properties and classify as Gleyic Luvisols. The valley floors of the Mtondia level start at the lower edge of alluvial fans present where a stream valley of the Majaoni level ends. A remarkable feature of the valley floors of the Mtondia level is that they do not reach the present shoreline. They generally cease to exist where the intermittent streams reach the outer raised reef-flat of the Mtondia-II level. When they do have a valley which crosses the outer raised reef-flat it is narrow and hard to detect on the 1:50 000 aerial photographs. The impression is given that the position of the present-day stream valley-floors of the Mtondia-I level is determined by that of older ones. These must have existed before the deposition of the Mtwapa limestones, as these rocks clearly block the valleys. The Mtondia levels are shown to consist of a reoccupied platforms abraded in these Mtwapa limestone. Therefore a connection between the Majaoni levels and the deposition of the Mtwapa limestones is likely. This would mean that the formation of the blocked valleys took probably place during a period low sea-level between the formation of the Tezo and Majaoni levels. The diagram of Braithwaite (1984, Fig. 3) shows that considerable dissection did take place between the deposition of the Watamu calcarenites and the succeeding Mtwapa Limestones. From this it may be concluded that the deposits related to the formation of the Majaoni levels are indeed the Mtwapa limestones. The Watamu calcarenites are most likely connected with the formation of the Tezo levels.
- The alluvial fans are constituted by accumulations of loose materials outspread in front of the mouths of valleys formed in the higher marine-terraces. The fan bodies can be recognised on aerial photographs by their form and varying grey tones. Their deposits consist of poorly to moderately well sorted sands with a varying amount of clay, depending on the nature of the material in which the valley was cut. The alluvial fans near

Kibarani and Tezo are examples of sandy fans, receiving materials from the older Pleistocene Sands. Those near Mtwapa and Ziwani are clayey examples as they receive most of their materials from Jurassic shales of the Mtomkuu Formation and Pliocene marls of the Marafa Formation. The deposits of the fans on the Mtondia-I level seem to be incorporated in the superficial platform deposits. It means that the fan formation was active before the re-submergence of the Mtondia level. At present it is not an active process. This indicates the existence of a former period with greater aridity than that of today. It must have occurred after the first emergence of the Mtondia level and the humid period which led to the formation of the deep weathered, red soils.

Eolian complexes

The eolian complexes occur in areas where the original platform deposits have been reworked by wind activity. This has resulted in a new association of land forms on parts of the marine terraces. So far they have only been recognized in the central section. Two components can be distinguished (Table 7). They are briefly described below.

- The sand-drift ridges consist of irregular shaped accumulations of wind-blown sand and occur especially near alluvial fans on the marine terraces. They have probably been formed by an eolian redeposition of the alluvial sediments during or shortly after the active fan deposition or during a dry period when vegetation on the poor fan sands was absent. A NNE-SSW trend in the direction of those ridges can be observed near Tezo and Mtwapa, indicating their formation by the NNE trade winds. This airstream at present dominates the longest dry season of the year. The presence and the direction of the dune complexes thus may be interpreted as evidence of a drier climate than that of today.
- The deflation pans consist of semi circular depressions formed in the raised platforms or beaches. Their recognition as such is connected with the presence of a low rim commonly found at its southwestern edge. A clear example is found on the Majaoni level at Ziwani. The larger pans are indicated as seasonal lakes on the topographical maps. Their existence is seen as additional evidence of the occurrence of a drier period after the completion of the Mtondia levels.

The southern section

Comparable evidence for the existence of elevated shorelines related to the Mtondia and Majaoni levels is found in the southern section of the littoral zone. However distinct abandoned cliffs are less frequent, which is probably due to the dominance of unconsolidated sands and clays in the subsurface. A gentle break of slope in the land surface is visible instead and has been used to mark the boundary between the various levels. The elevations at which the transitions occur seem to be slightly lower than those in the central section. It is clear however that a more accurate topographical survey of the levels is needed to confirm this impression. Two main land types are distinguished and discussed below.

Marine terraces
The marine terraces mainly comprise platforms of raised reef-patches, minor reef-segments and platforms with a more sandy subsurface. They are found between the Gazi and Funzi Bay and on the Shimoni peninsula. Their characteristic soils and sediments are comparable with those of the central section. The sediments tend to be more clayey as along the present shore . This is especially clear in the raised reef-lagoons on the Shimoni peninsula. The abraded nature of the raised reef-flats is accentuated by an accumulation of coral debris underlying the superficial sands and clays. It evidences that the coral reef existed before the Mtondia levels came into being. The absence of coral rock underlying the surface of the Majaoni level is remarkable. The remnants of this level are only found well behind the zone in which the coral reef occurs. The more dissected nature of the coastline probably caused a further landward penetration of the sea during the formation of the Mtondia level. The transgressing sea may have completely eroded the outer parts of the marine terraces at the Majaoni levels.

Bay or lagoon plains
The bay or lagoon plains occur at the landward side of the Gazi, Funzi and Vanga bays. The landform features in the former Gazi bay are rather vague. Those in the Funzi and Vanga bays reflect the pattern of a great elevated lagoon-plain. This once stretched out from the outfall of the Umba to that of the Ramisi river. Four components cane be distinguished (Table 7). They are briefly described and discussed below.

- The former tidal-flats consist of the flat areas around the present bays, which are characterised by clayey deposits and a rather open natural vegetation. Dark greyish brown soils with an A-B-(C) horizon sequence occur on the Mtondia-II level (Michieka et al., 1978, profile 202/1-267). They are characterised by a sodic subsoil with clay illuviation and hydromorphic properties and classify as Gleyic Luvisols with a sodic phase and Gleyic Solonetz. Comparable soils are found on the Mtondia-I level (Michieka et al., 1978, profile 202/1-282). They differ mainly in having stronger prismatic structures and can best be classified as Gleyic Solonetz. The soils on the Majaoni levels have more vertic properties (Michieka et al., 1978, profile 202/1-264) and classify as Vertic Luvisols. They have all been included in the unit PA5 on the soil map of the Kwale area (Michieka, 1978, Appendix 1b).
- The former tidal-swamps exist of the extensive flat plains south west of Mrima hill. They mainly belong to the Majaoni level and consist of heavy clays and an open scrub vegetation. The soils have an A-C horizon sequence with greyish brown subsoil colours and vertic properties. They classify as Pellic Vertisols with a sodic phase (Michieka et al., 1978).

- The ancient barriers and sand-bar complexes are formed by slightly higher and elongated stretches of land surrounded by raised tidal-flats. The ridges consist mainly of sandy deposits with a dense natural shrub vegetation. The soils of the ridges on the Mtondia-II level are light grey and have an A-E-(B) horizon sequence. They are classified as Albic and Luvic Arenosols (Michieka, 1978, Appendix 1b, unit PA3, profile 202/1-268, 202/2-78, 202/2-99) and are associated with Solodic Planosols (profile 202/2-123) which occur in the shallow swales between the barriers and sand bars. On the Mtondia-I level the soils are very pale to yellowish brown. They are classified as Albic and Ferrallic Arenosols (Michieka, 1978, Appendix 1b, unit PA1). On the Majaoni level yellowish red to strong brown soils with an A-B horizon sequence occur (Michieka et al., 1978, profile 202/1-269, 202/2-112). They are classified as Ferralic Arenosols and Cambisols. This difference in soil formation shows that also in the southern section a subdivision of Coastal Plain in several levels is justified.

In conclusion, it can be stated that the southern section differs from the central part of the littoral zone by the occurrence of landforms and deposits of former lagoonal plains. Distinction of the surfaces of the Mtondia and Majaoni levels is possible as each appears to have characteristic soils. More detailed work is needed to get a better insight in the spatial variability of the soils within each land component. This will provide the information needed to sustain the general validity of the observed differences between the soils of the various land forms.

Northern section

Along the northern section of the Kenyan coast several consistent breaks of slope are present between 20 and 40 m +MSL. The land surfaces they enclose have been correlated with those of the Bofa and Majaoni levels of the Central Coast. In the Sabaki embayment their flat surfaces are narrow and occur more or less parallel to the present-day shore. They have been interpreted as marine terraces on evidence of their landforms and character of superficial deposits.
The general land surface widens however to extensive plains in the Tana embayment. The breaks of slopes are in most places accentuated by ridges classified as elongated dune ridges and raised beach-barriers because of their sediments. The knicklines in the plain surfaces around the Tana River therefore represent elevated shorelines. The occurrence of raised sand-bar complexes is also characteristic of the landscape in the northern section. The ridges have a curvilinear shape and their orientation is more or less parallel to the present shore. At the eastern periphery of the Tana embayment at least four of these complexes can be recognized. They differ from each other by slight differences in orientation and soil development, reflecting the various stages in the emergence of the area. The sand-bar

complexes have been tentatively correlated with the surfaces of the Mtondia-I, -II and Majaoni-I, -II levels respectively. The remaining parts of the terrain consist of extremely flat plains characterised by thick clayey deposits. They have been interpreted as former tidal-flats. The land surface of the middle plain-levels of the Tana embayment is considered as the floor of an elevated lagoon or bay on account of this assembly of landforms. The characteristics of the three main land units and their components are described and discussed below.

Marine terraces
The marine terraces of the Sabaki and Tana embayments are underlain by calcareous sands, clays and marls. They probably belong for the major part to the Pleistocene Kilindini complex and the Changamwe deposits. The calcareous nature of the deposits is reflected at the surface by numerous sinkholes of various size. Three characteristic components are distinguished and briefly discussed below.

- The raised platforms are formed by the flat parts of the marine terraces. They are characterised by a superficial cover of sandy clays with a basal gravel layer overlying an abraded subsurface, like in the southern section. The deposits are generally less well sorted than those of the central section. This may be connected with greater sediment supply to the shore in the northern section. Soil development is comparable with that of raised reef-lagoons of the central section.
- The raised beaches exist of thick sand accumulations which in places have the shape of low ridges (e.g. near Merikabuni and Boma Upande). The raised beaches form the continuation of those found west of Malindi and dominate the surface of the marine terraces. The sand accumulations reflect an abundant local sediment supply at the time of the formation of the Mtondia and Majaoni levels. Soil and sediment characteristics resemble those described for the central section.
- The ancient foredunes are represented by eolian sand accumulations parallel to the elevated shorelines. They are present just north of the Sabaki mouth. The two most westward ridges consist of sandy loams with a well sorted, fine sand-fraction. Their base is formed by an abrasion platform at about 30 m +MSL. Therefore they are correlated with the formation of the Majaoni levels. Too little is known to arrive at a possible differentiation between the dunes per sublevels of the Majaoni terraces. The dunes are characterised by deep red soils with an A-B horizon sequence. The large difference in texture between the A- and B-horizon points to the presence of an well developed argillic B-horizon. Therefore the soils most likely classify as Ferralic Luvisols or Acrisols. The outer ridges have been correlated with the formation of the Mtondia levels as their base is situated at around 15 m +MSL. No further details about their soils and sediments are known.

Bay or lagoon plains
The bay or lagoon plains of the Tana embayment stretch from the Ngomeni

peninsula northwards. The nature and stratigraphy of the subsurface materials are hardly known. Scattered outcrops of coral limestone occur at both the western and eastern periphery of the Tana embayment. They form the remnants of a barrier reef which once must have existed across the present Tana delta. The presence of the two arches of reef patches of Ngomeni peninsula and Mwamba Zeboma suggests that reef growth also occurred during two later periods. The presence of sand bars on top of the abraded coral reef complex again shows that in the north there is also evidence for a later re-emergence of the Pleistocene coral and lagoonal complexes. Throughout the area of the elevated bay or lagoon plain four typical land components can be recognized (Table 7).

- The ancient barrier-islands are constituted by broadened, elongated sand ridges rising above the general level of the surrounding plain. They occur in the central part of the Tana embayment. The one found between Kumbi and Ngao consists of loamy sands. The sand fraction is moderately sorted and medium grained. The soils formed in the deposits are strong brown and have an A-B-(C) horizon sequence. They are tentatively classified as Ferrallic Cambisols. On account of the elevation and soil development this barrier complex is correlated with the surface of the Mtondia-II level. A second raised barrier-island occurs between Kitangali and Kibusu. This is characterised by reddish brown soils also with an A-B-(C) horizon sequence. It is correlated with the surface of the Mtondia-II level. Between Minjila and Idsowe a third raised barrier-island is present. It is typified by red soils with an A-B-(C) horizon sequence. It is correlated with the Majaoni-II level. The remnants of a fourth complex are found west of Garsen. Its soils and sediments are unknown. It is tentatively correlated with the Majaoni-I level. The fact that the raised barrier-islands of the Mtondia and the Majaoni levels extend into the present Tana delta is noteworthy. They have straight boundaries more or less perpendicular to the direction of the ridges. This points probably to the same neo-tectonic influence that was described for the surface of the Mackenzie-I level in this area. The presence of small fault scarps is evident from both the western and the eastern periphery of the Tana embayment. This shows that tectonics played an important role in determining the position and shape of the present Tana delta. The situation of the barrier islands across the present delta shows that a possible older delta was situated 25 to 45 km further inland.
- The raised sand-bar complexes exist of low sand ridges and enclosed swales. They occur at the eastern and western peripheries of the Tana embayment and are comparable to those of the southern section. The presence of small displacements along faults is particularly clear in the eastern periphery. This is also emphasized by an extra accumulation of alluvium in the swales at the foot of the fault scarps. The correlation of the four complexes east of the Tana valley with the levels of the Mtondia and Majaoni terraces is preliminary. The complex found between Nyangoro and Maleli may also represent the Mtondia-I surface instead of the Majaoni-II. More topographical, sedimentological and pedological data are

needed in this part of the study area to confirm the boundaries given on the geomorphological map

- The former tidal-flats are formed of the extremely flat terrains behind the ancient dunes, barriers and bars. The related superficial deposits vary from sandy clay to clay. The Mtondia levels in the western periphery of the Tana embayment are characterised by grey and brown soils with an A-B-(C) horizon sequence. They have clay illuviation and are often sodic and saline. The soils are classified as mainly Gleyic Solonetz (Sombroek et al., 1982, appendix I, unit Pc5). Vertic Luvisols and Orthic Solonetz have developed on the former tidal-flats of the Majaoni level. The soils in the western periphery are mainly Planosols. This may be related to a difference in mineralogy of superficial deposits in which the soils have been formed. The deposits in the western periphery of the Tana embayment are mainly derived from non-volcanic substrata. In contrast the northeastern part received its sediments mainly from areas dominated by volcanic or sub-volcanic rocks. A comparable situation occurs in the Vanga embayment at the southern section, where the Late Cretaceous syenites of the Jombo Complex are involved.

  Wide depressions with a dominant grass vegetation occur at the foot of low scarped ridges with a NNW-SSE direction. They are associated with the same minor faulting recognised in the sandbar complexes of the lower levels. This is evident from the continuity of the low scarps from the sand-bar complexes into the former tidal-flats. The flat floored depressions are therefore classified as former sag ponds. As they appear to have been connected with the Tana alluvial plain they have been included in the fluvial areas on the geomorphological map (Appendix I).
- The ancient foredunes are constituted by elongated dune ridges on the western periphery of the Tana embayment and on the raised barrier-beaches. Four generations are distinguished and correlated with the maximum transgressions which led to the formation of the four known Mtondia and Majaoni levels. The dunes consists of well sorted, medium and fine sands. Of note is the increase in clay content from about 10% in the youngest dunes to 30 % in the oldest ones. This is probably due to an increase in the amount of decomposed feldspar minerals. There is also an increase in ferrugination resulting in characteristic soils colour. They vary from strong brown on the Mtondia-II dunes to dusky red on the dunes of the Majaoni-I level. This is a clear indication for the age difference between the various levels as other soil forming factors are here more or less the same. The dune ridges of the Majaoni levels rise to a maximum of 30 to 40 m above their surroundings. Those of the Mtondia levels are considerably lower and narrower. This is considered as an indication for a gradual decrease in environmental energy with time. This is consistent with the general decrease in sand medians of the beach deposits of the central section.

Stream valleys

The stream valleys of the northern section are comparable to those of the

Table 8 Correlation of the higher littoral levels with surfaces referred to in earlier studies

Earlier publications	present study: Tezo (I+II) (40-85 m +MSL)	Cambini-II (70-90 m +MSL)	Cambini-I (85-130 m +MSL)	Sokoke II (120-150 m +MSL)	Sokoke-I (140-175 m +MSL)
Werth (1952)	Mittelterrasse ?	Hochterrasse ?			
Caswell (1953)	<----- Foot Plateau -----> (spans Tezo to Sokoke-I)				
Caswell (1956)	<----- Foot Plateau -----> (spans Tezo to Sokoke-I)				
Thompson (1956)	<----- Foot plateau -----> (spans Tezo to Sokoke-I)				
Hori (1970)	<----- Changamwe Terrace -----> (spans Tezo to Cambini-I)			<----- Matuga Surface -----> (spans Sokoke II to Sokoke-I)	
Toya et al. (1973)	Changamwe Terrace	<----- Marafa Surface -----> (spans Cambini-II to Cambini-I)		<---< dissected erosion surface >---> (spans Sokoke II to Sokoke-I)	
Rossi (1981)	Changamwe terrace	<----- la surface d'accumulation pliocène -----> (spans Cambini-II to Sokoke-I)			
Omi (1984)	Changamwe Terrace	<----- Matuga Surface -----> (spans Cambini-II to Sokoke II)			

Table 9 Land units of the higher littoral levels

southern section: *land unit*	*land component*	central section: *land units*	*land components*	northern section: *land unit*	*land component*
marine terraces, hills & plateaus	raised platforms interfluve ridges	marine terraces, hills & plateaus	raised platforms ancient foredunes interfluve ridges	marine terraces, plains	raised platforms ancient foredunes interfluve ridges
elevated bay plains	raised platforms interfluve ridges	elevated bay plains	raised platforms interfluve ridges	elevated bay or lagoon plains	raised platform interfluve ridges former tidal-flats ancient sand-bars ancient beach-dunes
stream valleys	valley heads valley slopes valley bottoms alluvial fans	stream valleys	valley heads valley slopes valley floors alluvial fans	*stream valleys*	valley heads valley slopes valley floors alluvial fans
		eolian complexes	sand-drift dunes deflation pans		

central part. They occur especially in the western periphery of the Tana embayment where they are connected with the valley systems on the eastern edge of the Rogge Plateau. The alluvial fans in front of the valley mouths can reach a diameter of 2 to 3 km. They are better visible on aerial photographs than in the central section due to the presence of natural vegetation. No further information on their characteristic soils and sediments exist.

3.1.1.2.4 Higher littoral levels

Three consistent breaks of slope occur in the littoral zone of the Kenyan coast between approximately 50 and 175 m +MSL. They form the landward limits of what is described in the present study as the higher levels. The difference in elevation between them is relatively large compared to the breaks in the middle levels (Section 3.1.1.2.3). Three higher littoral levels, called the Tezo, Cambini and Sokoke levels, are identified in this study. Each of these is further divided into two sub-levels.

The superficial deposits related to the Cambini and Sokoke levels consist of Plio-Pleistocene sands of the Magarini Formation. They commonly overly Pliocene marls and clays of the Marafa Formation, but may also occur on Miocene marls and limestones of the Baratumu Formation or Jurassic shales of the Mtomkuu Formation. The deposits characteristic of the Tezo level are also made up of sands overlying marls and clays. Caswell (1956, Geological map of the Kilifi area) incorporated the sands in Magarini Sands. They were regarded as belonging partly to the Magarini Formation and partly to the older Pleistocene Sands during the recent remapping of the Kilifi area (Siambi, 1977, Geological map of the Mazeras area). The underlying marls and clays were mapped as deposits of the Baratumu Formation. It will be shown in the following description that these latter classifications need correction. The grain-size characteristics of the sands on the flat surfaces are comparable with those of the marine terraces of the middle and lower levels. Therefore the surfaces of these three higher levels are interpreted in this study as the treads of high raised marine terraces. The breaks in slope which mark their landward boundaries are consequently seen as elevated shorelines.

Gregory (1921, p. 222-3) considered the areas to be part of the Foot Plateau, which he believed to have been formed as a sub-aerial erosion surface. This concept was also used by Caswell (1953, 1956), Thompson (1956) and Williams (1962) while mapping the geology of the coastal area. Ojany (1966, p. 196) includes the areas of the higher littoral levels in his Coastal Belt. In more recent geomorphological studies (Hori, 1970; Toya et al., 1973), further attention is paid to the first two higher levels. The use of the same name for different terraces is characteristic of references to the land surfaces of the higher littoral levels. One of the obvious reasons for this is that the influence of tilting is easily overlooked. Because of this, mapping and correlation of the different terrace remnants on the basis of elevation is liable to error. The designation of the higher levels in previous work and the correlation with the division proposed in the present study is given in Table 8. The proposed subdivision of the higher part of the littoral zone is further described below. In the same way as for the lower and middle littoral levels, use is made of the natural division between the southern, central, and northern sections of the coast. The central section has again been taken as a reference area. A synopsis of the various land units which have been distinguished is given in Table 9.

Central section

The land surfaces related to the higher plain levels of the central littoral zone are in general strongly dissected. Consequently, the remains of the original marine plains are normally found as small isolated hills and plateaus. A remarkable exception however is formed by the undissected, flat areas of the Sokoke and Arabuko forest. This might well be related to the sandstones found in the subsurface instead of the clays, marls and shales more common elsewhere. The presence of these sandstones is known from the borehole (C1159) near the old sawmill in Sokoke Forest. The position of the remnants of the Sokoke and Cambini levels is typically confined to the main watershed areas between the present-day embayments. The surface of the Tezo level, however, is found along the whole length of the central section. The best preserved remnants occur not in the main watershed areas but around the present-day embayments as is evidenced by the wide platform surfaces on the Changamwe peninsula and in the area around the Bandari ya Wali. This points to an important period of erosion along the major drainage lines following the formation of the Sokoke and Cambini levels.
The intense dissection of the coastal plains changed shoreline of Kenya from more or less straight to deeply embayed. The main land units of the three higher levels are marine terraces, hills and plateaus, elevated bay-plains, stream valleys and eolian complexes (Table 9).

Marine terraces, hills and plateaus
The marine terraces, hills and plateaus are formed by the remnants of the original marine plains. Often, a complete disconnection with the west-ward continuation of the surfaces has taken place through later erosion. Consequently, the remnants of the Sokoke and Cambini levels in particular are found as hills and plateaus. The difference between these two land units is seen as the absence or presence of a flat summit. The flat-topped remnants have been mapped as terraces when their surface does not rise above the surroundings. The minor land units which are present include raised platforms, ancient foredunes and interfluve ridges (Table 9).

- The raised platforms consist of the flat parts of the former marine plains and are normally characterised by a sand cover of several meters thick. The superficial deposits may include sands of raised beaches, but the frequent high clay contents indicate that much of the platform deposits were laid down in more sheltered positions. The sand fractions of the deposits on the Tezo level are in general moderately well sorted fine to medium sands. Their clay content is considerably higher when they are underlain by limestones or marls, compared with other areas underlain by sandy deposits.
  The areas with limestone in the subsurface can be recognized on aerial photographs by their darker grey tone. This is mainly due to their red coloured soils with an A-B-(C)-R horizon sequence. On the soil map of the Kilifi area (Boxem et al., 1987, Appendix 1) they are included in unit P2EI1 and are classified as Ferralic Luvisols. Unfortunately they have not been distinguished from those on the raised reef-flats of the Majaoni levels. Apart from a higher CEC of the clay fraction, these latter soils also show a smaller B/A-clay ratio than those on the Tezo level. This may be an indication of the age difference between the two levels. When marls and sandy clays are present in the subsurface, the soils are yellowish red to yellowish brown and are classified as Orthic and Chromic Acrisols and Luvisols.
  Important stretches of the Tezo platforms are characterised by intensely leached soils with an A-E-(B) horizon sequence. The dominant colour is light grey to white and causes light tones in the aerial photographs. The soils are classified as Albic and Luvic Arenosols and occur in particular near the back slopes, towards the terraces and plateaus of the Cambini levels. The areas are also characterised by large swampy depressions with an irregular shape. The groundwater level at these sites is normally about 2 to 3 m below the surface during the wet season. This is in sharp contrast to the neighbouring sands of the higher levels where borehole data shows that water is only found at great depth. It seems that at present a local groundwater level is formed by concentration of superficial drainage water at the foot of the back slopes. However, the deeply leached soils are found in a wide zone of 1 to 3 km. This shows that in the geological past the influence of a high fluctuating groundwater level was more profound, pointing to the occurrence of wetter climates than those of today. The Ferralic Luvisols and Albic Arenosols on the Tezo terrace probably developed during these humid periods. The groundwater percolation at the back slopes is likely to have caused additional dissolution of the calcareous components in the subsurface. It may explain the slightly lower position of these areas. Consequently, the large depressions found near the back slopes may be classified as sinkholes.
  The deposits of the Cambini and Sokoke platforms consist in general of well sorted fine to medium sands. The sediments have a considerable clay content of up to 30 %. Stratigraphically they belong to the upper member of the Magarini Formation. Intense soil formation on the Sokoke platforms

has turned the colours of the original yellowish deposits into dusky red. From borehole data near the factory of the Sokoke Plantation (C1079) the soils on the Cambini-I level are known to be over 25 m deep. The borehole record of a drilling near the former saw mill in the Sokoke-Arabuko forest (C1159) shows that on the Sokoke-I level the soils can be as deeps as 35 m. They are characterised by an A-B-(C) horizon sequence and are classified as Rhodic Ferralsols (Boxem et al., 1987, Appendix 1) or Rhodacric Ferralsols (Michieka et al., 1978, Appendix 1a, 1b). There is no apparent difference between the soils of the Sokoke-I and Sokoke-II sublevels. This may indicate that the humid climate which led to the intense ferrugination ocurred after the submergence of the Sokoke-II level.

A greater variation in soils exists on the platforms of the Cambini levels. Profile development in the sediments of the Cambini-I is at first sight identical to that of the Sokoke levels. The inner parts of the raised platforms have the same characteristic dusky red, oxic B-horizons. However the subsoils have more yellowish red colours and signs of clay illuviation at the edges. They are probably the remnants of partly eroded soils in which renewed soil development led to the formation of argillic B-horizons. The soils are classified as Chromic and Ferralic Luvisols.

The dusky red profiles are absent on the Cambini-II level. The colours of the B-horizons are yellowish red to strong brown and soils classify as orthic Ferralsols. The presence of brown oxic B-horizons instead of the dusky red ones may indicate that the drainage conditions on the Cambini-II level were less favourable during the time in which the intense ferrugination took place. A high ground-water level, for instance, may have been the reason, but confirmatory evidence for this explanation has not been found.

- The ancient foredunes consist of elongated accumulations of eolian sand in a direction parallel to the present shore. No clear examples have been found on the Tezo level. Several low ridges exist on the Cambini platforms (e.g. near the Sokoke plantation). However, whether they are real foredune ridges or consist of secondary sand-drift ridges is not certain. A high dune ridge rising approximately 30 m above the plain level is found at many places on the seaward edge of the Cambini-I platforms. It probably represents a true foredune. An even higher dune ridge occurs on the Sokoke-I level near Sokoke school, where it reaches a maximum altitude of 228 m +MSL. This represents an elevation of about 70 m above the raised Sokoke surface. Caswell (1956, p. 28) bases the eolian nature of the upper part of the Magarini sands on the occurrence of dune-bedding in the sediments exposed in the large alcove at this site. The presence of at least four buried soil profiles of approximately 5 to 10 m thick indicates that the dune formation was not a single event. It might point to even more periods of coastal emergence than can be reconstructed from the presence of raised platforms. The dunes consist of well to very well sorted fine sands. They can be distinguished in the field from the beach sands by their significantly lower clay content.

Soil formation in the dunes is comparable to that on the platforms. However, the high sand content precludes classification as Ferralsols. The soils consequently classify as Ferralic Arenosols.

- The interfluve ridges are formed of the lowered platform remnants occurring between the stream valleys of the strongly dissected areas. Due to continued erosion they have lost most of their original sediment cover. As a consequence typical soils appear to absent.

Elevated bay plains

The elevated bay plains of the higher levels in the central littoral zone are found around the present-day embayments and behind the elevated hills and plateaus of the Sokoke levels. Raised platforms and interfluve ridges occur as minor land units.

- The raised platforms consist of the flat interfluve areas covered with sandy deposits. The grain-size distribution of the sand fraction is comparable with that of the sands on the marine terraces of the same level. However, the clay content of the superficial deposits is in general higher.

  The Changamwe peninsula west of Mombasa is a clear example. At the landward side the surface of this raised platform remnant reaches an elevation of more than 80 m +MSL and rises above the elevation of the platforms of the Cambini level at their seaward margin. It is concluded that the Tezo level has undergone a seaward tilt after its formation. The topography of the contact between the sands is smooth and marked by a basal conglomerate with numerous quartz pebbles and stone age implements. The materials underlying the superficial sands consist in most places of clays and sands of the lower Magarini Formation overlying shales of the Mtomkuu Formation. The contact between the shales and the overlying deposits is irregular and in places the superficial deposits of the Tezo level overly the shales directly. This indicates that the area had a dissected topography before the sands and clays of the Magarini Formation were deposited. Even more important is the fact that in the deposits of the lower Magarini Formation old channels or valleys can be found which have been filled in with heavy blue clays overlain by layered fine sands, silts and marls. As the former channels are found almost at the present sea level, it may be assumed that the phase of erosion took place at a lower sea level than that of today. The channel fills in their turn have been abraded and are overlain by the superficial deposits of the Tezo level. The sequence can be seen in exposures near the Sinawe bridge of the E 949 and in the quarry of the tile factory near Miritini along the A109 (Fig. 13). A sample (198/3-265B) of heavy clay from the filled-in channels shows that it contains nannoplankton belonging to the *Pseudoemiliana lacunosa* Zone, indicating a marine flora with a Pleistocene age of 0.44-0.92 my (Verbeek, 1980, Nannoplanktonrapport 32). Therefore the clays and associated marls underlying the Tezo level have to be distinguished from those of the Pliocene Marafa Formation and of the Miocene Baratumu beds. This also justifies the differentiation between the superficial sands of

Fig. 13 Exposure of the Changamwe deposits underlying the marine terrace of the Tezo level near Miritini

the Tezo level and those of the Cambini and Sokoke level which were previously included in the sands of Plio-Pleistocene Magarini Formation. The dating of the clays provides a lower age limit for the formation of the Tezo level. The artefacts found in the basal conglomerates above the clays could even provide a closer dating if they were properly classified and correlated with dated industries elsewhere. Current archeological research on a nearby site at Mtongwe (Omi, 1984, 1986) has revealed that the implements belong to Middle Stone Age industries. Comparable artefacts have been found in the yellow sands (= Watamu Calcarenites) underlying the coral limestones (= Mtwapa Limestones) in the Nyali quarry (Omi, 1984, p. 141). This leads to the following preliminary conclusions. Firstly the age of the Tezo level is older than that of the Mtwapa Limestones. Secondly the Watamu calcarenites are probably the correlative sediments of the younger part of the Tezo level.

A platform remnant of the Cambini level is found at Lutsangani along the C959. The sand-covered summit at this site is situated on the watershed between the drainage areas of two small rivers flowing to the Bandari ya Wali and Mtwapa Creek, respectively. Reaching an elevation of approximately 125 m, it can be correlated with the Cambini level on account of its deposits and elevation.

The limestone plateaus occurring between the Mombasa-Nairobi road and the Sabaki river correlate with the raised platform remnants of the Sokoke level. The connection can be seen in the area between the Sokoke forest and Mangea Hill. Here the abraded surface on Jurassic limestones of the Kambe Formation, merge without any topographic change with the platform of the Sokoke level. Evidence for the classification of the surface of the limestone plateaus as abrasion platforms is found near the gorge of the Nzovuni river, where the limestones beds dip more than 25 degrees to the east. The surface of the abrasion platform, however, is almost horizontal and shows only a low meso relief caused by large sinkholes. Outcrops related to the hard and massive limestone beds seen in the valley gorge are not found on the platform surface. This is in contrast to the areas which rise above the Sokoke level, where impressive tower-karst formations occur (Ojany, 1984, p. 122). The clay content of the platform deposits on the limestones can rise up to 45 %. Consequently, the difference between the deposits of the littoral zone and those of the paralic zone becomes uncertain. The lithological boundary between the Jurassic limestones and the eastward lying Jurassic shales is easily to recognize. Therefore this transition has been taken as the boundary between the littoral and the paralic zones.

An old sea cliff at the eastern front-slope of limestone plateau is present near Jaribuni. It has been reported by Caswell (1956, p. 19) and is characterised by oversteepened rock exposures and cliff-foot caves. The features occur at about 80 to 85 m and probably mark the raised shoreline of the Tezo level.

- The interfluve ridges are formed of the eroded watershed areas between the stream valleys in the dissected country west of the marine terraces. The position of the elevated shorelines of the Tezo and Cambini levels can be recognized by the presence of knickpoints in the longitudinal profile of the interfluve ridges. When developed on Jurassic shales the erosional nature of the knicklines is evident since the lithology of the subsurface is uniform. The identification of the shorelines becomes more difficult in those areas where the interfluve ridges are made up of Triassic sandstones of the Mazeras Formation. The sandstone deposits and intercalated clay and shale beds give rise to lithologically determined benches and knickpoints. This is especially true for the area south west of the Shimba Hills. Nevertheless, the summit level of the interfluve ridges in this area occurs at a consistent height between 140 and 170 m and cuts discordantly the northeast ward dipping sandstones. The abraded nature can be observed in many road cuts and is evidenced by a basal conglomerate consisting mainly of quartz pebbles. The transition to the paralic zone in the west is again difficult to define. However, the areas of the Sokoke level underlain by deposits of the Magarini Formation are relatively easy to differentiate from those underlain by the sandstones of the Mazeras Formation. Therefore, this transition has been taken as the westward boundary of the littoral zone. Consequently, for practical reasons the whole of this dissected sandstone platform east of the Shimba Hill is assigned to the paralic zone. It may well be that the steep scarp of the Shimba Hills is in fact an old sea cliff, but clear evidence for the occurrence of littoral deposits at its base have not yet been found.

Stream valleys

The stream valleys of the higher littoral levels are generally larger than those on the middle levels. The valleys on the Tezo level are seldom deeper than 10 to 20 m and normally less than 50 m wide, whereas those on the marine terraces of the Cambini and Sokoke levels are more pronounced. Depths and widths of 100 and 500 m respectively are common. The difference in size suggests the presence of younger and older valley generations.

The valley morphology in the strongly dissected areas of the elevated bay plains is complex. Often two-cycle valleys are found which also indicates that their formation took place during several periods of erosion and deposition. Three characteristic valley components are distinguished (Table 9). A fourth minor land unit is formed by the alluvial fans in front of the valley mouths.

- The valley heads are formed by the upper parts of the valleys in the marine terraces and elevated bay or lagoon plains. Those on the Tezo level are vague and often coincide with one of the depressions found near the back slopes on the raised platforms of the marine terraces. The valley heads of the Cambini and Sokoke levels commonly consist of steep alcoves formed in unconsolidated sands and clays of the Magarini and Marafa Formations.
- The valley slopes are formed by the sloping terrains connecting the raised platforms or the summits of the interfluve ridges with stream beds or valley floors. Those cut into the terraces of the Sokoke level are characterised by a soil formation which is identical to that on the related raised platforms. The valley slopes of the Cambini levels have soils which differ from those on terrace tread. This indicates that the soil formation which resulted in the intense ferrugination, took place after the formation of the Sokoke levels and before or during the final dissection of the Cambini terraces. The slopes of the valleys eroded in the dissected bay-plain areas are commonly characterised by shallow to moderately deep soils.

  When underlain by the Jurassic shales of the Mtomkuu Formation, they have an A-(B)-C-R horizon sequence. In general, they are classified as Vertic Cambisols and Phaeozems with Chromic Vertisols occurring at the upper and lower parts of the valley slopes.
- The valley floors are formed by the flat parts between the valley slopes and commonly consist of recent and subrecent alluvial deposits. The grain size of the deposits is strongly dependant on the character of the adjacent outcropping subsurface rocks. The soils have often hydromorphic

properties and are classified as Gleyic Cambisols and Luvisols with in places sodic phases.

- The alluvial fans are formed by wide accumulations of alluvial materials spread at the mouth of the stream valleys. In contrast with those on the middle levels these fans are made up almost entirely of sand. The grain size of the sands is slightly coarser than that of the surrounding beach sands. This is probably caused by admixture of the underling poorly sorted sands of the lower Magarini Formation.
  Strong bleaching at the foot of the alluvial fans has occurred in some areas (e.g. north of Sokoke stores). Albic, Luvic and Cambic Arenosols have developed at these sites. The soils are included in unit UE1m2 on the soil map of the Kilifi area (Boxem et al., 1987, Appendix 1). Their formation may have been contemporaneous with that of the surrounding Ferralsols which may be considered as typical soils of the humid tropics (Buringh, 1979, p. 38). The formation of albic horizons on the other hand point to fluctuating groundwater conditions which may be more related to a savannah climate with marked wet and dry seasons.

Eolian complexes

The eolian complexes are known to occur on the Tezo level south of the Bandari ya Wali embayment and southwest of Port Tudor on the Changamwe peninsula. Buried soil profiles indicate the original terrace level and show that the formation of the eolian landforms is of a later age than that of the Tezo level itself. In the same way as on the middle levels, the position of the eolian complexes indicates that eolian redistribution of materials is especially connected with the NNE trade winds. It is yet unclear whether this involved a redeposition of fresh alluvial materials or a local blow-out of degenerated soils. A connection with large alluvial fans seems to be absent. Occurring south of the large present-day embayments, the position of the complexes points to a relationship with the formation of these bays. On the Cambini and Sokoke levels they have not yet been identified. Two minor land units can be distinguished and are indicated in this study as sand-drift dunes and deflation pans.

- The sand-drift dunes are formed by low irregular hills and ridges consisting of very well sorted, fine sands. South of the Bandary ya Wali embayment yellowish brown soils with an A-B-2B-(2C) horizon-sequence have developed. The soils are mainly classified as Orthic Luvisols.
- The deflation pans consist of the cup or saucer-shaped depressions formed by wind erosion on the raised platforms. They are commonly characterised by hydromorphic soils developed in the subsurface marls or clays. Well developed blowouts are found near the Arabuko dispensary and at Mwakola.

Southern section

Remnants of the three higher littoral levels in the southern section of the coast have a configuration similar to that of the same levels in the central section. An exception is made by the remnants of the Cambini and Sokoke levels between the Mwena and Ramisi River, which mainly occur as rounded summits of hills and interfluve ridges. This reflects the stronger dissection of the landscape in this part of the study area. South of the Mwena river the Sokoke level is absent and the highest land surface correlates with the Cambini level. A well defined coastal plateau did not develop and the flat littoral plain surface merges without clear transition into the plains of the paralic zone. On the geomorphological map the plains of this littoral surface have been included in the Coastal Plains and indicated with the name Mahuruni level.

As in the central section, the landward termination of the deposits of the Magarini formation forms the western boundary of the littoral plains. The characteristics of both the soils and the superficial sediments are comparable to those of the central coast. The major land units which have been distinguished in the southern section are marine terraces, hills and plateaus, elevated bay plains and stream valleys.

Marine terraces, hills and plateaus
The marine terraces, hills and plateaus occur north of the Ramisi river. They are a continuation of the marine plain remnants found in the central section. The main land components are raised platforms and interfluve ridges. The Buda (Mafisini) Forest is situated on a raised platform which correlates with the Cambini-II level. The rounded ridges of the westward Kisiweni area are interpreted as interfluve ridges. Their form is similar to the dune ridges in the central section. However, the high clay content of their deposits makes a classification as eroded remnants of the Sokoke and Cambini levels more obvious. The soil development on the raised platforms is also comparable with that on the higher marine terraces of the central section.

Elevated bay plains
The elevated bay plains are formed by the raised platforms and interfluve ridges southwest of the Ramisi River. Here the typically deep, dusky red Ferralsols of the Sokoke and Cambini-I levels are replaced by brown and yellow soils. This may point to less well-drained conditions under which the soils were formed. Furthermore, there is a sudden widening of the littoral zone which also indicates the presence of an old embayment at these higher levels. Between Kikoneni and Kigomberu examples of lowered interfluve ridges are found. The advanced erosion hampers the recognition of the different levels in this part of southeast Kenya. The area of the Marenji Forest is considered as to be a residual hill of the former Sokoke and Cambini marine plains. However, more fieldwork is needed confirm this interpretation. It is not known how far the lithological structure of its subsurface may be responsible for the flat summit and shoulder levels. The platform between Bwaga Macho and Perani is considered to be representative of the Tezo level.

It can be identified by its soils and sediments which are comparable with those of the embayments in the central section. The flat terrain west of Mahuruni is an example of a raised platform of the Cambini level, which because of its elevation and soils, is correlated with the Cambini-II sublevel.

Stream valleys
The stream valleys occupy an important part of the landscape in the southern section. There is a difference in both size and shape between the valleys formed in the Sokoke and Cambini levels and those of the Tezo level. This may indicate that the erosion history of the landscape in the south was not essentially different from that in the central section.

Northern section

Several summit levels can be recognized in the dissected country of the northern sector of the littoral zone. They occur at elevations comparable with those of the higher levels of the central section. A relationship between the deposits of the upper member of the Magarini Formation and the presence of the Sokoke and Cambini levels is found in only a few places just north of the Sabaki River. On the eastern edge of the Rogge Plateau unconsolidated sediments occur which may correspond with the deposits of the Lower Magarini Formation. However as the beach and dune sands of the upper Magarini Formation seem to be missing here, the area has been provisionally excluded from the littoral zone. The Sokoke and Cambini levels are definitely absent north of the Rogge Plateau. Whether this is due to subaerial erosion or tectonic subsidence is uncertain. A tectonic factor is likely to have played a role, considering the evidence of faulting on the middle levels and the whole structure of the Tana basin. In contrast remnants of the Tezo level are found throughout the northern section.
The land units which have been distinguished (Table 9) are comparable with those of the southern section. They are briefly discussed below.

Marine terraces, hills and plateaus
The marine terraces, hills and plateaus occur between the Sabaki River and the northern end of the Rogge Plateau. The terraces of the Tezo level are most widespread. Those in front of Magarini hill are comparable with terraces of the central section. Further north they are narrow and seem to have been formed mainly in old alluvial fan deposits. The remnants of the Sokoke and Cambini terraces have been preserved near Magarini and Shauri Moyo, where they are recognized as narrow raised platforms. The surfaces have been tilted and are locally overlain by dune ridges.

Elevated bay plains
The elevated bay plains are found on the peripheries of both the Sabaki and Tana embayment. Their surface is correlated mainly with the Tezo level. The

bay plains along the Sabaki can be recognized by their sediments and the characteristic basal conglomerate with Middle Stone Age implements. Due to the impervious character of the underlying deposits of the Baratumu Formation the terrain is strongly dissected. The raised platforms are only found as small remnants associated with rounded interfluve ridges. On the northeastern periphery of the Tana embayment the presence of a littoral zone at the Tezo level is marked by sand bars and low dune ridges. Here the terrain is generally undissected. Elongated depressions separated by low ridges stretch out in a southeast to northwest direction. They form the southern continuation of the ridges and depressions described by Muchena (1987, p. 19). In the study area the depressions are filled in with alluvium and strongly resemble those found on the middle levels in this part of the study area. Consequently, a similar tectonic origin is suggested. As in the south, the platform of the littoral plain merges with that of the paralic plain without a marked topographical transition.

Stream valleys
The stream valleys of the northern section are comparable with those of the central and southern sections. Their differing configurations on the various levels reflect the influence of age and subsurface materials.

3.1.1.3 Origin and development

The morphological structure of the littoral zone provides important information on the origin and later development of southeast Kenya. As in many other coastal areas of the world, the association of landforms reflects changes in climate and sea level. A reconstruction of its history is in fact an attempt to translate this natural record into a sequence of events and to correlate it with information known from other areas. This inevitably involves simplification and assumptions since there is a lack of sufficiently consistent and reliable datings. Thus correlation with other areas is often tentative.

In the next section a floating chronology is presented in which the sequence of events in the littoral zone fit. The scarce and sometimes conflicting radiometric datings have been used for provisional correlations with other chronostratigraphic frameworks. This involved in the first place the data on paleo-sea levels and coral reefs in the South Pacific (Bloom et al., 1974; Aharon & Chappell, 1986). For a correlation with the paleobioclimatic history of NW Europe, the most recent stratigraphic and climatic subdivisions of the Quaternary in The Netherlands (Zagwijn, 1985) has been used. Finally also the stratigraphic framework of polarity and oxygen isotope subdivisions based on data from deep sea cores of the Northern Hemisphere (Shackleton & Opdyke, 1973, 1976; Van Donk, 1976) has been taken into accounted. The results of the provisional correlations can be found in

Table 10 Subdivision of the Nyika period in the littoral zone.

period	surface	littoral level	sea level	coastal events	morphological record	lithostratigraphical record
Late Nyika	lower	Bofa	high	emergence	dunes, cliffs	Recent dune deposits
	middle	Uhuru-II	high	emergence submergence	beaches, dunes	Recent beach and dune deposits Recent tidal-flat deposits
		Uhuru-I	high	emergence submergence	beaches, dunes	Recent beach and dune deposits Recent tidal-flat deposits
	upper	Mackenzie-II	high low	emergence submergence dissection	beaches, dunes marine platform stream valleys	Younger pleistocene sands
		Mackenzie-I	high	emergence submergence	beaches, dunes marine platform	Younger Pleistocene sands
Middle Nyika	lower	Mtondia-II	high	emergence submergence	beaches, dunes marine platform	Younger Pleistocene sands Tiwi sandstones ?
		Mtondia-I	high low	emergence submergence dissection	beaches, dunes marine platform stream valleys	Older Pleistocene sands Tiwi calcarenites ?
	upper	Majaoni-II	high	emergence submergence	beaches, dunes marine platform	Older Pleistocene sands Mtwapa limestones ?
		Majaoni-I	high low	emergence submergence dissection	beaches, dunes marine platform stream valleys	Older Pleistocene sands Nyali sands ?
Early Nyika	lower	Tezo-II	high	emergence submergence	beaches marine platform	Older Pleistocene sands Watamu calcarenites, Changamwe deposits
		Tezo-I	high low	emergence submergence dissection	marine platform stream valleys	Shimoni limestones, Changamwe deposits
	middle	Cambini-II	high	emergence submergence	beaches dunes marine platform	Upper Magarini Formation Msambweni limestones ?, Changamwe deposits
		Cambini-I	high low	emergence submergence dissection	beaches dunes marine platform stream valleys	Upper Magarini Formation Changamwe deposits
	upper	Sokoke-II	high	emergence submergence	beaches, dunes marine platform	Upper Magarini Formation ?
		Sokoke-I	high low	emergence submergence dissection	beaches marine platform stream valleys	Upper Magarini Formation Lower Magarini Formation ?

Section 3.1.1.3.2. The effects of tectonic and eustatic changes on the development of the littoral zone are interpreted in Section 3.1.1.3.3.

3.1.1.3.1 Sequence of events

The interval of time during which the repetitious environmental changes in the coastland of southeast Kenya took place is provisionally called the Nyika period. The lower limit of this period is marked by the destruction of the End-Tertiary surface, marked by the dissected ferricrete layer on top of the Marafa Formation. For practical reasons an early, middle and late series of events has been distinguished conforming to the formation of the higher, middle and lower littoral levels. A further subdivision is made to distinguish sedimentary surfaces. A synopsis of the subdivisions and the main events is given in Table 10.

Early Nyika period
All events leading to the formation of the higher littoral levels are assigned to the early phase of the Nyika period. This time interval comprises three episodes (older, middle and younger) during which the Sokoke, Cambini and Tezo levels were formed. These levels are considered to be the littoral representatives of the upper, middle and lower Early Nyika Surfaces respectively.

- The older Early Nyika episode starts with a phase of strong dissection of the End-Tertiary surface, represented by the ferricrete horizon in Pliocene deposits of the Marafa Formation. Whether this erosion was initiated by tectonic movement or by climatologic change and lowering of sea level is as yet uncertain. However a change from a wetter to a drier climate must have occurred since a comparable ferricrete has never been formed at the coast since that time. The deep channels cut into the deposits of the Marafa Formation indicate a lowering of the base level of erosion. In the northern section of the coast, the depth of the channels amounts about 50 m, while in the central section depths of 80 m below the remnants of the End Tertiary surface are known to occur. From this it may be deducted that tectonic movement was also involved. After the period of deep incision the sea level rose again. The wide valleys in the End-Tertiary surface were filled in with gravels, sands and clays of the Lower Magarini Formation. The sedimentation continued until the ferricreted surface in the northern section of the littoral zone was completely buried. A thickness of over 30 m is seen in exposures near Gaji Hill. In the central and southern sections of the coast remnants of the ferricreted surface are found above the deposits of the Lower Magarini Formation. This indicates that during this phase considerable down-faulting of the coast took place.
  No details are known about the stratigraphy of the Lower Magarini Formation and it is uncertain whether accumulation took place during a

single transgression or if a series of higher and lower sea levels was involved. However, the presence of various horizontal beds in between the predominantly fluvial sediments does suggest that the latter was probably the case. The abrupt transition towards sands of the Upper Magarini Formation represents a stratigraphical break and correlates with the basal surface of the Sokoke levels. The presence of two sub-levels indicates that the upper Magarini Sands was deposited or redeposited in at least two different stages. The dune ridge found at Sokoke beacon is part of a foredune ridge which must have been formed during the second stage. The buried soil profiles in this dune ridge shows that still a further subdivision of the events of this period is possible.
The absence of topographical barriers toward the interior indicates that the Sokoke platforms probably belonged to some kind of coastal barrier islands. A vast paralic zone, which apparently formed part of the Lamu Basin stretched out behind them. In Section 3.1.2.2.3 the details of these paralic areas are further described and discussed.

- The middle Early Nyika episode is associated with the formation of the Cambini levels and began with a phase of strong erosion. This is clear from the isolated position of remnants of the Sokoke platforms surrounded by those of the Cambini level and from the deep channels in the lower Magarini deposits. The bottoms of these channels lie as deep as 100 m below the surface of the Sokoke-II platform, which shows that a considerable lowering of the base level of erosion must have taken place. Both uplift and sea-level lowering are believed to have been involved. The channels have been filled in with the Changamwe deposits of which the lower parts are provisionally dated by fossil evidence as 0.44 to 0.92 my BP. Although the in filling took place in at least two stages, more stratigraphic details are needed to allow a correlation with the formation of the two raised platforms of the Cambini levels. The transgressions which led to the cutting of the Cambini platforms caused a redistribution of a part of the deposits of the Magarini Formation and coincided with the formation of foredune ridges. The coral limestones underlying the platforms of the Cambini surfaces (Omi, 1984, p. 10) indicate that reef deposits were accumulating during the maximum transgressions of the Cambini levels.
A period with a tropical humid climate followed the emergence of the Cambini levels and resulted in the formation of the 10 to 30 m deep, dusky red Ferralsols. The presence of quartz implements in the basal conglomerates of both Cambini sub-levels shows that hominids were living in the coastal area of that time.
- The younger Early Nyika episode is related to the formation of the Tezo level and started with a period of intense erosion. Large areas of the Cambini terrace were completely removed or dissected by deep valleys. This was probably induced by a major lowering of the sea level and coincided with a considerable tectonic movement which resulted in a down-faulting of the eastern half of the coastal plains. Data from available borehole logs suggests that the throw amounted about 70 m in the central section. In a

later stage the sea level rose again and another barrier reef developed. Only its lagoonal and back-reef facies have been preserved under the platform deposits of the Tezo level. The first are the flat bedded Changamwe Beds and Mtongwe Silt beds. The latter is thought to correspond with the Mtongwe Limestone beds and the Shimoni Limestone.
The widespread occurrence of Middle Stone Age implements in the basal conglomerates of the Tezo platform deposits shows that after a first period of emergence the surface was inhabited by a probably dense population of hominids. Before the land surface submerged again climatic conditions became dry. This is evidenced by the pronounced desert varnish coatings on artefacts and other rock fragments. The final transgression is provisionally correlated with the deposition of the Watamu calcarenites in the Pleistocene reef complex. The climatic conditions during the final submergence of the Tezo platform appear to have been savannah-like, but probably wetter than today. This is evidenced by deep, red, ferric Acrisols and strongly leached albic Arenosols found on the present Tezo terraces.

Middle Nyika period

The events associated with formation of the Majaoni and Mtondia levels are assigned to the middle phase of the Nyika period. This time interval comprises an older and younger episode, during which the Majaoni and Mtondia levels respectively were formed at the coast. These levels are considered as the littoral representatives of the lower and upper Early Nyika Surfaces, respectively.

- The older Middle Nyika episode began with a period of extensive erosion which resulted in the formation of deep and wide valleys. The present embayments near Kilifi and Mombasa are considered to be the drowned valleys initially formed during this time. The erosion appears to have been accompanied by the formation of large sand-drift complexes. This indicates that, as during the younger Early Nyika episode, a period of erosion and lowering of the sea level coincided with arid or semi-arid conditions. The corresponding relative sea-level lowering is evidenced by the depth of the bays and must have amounted 80 to 100 m. Major faulting took place during this phase of dissection which resulted in displacement of the central littoral zone of about 100 to 150 m relative to the level of the paralic zone.

  Fresh corals started to grow on the remnants of the old reef body during the transgression which followed. The related reef deposits are most probably the Mtwapa Limestones. The sedimentary break is marked by deep solution pits filled with red sands and sandstone. The reef growth led to the partial or complete closure of the embayments along the coast. Yellow sands, clays and marls accumulated in a landward lagoon. These now constitute the deposits of the Kilindini Complex.

  The subsequent emergence of the Majaoni level took place in at least two stages. These are represented by the two raised platforms of the Majaoni level. Whether the two stages were separated by a phase of erosion is unknown. The climate is likely to have been wetter than that of today, but with a comparable bimodal rainfall distribution. This is evidenced by the red and reddish yellow Luvisols on the raised reef-platforms of the Majaoni levels.

- The younger Middle Nyika episode is associated with the formation of the Mtondia levels. An initial phase of erosion and lowering of sea level led to the re-opening of the closed river mouths. This again appears to have coincided with dry climatic conditions. Large alluvial fans with sand-drift dunes at their edges were formed on the Majaoni platforms. A tectonic movement along the entire coast led to the down-throw of the outer-reef formed during the older Middle Nyika episode. This explains why the deposits of the Mtwapa Limestones occur mainly as a back-reef facies. During the following transgression coral growth probably continued in the central section and formed relatively thin veneers of deposits known as the Tiwi sandstone and calcarenites. The extensive occurrence of clastic deposits in the northern and southern sections of the coast shows that here reef growth was absent or greatly slowed down. Large parts of the Majaoni platform became re-submerged during this transgression. The subsequent emergence took place in at least two stages. It left behind a series of foredunes, raised beaches and barrier beaches. Soil formation in the sandy deposits led to the development of Ferrallic Cambisols.

Late Nyika period

All events leading to the formation of the lower levels in the littoral zone are assigned to the late phase of the Nyika period. This time interval comprises three episodes (older, middle and younger), during which the Mackenzie, Uhuru and Bofa levels were formed at the coast. These levels are considered as the littoral representatives of the upper, middle and lower Late Nyika Surfaces respectively.

- The older Late Nyika episode is associated with the formation of the Mackenzie levels. Whether it started with a period of erosion is uncertain. The initiation of the Mackenzie-I level was probably due to a sea level oscillation comparable with the one which formed the Mtondia-II level. Minor tectonic activity led to the formation of low fault scarps crossing the sand bars on the Mackenzie-I level. The crustal movement resulted in the down throw of the shore in front of the Tana River. Whether this involved deep-seated tectonics or a kind a sedimentary induced deformation in the form of growth-faults is unknown.
  A down-cutting of valleys near the coast took place before the formation of the Mackenzie-II level. This is evidenced by the valleys in the south and north. The platforms of the Mackenzie-II level were formed during the transgression which followed. In the northern section this led to the initiation of barrier islands in front of the Tana river. Low foredune ridges and narrow raised beaches were formed in the central section. Their deposits are commonly included in the Pleistocene succession. A complex tidal-flat and mangrove coast developed in the southern section. The shoreline took in general the form the form it stills has today.

Table 11 14C datings of deposits in the littoral zone

Sample number	Sampled material	14C Age (ky BP)	Location	Elevation (m +MSL)	Littoral level	Situation of sample site
St-6343	mollusc (f1)	0.640 (+ 0.090)	Likoni	11.6	Mtondia-II	top of platform deposits
St-6344	mollusc (f2)	0.685 (∓ 0.090)	Likoni	11.6	Mtondia-II	top of platform deposits
St-6342	mollusc (f3)	0.710 (∓ 0.100)	Likoni	11.6	Mtondia-II	top of platform deposits
St-6347	mollusc (f1)	0.550 (∓ 0.100)	Twiga	+ 8	Mackenzie-I	top of platform deposits
St-6348	mollusc (f3)	0.670 (∓ 0.090)	Twiga	∓ 8	Mackenzie-I	top of platform deposits
St-7894	mollusc (i.f)	0.81 (∓ 0.090)	Kikambala	4.15	Uhuru-II	crest of beach ridge
St-7893	mollusc (o.f)	1.00 (∓ 0.135)	Kikambala	4.15	Uhuru-II	crest of beach ridge
St-7891	mollusc	1.745 (∓ 0.130)	Watamu	1.6	Uhuru-II	ancient lagoon-plain
St-6346	mollusc (f1)	2.030 (∓ 0.100)	Shelly Beach	7.4	Uhuru-I	0.5 m in beach ridge
St-6345	mollusc (f2)	2.225 (∓ 0.090)	Shelly Beach	7.4	Uhuru-I	0.5 m in beach ridge
Gak-4050	mollusks	2.25 (∓ 0.105)	Mida Creek	0.4 ?	Uhuru-II	ancient lagoon-plain
Gak-4060	mollusks	2.39 (∓ 0.100)	Mida Creek	0.3 ?	Uhuru-II	ancient lagoon-plain
Gak-4057	beachrock	2.64 (∓ 0.105)	Lamu Island	0.9 ?	Uhuru-II ?	raised platform surface
Gak-2996	beachrock	2.82 (∓ 0.120)	Nyali Beach	1.0	Uhuru-II	raised platform surface
Gak-4056	beachrock	5.25 (∓ 0.130)	Ngomeni	0.2 ?	Uhuru-I	raised platform surface
Gak-2971	coral head	21.6 (∓ 2.3 - 0.7)	Tiwi Beach	7.5	Mackenzie-I	raised platform surface
Gak-2972	coral head	25.4 (+ 1.5 - 1.4)	Nyali Quarry	15.0	Mtondia-II	raised platform surface
Gak-4061	beachrock (?)	25.6 (+ 1.1)	Malindi	4.5 ?	Mackenzie-II	raised platform surface
Gak-2970	coral head	26.5 (∓ 1.3 - 1.5)	Shelly Beach	4.5	Mackenzie-II	raised platform surface
Gak-4062	coral head	27.49 (+ 1.3)	Malindi	5.0 ?	Mackenzie-II	raised platform surface
GrN-9716	coral head	31.25 (∓ 0.36)	Bofa	14.5	Mtondia-II	raised platform surface
GrN-9718	limestone	33.10 (∓ 0.55)	Seahorse Hotel	+ 5	Tezo	abandoned cliff
GrN-9717	coral head	40.30 (∓ 1.5 - 1.3)	Kilifi	25.5	Majaoni-II	raised platform surface
GaK 4058	coral head	>33.2	Malindi	4.3 ?	Mackenzie-II	raised platform surface

remarks:
GrN numbers determined at Isotope Physics Laboratory, State University of Groningen; GaK numbers determined at Gakushuin University, Japan (Hori, 1970; Toya et al., 1973); Ts numbers determined at Laboratory for isotope Geology, Stockholm (Åse, 1978, 1981). (o.f, i.f) stands for outer and inner fraction of the same shells respectively (f1, f2, f3) meaning not explained in original paper, but stands probably for inner, middle and outer fraction respectively).

- The middle Late Nyika episode is associated with the events leading to the formation of the Uhuru levels. The existence of two sub-levels show that the sea level has slightly fluctuated. The climate during this episode was probably comparable with that of today. One exception occurred during the interval when the beach-dunes of the Uhuru-I level were blown into parabolic dunes. The precipitation at that time must have been lower than that of today as the dunes are now vegetated. The Recent beach and dune deposits are shown to be related to this episode.
- The younger Late Nyika episode extends to present-day times. Its events are related to the development of the present-day shore. Erosion is a dominant process along most of the shore-line and points to an active rise of the relative sea level.

3.1.1.3.2 Chronological correlation

Radiometric dating of the limestones underlying the marine terraces is one of the methods for establishing fixed points in the floating sequence of events in southeast Kenya. Using these points a correlation can be made with existing stratigraphic frameworks.
Several 14C ages of coral and beachrock samples have been published in the geomorphological studies of Hori (1970, p. 38), Toya et al. (1973, p. 101) and Åse (1978, p. 218; 1981, p.308). In addition, three new 14C datings were carried out during this study. Besides these 14C data only one 230Th/234U age has been reported (Battistini, 1977, p.78). In the following parts of this section these datings are reviewed and provisional correlations made.

Correlation options based on the 14C data

The previously reported 14C data are listed in Table 11 together with the three new 14C datings carried out for the present study. They can easily be divided in two categories of younger and older datings.

Younger 14C datings

The younger datings range from 0.64 to 5.25 ky BP. The samples have been derived from materials constituting the landforms of the Uhuru level. They confirm the Holocene age provisionally ascribed to the deposits by Thompson (1956, p. 36-37) and Williams (1962, p. 48-49). The possible effect of contamination has been checked before using the datings for more detailed correlations.
In Table 12 the deviation from the determined mean dates is given at various levels of contamination. It can be seen that at a 1% contamination level the extra errors stay within the standard deviation of the apparent age. At a 10 % contamination level only the datings of 2 ky and more are influenced by errors which are less than 10% of the apparent age. The error at a 30%

Table 12 Contamination effects on the younger 14C datings (based on calibration curves given by Olsson, 1974; in: Bowen, 1978, p. 121).

Sample	Apparent age (ky BP)	Extra error (ky) at various contamination levels					
		old carbon			young carbon		
		1%	10%	30%	1%	10%	30%
St-6343	0.640 (± 0.090)	0.002	0.003	0.10	0.007	0.04	0.17
St-6344	0.685 (± 0.090)	0.002	0.003	0.11	0.007	0.05	0.18
St-6342	0.710 (± 0.100)	0.003	0.004	0.12	0.008	0.06	0.19
St-6347	0.550 (± 0.100)	0.001	0.002	0.08	0.006	0.04	0.14
St-6348	0.670 (± 0.090)	0.002	0.003	0.11	0.007	0.05	0.18
St-7893	1.00 (± 0.135)	0.007	0.067	0.19	0.009	0.08	0.26
St-7894	0.81 (± 0.090)	0.004	0.05	0.16	0.009	0.06	0.22
St-7891	1.745 (± 0.130)	0.016	0.13	0.39	0.012	0.13	0.42
St-6346	2.030 (± 0.100)	0.017	0.15	0.48	0.014	0.16	0.49
St-6345	2.225 (± 0.090)	0.018	0.17	0.53	0.015	0.17	0.50
Gak-4050	2.25 (± 0.105)	0.018	0.17	0.52	0.015	0.17	0.51
Gak-4060	2.39 (± 0.100)	0.018	0.18	0.57	0.017	0.18	0.54
Gak-4057	2.64 (± 0.105)	0.019	0.20	0.65	0.018	0.19	0.60
Gak-2996	2.82 (± 0.120)	0.020	0.23	0.70	0.019	0.20	0.63
Gak-4056	5.25 (± 0.130)	0.042	0.52	1.49	0.035	0.33	1.03

contamination level is up to 30% of the apparent age. This shows that even at high contamination levels the datings still indicate a Holocene age of the deposits which are related to the formation of the Uhuru levels. It is therefore concluded that the errors generated by contamination with young or old carbon does not essentially change the chronostratigraphy of the Holocene levels.
Another factor which influences the deviation from the true age is the apparent age of sea water of about 0.6 ky (Mangerud and Gulliksen, 1975). This must taken into account in detailed correlations of the youngest Holocene events.

The oldest dating (GaK-4056) of about 5.25 ky gives an age for the beach deposits of the Uhuru-I level at the Ngomeni peninsula. The samples Gak-2996 and Gak-4057 indicate a possible maximum age of about 2.8 to 2.6 for the beach deposits of the Uhuru-II level. The date of approximately 2.23 to 2.03 ky for the shells buried under windblown sands in a beach ridge at Shelly Beach (St-6345 and St-6346) gives an age for the period of eolian redeposition of the beach and dune ridges.
The dates of the shells of Mida Creek and the Watamu lagoon (GaK-4050, Gak-4060 and St-7891) of about 2.3 to 1.7 ky BP give further evidence for the late Holocene age of the Uhuru-II level. The dates of the shells in the beach ridges of Kikambala (St-7893 and St-7894) bordering the present shoreline may indicate a minimum age of about 1.0 to 0.8 ky BP for the Uhuru-II level. The very recent dates of shells found on top of raised beaches at Likoni and Twiga are not considered since they may well have be brought there by birds, men or the Krakatoa shockwave as suggested by Åse (1978, p. 220).
In Table 13 a dated correlation between the paleobioclimatic classification of the Holocene on Mt. Kenya and in NW Europe is given. It can be seen that the first cooler phase during the Holocene at Mt. Kenya correlates most

Table 13 Chronology of the Holocene events in the littoral zone of southeast Kenya

Paleobioclimatic units of NW Europe (*)		time (ky BP)	Littoral chronology SE Kenya: level	Littoral chronology SE Kenya: events	Chronology for Mt. Kenya (**): Geological events	Chronology for Mt. Kenya (**): vegetation	Chronology for Mt. Kenya (**): Humidity	Chronology for Mt. Kenya (**): Temperature
Subatlanticum	Late	- 1.0 -	Bofa	submergence ?	Neoglaciation	Dry Montane Rain-forest (Z)	drier (more misty)	cooler
	Middle	- 2.0 -	>> << >> <<	dune building	Dune building Alluviation			
	Early	- 2.5 -	Uhuru-II	emergence				
Subboreal	Late	- 3.0 -	>> <<		Colluviation	Max. Humid Forest (Y)	wet	optimum
	Middle	- 4.0 -		submergence				
	Early	- 5.0 -	>> <<	emergence	Darwin Formation	(X)	humid	cooler
Atlantic	Late	- 6.0 -				Humid M.-forest (W)	wetter	warmer
	Middle	- 7.0 -						
	Early	- 8.0 -	Uhuru-I			(V)		
Boreal	Late	- 8.5 -		submergence			wetter	warmer
	Early	- 9.0 -						
Boreal	Late	- 9.5 -						
	Early	-10.0 -						

* (after Mangerud et al., 1974)

* * (after Coetzee, 1967; Maheney & Spence, 1986); >> << fixed point 14C dated

likely with the emergence of the Uhuru-I level. A global cooling may than have been involved. This seems to be confirmed by the decreased relative sea-level rise in the Netherlands during the Subboreal and the strong extension of the Hollandveen deposits (Zagwijn et al. 1985, p. 13). In future research the peat deposits at the Uhuru Farm should reveal more details of this period.
The submergence leading to the formation of the Uhuru-II level correlates approximately with the climatic optimum at Mt. Kenya, while its subsequent emergence may have coincided with the onset of the cooler conditions at about 25OO y BP. In the Netherlands a possible correlative event was the first Duinkerke transgression. Probably the most striking fact is the near coincidence of the dry phases at Mt. Kenya and at the coast as evidenced by eolian activity. The dating of the onset of the actual phase of submergence is uncertain.

Older 14C datings
The older 14C datings range from approximately 21 to 40 ky BP. The samples have been mainly derived from reef rocks underlying the Mackenzie, Mtondia and Majaoni levels. As pointed out in Section 3.1.1.2.2 the dating of a coral sample from Tiwi Beach (Gak-2971) gives a 14C age of approximately 21.6 ky for either the Tiwi sandstones or the Mtwapa limestones. In the first case this may provide a possible date for the Mackenzie-I which is underlain by the Tiwi sandstones. The dating of a coral sample from the Nyali quarry (Gak-2972) gives a 14C age of about 25.4 ky for the upper part of the Mtwapa limestones. The beachrock (?) and coral head samples collected at 4.5 m +MSL near Malindi (Gak-4061, Gak-4062) indicate an age of around 25.6 to 27.5 ky for the base of the Mtwapa limestones. Another coral dating from Shelly Beach (Gak-2970) confirms this lower limit for the Mtwapa limestones. However, a coral dating carried out during the present study (GrN-9716) gives an age of 31.25 ky for the upper part of the Mtwapa Limestones. This dating can be understood if it is assumed that older coral heads occur in the limestone unit. If this is not the case then the reliability of the 14C datings is at issue. As the Mtondia levels have been cut into the Mtwapa Limestones this uncertainty has to be kept in mind when the age of this raised coastal terrace is considered. If the datings are accepted this would mean that the Mtondia-II level is younger than approximately 25 ky BP.
Consequently its formation must have coincided with one of the coldest episodes of the Weichselian. From detailed oxygen isotope records from the East Pacific (Shackleton et al., 1983) it is known that a relative optimum occurred at around 25 ky PB, but below that of 30 ky BP. Therefore the sea level will have been lower than the 30 ky paleosea-level of -42 m known from the Huon Peninsula in New Guinea (Aharon and Chappell, 1986, Table III). This would imply a relatively high uplift rate of about 2 m/ky for the coastal area of southeast Kenya. In Section 3.1.1.3.3. this problem is discussed more fully.
Another new coral dating (GrN-9717) has been carried out on the limestones

underlying the Majaoni level. The sample either represent the lower part of the Mtwapa limestones or the upper part of the Shimoni limestones. The dating of the limestones gives a maximum 14C age of about 40.3 ky BP for the Majaoni-II level, which has been cut in these reef deposits.
A third dating carried out during the present study concerns the limestones found behind the Seahorse Hotel on the Bandari ya Wali Creek (Kilifi). The layered chalks and soft limestones at this site underlie the Tezo level. Stratigraphically they appear to occur below the coral limestones of the Majaoni and Mtondia levels. Therefore the sediments are provisionally considered as part of the Changamwe deposits. Their dating of about 33.1 ky BP is contradicted by field evidence since it is younger than that of the apparently overlying corals of the Majaoni level. The stratigraphy of the deposits around the Bandari ya Wali have to be established in more detail in order to resolve this discrepancy.

From the above considerations it is clear that the older 14C data have to be used with care when setting the age of the events in the littoral zone of southeast Kenya. The dating Gak 4058 of >33.2 ky BP for a coral head from the limestones near Malindi likewise shows that there are potential sources of error. Contamination with modern carbon is the one of these.
In Table 14 the possible true ages of the samples at various contamination levels are shown. The figures have been obtained from calibration curves based on the data collected by Bowen (1978, p. 122).
The data in Table 14 show that at contamination levels of 5 % and above most datings are unreliable. The dating of sample GaK 4058 is the first of those determined at the Gakushuin University of which the result is uncertain. In this case a contamination level of 5 % and more is possible. However the analysis carried out at the Groningen Isotope laboratories (GrN numbers) indicate apparent ages of up to about 40.3 ky. Therefore the level of contamination in these samples is probably less than 1%.
From this it is concluded that, if contamination by young carbon affected the determination of the 14C ages of samples, it must have been at levels of less than 5%.

Table 14 Contamination effects on the older 14C datings

Sample	measured 14C age (ky BP)	Mean true 14C age (ky BP) at various contamination levels with modern carbon					
		0.1%	0.2%	1.0%	2.0%	5.0%	10.0%
Gak-2971	21.6 (+2.3 -0.7)	21.8	22.0	22.9	24.4	29.9	>29.9
Gak-2972	25.4 (+1.5 -1.4)	25.6	26.0	27.2	30.2	>30.2	>30.2
Gak-4061	25.6 (+1.1)	25.8	26.2	27.4	30.6	>30.6	>30.6
Gak-2970	26.5 (∓1.3 -1.5)	26.8	27.1	28.4	32.3	>32.3	>32.3
Gak-4062	27.49 (+1.3)	27.8	28.2	29.5	34.3	>34.3	>34.3
GrN-9716	31.25 (∓0.36)	31.8	32.4	37.8	48.0	>48.0	>48.0
GrN-9718	33.10 (∓0.55)	33.7	34.4	44.0*	>46.0	>46.0	>46.0
GrN-9717	40.30 (∓1.5 -1.3)	41.5	43.0	>43.0	>43.0	>43.0	>43.0
GaK 4058	>33.2	-	-	-	-	-	-

* date uncertain due to possible typing error in Table 5-4 of Bowen (1978)

In the present study the only means to evaluate the reliability of the available datings was to see how they fitted in the chronostratigraphy of the Pleistocene. A correlation of the sequence of events in the littoral zone with the Late and Middle Pleistocene chronostratigraphy of NW Europe is presented in Table 15. This stratigraphy is based mainly on the subdivision of the Pleistocene of the Netherlands (Van der Vlerk, 1957, Van Eysinga, 1975; Bowen, 1978), which has been revised recently by Zagwijn (1985) and Zagwijn et al. (1985). The updated outline of the Pleistocene in the Netherlands has again been used as a standard stratigraphy for NW Europe. The various oxygen isotope stages distinguished by analysis of fossil foraminifera from deep sea cores, as reported by Shackleton and Opdyke (1973; 1976) and Shackleton et al. (1983), are also indicated in Table 15. They reflect the changes in world ice-volumes and provide another excellent stratigraphic tool for the Middle and Late Pleistocene (Shackleton & Opdyke, 1976, p. 462). The well known and properly dated terrace sequence from the Huon Peninsula of New Guinea (Bloom et al., 1974; Chappell, 1974; Aharon and Chappell, 1986) has been added in Table 15 as a reference with which the outcome of the attempted correlation can be compared.

The start of the formation of a new littoral level is considered to occur at the beginning of a new transgressive phase. This is supposed to coincide with an decrease of world ice volumes and a rise of mean summer temperatures in NW Europe.

The correlation based on the available 14C datings are referred to as the young options. Using the data presented in Table 14 it is possible to consider four variants. They are indicated as option Y-1, Y-2, Y-3, and Y-4 which correspond to correlations based on datings of coral samples with a contamination level of 0, 0.2, 2 and 5 % respectively. The results of a correlation based on data obtained at a contamination level of 0.1 % does not differ from those of option Y-1. At a 1 % contamination level the correlation is largely similar to that of option Y-3. A fifth possibility is that all 14C data are unreliable and this will be discussed after the correlation options based on the 230Th/234U data has been treated.

- Option Y-1 gives a stratigraphical correlation based on the available 14C data without taking into account any contamination effect. The first fixed point is provided by the dating of the Tiwi sandstones from which the sample Gak-2971 is thought to have been derived. In option Y-1 it has been assumed that the deposits are related to the formation of the Mtondia-II level and served as the parent material in which the later Mackenzie-I level has been cut. The dating of the Mtwapa limestones given by the other Gak-samples are considered to provide a fixed age for the Mtondia-I level. The samples GrN 9716 and GrN 9717 are believed to represent coral limestones which were deposited during the formation of the Majaoni-II and Majaoni-I levels respectively. From Table 15 it can be seen from these last two fixed points that the formation of the Majaoni level correlates with that of the crests of Reef II and Reef IIIb of the Huon Peninsula. In the chronostratigraphy of Northwest Europe this coincide with the Denekamp and Hengelo interstadials. Consequently the Tezo-II level is likely to

Table 15 14C dated correlation options of the littoral levels

Paleobioclimatic units of NW Europe			Oxygen isotope stages		Time (ky BP)	Huon Peninsula	Option Y-1 (0% cont.)	Option Y-2 (0.2% cont.)	Option Y-3 (2% cont.)	Option Y-4 (5% cont.)
	L	Younger Dryas			10.0					
	a	Allerød			11.0	Reef	Mackenzie-	Mackenzie-	Mackenzie-	platform
			1		11.8					reoccupied
	t	Older Dryas			12	I	II	II	II	at present
	e	Bølling			13					
		Earliest Dryas			14		Mackenzie-			
W			2		17	Reef	I	Mackenzie-I	Mackenzie-I	Mackenzie-
E		- ? -			20	II	Mtondia-II >> <<	>> <<	>> <<	II
I	M				25					
C	i				29		>Mtondia-I<<	>Mtondia-II<		Mackenzie-
H	d	Denekamp			32	>> <<	>> << Majaoni-II	>> << Mtondia-I	>> << Mtondia-II	>> << I
S	d				35					
E	l	Hengelo			37	Reef				
L	e				39	IIIb >> <<	Majaoni-I	Majaoni-II	Mtondia-I	Mtondia-II
I			3		42					
A		Moershoofd			43	Reef >> <<	Tezo-II	Majaoni-I	>Majaoni-II<	Mtondia-I
N					50	IIIa				
	---				55					
		Odderade			57	Reef >> <<	Tezo-I	Tezo-II	Majaoni-I	Majaoni-II
	E				64	IV				
			4		70					
	a				75					
	r	Børup (?)		a	87	Reef >> << V	Cambini-II	Tezo-I	Tezo-II	Majaoni-I
	l			b	90					
	y				92					
		Amersfoort (?)	5	c	108	Reef >> << VI	Cambini-I	Cambini-II	Tezo-I	Tezo-II
				d	115					
E E M I A N				e	118	Reef >> << VIIb	Sokoke-II	Cambini-I	Cambini-II	Tezo-I
					128					
S					130					
A		Bantega ?			133	Reef >> << VIIa	Sokoke-I	Sokoke-II	Cambini-I	Cambini-II
A					140					
L					150					
I		Hoogeveen ?	6		155			Sokoke-I	Sokoke-II	Cambini-I
A					165					
N					170					
					175				Sokoke-I	Sokoke-II
					180					
H O L S T E I N I A N			7		195					
					210					Sokoke-I
					220					
					225					

>>   << 14C dated coral reef

have been formed during the high sea-level which correlates with the Reef IIIa and the Moershoofd interstadial. Consequently, Reef IV and the Odderade interstadial are most likely are contemporary with the formation of the Tezo-I level. This fits well with the supposed maximum age of about 50 to 40 ky (Clark, 1970) of the Middle Stone Age industries to which the Levalloisian artefacts in the basal gravel on the Tezo platform belong. Subsequently the Cambini levels may correspond to the Reefs V and VI and correlate with the Borup and Amersfoort interstadials respectively.
Finally the Sokoke levels are possibly contemporary with the Reefs VIIa and VIIb of the Huon Peninsula and the Eemian interglacial and Bantega (?) interstadial of Northwest Europe.
Two important objections to this option can be mentioned. The first is that it leaves hardly any space for the formation of the Mtondia and Mackenzie levels and for the cutting of the reef platform which is reoccupied by the present-day shore. In the second place this correlation option creates a relatively large time gap between the formation of the marine terraces and the fossil dated Changamwe deposits (440 to 920 ky). It would mean that, in contradiction to field evidence, there is no relation between the higher terrace levels and the unconsolidated deposits in the near subsurface.

- Option Y-2 is based on the available 14C data corrected for a possible contamination with 0.2 % modern carbon. It assumes that the coral limestones from which the samples GrN 9716 and GrN 9717 have been taken are related to the formation of the Mtondia-I and Majaoni-I respectively. Consequently the deposition of the coral limestones from which sample Gak-2971 has been taken must be connected with the formation of the Mackenzie-I level. In Table 15 it can be seen in what other ways option Y-2 differs from Y-1.
  One of the most important consequences is that more space is available for the formation of the Mtondia levels of which the higher one now can be correlated more conveniently with Reef II. The age of the Mtondia-II level is determined by the dating of the Mtwapa limestones (Gak-2972, 4061, 2970 and 4062). However whether the short climatic improvement at around 25 ky BP can have been responsible for the intense weathering of the Mtwapa limestones (Braithwaite, 1984, p. 695) is unlikely. Therefore the whole option Y-2 becomes questionable. Another complication is the fact that the Tezo level becomes older than is expected on archeological grounds. This questions either the correlation option or the current dating of the Levalloisian industry or both. Although the formation of the Sokoke levels may now be connected with the high sea-levels during the interstadials of the Saalian, the large stratigraphical discontinuity remains.
- Option Y-3 is based on the available 14C data when a 2% contamination with modern carbon is accounted for. It assumes that the coral limestones from which sample GrN 9716 has been taken represents the formation of the Majaoni-II level.
  This correlation option gives more space for the formation of the Mtondia levels. However the correlation of the Mackenzie levels and the reef

platform at present-day mean sea-level with any of the known terraces in New Guinea and interstadials in Northwestern Europe remains obscure. Any confirmation of the age of the Tezo level by the artefacts in its basal gravel layer is now absent. The correlation of the Cambini and Sokoke levels with the Eemian and Saalian interstadials may explain their deviating soil formation compared with that on the lower situated Tezo, Majaoni and Mtondia levels. The problem of the large stratigraphic hiatus still remains.

- Option Y-4 is based on the available 14C data when a 5 % contamination with modern carbon is taken into account. The consequence of this option is that only sample GaK 2971 gives a reliable dating. In this fourth option it is again assumed that the sample represents the corals in the Tiwi sandstones and that they are related to the formation of Mackenzie-I level. Consequently a connection has been made with the formation of Reef II in New Guinea and the occurrence of the Denekamp interstadial in NW Europe. Table 15 shows the further correlations of option Y-4.
  A reasonable space is available for the formation of the Mackenzie-I level but the correlation of the reef platform reoccupied at present, remains a problem. Unless the Sokoke-I level dates back to the first high sea-level of the Holsteinian, the time gap between the formation of the higher levels and the deposition of the older Pleistocene littoral sediments is not bridged.

In conclusion, various chronologies based on available 14C datings can be established. Most seem to fit well with the known changes in world climate during the Late Pleistocene and with the terrace sequence in New Guinea. However, there are several reasons to question these correlations. Firstly they all leave a relatively large gap in the geomorphological history between the destruction of the End Tertiary surface and the formation of oldest known terrace of the Sokoke level. This can be explained if a coastal downwarp is assumed which lasted until the end of the Middle Pleistocene. However, there is no major tectonic event known which could have led to the reversal of this trend at that point of Pleistocene history.
In addition, all the young options create a sedimentary hiatus in the Pleistocene succession of southeast Kenya. This leads to a total disconnection of the higher terraces and the littoral deposits older than those belonging to the Pleistocene reef complex. Therefore the results of the young correlation options are probably all incorrect. This preliminary conclusion will be discussed further in Section 3.1.1.3.3.

Correlation options based on the 230Th/234U dating

A remarkable deviation of a factor of 10 exist between the results of the available 14C and 230Th/234U datings of the Pleistocene reef complex. The number ratio of nine 14C analysis against one 230Th/234U may easily lead to

the rejection of the latter. However, as it is known that highly successful 230Th/234U datings of fossil corals have been made (Bowen, 1978, p. 125), the result of this one dating reported by Battistini (1977, p. 78) has to be given serious attention. In Table 16 information on the dating is given.
Battistini (1969) distinguished in first instance only two major transgressions evidenced by two reef complexes along the coast of Kenya. The older 'recif I' was described as consisting of recalcified corals with red clay pockets and was correlated with the Tasimien of Madagascar (~ Tiglian of Northwest Europe). According to Battistini (1969, Fig. 2, p. 232) this reef underlies major parts of the Mtondia levels of this study. The younger 'recif II' was found to be characterised by less recalcified corals and the absence of clay pockets. The formation of the reef was correlated with the Karimbolian of Madagascar (~ Eemian of NW Europe). According to Battistini's Fig. 4 (p. 236) it is the reef which mainly underlies the Mackenzie-I level of this study. With his stratigraphy Battistini tried to simplify the whole Quaternary history of the coast. During a later study of the Pleistocene marine deposits of Madagascar and the neighbouring islands Battistini also sampled the reef limestones of the Kenyan coast near Sun and Sand Beach. According to the description given (Battistini, 1977, p. 78) the sample apparently not represents the limestones of the 'recif I'. As the age of 240 (-40 +70) ky BP resulting from the dating was to old for the earlier correlation with the Karimbolian, a 'niveau intermediaire' was introduced (Battistini, 1969, p. 79).
Rossi (1981, p. 50) used the dating to correlate his coral complex of the Upper Mombasa II series. It is the reef which underlies the Mtondia levels of this study and correlates with the 'Recif-I' of Battistini. Braithwaite (1984, p. 698) also considered the sample to have come from the older limestones of his unit 2 (= Shimoni limestones). Consequently he correlated the younger limestones (=Mtwapa limestones) with the Aldabra Limestones (118 to 136 ky BP) on the Aldabra Atoll.
From this it is clear that there is absolute certainty about the stratigraphic position of the sampled coral head. In this study the sample is considered to have been derived from the Mtwapa limestones as this is in accordance with the description by Battistini of both the material and the sample site.
Three correlations, referred to as the old options 1 to 3 in Table 17, have been attempted between the chronology of the littoral levels and the stratigraphic division of the Pleistocene Epoch. The framework used is based on the oxygen isotope stages defined by Shackleton & Opdyke (1973, 1976) and Van Donk (1976). The stage boundaries indicated in Table 17 have been

Table 16 230Th/234U dating of deposits in the littoral zone

sampled material	230Th/234U age (ky BP)	Location	Elevation (m +MSL)	Littoral plain-level	Position of sample site
coral head	240.0 (+70.0 -40.0)	Kikambala	3.5-4.0	Mtondia-II	abandoned cliff

calculated using the data from the Pacific core V28-239 (Shackleton & Opdyke, 1976). The data from Equatorial Atlantic core V16-205 (Van Donk, 1976) correlate well with this and are used to differentiate the oldest Pleistocene stages. The fixed points in the isotope stratigraphy are the dates of the extinction level of *P. lacunosa* (0.44 my) and the boundaries of the Brunhes-Matuyama epoch (0.69 my), the Jaramillo event (0.87 to 0.92 my) and the Olduvai event (1.71 to 1.86 my).
Table 17 shows a further provisional correlation with the paleoclimatic classification of NW Europe (Van Eysinga, 1975), which has been updated by the most recent outline of the Quaternary stratigraphy of The Netherlands (Zagwijn 1985). The ages of the stages have been derived from the climatic curve (Zagwijn, 1985, Fig. 2).

In the following discussion of the various old options the ages of the isotope stages are mainly used. It is stressed that they should be considered as provisional in the same way as those used in the paleoclimatic stratigraphy of the Netherlands.

- Old option 1 is based on the assumption that the deposition of the 230Th/234U dated Mtwapa limestones is related to the formation of the Majaoni-I level. This leads to a correlation of the Majaoni-I level with the high sea-stands during the Pacific and Atlantic isotope stage 9 and the Noordbergum interstadial in NW Europe. The formation of the Majaoni-II level may then be associated with the next warm episode of isotope stage 7 and the climatic stage known as the Holsteinian interglacial of NW Europe. Consequently the formation of the Mtondia levels may be related with high sea-stands during isotope stage 5 and the Eemian and Early Weichselian of NW Europe.
  For the higher terraces the correlation of this first option means a connection of the Tezo and Cambini levels with the Late and Early Cromerian respectively. The formation of the Sokoke levels is correlated with the occurrence of the glacial and interglacials of the Bavelian. This option implies that no terrace levels have been preserved from the interglacial periods know as the Waalian and Tiglian in NW Europe. Consequently a hiatus of about 1.4 my between the destruction of the ferricreted End-Tertiary surface and the formation of the Sokoke level must be assumed.
  Old option 2 is based on the assumption that deposition of the 230Th/234U dated coral limestone is related to the formation of the Majaoni-II level. An interesting point in this option is the fact that the formation of the Tezo levels is now dated at approximately 335 to 625 ky BP. The break between the two sub-levels is formed by the low sea-stands connected with isotope stage 16 at c. 540 to 605 ky BP. This coincides with a period which is known to have been dry (Van Zinderen Bakker & Mercer, 1986, p. 217). The desert varnish on rock fragments and artefacts in the basal gravel layer of the Tezo level may be connected with this interval of aridity.

Table 17 230Th/234Ur dated correlation options of the littoral levels

Stratigraphic framework of polarity and oxygen isotopic subdivisions						Old option	Old option	Old option	Paleobioclimatic units of NW Europe		
Time unit		Paleomagnetic stratigraphy		isotope stages	Age (ky BP)	1	2	3	Age (ky BP)	Bioclimatic stages	
				1		Uhuru-I, II	Uhuru-I, II	Uhuru-I,II			
					13						
				2			present-day platform	submerged levels			
					32	Mackenzie-II					
				3							
	Late				64						
				4				present-day platform			
					75	Mackenzie-I	Mackenzie-II			Weichselian	
				5a							
					87						
				5b							
					92	Mtondia-II	Mackenzie-I	Mackenzie-II			
				5c							
					108						
		BRUNHES		5d							
					118	Mtondia-I	Mtondia-II	Mackenzie-I	110		
			<< Blake >>	5e						Eemian	
					128				130		
				6						Saalian	
					175	Majaoni-II	Mtondia-I	Mtondia-II	180		
PLEISTOCENE				7						Holsteinian	
					225				250		
				8						Elsterian	
					265	Majaoni-I	Majaoni-II	Mtondia-I	300		
				9						Cromerian	Noordbergum
					300				375		
	Middle			10							Glacial C
					325	Tezo-II	Majaoni-I	Majaoni-II	425		
				11							Rosmalen
					355				475		
				12							
					410						
				13							Glacial B
					450	Tezo-I	Tezo-II	Majaoni-I			
				14							
					475				590		
				15							Westerhoven
					540				650		
				16							
					605	Cambini-II	Tezo-I	Tezo-II			
				17							
					625						Glacial A
				18							
					680				680		
				19							
					690	Cambini-I	Cambini-II	Tezo-I	690		
				20							
					725						Waardenburg
				21							
					750				750		
				22							Dorst
					800	Sokoke-II	Cambini-I	Cambini-II	775		
				23							Leerdam
		MATUYAMA			870				825	Bavelian	
			Jaramillo	24							Linge
					920	Sokoke-I	Sokoke-II	Cambini-I	875		
				25							Bavel
					975				950		
	Early			26-32	(my)		?	?	(my)	Menapian	
					1.19		Sokoke-I	Sokoke-II	1.10		
				33							C
					1.23				1.17	Waalian	
				34							B
					1.28			Sokoke-I	1.23		
				35-39							A
					1.38				1.30		
-?-				32-36*	1.71					Eburonian	
			Olduvai	-------	1.73	End-Tertiary	End-Tertiary	End-Tertiary	1.65		
				37-39*	1.86						C
PLIOCENE					1.88	Surface (II)	Surface (II)	Surface (II)	2.03	Tiglian	
				40*							B
					1.92				2.07		
			<<Reunion >> << events >>	41*							A
					2.17				2.15		
				42*						Pretiglian	
					2.25				2.30		
	Early	GAUSS		43*							
					2.41	End-Tertiary	End-Tertiary	End-Tertiary			
			<< Kaena >>							Reuverian	
						Surface (I)	Surface (I)	Surface (I)			
			<< Mammoth>>								

* stage numbers as used by Van Donk (1976)

Old option 3 is based on the assumption that the deposition of the 230Th/234U dated coral limestones is related to the formation of the Mtondia-I level. This leads to a correlation of the Mtondia-I level with high sea-stand during the oceanic isotope stage 9 and the terrestrial climatic stage known as the Noordbergum interstadial in NW Europe. Consequently the formation of the Mtondia-II level may be related to the climatic optima of the Holsteinian, while the Mackenzie-I level probably corresponds to the high sea-level of the Eemian. The Mackenzie-II and the submerged reef platform at the present shore than then be connected with the two high sea-levels at 107 and 85 ky BP found on the Huon Peninsula (Bloom et al., 1974, Aharon & Chappell, 1986).
The Majaoni levels are most likely to be related to the climatic optima of the oceanic isotope stages 11 and 15. They are believed to correspond with the Rosmalen and Westerhoven interglacials of NW Europe. The Tezo levels in this option are related to the climatic optima of isotope stage 17 and 19 to 21. respectively. They probably correspond with the climatic changes during the Early Cromerian in NW Europe. The Cambini levels are now connected with the climatic optima of isotope stage 23 and 25, which may correspond to the Leerdam and Bavel interglacials of the Bavelian in NW Europe. Finally the Sokoke levels are connected with the climatic optima of isotope stages 33 and 35 to 39 respectively. They probably correspond to the two known warm stages of the Waalian in NW Europe.

Of the three provisional old options the last one is preferred. The major breaks between the various coastal levels all coincide with major changes in the Pleistocene climatic and isotope stratigraphy. It also bridges the gap with the destruction of the End-Tertiary Surface, on which the correlative deposits of the Sokoke level rest. Rossi (1981) correlated the ferricrete of the End-Tertiary Surface found on top of the Marafa Formation with a similar horizon on Madagascar which has been dated at approximately 2.2 my BP. However, he places in his Table 3 (p. 51) the deposits of the upper Magarini Formation before the formation of the ferricrete on the deposits of the Marafa Formation. Therefore his proposed stratigraphy is either incorrect or there are two ferricretes: one in the Marafa beds and one in the Magarini sands. No evidence of the latter ferricrete was found during the present study, but it was reported to occur near the top of dunes constituted by the Magarini sands by Thompson (1956, p. 31). From his description of the position it is clear that it is not comparable with the normal ferricretes which are formed by fluctuating ground water. Table 17 shows that the formation of the End-Tertiary surface may have taken place in two phases of which the first can be connected with the Reuverian and the second with the Tiglian of NW Europe.
An argument in favour of both the second and third old options is that the initiation of the Tezo levels coincides more or less with the fourth phase of tectonic activity (0.9 to 0.4 my) in central Kenya (Baker et al. 1978, p. 35). In the Kenya Rift Valley this event resulted in the formation of a dense, parallel fault pattern. The renewed tectonic activity may well be the

cause of the sudden increase in the coarse fraction of the sands of the Tezo level compared with those of the Cambini and Sokoke levels.

In conclusion it must be said that so far none of the young or old options could be proved to be false or correct. Of the young option the fourth is probably the best. Of the old ones the third option is preferred. A final choice of one or more of the provisional correlation options may be possibly made when further study of the tectonic and climatic/eustatic effects is made. The influences of tectonic uplift and eustatic sea-level changes are analysed in Section 3.1.1.3.3.

3.1.1.3.3 Tectonic and climatic effects

The influence of tectonics on the genesis and later development of the marine terraces was first advocated by Gregory (1921). His views were questioned in the publications of Caswell (1953, 1956), Thompson (1956) and Williams (1962). They argued for a pure eustatic cause of the presence of raised terraces. Battistini (1969) returned the idea that also tectonic uplift must also have played an important role in the coastal history of Kenya. His views were shared by Rossi (1981) in a later publication on the littoral geology of the coast.

The elevation of the middle and higher littoral levels differentiated in the present study clearly shows that tectonics did play a role in the morphogenesis of the littoral zone. The presence of parallel step faults on all but the Uhuru levels also indicate that tectonic movements occurred up to almost the youngest episode in the development of the present-day landscape configuration. The absence of a true fore-reef facies in the raised coral reefs may also be considered as an indication of partial uplift and downwarp of the former shore-zone.
The rate and timing of tectonic influences against the background of the climatic and related eustatic changes is still open to discussion. The construction of an uplift-rate curve would provide more insight in the relationships between those two factors in landscape formation. This, however, needs a well dated terrace sequence which is unfortunately still lacking in the study area. Nevertheless, when the elevation of the various levels is plotted against their supposed age, as derived from the chronological correlations (Section 3.1.1.3.2), the validity of the correlation options can be further checked.

14C dated uplift-rates

In Fig. 14 the supposed ages of the terrace levels in the central section have been plotted against their elevation with a correction for the height

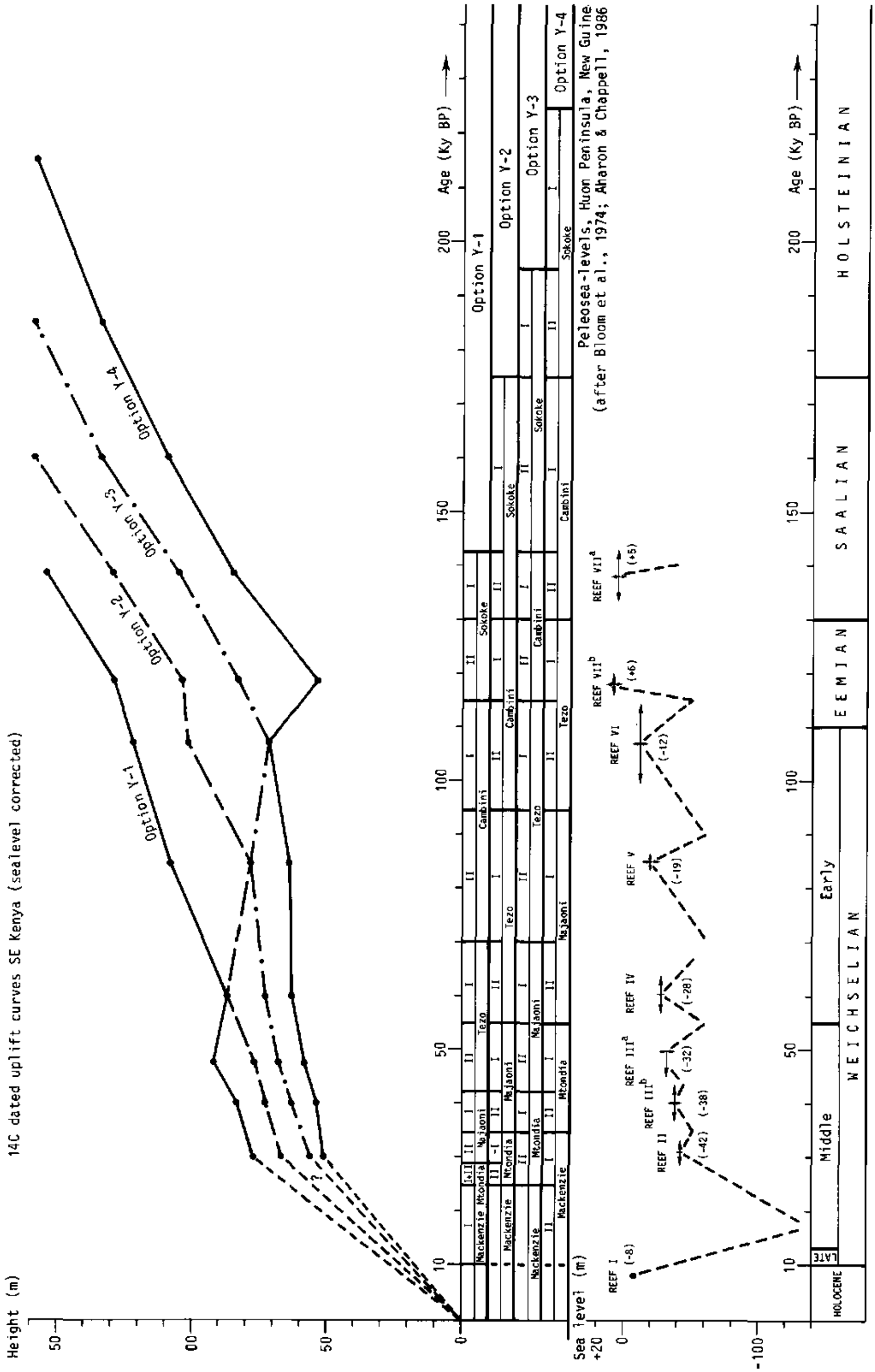


Fig. 14 14C dated uplift-rates

of the sea levels of that particular time. Use is made of data on the paleosea levels derived from the work on the Huon Peninsula in New Guinea, where relatively high sea-stands are known to have occurred of approximately +5, +6, -12, -19, -28, -32, -38 and -42 m at 138, 118, 107, 85, 60, 45, 40 and 31 ky BP respectively (Bloom et al. 1974, Aharon and Chappell, 1986). No data on former sea-levels are known for the interglacials older than the Eemian and a comparable level to that of today is assumed.
The approximate elevations of the marine platforms in the central section have been put at 8, 10 (Mackenzie-II and I), 15, 25 (Mtondia-II and I), 35, 45 (Majaoni-II and I), 60 (Tezo-I and II), 90, 110 (Cambini-II and I), 135 and 160 m +MSL (Sokoke-II and I). It is stressed that this is a first approximation in which the tilt of the higher levels is ignored by using mean heights. More detailed field measurements are required to refine the construction of the uplift curves.
Fig. 14 shows that all four young options have relative rapid uplift rate of 2.5 to 1.7 m/ky between the present and 30 ky BP. The uplift rates are comparable in magnitude to the highest figures reported by Bloom et al. (1974, p. 201, Table 3) for the most rapid rising part of the Huon peninsula. The mean uplift-rates between 0 and 140 ky vary from 1.1 to 0.6 and are equal or slightly lower than the lowest figures reported by Bloom. These data show that the tectonic activity at the eastern edge of the Kenya-Somalia block would be comparable to that of an area situated near the subduction zone of the Pacific Plate under the Indian Plate. In other words the Late Pleistocene uplift of the stable Karroo platform of southeast Kenya is as fast as that of the active fold areas of New Guinea. However, the morphology of the coast and the interior of east Kenya bears no evidence for such a rapid uplift during its Middle to Late Quaternary history. The correlation options based on 14C data, therefore, can not be correct.

It is clear that such a conclusion has far reaching consequences as it questions the suitability of the 14C methods in the range above 20 ky. The conclusion also contradicts the dating of the beginning of the Middle Stone Age Levalloisian industry at about 40 to 50 ky BP.

230Th/234U dated uplift-rates

Using the ages derived from the correlations in the old options (Section 3.1.1.3.2) the problem of the high uplift rates does not exist.
It can be seen in Fig. 15 that they vary from 0.17 to 0.10 m/ky for the old options 1 to 3 respectively. The curves resemble each other and there is no reason to reject one or more of them on grounds of abnormalities in the uplift rates after about 130 ky BP. However, when the uplift during the Late Pleistocene is corrected for the known paleosea-levels from the Huon Peninsula (Bloom et al., 1974), old option 3 is to be preferred above the others as it give the most constant uplift rate.

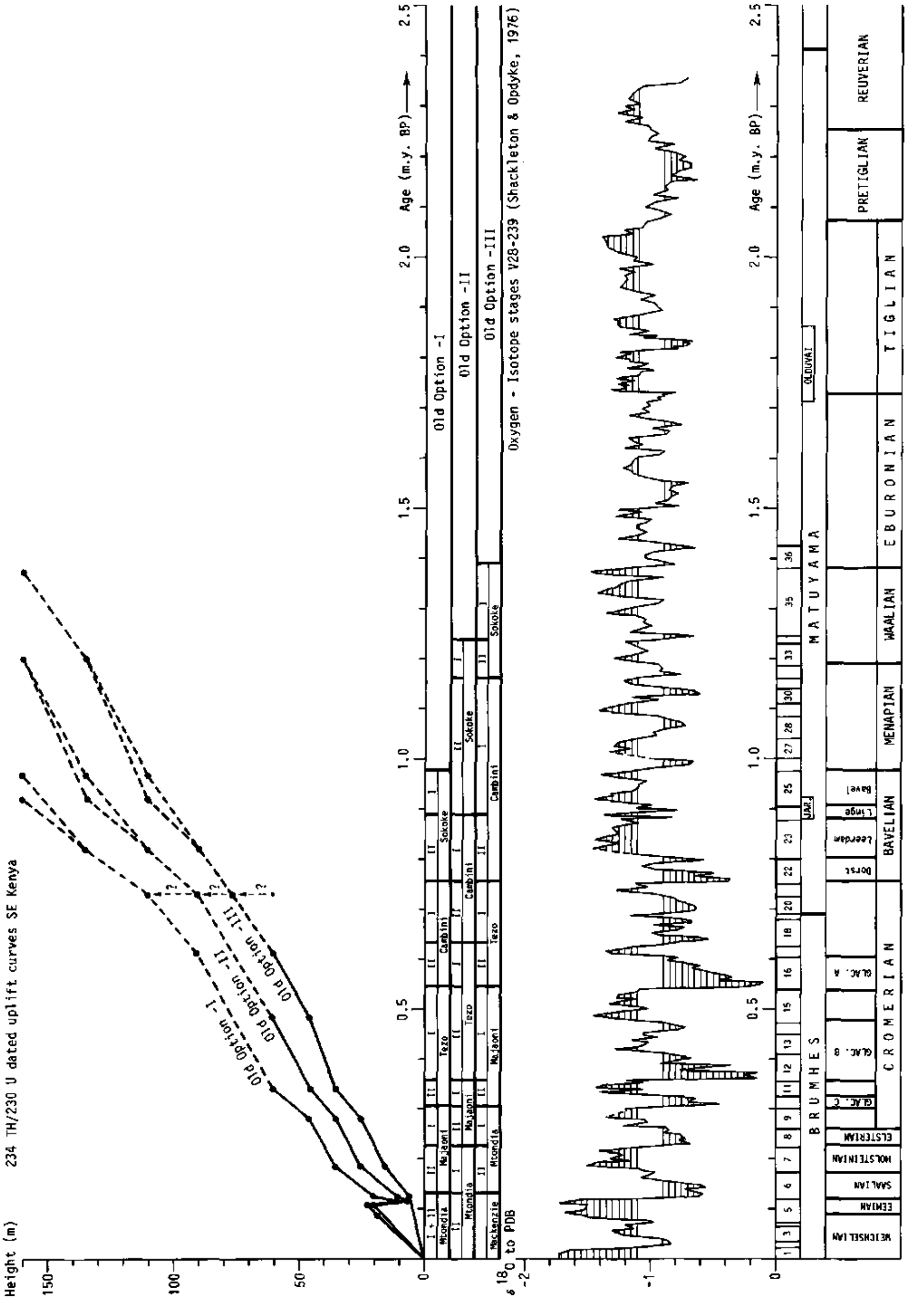


Fig. 15 230Th/234U dated uplift-rates

One inference resulting from the preference of this third correlation option is that the present-day reef platform is probably an reoccupied Early Weichselian surface, connected with the relative high sea-level of about -12 m at 107 ky BP. This implies a mean uplift rate of 0.11 m/ky which is well in line with the general trend in the curve of the Old option 3. The presence of reoccupied platforms is a well known feature along other shores (Bloom, 1978, p. 444). Braithwaite (1984, p. 697) first interpreted the present-day reef as such, but his suggested age of 30 ky implies a uplift rate of approximately 1.4 m/ky. This high rate is unlikely for the Kenyan coast and his assumption is rejected.
The break in the curve at about 110 ky may be a reflection of the tectonic activity which took place after the completion of the Mackenzie-I level. It is remarkable that the tectonic activity seems to coincide with the Blake polarity event. A second change in uplift rate occurs between 600 and 800 ky BP. This may be a reflection of the tectonic activity which took place somewhere between the completion of the Cambini-II and the formation of the Tezo-II levels. Alternatively it could also be caused by a relatively high paleo sea-level at about 725 ky BP which remained approximately 15 m below that of the present-day. However the abnormality falls entirely with in the period of intense grid faulting which occurred in the Kenyan Rift Valley between 900 and 400 ky BP (Baker et al., 1978, p. 35) and the first possibility is to be preferred. The coincidence of the break in uplift rate with the paleomagnetic boundary of the Brunhes-Matuyama reversal is striking. A relationship between the timing of worldwide paleomagnetic changes and tectonic events at the coast of southeast Kenya is suggested.
In conclusion it can be said that the morphogenesis of the littoral zone probably took place throughout the whole Pleistocene period. The break between the older landforms related to the End Tertiary surface is believed to have coincided with period of low sea-levels related to the Pretiglian of NW Europe (2.25 to 2.17 my BP). The fluvial deposits of the Lower member of the Magarini Formation may have been deposited during this time. Their deposition was accompanied in its later stage by differential down warp of the coast. It was probably this event which Saggerson and Baker (1965, p. 64) meant when describing the downflexing of the Tana basin. The downwarp correlates well with the third phase of rifting in central Kenya dated at 2 to 1.7 my BP and which is evidenced by a displacement of the Limuru trachytes of about 500 m (Baker et al. 1978, p. 35). The period in which this third phase of rifting and coastal down-warp took place coincides with the Tiglian in NW Europe. It is known as an interglacial period with relatively high sea-levels (Zagwijn, 1985, p. 20). This combination is likely to have caused the far inland reaching incursion of the sea mentioned by Saggerson and Baker (1965, p. 65). It is likely that the initial deposition of the Plio-Pleistocene sediments (Baker & Saggerson 1965) started at this time. Therefore they correlate best with the deposits of the Lower Magarini Formation and not with the sediments of the Marafa Formation as suggested by Sombroek et al. (1982, p. 32). As a result of this coastal submergence only the End-Tertiary surface in the interior of Kenya underwent

a second phase of development during the Tiglian of NW Europe. At the coast its formation ended through subsequent burial beneath the deposits of the Magarini Formation.

During the low sea-levels connected with the Eburonean glatiations in NW Europe dissection and redistribution of the both Plio-pleistocene sediments as well as the deposits of the Lower Magarini Formation is likely to have taken place. It is evidenced by the local fluvial character of the deposits. A more detailed study of the erosion alcoves in the Magarini Formation may reveal more detailed information on the various events of this period. The age derived for the lower Magarini Formation shows that setting the Sokoke-I level later than that of the Waalian of NW Europe is unlikely.

Since the Plio-Pleistocene down warp of the coast, southeast Kenya is subject to general uplift. Probably two different tectonic mechanisms have been involved in the geomorphological development of the study area. One may be related to a continental uplift with its hinge-point east of the present-day shore and the other may be related to the regional development of the Rift Valley with a hinge-point west of the present-day shore. This means that when the uplift connected with the formation of the Rift Valley is greater than the continental uplift downwarp of the coast takes place, resulting in the destruction of the existing landscape. The present landscape of the littoral zone has been formed during the last period of predominant continental uplift. The coincidence of this uplift with the world wide climatic induced oscillations of the sea level during the Pleistocene caused the initiation of the various littoral levels.

The soil formation on the terrace treads reflect the climatic conditions under which their later development took place. The deep, dusky red Ferralsols of the Sokoke and Cambini show that the last tropical humid climatic conditions occurred at the end of the Early Pleistocene. During the Middle Pleistocene a tropical Savannah climate prevailed which led to the formation of the Acrisols and Luvisols in the sandy deposits of the Tezo and Majaoni levels. The Albic Arenosols near the back slopes of the terraces in the central section show that the general conditions were wetter than that of today. The occurrence of mainly Cambisols in the sandy deposits on the Mtondia and Mackenzie terraces may indicate the presence of a drier savannah climate towards the end of Pleistocene period.

Extreme dry conditions may have occurred at 650 to 700 ky BP as evidenced by the desert varnish of the artefacts and rock fragments on the Tezo terrace. Other periods of comparatively low rainfall probably occurred at about 500, 400, 275, 225 and 150 ky BP. This is evidenced by the various sand-drift complexes near alluvial fans and major river outlets. One dry Holocene phase is known to have occurred at about 2.2 ky BP. It is evidenced by the eolian reworking of beach ridges and foredunes.

3.1.2 The paralic areas

Enclosed between the littoral areas of the coast and the denudational areas of the interior, a transitional zone can be identified. It corresponds broadly with the Nyika and the Giriama hill country defined by Gregory (1896, p. 222-223). In the geographical division of Ojany (1966, p. 195) the areas are included in the Kwale and the Galana-Tana River Low Belt.
The zone is characterised by planed-off surfaces unconformably overlain by unconsolidated superficial deposits (Fig. 16). On geological maps these materials are usually indicated as soils or superficial sands. The reconnaissance soil map of the Tsavo area (van Wijngaarden & Van Engelen, 1985, Appendix 1a, 1b), indicates them as Plio-Pleistocene Bay deposits and Quaternary Continental or superficial deposits. In the Kilifi area, they are known as the Bay deposits (Boxem et al., 1987, Appendix 1).
The inland boundary of the zone has the shape of an embayed shoreline. This shows that the deposits form a fill in a previously dissected area. The eastern limit is formed by the marine terraces of the littoral zone.

Fig. 16 Exposure of unconsolidated superficial deposits unconformably overlying sandstones of the Lower Mariakani Formation west of Mazeras

The unconsolidated superficial deposits are therefore considered to consist of terrestrial materials laid down in or near a shallow water environment at the landward part of the coast. It is likely that during periods of high sea-level the area was subject to marine invasion. If not bringing in true marine sediments, this at least caused a redeposition of the unconsolidated superficial deposits.

The term paralic is proposed and used in the present study to indicate this transitional coastal environment. The area which emerged after the sea had retreated is consequently called the paralic zone. In the following sections the geological and morphological structure of the paralic zone is described. This is followed by a discussion of its genesis and later development.

3.1.2.1 Stratigraphical record

The subsurface rocks of the paralic areas consist mainly of Paleozoic-Mesozoic sediments of the Karroo System. Metamorphic rocks of the Mozambique Belt System occur locally in the most western parts, while at the seaward side rocks of the mainly Jurassic System are found. In the northern part the subsurface is made up of unconsolidated Tertiary and Quaternary deposits. They form part of the sedimentary succession in the Lamu Embayment. Their stratigraphy has been established from borehole data by Walters and Linton (1973, p. 142). In Table 18 a preliminary stratigraphical framework is presented for the sedimentary rocks of the entire paralic zone. Its structure follows the provisional stratigraphy of Cannon et al. (1981a, p. 421). The stratigraphic units of the framework and their correlation are briefly described and commented on below. The metamorphic rocks are further dealt with in Section 3.2.1.1.

Taru Formation
The Taru Formation is mainly composed of fluviatile deposits of braided rivers (Karanja, 1983, p. 5). Their deposition took place at the foot of scarps initiated by Late Carboniferous to Early Permian major faulting (Cannon et al., 1981a, p. 422). In the area west of Mombasa an apparent thickness of about 2700 m has been reported by Walters & Linton (1973, p. 137).
The Taru Formation correlates with the Taru Grits mentioned in earlier reports and is subdivided into three members.
- The Lower Taru Member consists of Late Carboniferous (?) to Early Permian fluviatile and glacial (?) sedimentary rocks. This unit correlates with the Basal Group distinguished by Sanders (1959, p. 15).
- The Middle Taru Member consists mainly of Early (?) Permian, fluviatile, arkosic sandstones. This unit correlates more or less with the Arkose Group of Sanders (1959, p. 15).

Table 18 Preliminary stratigraphy of the paralic zone

Period	Epoch	Group	Formation	/ Member	Predominant lithology
Quaternary	Pleistocene		Plio-pleistocene lagoonal deposits		argillaceous sands with subordinate clays and rare limestone stringers
	Pliocene				
	Miocene		(not exposed)		mudstones with thin bands of calcareous sandstones and sandy limestones
	Eocene		(not exposed)		mudstones/sandstones
Cretaceous	Late		(not exposed)		shales
	Early		Mtomkuu	upper	limestones with shale partings
Jurassic	Late			middle	shales with subordinate limestones and sandstones
				lower	shales/siltstones/sandstones/limestones
	?				
	Middle		Kambe		limestones with subordinate shales/siltstones
	Early		Mazeras	upper	pebbly arkosic sandstones with abundant quartz-pebble horizons
				middle	arkosic sandstones with quartz-pebble and shale horizons and siltstone/shale/sandstone beds
	?				
Triassic				lower	"banded" arkosic sandstones
			Mariakani	upper	sandstones with a basal siltstone/shale/sandstone bed
		D		middle	flaggy sandstones with shaly and micaceous horizons and a basal siltstone/shale/sandstone horizon
		U		lower	mottled sandstones with siltstone/shale/sandstone beds
		R	Maji ya Chumvi	upper	flaggy sandstones with subordinate siltstones/shales
		U		middle	siltstones/shales with interbedded sandstones and subordinate limestones
	?	A			
Permian				lower	siltstones/shales with interbedded sandstones and subordinate limestones
		A	Taru	upper	arkoses/sandstones with subordinate siltstones, shales, limestones and sparse conglomerate beds
				middle	arkoses/sandstones with subordinate siltstones, shales, limestones and abundant conglomerate/pebble sandstone beds
	?				
Carboniferous	Upper			lower	arkoses, siltstones, conglomerates, tilloids

- The Upper Taru Member consists of Middle (?) Permian, fluviatile, arkosic sandstones with subordinate lacustrine deposits. This unit includes the Calcareous and Sandstone Groups of Sanders (1959, p. 15).

Maji ya Chumvi Formation

The Maji ya Chumvi Formation is composed of predominantly lacustrine deposits. Their deposition is thought to have taken place under arid conditions evidenced by mud cracks and salty horizons (Karanja, 1983, p. 6). In earlier reports this unit is shown as Maji ya Chumvi Beds. Estimates of the total thickness vary from 1200 m (Walters & Linton, 1973, p. 138) to 2300 m (Karanja, 1983, p. 8). Cannon et al. (1981a, p. 421) proposed in their provisional stratigraphy a subdivision into a lower, middle and upper member.

- The Lower Maji ya Chumvi Member consists of Upper Permian lacustrine siltstones and shales. The unit correlates with the Lower Shale Group in the stratigraphy of Sanders (1959, p. 15).
- The Middle Maji ya Chumvi Member consists of Early Triassic lacustrine shale and siltstones. It correlates with the lower part of the Upper Shale and Flagstone Group distinguished by Sanders.
- The Upper Maji ya Chumvi Member consists of Early to Middle Triassic, flaggy sandstones and subordinate siltstones or shales. The unit correlates with the upper part of the Shale and Flagstone Group of Sanders.

Mariakani Formation

The Mariakani Formation is composed of predominantly deltaic deposits (Cannon et al. 1981a, p.422). The unit is known as the Mariakani Sandstones in earlier reports. The estimates of the total thickness range from 1900 m to 2300 m (Walters & Linton, 1973, p. 138). Three members have been distinguished in the provisional stratigraphy of Cannon et al. (1981a, p. 421).

- The Lower Mariakani Member consists mainly of Middle (?) Triassic, mottled sandstones. The unit correlates with the Mottled Sandstone Group of Sanders (1959, p.15).
- The Middle Mariakani Member consists mainly of flaggy sandstones with shale and micaceous horizons. Caswell (1956, p. 9) included these rocks in his Lower Division of the Mariakani Sandstones.
- The Upper Mariakani Member consists of massive sandstones with minor shale horizons. The unit correlates with the Upper Division of the Mariakani Sandstones mentioned by Caswell (1956, p. 10).

Mazeras Formation

The Mazeras Formation is composed of deltaic storm and eolian deposits (Karanja, 1983, p. 8). The unit was formerly known as the Mazeras Sandstones. The estimates for its thickness range from 450 m (Walters & Linton, 1973, p. 138) to approximately 1000 m (Karanja, 1983, p. 9). Three members have been distinguished.

- The Lower Mazeras Member consists of Late Triassic, partly silicified, banded sandstones (Karanja, 1983, p. 8). In the older geological reports of Caswell (1953; 1956) and Thompson (1956) the unit is largely included in the Upper Division of the Mariakani Sandstones.
- The Middle Mazeras Member consists mainly of Early (?) Jurassic, arkosic sandstones with pebble and shale horizons.
- The Upper Mazeras Member consists of Early Jurassic, pebbly, arkosic sandstones with abundant pebble horizons. In the older stratigraphies the unit is known as the Shimba Grits.

Kambe and Mtomkuu Formations and Upper Cretaceous
For description of these lithostratigraphical units see Section 3.1.1.1.

Eocene
An unfossiliferous sequence of mudstones and feldspatic sandstones has been reported in the northwestern part of the Lamu embayment (Walters & Linton, 1973, p. 141). They reach a thickness of about 1000 m and are believed to be contemporary with the Middle Eocene beds at the southeastern part of the embayment. In early geological reports the lower part of the sediments near Hadu were considered as Eocene (Gregory, 1921, p. 73-4 and 383-4) but during a later survey carried out by Williams (1962) no conclusive evidence for their existence could be found. The presence of Eocene outcrops in the study area is therefore still uncertain.

Miocene
Along the margins of the Lamu embayment Miocene mudstones with interbedded sandstones have been reported by Walters & Linton (1973, p. 143). The beds, with a thickness of up to about 1400 m, are contemporary with the Miocene limestones in the littoral succession. The mudstones have not yet been recognized in outcrops in the study area. However is it is likely that they form an important part of the subsurface in the most northern part of the paralic zone.

Plio-Pleistocene
Approximately 100 m of unfossiliferous Plio-Pleistocene sands and clays occur in the Lamu embayment. The are believed to have been laid down under fluviatile and eolian conditions (Walters & Linton, 1973, p. 143). In the unpublished maps and reports of Matheson (1961a, b) the deposits are indicated as Pliocene sands and clays (unit Tpl). Saggerson and Baker (1965, p. 65) described them as lagoonal sediments connected with the incursion of a shallow sea over the end-Tertiary surface. In more recent soil survey reports they became known as Plio-Pleistocene Bay sediments (Sombroek et al., 1982, Van Wijngaarden & van Engelen, 1985). The superficial deposits of the paralic zone consist for the larger part of reworked materials derived from these Plio-Pleistocene clays and sands. Matheson (1961a, b) divided the Quaternary surface materials into three units: red sandy soils (unit Qr),

grey sandy clays (Qg) and black cotton soils (Qb).

- The red sandy soils correspond partly with the deposits of the higher-level sedimentary plain (Red Sand Plain) on the exploratory soil map of Kenya (Sombroek et al., 1982, p. 31). The Quaternary superficial deposits of the Tsavo Area (Van Wijngaarden & van Engelen, 1985) are provisionally correlated with this unit.
- The grey sandy clays correlate more or less with the deposits of the Sealing Loam Plain of the middle-level sedimentary plains on the exploratory soil map of Kenya. The Red-brown sands distinguished in the Malindi area (Thompson, 1956, p. 31) are provisionally included in this unit.
- The black cotton soils correspond largely with the deposits of the lower-level sedimentary plain (Grey Clay Plain) on the exploratory soil map of Kenya. On most geological maps they are indicated as black cotton soils.

3.1.2.2 Morphological structure

A southern, central and northern section can be distinguished in the paralic zone which is analogous to the division of the littoral part of the coast.

- The southern section embraces the drainage basins of the Umba and Mwena rivers. The area is characterised by a narrow strip of dissected country extending into wide undulating plains which form the northern part of the Coastal Plateau of Tanzania.
- The central section covers the area northward up to the Voi-Sabaki watershed. The area has a moderate to strong dissected seaward part of about 100 to 125 km wide. Residual hills of the Coast Range occur on each of the major watershed areas. In terms of tectonic structure, the central section forms the coastal termination of the Maktau dome mentioned by Saggerson & Baker (1965, p. 57).
- The northern section comprises the drainage basins of the Galana and Tana rivers. The area is characterised by extremely flat plains in the west and north. A hill country, with a varying degree of dissection, occurs in the southwestern part. Geographically the areas belong to the Nyika and the Rogge Plateau, respectively. Structurally they form part of the Lamu embayment distinguished by Walters & Linton (1973, p. 134). In the division proposed by Karanja (1983, p. 5), the northeastern part belongs to the Lamu sedimentary basin and the remaining part to the Mombasa basin.

The configuration of the landscape in these three sections reflects changing conditions of erosion and sedimentation. In the undissected areas, this is evidenced by the presence of at least three major erosion and sedimentation levels. In the more dissected terrains, two summit levels can be recognised. The paralic levels appear to be correlative with the higher levels of the littoral zone (Table 19).
Another factor which influences the morphology of the paralic zone is the

Table 19 Classification of the paralic levels

	plain levels		summit levels		correlative littoral level	
category	name	elevation (m +MSL)	name	elevation (m +MSL)	name	elevation (m +MSL)
lower	Mitangani	50 to 300	-	-	Tezo	40 to 85
middle	Samburu	100 to 400	Bore	85 to 300	Cambini	85 to 130
higher	Taru	175 to 500	Mtsengo	150 to 300	Sokoke	130 to 175

structure of the rocks in the subsurface. The presence of alternating soft shales and massive sandstones in the succession of the Duruma Group has led to the development of a series of cuestas. Later, stream erosion caused strong dissection in places or even complete removal of these landforms. In the northern section, the structural ridges in the Duruma deposits seem to have been buried by the Plio-pleistocene sediments of the Lamu embayment. This shows that the formation of the cuesta landscape most probably took place before the inset of the Plio-Pleistocene period.
The morphology of the paralic zone is analysed in more detail below. The various sedimentary and erosional levels are used to derive a relative chronology of the landscapes. The individual landforms are described and discussed in order to characterise levels in a same way as has been done for the littoral zone.

3.1.2.2.1 Lower paralic levels

Between about 50 and 300 m +MSL a gently coastward sloping plain level occurs which is the lowest in the sequence of three erosional and sedimentary surfaces found in the paralic zone. In the present study it is referred to as the Mitangani level.
Typical characteristics are the abraded nature of the underlying rocks of the Duruma Group and the basal gravel lag beneath a cover of clayey deposits. These superficial materials are partly indicated as the bay sediments or deposits on the soil maps of the Voi and Kilifi areas (Van Wijngaarden & van Engelen, 1985; Boxem et al. 1987). They generally correlate with the Black Cotton Soils distinguished by Matheson (1961a, b). The basal gravel layer consists of rounded and subrounded quartz and sandstone fragments. It also contains numerous Middle Stone Age implements. This shows a strong resemblance with the gravel layer of the Tezo level in the littoral zone. In the northern section a correlation between the two is confirmed by the smooth transition of the surface of the Mitangani level to that of the Tezo level. However, in the central section both levels are separated by an escarpment the position of which coincides with the Kazakini-Mombasa Fault. Therefore a tectonic displacement of the Mitangani level and the Tezo level in the central section is understandable and probably due to a reactivation of this Mesozoic fault zone.

Table 20 Land units of the lower paralic levels

southern section		central section		northern section	
land types	components	land types	components	land types	components
paralic plains	plain platforms interfluve ridges	paralic plains	plain platforms interfluve ridges scarped ridges	paralic plains	plain platforms interfluve ridges
stream valleys	valley slopes valley bottoms	stream valleys	valley slopes valley bottoms	stream valleys	valley slopes valley bottoms

In Table 20 a synopsis is given of the various land units which have been distinguished. They are described and discussed in more detail below.

Central section

The general configuration of the landscape in the central section is determined mainly by a varying degree of dissection. On the geomorphological map non, slightly and moderately dissected parts are distinguished. In terms of topographic relief they correspond with flat to almost flat, undulating and rolling areas respectively. As a result of this dissection two major land types, indicated as paralic plains and stream valleys, are found.

Paralic plains

The paralic plains are formed by the remnants of the original surface of the Mitangani level. They are underlain by the rocks of the Taru, Maji ya Chumvi, Mariakani and the Mazeras Formations. Three components can be distinguished (Table 20).

Fig. 17 Undulating area of the Mitangani level west of Gotani

- The plain platforms are represented by the flat parts of the Mitangani level. They can occur as extensive plain surfaces or as isolated remnants surrounded by stream valleys. In the central section large plain platforms are found only on the Mwatate-Voi and the Voi-Galana watersheds. The smaller ones occur on most main divides of the rivers in the area. The thickness of the superficial clayey or sandy deposits varies according to the degree of dissection. Near the edge of the undissected Mitangani area, west of Bamba, 3 to 4 m of unconsolidated material is exposed in fresh gullies eroding backward from the more dissected areas along the Voi river. On the interfluve on which the Mombasa-Nairobi road is situated the deposit unconformably overlying the rocks of the Duruma group is not more than 1 to 2 m thick.

  When looking at the details of the terrain it is possible to differentiate higher and lower parts of the platforms (Fig. 17). The lower parts form a vague pattern of broad, flat bottomed areas which form part of an filled-in creek or valley system. In the case of a creek system, these lower parts may represent an original sedimentary pattern of the paralic areas. If they are filled-in stream valleys their presence points to two different phases in the genesis of the Mitangani level. This may be an indication that on the Mitangani level an older and a younger sublevel need to be distinguished.

  The soils in the platforms consist in general of Solonetz and Vertisols with a high ESP. On the lower parts of the large platforms grey, gleyic and Vertic Solonetz, often with a saline phase, are common. The soils on the higher parts are brown, Orthic Solonetz. On the more isolated platform remnants the soils do not often meet the structural or chemical requirements for a natric B-horizon. Therefore they are classified as gleyic, vertic and Orthic Luvisols respectively. The characteristic high sodium percentage is then reflected in their sodic phase. The Vertisols are very dark grey to black and occur mainly in semi-circular depressions on the higher parts. They are also found in places where in the near subsurface the shale beds of the rocks of the Duruma group occur. On the reconnaissance soil map of the Voi area (Van Wijngaarden & van Engelen, 1985, Appendix 1b) they correspond with the soils of unit PsA22. In the Kilifi area (Boxem et al., 1987, Appendix 1) they correlate with the soils of unit P1O1.
- The interfluve ridges are represented by the rounded ridges between the stream valleys in the dissected parts of the Mitangani level. They are commonly covered by a residual mixture of redeposited, superficial clays and erosional products of the underlying rocks of the Duruma Group. In these areas the artefacts from the basal gravel layer can be found on the summit of the interfluve as well as on its edges and adjacent valley slopes. The thickness of this mixed superficial deposit varies from less than 20 cm to more than 1 m. Consequently, the textural characteristics of the deposits on the interfluve ridges in particular vary with the nature of the underlying rocks.

  The soil profiles have commonly a AB(C2R) horizon sequence. They are classified in most cases as Cambisols and Luvisols with a sodic phase. On the soil maps of the Kenya Soil Survey they are included in the soils of the Coastal Uplands.

- The scarped ridges are represented by low cuestas which occur in places where the structural influence of hard sandstone beds dominates the surface morphology. The ridges are known to occur especially in the area underlain by the rocks of the upper Maji ya Chumvi and lower Mariakani Formation. The superficial Mitangani deposits are often absent. The soils are shallow and formed from materials derived primarily from the subsurface rocks.

Stream valleys

The stream valleys of the Mitangani level consist of elongated depressions carved by fluviatile activity in the general plain level. They are often shown to have a complex shape caused by alternating periods of dissection and in-fill. Two components can easily be distinguished (Table 20).

- The valley slopes are represented by the often sloping terrains which form the connection between the valley bottom and the edge of the interfluve ridge or plain platform. This last boundary is often hard to delineate on aerial photographs, but can be recognized in the field by a slight break of slope and a decrease in soil depth. As on the interfluve summits the superficial deposits consist of a mixture of reworked paralic deposits and debris from the underlying rocks. Most soils which developed in them have an A(B)C2R horizon sequence. They are classified in general as Luvisols, Cambisols and Regosols.
- The valley floors are formed of the flat bottoms of the stream valleys. Present-day erosion is often actively excavating this unit. This shows that the last in-fill which led to the formation of the valley floors belongs to a former episode in the geomorphological history of the area. It probably concerns a drier phase with a high sediment supply which choked the valleys. The complex shape of many stream valleys shows that this process of filling-in and later dissection took place at least twice after the formation of the Mitangani level.
  The soils of the valley floors vary from Eutric Fluvisols in the recently displaced deposits to Pellic and Chromic Vertisols in the older deposits.

The larger stream valleys with recognizable terraces and other fluviatile forms have been mapped separately and are described in Section 3.2.3.

Southern section

The landscape of the southern parts of the Mitangani level is comparable with the dissected parts of the central section. The main difference is that the plains of the Mitangani level become narrower towards the south. The last connection with the Tezo level of the littoral zone is found along the valleys of the Mwena and Ramisi rivers. Its total absence in the Umba basin leads to the impression that the erosion preceding the formation of the Mitangani level was mainly active in the central and northern sections of the coast. This may indicate that during the Pleistocene period there was a climatic zonation comparable to that of today. During the drier periods, which led to the dissection of the area prior to the formation of Mitangani, level the boundaries of the arid zones lay further south but possibly never as far as the Kenya-Tanzania border.

Northern section

The landscape of the northern parts of the Mitangani level is typified by its extensive and extremely flat plains. Dissection is only present in a narrow zone around the Galana River. The thickness of the superficial Mitangani deposits increases towards the north. It causes the almost complete disappearance of the structural influence of underlying consolidated rocks. As in the central section two major land units can be distinguished (Table 20). They are briefly described and discussed below.

Paralic plains
The paralic plains of the northern section mainly differ from those in the central and southern section by a lesser degree of dissection and a thicker superficial sediment cover. As a result of this, the areas have an impeded internal and external drainage. Many waterholes and pans occurs as minor landforms. Their character and origin has not yet been studied.
The soils also reflect the imperfect drainage conditions of the area. On the plain platforms mainly Solonetz occur. Those of the lower parts are greyish brown, slightly calcareous, moderately saline and classify as Gleyic Solonetz with a saline phase. On the Exploratory Soil Map of Kenya (Sombroek et al., 1982, Appendix 1) the soils are included in the units Ps16 and Ps19. On the higher parts intergrades between Luvisols and Solonetz are found. The soils are brown and moderately calcareous and sodic. The moderately deep ones to the south classify as Orthic Luvisols and Solonetz and correspond with the soils of unit Ps19 on the Exploratory Soil Map of Kenya. The deeper soils to the north are the orthic Luvisols and Solonetz of unit Ps23 on the same exploratory soil map. They have in addition a saline phase and a sealing thin topsoil (Sombroek et al., 1982, p. 33).

Stream valleys
The stream valleys mainly occur as branches of the main valley of the Galana river. Their shape and position is often structurally controlled. Like the stream valleys of the central section they usually have a thin cover of superficial deposits on their slopes. The valley floors are undergoing active erosion at present.
The main valleys of the Galana, Tiva and Tana rivers have mappable remnants of fluviatile terraces. They are further described in Section 3.2.3.

Table 21 Land units of the middle paralic levels

southern section		central section		northern section	
land types	components	land types	components	land types	components
paralic plains	plain platforms interfluve ridges	paralic plains	plain platforms interfluve ridges	paralic plains	plain platforms interfluve ridges
paralic hills & plateaus	plateau plains interfluve ridges	paralic hills & plateaus	plateau plains interfluve ridges scarped ridges	paralic hills & plateaus	plateau plains interfluve ridges
stream valleys	valley slopes valley bottoms	stream valleys	valley slopes valley bottoms	stream valleys	valley slopes valley bottoms

Fig. 19 Exposure of deposits underlying the plains of the Samburu level at Aruba dam (Tsavo National Park East)

with an earlier phase of deposition. However, since a sharp break in the succession is absent, it is provisionally assumed that the deposits are indeed connected with the formation of the Samburu level.
Van Wijngaarden (1978, p, 58) proposed a tectonic closure of the Voi valley and a subsequent in-filling of the basin. This would mean that the lower part of the deposits could have accumulated independently of the other sediments of the Samburu level.
Of particular interest is the presence of hundreds of holes in the sandstones which outcrop at this eastern edge of the Samburu level. Their form and size varies but, when excavated, they all appear to be filled with almost pure gravel underlying an disturbed cover of mud and sands. Both their form and fill cause them to resemble the potholes seen in most major rivers (e.g. at Luggards Falls in the Galana river). However, a similarity also exists between these holes and the pits on the abrasion ramps of the present-day shore. If their origin is fluviatile, this points to a period in which the streams of the central part must have had a far

Fig. 20 Rock basins near Samburu along the Nairobi-Mombasa road

greater discharge than they have today. When a tidal and wave-induced origin is accepted it is tempting to connect their formation with a transgressive phase which resulted in the cutting of one or more of the paralic levels. However the potholes are not necessarily contemporaneous with these events. They may also be the relics of much earlier processes and conditions, although their fresh appearance contradicts this suggestion. Possible origin as weather pits or gamnas by weathering and solution (Twidale, 1976, p. 203) is unlikely since the smooth inner surfaces are different from those of hollows which are found to develop along fractures. Moreover the composition of the gravel fill shows that a considerable amount of the material is not derived in situ but comes from formations to the east. This contradicts both the fluviatile and the weathering option. More detailed observations must be made in order to unravel the history of these minor landforms.

The soils of the undissected plains of the Samburu level in the central section consist in general of reddish brown to red Luvisols and Acrisols. On the soil map of the Voi Area (Van Wijngaarden & van Engelen, 1985, Appendix 1b) the parts of the Samburu level with deep unconsolidated deposits are included in the sedimentary plains. The related soils have been classified as Chromic Luvisols (unit PsFr2). The areas where the superficial deposits are relatively thin are indicated as erosional plains on the soil maps. The character of the subsurface lithology has had a greater influence on the soil formation. Where sandstones occur in the subsurface the soils consist mainly of chromic Luvisols, partly with a petric phase. If the substratum consists of shale, Vertic Luvisols and Chromic or Pellic Vertisols occur. The detail on the soil maps of the Kenya Soil Survey does not permit a straightforward correlation between the soil mapping units of the erosional plains and the Samburu level of the present study. The presence of a filled-in valley system with Vertisols and Solonetz, is an indication that a further division of the Samburu level may be made. Similar Vertisols and Solonetz occur in many of the semi-circular waterholes.

- The interfluve ridges are represented by the often lowered plain remnants between the stream valleys at the eastern edge of the Samburu level. As a result the superficial deposits are either thin or even absent completely. The soils are characterised by an A(BC)2R horizon sequence and classify as Orthic Luvisols or Acrisols with associated Eutric Cambisols and Lithosols. On the soil map of the Kwale area (Michieka, 1978, Appendix ia), the soils are included in mapping units PSTb and PKT1P.

Paralic hills and plateaus

The paralic hills and plateaus consist of the elevated remnants of the middle level in the paralic zone. The morphology of the landscape is mainly determined by the degree of dissection and the character of the subsurface rocks. Two major land units have been distinguished (Table 21).

- The plateau plains are represented by the flat summit areas of the Bore level. They are characterised by superficial deposits consisting of sands and sandy clays. On the geological maps of the Kilifi and Kwale areas these deposits have not been identified. However, on the Exploratory Soil Map of Kenya (Sombroek et al., 1982, p. 21, unit Lc3), they are partly indicated as cover sands (mainly derived from Magarini sands). Grain size analysis carried out during the present study shows that the sand fraction of the deposits is moderately well sorted. When compared to the good to very good sorting of the dune and drift sands of the littoral zone a wind blown origin is unlikely. Although not observed, a local redeposition of the sands by eolian activity is nevertheless possible. The term cover sands should be avoided, however, as it is by definition associated with materials that have been deposited by heavy snowstorms during a glacial epoch (Bates & Jackson, 1980, p. 144).

  The plateau plains of the Bore level are characterised by an association of strongly bleached and ferruginated soils when underlain by the sandstones of the Duruma Group. The bleached soils are white to pale yellow and have an A-E-(B) horizon sequence. They generally occur in relatively lower positions and classify as Albic and Luvic Arenosols. On the soil map of the Kilifi Area (Boxem et al., 1987, Appendix 1) they correspond with the soils of unit USs1 and USKf. The ferruginated soils seem to be connected with relatively higher positions. They are commonly yellowish red and have an A-B-(C) horizon sequence and classify mainly as ferralic Arenosols. On the Kilifi soil map they largely correspond with the soils of unit USs2p and USs3. When underlain by the limestones of the Kambe Formation the plateau plains are characterised by dark red Luvisols and Acrisols.

- The interfluve ridges are represented by the eroded remnants of the middle level found between two adjacent valleys. They dominate the landscape of the Bore level in the central section. The superficial deposits have been either completely removed or redeposited and mixed with residual material derived from the underlying rocks. The soil variation becomes greater and more related to the character of the subsurface lithology.
  The soils consist largely of Albic and Luvic Arenosols when underlain by the sandstones of the Mariakani and Mazeras Formations. On the soil map of the Kilifi area (Boxem et al., 1987, Appendix 1), the soils are included in the mapping units USkf and USs1. In the Kwale area they are part of the soil mapping units USk1 and USk5 (Michieka, 1978, Appendix 1a).
- The scarped ridges are represented by the isolated cuestas of the massive sandstone beds in the upper Maji ya Chumvi and Mariakani Formations. Good examples can be seen at Mariakani-Gotani-Bamba, Mapotea, Dundani and Ndavaya. They have usually lost most of the superficial deposits and soils are characterised by shallow A-(B)-C-R profiles.

Stream valleys

The stream valleys of the Samburu and Bore levels are characterised by a complex soil pattern on the valley slopes and various partly excavated valley floors. This configuration gives an important record of the climatic and tectonic history of the coastal area. A detailed analysis of landforms was not carried out as it goes beyond the possibilities of the present study.

Southern section

In the most southern part of the coast, the plains of the Samburu level extend into the eastward plains of the Mahuruni/Cambini level in the littoral zone. This provides evidence for the correlation of the Samburu level with the marine terrace sequence. The landscape consists of a non to slightly dissected plain and is essentially the same as that described for the central section.

Northern section

In the north the Samburu level is represented by extensive areas of extremely flat plain land north of the Galana river. The Bore level at the eastward side of the paralic zone is found as a summit level of the Rogge Plateau. In the studies of Toya et al. (1973, p. 87) the term Marafa Surface is used for the flat parts of the Bore level around Marafa and the Arabuko Forest. However, in the exposures of the erosion cirques near Marafa and Bore it can be seen that the Marafa Beds are truncated by the superficial deposits of the Bore level. The conclusion that the Marafa Surface represents an accumulation surface related to the Marafa beds (Toya et al., 1973, p. 87-8) is therefore incorrect.

Especially around the Galana river additional evidence is found for the correlation of the Samburu/Bore level with the Cambini level of the littoral zone. As in the south, the levels pass into each other without a clear topographical break. Consequently, the boundary definition has been based largely on the differences in soils and subsurface geology.

On the Rogge Plateau the landscape is composed of wide plateau plains with stream valleys and interfluves ridges in the more dissected areas. The thickness of the superficial deposits increases towards the north. This is reflected in the more uniform soils which occur as a result of the decreasing influence of the subsurface geology. The superficial deposits correlate partly with the Reddish brown superficial sands distinguished by Williams (1962, p. 48, unit Qr) and the Red-brown Sands of Thompson (1956, p. 31, mapping unit Qr).

The soil pattern on the Bore level is similar to that of the central area with the exception of the most northern part of the Rogge Plateau. Here mostly sodic, brown soils with an A-(E)-B horizon sequence are found. They have been classified as Solodic Planosols with Orthic Solonetz and Luvisols (Sombroek et al., 1982, p. 32, unit Ps20, Ps15). This change in soils seems to be related to the increasing depth of the superficial deposits and the presence of Plio-Pleistocene sodic and alkaline clays in the subsurface.

In the western part of the Samburu level red to reddish brown soils with an A-(E)-B horizon sequence predominate. It is possible to differentiate between a higher and a lower sublevel. On the higher mainly orthic Luvisols are found. They correlate loosely with the soils of unit PsA12 on the soil map of the Mtito Andei Area (Van Wijngaarden & van Engelen, 1985, Appendix 1a). The lower sublevel is characterised by intergrades between Solodic Planosols and Orthic Solonetz with a saline phase (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, unit PsA13). On the Exploratory Soil Map of Kenya the soils of the units Ps6, Ps5 and Ps15 correlate with those on the higher and lower Samburu sublevels respectively. This means that there is not always a straightforward correlation with the higher, middle and lower-level sedimentary plains on the exploratory soils map. However, in general the correlation seems to be correct. More fieldwork is needed to clarify the differences and to improve the definitions of the various levels.

Table 22 Land units of the higher paralic levels

southern section		central section		northern section	
land types	components	land types	components	land types	components
paralic plains	plain platforms interfluve ridges	paralic plains	plain platforms interfluve ridges	paralic plains	plain platforms interfluve ridges
paralic hills & plateaus	plateau plains interfluve ridges	paralic hills & plateaus	plateau plains interfluve ridges scarped ridges	paralic hills & plateaus	plateau plains interfluve ridges
stream valleys	valley slopes valley bottoms	stream valleys	valley slopes valley bottoms	stream valleys	valley slopes valley bottoms

3.1.2.2.3 Higher paralic levels

Between about 150 and 500 m +MSL a third gently coastward-sloping level is found in the western part of the Nyika. It has been called the Taru level in the present study. Its upper boundary is formed by a slight break in slope at the transition to the denudational plains of the Tsavo area. The lower boundary is similarly found at the transition to the Samburu level. The Taru level is mainly underlain by sedimentary rocks of the Taru and Maji ya Chumvi Formation of the Duruma Group. In the most western parts metamorphic rocks of the Mozambique belt are found in the subsurface.
Towards the coast an apparently correlative summit level occurs in the eastern parts of the Giriama hill country and on the Foot Plateau. It has been named the Mtsengo level in the present study. Between Mangea Hill and the Sokoke Forest the Mtsengo level is shown to pass into the Sokoke level of the littoral zone. The Mtsengo level is underlain by Mesozoic sandstones, shales and limestones of the Mariakani, Mazeras and Kambe Formations.
The abraded platforms of the Taru and Mtsengo levels are unconformably overlain by unconsolidated superficial deposits which vary from clayey sands to sandy clays. Directly on the abraded surface a basal gravel lag occurs. The gravel consists mainly of rounded and subrounded quartz fragments with a few, usually large implements made of quartzitic sandstone. The superficial deposits form the eastward continuation of the fills of wide valleys found in the Tsavo area. On the geomorphological map (Appendix 1) these valleys are partly included in the fluvial areas. The very existence of these infilled valleys shows that, prior to the formation of the highest paralic plain, there was a period of intensive and prolonged erosion which led to the formation of the wide valleys of the Tsavo area and gave rise to a far greater relief intensity than is found at present. Table 22 gives a synopsis of the major land units distinguished during the present study. A more detailed description of the units is given below.

Central section

The areas of the Taru level in the central section are non to slightly dissected and part of an almost flat to gently undulating plain landscape with wide shallow valleys. In contrast the areas of the correlative Mtsengo surface at the seaward part of the coast rise above the level of the surrounding coastal plains and are usually more dissected. Consequently the landscape consists of a rolling to steeply dissected hill and plateau landscape often with complex, steep walled valleys.

Paralic plains
The paralic plains consist of the non-elevated remnants of the higher levels in the transitional zone of the coastland towards the interior. As on the lower and middle levels, the plains can be further subdivided into three components.

- The plain platforms are represented by the flat parts of the Taru level. They occur as extensive plain surfaces or as isolated remnants between stream valleys. The platforms are characterised by unconsolidated superficial deposits of around 1 to 4 m thick, consisting of mainly clayey sands. They loosely correlate with the Red Sandy Soils of Matheson (1961a, b) and are considered to be partly reworked Plio-Pleistocene deposits (Table 18). The basal gravel layer does often contain pisoferric or pisocalcic material beside the dominating quartz gravel. This shows that ferricretes and calcretes must have been present before the deposition of the superficial sediments.
Numerous potholes occur in the rock outcrops at the transition to the lower Samburu level. An impressive site occurs at about 500 m east of the branch to the Taru station, just north of the Mombasa-Nairobi road (Fig. 21). As on the Samburu level, the potholes have gravel deposits in the deeper parts of the pits. Samples of the gravel have been shown to contain artefacts and skeleton remnants. The small bone and molar fragments have been identified as parts of a pig (probably Tapinochoerus), antelopes,a duiker and tortoises and may be the dietary

Fig. 21 Rock basins east of Taru railway station

remains of crocodiles (G. Kortenbout van der Sluis, Rijksmuseum van Geologie en Mineralogie. Leiden, pers. communication). All species, as far as their age is known, come from the Middle Pleistocene and probably from its upper part. The skeleton fragments of the pig may point to a wetter period. If the skeletal fragments are indeed dietary remains of crocodiles this shows that during the end of the Middle Pleistocene the climate in the present Taru Desert was more humid. It remains uncertain as to whether these wetter conditions were responsible for the formation of the potholes. Their size of 1 to 3 m in diameter is relatively large compared with that of the potholes at Luggards falls. Valleys with a size comparable with that of the present-day Galana River are absent along the edge of the Taru level at the places where the potholes occur. Therefore it seems more likely that the potholes of the Taru level either originate from an earlier date or were formed by non-fluviatile processes.
Soil formation has led to the development of deep argillic B-horizons which are red to dark red in the well drained positions. The soils classify mainly as Ferric Acrisols and Luvisols. On the soil map of the Voi area (Van Wijngaarden & Van Engelen, 1985, Appendix 1b), they are included in mapping unit PSFr1 and probably are also part of the units PN2Stbp and Pn2Strp.

- The interfluve ridges are represented by the eroded remnants of the original surface of the Taru level. They occur mainly at the transition towards the dissected plain area around the Galana river. The superficial deposit is usually less than 50 cm thick.
  The soils are often truncated and classify as Chromic Cambisols and Luvisols. They form part of unit PdStC on the soil map of the Voi area.

Paralic hills and plateaus

The paralic hills and plateaus consist of the elevated remnants of the higher level of the transitional zone towards the interior. The morphology of the landscape is dictated primarily by the degree of dissection and the character of the subsurface rocks. As on the middle level, two land types can be distinguished.

- The plateau plains are represented by the flat summit areas of the Mtsengo level. The superficial cover mostly consist of sandy clays and is shown to be about 2 m to more than 5 m thick. A characteristic of the basal gravel layer is that it contains abundant pisoferric material. The plateau plains are well preserved on the limestones and sandstones of the Kambe Mazeras Formations in the Kilifi area.
  The soils consist in general of Chromic Luvisols and Acrisols and Dystric Nitosols (Boxem et al., 1987, Appendix 1, mapping unit USc1 and ULc1).
- The interfluve ridges are formed by the partly eroded remnants of the higher paralic level situated between two adjacent stream valleys. The superficial deposits are either completely removed or have been partly reworked. Consequently the lithology of the substratum has more influence on the landscape.

The soils of the interfluve ridges show evidence of prolonged clay eluviation. In the Kwale area this has led to the formation of thick E-horizons on the better preserved interfluve summits. Here the soils classify as Albic Luvisols or Albic and Luvic Arenosols. On the more eroded interfluve ridges the truncated B-horizon directly underlies the A-horizon and the soils classify mainly as Chromic Acrisols. On the soil map of the Kwale-Mombasa area (Michieka et al., 1978, Appendix 1a) the soils are included in mapping unit UssCland USsC2. In the Kilifi area the soils are part of the mapping unit USc1 (Boxem et al., 1987, appendix 1).

Stream valleys

The stream valleys occur mainly in the eastern part of the paralic zone. They are complex and can be classified as multi-cycle valleys. Valley shoulders are most common in the Mtsengo hills and plateaus. Some are structural benches connected with resistant layers in the sedimentary rocks of the Duruma group. Others are clearly remnants of old valley bottoms as evidenced by soils with deep dark A-horizons.

Southern section

In the southern section of the coastland the plains of the Taru level are probably present in the western-most part of the Umba basin. The mapping of the level in this part of the study area is based on satellite image interpretation only and more fieldwork is needed to confirm the boundaries. Further towards the coast paralic hills occur between the Ramisi and Mwena rivers. The area is partly underlain by the sub-volcanic rocks of the Jombo complex, which is reflected in the more clayey nature of the superficial deposits. The soils in these mixed materials have been mapped as Eutric Nitosols (Michieka, 1978, appendix 1a, unit Ulr).

Northern section

In the northern section, the Taru level is represented by the higher parts of the extreme flat plains to the north of the Galana river. On the soil map of the Mtito Andei area (Van Wijngaarden & van Engelen, 1985, Appendix 1a) the area is part of the Sedimentary Plains with unconsolidated sandy deposits indicated as Quaternary superficial deposits. The soils are primarily Ferric Luvisols with a sodic phase (mapping unit PSA11 of the Mtito Andei soil map).

In the eastern part of the northern section, relatively small summit areas of the Rogge Plateau have been identified as remnants of the Mtsengo level. More fieldwork is necessary to confirm the geomorphological boundaries of this area.

In conclusion, it can be said that the higher paralic levels are characterised by unconsolidated superficial deposits which correlate loosely

with the Red sandy soils of Matheson (1961a, b). The deposition took place after a period of prolonged erosion during which the wide valleys, connected with the paralic plains, were formed. In the west, the paralic plains are best preserved and still form part of an extremely flat landscape. The hills and plateaus in the eastern part of the paralic zone show that during the later development of the area dissection prevailed near the transition to the littoral zone.
The soils which developed in the western parts of the paralic zone are mainly Ferric Luvisols where the superficial deposits are thick. In areas where the deposits are thinner Chromic Luvisols and Acrisols occur. In the lower and middle levels the sodium content of the deposits increases towards the Lamu embayment. The soils of the eastern part are also characterised by clay illuviation which seems to have been most intense in the southeastern part of the paralic zone.

3.1.2.3 Origin and development

The morphological structure of the paralic zone of southeast Kenya reflects the influence of three main erosional and sedimentary episodes. The sequence of events which led to the genesis and later development of these transitional coastal areas is summarised in Section 3.1.2.3.1. No 14C or other radiometric datings are available to establish a direct correlation with the Plio-Pleistocene stratigraphy known from other areas. The only means of dating the various paralic levels is through correlation with the littoral levels. In next sections this correlation and the possible tectonic and climatic effects which played a role in the development of the paralic areas are described and discussed.

3.1.2.3.1 Sequence of events

The topographical transition of the main paralic levels into the higher levels of the littoral zone shows that a clear connection exists between both parts of the coastland. Therefore the terminology used for the subdivision of the time during which the littoral part of the coastland developed has also been used for the paralic areas.
A synopsis of the main events in the two coastal zones is given in Table 23 and is further discussed below.

Early Nyika period
The early stage of the Nyika period embraces the time during which the land surface of the paralic zone was initiated. This interval comprises the three episodes (older, middle and younger) during which the Taru/Mtsengo, Samburu/Bore and Mitangani were formed. These levels can be considered as

Table 23 Subdivision of the Nyika period in the paralic zone

period	surface	littoral level	sea level	paralic level	major event	stratigraphical record
Late Nyika	lower	Bofa	high			
	middle	Uhuru-II Uhuru-I	high high		dissection	
	upper	Mackenzie-II Mackenzie-I	high low high		dissection	
Middle Nyika	lower	Mtondia-II Mtondia-I	high high low		dissection	
	upper	Majaoni-II Majaoni-I	high high low		dissection	
Early Nyika	lower	Tezo-II Tezo-I	high high low	Mitangani	faulting, in-fill ? dissection? in-fill dissection	Black cotton soils
	middle	Cambini-II Cambini-I	high high low	Samburu/Bore	in-fill ? dissection? in-fill dissection	Grey sandy clay
	upper	Sokoke-II Sokoke-I	high high low	Taru/Mtsengo	in-fill ? dissection? in-fill dissection	Red sandy soils

the paralic representatives of what is indicated regionally as the upper, middle and lower Early Nyika Surfaces respectively.

- The older Early Nyika episode started with a phase of strong dissection of the then existing land surface. It resulted in the formation of wide valleys the outlines of which are still visible in the area west of the paralic zone. This phase of erosion is believed to be the same as the one which at the littoral zone led to the dissection of the ferricreted End-Tertiary surface found on top of the Marafa Formation. The presence of abundant pisoferric material in the basal gravel lag under the paralic deposits of the Taru and Mtsengo levels seems to indicate that to the interior a ferricrete cap had also developed.

  After the period of deep incision the wide valleys were filled-in with gravels, sands and clays. Continuing deposition caused the whole eastern half of the study area to become covered by unconsolidated sediments. This event is believed to be the southern equivalent of the incursion of a shallow sea in the Tana basin mentioned by Saggerson and Baker (1965, p. 65). The deposits connected with this event in the paralic zone of southeast Kenya are therefore thought to be correlated with the Plio-Pleistocene lagoonal deposits of the Tana basin and the Lower Magarini

Formation of the littoral zone. Part of the sedimentary succession exposed near the Aruba dam in the Tsavo National Park East may be related to this event, however, the absence of a clear break between the top and lower beds points to a relationship with a later phase of deposition.
Later fluctuations of the sea level probably caused the Plio-Pleistocene deposits to be reworked and mixed with sheet wash deposits. In the littoral zone these events led to the formation of the Sokoke levels. The sea level lowering at the end of this episode caused the final emergence of the Taru/Mtsengo level and the beginning of soil formation.

- The middle Early Nyika episode is connected with the formation of the Samburu and Bore levels. It started with a phase of strong erosion which is evidenced by the isolated position of remnants of the Mtsengo level in the eastern parts of the paralic zone. The erosion involved, beside a general lowering of the surface in the central and northern parts of the littoral zone, a partial excavation of the in-filled valleys which reach further inland. This again shows that a considerable lowering of the erosion base must have taken place in which both uplift and sea-level lowering are believed to have played a role.
During a subsequent stage of high sea-levels the excavated parts of the paralic zone became filled in again. In the littoral zone the Changamwe deposits were laid down. The deposits near the Aruba dam in the Tsavo National park are most probably the paralic equivalents of these.
The presence of a vague pattern of in-filled valleys on the Samburu level indicates that the subsequent emergence of the area may have taken place in two separate phases. More fieldwork is needed to confirm a direct link with the two Cambini sublevels found in the littoral zone.
A period with a tropical humid climate followed the emergence of the Samburu/Bore levels which resulted in the formation of the deep, red to dark red Luvisols, Acrisols and Solonetz. The presence of Stone Age implements in the basal gravels of the Samburu levels shows that hominids were living in the coastal area during this period.
- The younger Early Nyika episode is related to the formation of the Mitangani level. It started with a period of intense erosion during which large areas of the paralic plains of the Samburu level were completely removed or dissected by deep valleys. This was probably induced by a major lowering of the sea level and coincided with considerable tectonic movement in the eastern half of the littoral areas.
During the next stage the sea level rose again and in-fill of the eroded paralic areas recommenced. This led to the deposition of clays and sandy clays corresponding to the Black Cotton Soil deposits of Matheson (1961a, b). Like the other paralic deposits, the sediments apparently do not contain any fossils to provide an independent dating.
The widespread occurrence of Middle Stone age implements in the basal gravels of the Mitangani platform-deposits shows that the surface was once inhabited by a probably dense population of hominids. As in the littoral zone, the pronounced desert-varnish coatings on artefacts and other rock fragments provide evidence of dry conditions before the transgression

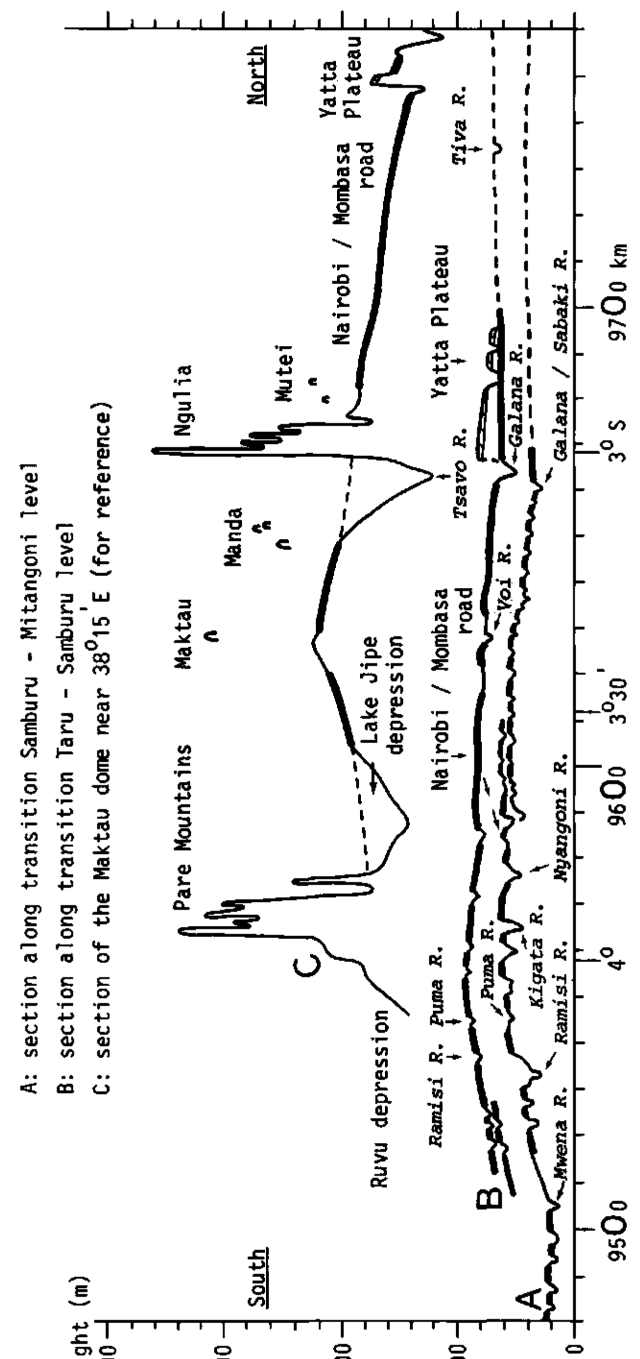


Fig. 22 North-south sections of the paralic levels

3.1.2.3.3 Tectonic and climatic effects

The influence of tectonic movement and climatic fluctuations on the features of the paralic zone has been extensively covered. However some special attention to the updoming of the area is given in this section. In Fig. 22 the elevations of both the inland and the seaward terminations of the paralic levels are shown in a north-south direction. It can be seen that uplift was strongest in the central section. The area of maximum uplift is simultaneously characterised by the strongest degree of dissection.
The exact mechanism of the uplift which produced this tectonic structure, known as the Maktau dome, is uncertain. As the whole paralic zone was affected in almost the same way, it is most likely that the uplift occurred after the emergence of the Tezo and Mitangani levels (550 to 600 ky BP). The most important regional event after this date was the main eruption of Mt. Kilimanjaro from the Kibo centre. Four K/Ar datings of the lavas gave ages ranging from 514 to 365 ky (Baker et al., 1971, p. 207, Table IX). During this impressive event a volcanic cone of about 5900 m high was formed. It is now suggested that this local burden of volcanic rocks caused an isostatic uplift of the areas west and north of it leading to the formation of the Maktau dome.

From the presence of the paralic plains behind a zone of higher coastal hills and plateaus it is concluded that in the Early and beginning of the Middle Pleistocene period a climatic zonation existed which was comparable to that of today. That the effect of the lithology in the subsurface has been of a secondary importance is shown by the fact that the paralic plains occur on different formations with different lithological characteristics. Hills and plateaus have also been formed in the same rocks. From this it is concluded that the repeated excavation of the central and northern parts of the paralic zones was probably mainly determined by the local arid conditions of those areas. At the coast a more stable vegetation may have occurred allowing valley incision but not extensive surface lowering. Towards the interior the vegetation was probably sufficiently dense to slow down the processes of removal of soil material by surface wash.

3.2 Interior region

The interior of southeast Kenya consists of flat to rolling plains with prominent residual hills west of the coastland. The region can be further subdivided into four main units (Appendix I).

- The denudational areas occupy the greater part of the interior and are characterised by the presence of residual deposits underlain by sedimentary or metamorphic rocks. Wide, flat to undulating plains predominate and form part of the Low Foreland Plateau distinguished by Ojany (1966, p. 193). Isolated or associated residual hills and low structural ridges which often rise abruptly from the surrounding plains are the main associated landforms. The higher residual hills have been previously described as parts of the Old upland massifs or the Intermediate Plateaus (Ojany, 1966, p. 189, 193). The residual hills and plateaus of the Coastal Range are likewise considered as denuded remains of former land surfaces. As a consequence of the way coastland and inland are defined, they have been mapped as isolated outliers of the interior landscape.
- The volcanic areas are present in the northwestern corner of the interior and are characterised by the presence of volcanic deposits. Geographically the areas are known as the Yatta Plateau and the Chyulu Range or Hills. The Yatta Plateau forms part of the Intermediate Lava Plateaus and Slopes. The Chyulu Hills belong to the Tertiary to Recent Volcanic Highlands and Plateaus (Ojany, 1966, p. 189, 192).
- The lacustrine areas are present at the southeastern end of the Chyulu Range. They are characterised by the presence of lacustrine limestones and redeposited volcanoclastic materials. The lacustrine areas are further described and discussed together with the volcanic areas, since they are closely related.
- The fluvial areas are found throughout the study area and characterised by the presence of fluvial deposits or landforms. According to the definitions of coastland and inland the fluvial areas are described as part of the interior. However this classification is not always appropriate where rivers reach the littoral zone and deltas start to be part of the landscape. This shows that the morphological classification proposed in the present study should be further to be further refined if the system were to be used in future geomorphological mapping.

3.2.1 Denudational areas

The existence of a widespread End-Tertiary planation surface in East Kenya is often quoted and generally accepted (King, 1962, Ojany, 1966, Toya et al., 1973). Less agreement exists about the presence of remnants of older planation surfaces (Saggerson & Baker, 1965). One of the objectives of the present geomorphological work has been to study the occurrence of the planation surfaces in southeast Kenya and to discover the connection with

their correlative sediments at the coast.
The Late Carbonaceous to Early Jurassic succession of the Duruma Group in the study area has an estimated thickness of around 8000 m (Karanja. 1983; Walters & Linton, 1973, p. 138). This gives an idea of the type of sedimentary record which can be expected when a landscape is intensely eroded and planed off. However from the coastal succession (Sections 3.1.1.1 and 3.2.1.1) it is clear that there is ample evidence for the existence of widespread Late-Jurassic, Cretaceous and Tertiary planation surfaces in southeast Kenya. Moreover it has been shown that in the coastal region hardly any remnant of the widespread End-Tertiary surface or any older planation surface can be found. The present-day coastal landscape consists for the most part of Pleistocene landforms with Pleistocene deposits and soils. Ojany (1966, p. 195) was correct in considering the Nyika as a record of an Early Pleistocene cycle distinguished from the Late Tertiary cycle of erosion. This means that erosion processes and the subsequent surface lowering have occurred throughout the Mesozoic and Cainozoic periods in the coastal region. This conclusion raises two important questions:
- What impact had the geomorphological processes on the landscape of the interior during the Pleistocene? If the landscape forming processes were so active in the coastal region why not in the interior? In other words is the plain surface of the interior indeed the result of an End-Tertiary planation as generally accepted?
- What actually happened during the Cretaceous and Tertiary and where are the correlative deposits of the assumed planations since they appear not to be present in the coastal succession of southeast Kenya?

With the gradual gathering of more information about the sedimentary basins of Kenya the answer to the last question appears to be found in the Lamu embayment. Walters & Linton (1973, p. 142) have shown that at least 4000 m of Tertiary and Late Cretaceous deposits are present in the sedimentary basin between the Kenyan and Ethiopian dome. The connection between the geological history of the Lamu embayment and the development of the landscapes in the denudational areas of southeast Kenya is described and discussed more fully in the following sections.

3.2.1.1 Stratigraphical record

The subsurface of the denudational areas consists mainly of Precambrian metamorphic rocks belonging to the Mozambique Belt System. Minor areas are underlain by Permian arkosic sandstones of the Taru Formation. The isolated outliers of the Coastal Range consist mainly of Triassic to Jurassic sandstones of the Mazeras Formation. The characteristics of these sedimentary formations have been mentioned in Section 3.1.2.1. In Table 25 a synopsis of the provisional stratigraphy of the metamorphic basement rocks is given. It follows the results of recent geological mapping in the southwestern part of the study area (Pohl & Niedermayr, 1979; Horkel et al. 1979).

Table 25 Provisional stratigraphy of the metamorphic rocks of the Mozambique Belt System

Era	Period	Group	Formation	Member	Predominant Lithologies
PRECAMBRIAN	Middle	KASIGAU	Sobo	Upper	(para)gneisses, granulites with marbles, schists and amphibolites
				Lower	(para)gneisses
					migmatites with bands of amphibolite and marble
					gneisses with amphibolites
		KURASE	Mugeno		marbles, gneisses
			Mwatate		gneisses amphibolites with minor bands of marbles and quartzites
			Mgama-Mindi	upper	gneisses, marbles
				lower	gneiss with bands of granitoids, marbles and amphibolites
				Lualenyi	gneisses, schists
			Mtongore		gneisses, marbles
	?	Mtonga-Kore Complex			charnokites

Mtonga-Kore Complex

The Mtonga-Kore Complex possibly form part of an older basement on which the metasediments of the Kurase and Kasigau Groups have been deposited (Pohl & Niedermayr, 1979, p. 9). The main rock type, exposed at the Mtonga and Kore residual hills, is of intermediate, calc-alkalic composition.

Kurase Group

The Kurase Group embraces the lower part of the metasedimentary rocks laid down on an older cratonic basement. The unit consists in general of metamorphosed pelitic, arenaceous and calcareous sediments with intercalated basic sills or lava flows. The materials are part of the Usangaran Metasediments distinguished by Hepworth (1971). The rocks are exposed in the southwestern part of the study area. Pohl & Niedermayr (1979, p. 8) distinguished four formations (Table 25).

- The Mtongore Formation occurs in the most southwesterly part of the study area and is characterised by monotonous flat plains. The rocks comprise mainly biotite-garnet gneisses with banded gneisses, marbles and quartz-feldspar gneisses.
- The Mgama-Mindi Formation occurs in a NW-SE zone just south of the Taita hills and is characterised by many residual hills and structural ridges. The lower part of the succession consists mainly of graphite-sillimanite gneisses with bands of granitoid and quartz-feldspar-garnet gneisses, marbles and amphibolites. The Lualenyi Member is host to the special green grossularite deposits of the area. The upper part of the succession mainly comprises biotite-graphite gneisses with thick bands of marble.

- The Mwatate Formation occurs in a NW-SE zone across the southwestern half of the Taita Hills. The rocks consist essentially of thick, uniform banded, biotite gneisses with layers of amphibolite and minor bands of quartz-feldspar gneisses,marbles and kyanite quartzites.
- The Mugeno Formation occurs in a zone southeast of the Taita Hills and is characterised by numerous structural ridges. The rocks consist of bands of marbles, with intercalated biotite and quartzfeldspar gneisses.

Kasigau Group

The Kasigau Group embraces in general a monotonous succession of metamorphosed metasediments and overlies the more complex Kurase Group. These rocks form the subsurface of the northeastern half of the interior region of the study area. No formal subdivision of the Kasigau Group has yet been made.

- The lower part consists of a thick, monotonous sequence of massive quartz-feldspar gneiss with intercalated amphibolite (Horkel et al., 1979, p. 5). The rocks are exposed in the northeastern part of the Taita hills and other nearby, prominent residual hills. They also underlie extensive parts of the plains west-southwest of the Yatta Plateau.
- The middle part of the succession mainly consist of biotite-hornblende migmatites found in a zone north-northeast of the Yatta Plateau which extends south of the Galana river. The rocks are also known as the Lugards Falls- Ithangani migmatites (Sanders, 1963, p. 10).
- The upper part of the succession is also known as the Sobo Formation (Sanders, 1963, p. 11). It consists of garnetiferous para-gneisses and granulites with intercalated limestones and muscovite quartzites.

In most places the rocks are covered by residual deposits and soils. In the geological reports they are indicated as Quaternary colluvium, Red sandy or Black cotton soils and ferruginous or calcareous crustal deposits.

3.2.1.2 Morphological structure

The landscape of the denudational areas of the interior is formed in general by monotonous plains with scattered residual hills. The general physiography has been described during early geological surveys and part of the area has been geomorphologically surveyed recently (Kadomura, 1970: Kadomura & Hori, 1984). Further morphological information has emerged from exploratory and reconnaissance soil surveys carried out in the region (Sombroek et al., 1982; Van Wijngaarden & Van Engelen, 1985). During the present study the denudational areas have been subdivided into two main units:

- The denudational plains, occupying the majority of the wide, flat to undulating surfaces of the area;
- The denudational hills and plateaus, often found as isolated and scattered residual features rising abruptly from the plains.

Table 26 Classification of the denudational levels

metamorphic areas				sedimentary areas	
plain levels		summit levels		summit levels	
name	Elevation (m +MSL)	name	Elevation (m +MSL)	name	Elevation (m +MSL)
Buchuma Mtito Andei	250 to 1000 800 to 1000	Zagatisi Sagala Taita	700 to 800 1000 to 2000 1500 to 2500	Majimboni Shimba	250 to 300 350 to 900

The distribution of the two units is apparently independent of the character of the substratum. Plains underlain by metamorphic rocks pass without clear topographic transition into those developed on sedimentary rocks. The process which initially planed them off seems to have been uninfluenced by those important lithological differences. In the same way the residual hills are often underlain by the same parent material as the country rock of the surrounding plain, but their position appears to reflect the presence of old morphological structures. In the metamorphic terrains the most prominent residuals are lined up in a NNW-SSE direction, following the fold-trend of the Precambrian basement. It may be that the residual hills are remnants of old watersheds of the fold mountains which were formed during the Late Precambrian to Cambrian orogenesis. In the areas underlain by the sedimentary rocks of the Duruma group the isolated hills occur along the most westerly outcrops of the Taru and Mazeras Formations. The hills appear to exist as remnants of old cuesta ridges preserved by the resistant, coastward dipping grits.

Two plain and three summit levels have been identified in the areas underlain by metamorphic rocks. Two summit levels are present in the areas characterised by the sandstones of the Duruma Group. The names used in this study and the approximate elevations are given in Table 26. In the following sections the characteristic of the denudational areas are described and discussed in more detail.

Table 27 Land units of the denudational plain levels

land types	components
denudational plains	plain platforms structural ridges interfluve ridges enclosed depressions
stream valleys	valley heads valley slopes valley bottoms

3.2.1.2.1 Denudational plains

The areas included in the denudational plains have a faint to low relief and are not elevated above the general surroundings. Their denudational nature is shown by the presence of residual deposits. The superficial materials are normally very poorly sorted clay bound sands with a basal gravel layer near the transition to the underlying rocks. The plains have been further subdivided by the distinction of two geomorphological levels (Appendix I).

- The Buchuma level occurs directly west of the paralic plains of the coastland at elevations of between approximately 250 and 1000 m +MSL. The level correlates with the western part of the Nyika level on the soil map of the Mtito Andei and Tsavo Areas (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, 1b). It further comprises the western parts of the End-Tertiary peneplain distinguished by Saggerson (1962b, p. 5), Sanders (1963, p. 6), Walsh (1963, p. 5) and Rix (1964, p. 4).
- The Mtito Andei Plain level occurs in the very northwestern part of the study area at elevations of between approximately 800 and 1000 m +MSL. It is the continuation of the Mulango level first named and described by Ojany (1978, p. 469) for the Machakos-Kitui Area. A Pliocene age was suggested on the basis of its relationship to the Mid-Miocene Yatta phonolites (Ojany, 1978, p. 477).

Depending on the degree of dissection both denudational areas have been further divided into flat to almost flat and undulating plain landscapes. Dissection of the areas of the Buchuma level occurs only in a narrow zone along the major rivers. By contrast the plains of the Mtito Andei level are dissected throughout. Table 27 gives a synopsis of the land units which have been distinguished during the present study.

Denudational plains

The denudational plains occupy the greater part of the interior region. They include four components which are briefly described below.

- The plain platforms are represented by the flat or almost flat parts of the denudational plains. In the undissected parts they form extensive surfaces, while in dissected areas they occur as relatively small, flat remnants on the interfluves.
  The platforms are overlain by 1 to 2 m of superficial deposits with a basal gravel layer mainly consisting of angular to subrounded quartz and feldspar fragments. On the Buchuma level the gravel lag also contains extremely well rounded quartz fragments. They must have been shaped during earlier times when fluvial or other abrasion processes played an important role in landscape formation. Comparable well rounded quartz fragments are known to occur in the deposits of the Lower and Middle Taru Formation. It is possible that the area of the Buchuma level was once covered by the deposits of the Duruma group. This is further evidenced by the presence of blocks of the Duruma sandstone at positions more than 40 km beyond their

present, most western outcrop (Saggerson, 1962b, p. 35). This shows that the present-day flat plains of the Tsavo area may have had an initial flatness long before the often quoted Cretaceous and Tertiary planation cycles began. In other words the plains were not necessarily flattened by the gradually down-wearing of the relief or by slope retreat during the Mesozoic and Cainozoic periods. The Buchuma level may well represent an exhumed older surface which was flattened as a result of abrasion processes at the former shore of the sedimentary basin to the north and east. Whether such a coverage by sedimentary rocks occurred only during the Permo-Triassic-Jurassic period is still uncertain.

Dusky red to strong brown soils with an AB(CR) horizon sequence have developed in the residual deposits on the plain platforms. On the Mtito Andei level they have been classified as Orthic and Xanthic Ferralsols (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, unit Pn1Fb). On the Buchuma level they consists mainly of Rhodic and Orthic Ferralsols (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, 1b, unit Pn2Fr, Pn2Ub). No morphological evidence for the presence of the Mtito Andei level east of the Chyulu Range (as indicated on the reconnaissance soil map) could be found during the present study. The fact that the soils in this region have a thicker A-horizon, a higher CEC and show signs of clay illuviation (Van Wijngaarden, 1978, p. 106-108; Appendix 1a, unit Pn1Fr, Pn1Rb) may be due to the influence of volcanic ash-falls. The general absence of significant differences between the soil properties hamper the distinction of the Buchuma and Mtito Andei levels on basis of pedologic criteria.

In contrast to remnants of the Late Pliocene surface at the coast and Late Pliocene lava plateaus west of the study area, the Buchuma and Mtito Andei levels are not characterised by a continuous ferricrete or calcrete. It appears that either no ferricrete developed or the late Pliocene ferricrete has been removed by later erosion. The second option is more likely since surface remnants with ferricretes and calcretes are known to occur on the slightly elevated ridges in the plains. If accepted, this supposition implies that the extensive plains of the interior of southeast Kenya are more accurately described as parts of a Pleistocene land surface.

At the edges of the plains towards valleys or depressions, patches of calcretes and ferricretes occur. They are often thin and may be the remnants of earlier, more extensive duricrusts. However, their occurrence may also indicate that at these particular places accumulation of calcium or iron took place under the influence of local groundwater discharge. This process is still active in, for example, the Nyanza Lowlands around Lake Victoria (Wielemaker & Van Dijk, 1981, p. 62).

- The structural ridges are represented by the low NNW-SSE tending elevations rising 10 to 20 m above the general plain level. They are shown to be mainly underlain by marbles. Saggerson (1962b, p. 7) considered most of them to be remnants of the Ichenze surface which he defined as an intermediate surface between the End-Tertiary and the Sub-Miocene peneplains.

On the soil map of the Tsavo area the structural ridges have been indicated as Low Ridges. They are characterised by the presence of Calcic Cambisols with a petrocalcic phase (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, 1b, unit HL2k). The presence of the calcretes is remarkable as they occur on top of the ridges. This seems to prove that the ridges are indeed the remnants of an old land surface with calcretes and possibly ferricretes. A correlation with the Late Pliocene surface at the coast is probable since the ridges occupy an intermediate position between the Buchuma level and the Middle Miocene land surface preserved under the Yatta Plateau.

- The interfluve ridges are represented by the lowered and often rounded plain remnants between the stream valleys. They occur in the areas indicated as Dissected Plains (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, 1b; Kadomura, 1970, p. 14).
The interfluve ridges on the Mtito Andei level are characterised by approximately 1 to 2 m thick residual deposits abruptly overlying a slightly weathered subsurface of various metamorphic rocks. The soils have an AB(C)R horizon sequence with clear transitions. The B-horizons are dark red and contain moderately thick clay-cutans. The profiles are often truncated and have been classified as Chromic Luvisols (Van Wijngaarden, 1978, p. 100, Appendix 1a, unit U2Frp). In areas of more advanced stripping of the soils the basal gravel layer occurs near the surface. This causes the soils to be characterised by a petric phase.
On the Buchuma level comparable residual deposits occur with basal gravel-layer of mainly quartz fragments. The soils have a similar AB(C)R horizon sequence with clear transitions. The B-horizons are dark red and have an angular blocky structure and weak to moderately thick clay cutans. The soils have been classified as Chromic Luvisols with a petric phase (Van Wijngaarden, 1978, p. 131, Appendix 1a,1b, unit PdFrp). The major difference is the presence of lower CEC-values for the clays in the B-horizon compared with those on the Mtito Andei level. This is the opposite of what would be expected had the Mtito Andei level an older planation level. The rejuvenating influence of the pyroclastic deposits of the nearby Chyulu Range may be the main reason for these difference. Consequently the properties of the soils on the interfluve ridges do not give conclusive evidence to confirm an age difference between the Buchuma and Mtito Andei levels.
In places where the denudation of the ridges is almost complete, the gravel layer is exposed or rock outcrops are found. Here the soils have been classified either as Ferralic Cambisols with a petric or (para)lithic phase or as Lithosols (Van Wijngaarden, 1978, p. 132, Appendix 1a, 1b, unit PdFrP).
- The depressions are represented by low-lying areas surrounded by higher ground and often lack a natural outlet for surface drainage. The unit embraces at least three types.
The first occurs on the interfluve summits of the Mtito Andei Level and is characterised by Pellic Vertisols (Van Wijngaarden, 1978, Appendix 1a,

unit Pn1Fdk). These soils evidence the presence of former poorly drained depressions. Their situation on both sides of the Yatta Plateau suggests that they once formed part of a fluvial system which developed after the extrusion of the Yatta lava. However Pellic Vertisols are also widespread on interfluve areas to the north and northwest (Muchena et al. 1978, Appendix 1a, unit U2Fd; Sombroek et al. 1982, Appendix I, unit Up4). The wide areas which they cover seem to indicate the presence of former lakes or swamps on the Mulango (=Mtito Andei) level. Their position at approximately 100 m below the level of the Yatta Plateau suggests that they are of Pliocene to Pleistocene age and may be evidence for former wet climates.

On a smaller scale semi-circular depressions are found throughout the areas occupied by the denudational plains (Fig. 23). They are indicated on the topographical maps as waterholes. Ayeni (1975) studied their utilization by the wild-life population of the Tsavo National Park. He suggested a biogenetic origin mainly caused by the wallowing of elephants and other larger mammals. However, depressions of similar size and shape which are not used by the wildlife are also widespread in the same area.

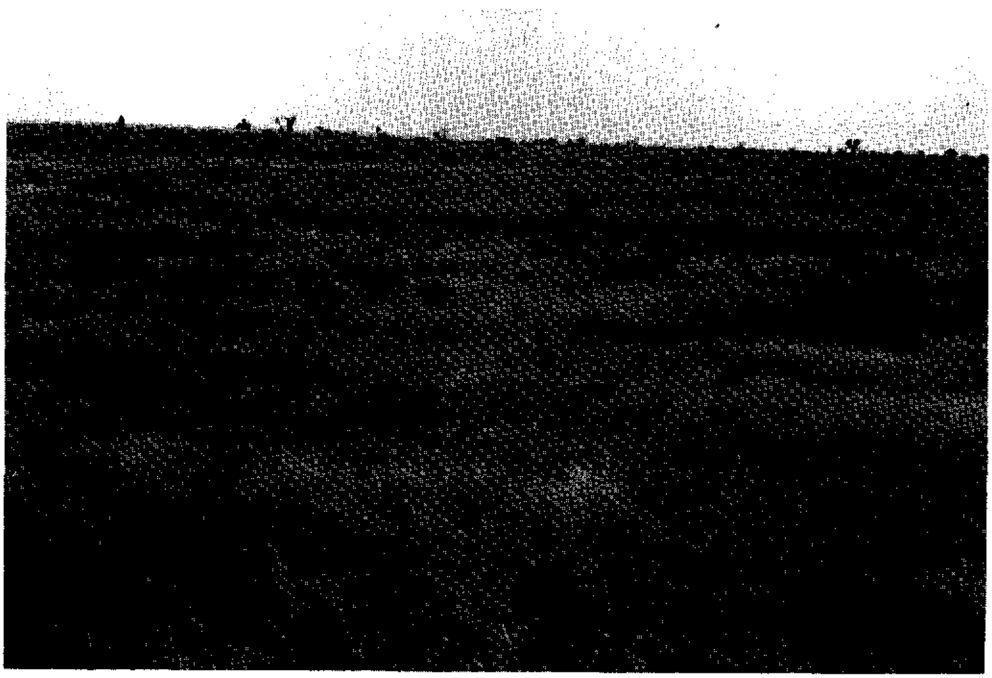


Fig. 23 Waterhole on the plain platform of the Buchuma level

The depressions can be recognized by differing vegetation and soils. A yellowish or grey clay with dark red mottles is often found. Van Wijngaarden (1978, p. 105-7) recorded them in the extreme west of the denudational areas. He classified the soils as Plintic Ferralsols and Acrisols. During the present study they were also observed in the eastern part of the denudational plains. Comparable mottled subsoils can be observed in the artificially deepened waterholes of the Tsavo East National Park. Of note is the fact that the mottled clays of the depression are overlain a basal gravel layer similar to that which occurs on the surrounding plains. This suggests that the mottled plintic clay is a truncated remnant of a former soil profile. The mottled subsoil classification as soft plinthite is doubtful. A sample of this mottled layer taken from a waterhole on the Maungu Plains proved to consist of mainly amorphous material with clear quartz lines, poorly crystallized illite and little feldspar (Van Doesburg, pers. communication). This shows that the mottled subsoils are more accurately interpreted as the remnants of a soft saprolite.

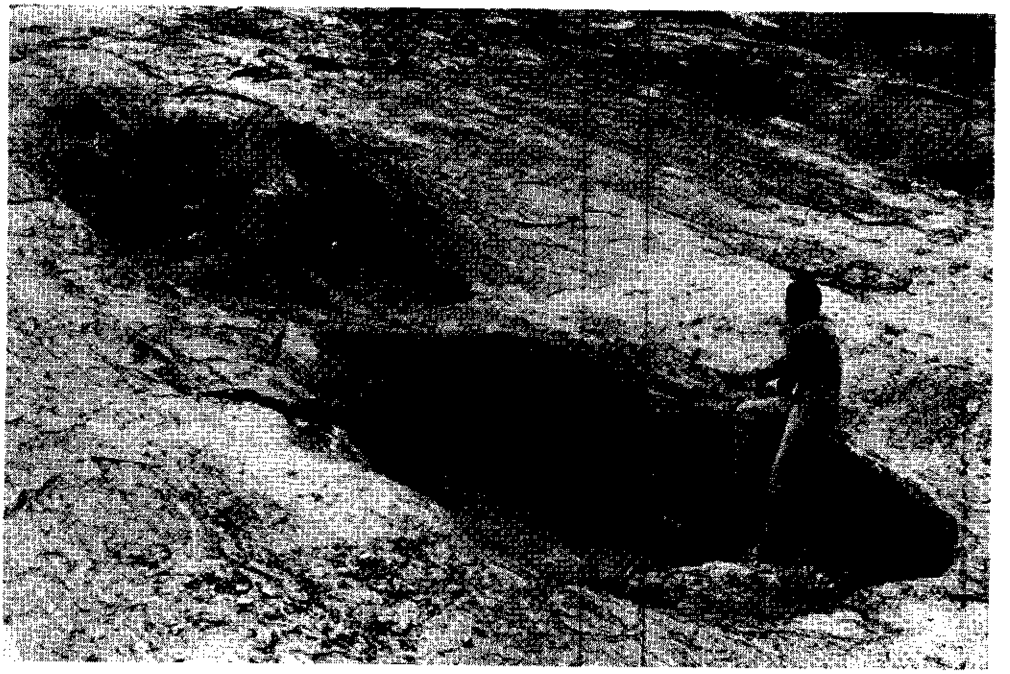


Fig. 24 Rock basins at Buchuma waterhole

A third type of the enclosed depressions is formed by the rock basins found in places where the hard rock of the subsurface is exposed. Those at Buchuma waterhole were the most impressive ones found during the present study. Basins of 2 to 4 m deep and with diameters of up to 6 m are present (Fig. 24). They have been developed in migmatites and some are comparable in shape with those of the paralic zone. Elongated forms are more abundant and are apparently related to the direction of the trend of the banding in the migmatites. The contents of two excavated rock basins showed sandstone fragments of the Duruma Group.
The origin of rock basins is often described as the result of differential weathering (Twidale, 1976, p. 203). On the basis of the present observations however this weathering origin seems unlikely. The pieces of Duruma sandstone which have been found in it may be the remnants of a former exposure of the rocks to the west. However if the rock pools were formed by weathering it is unlikely that the sandstone fragments would have survived while the resistant migmatites weathered away. The fresh-look of the forms is also striking. This may mean that the rock basins are either newly formed Pleistocene features or are exhumed paleoforms.

Fig. 25 Potholes at Luggards Falls

If they are of Pleistocene age than a fluvial origin near rapids is possible, considering their striking resemblance to the potholes found at, for example, Luggards Falls (Fig. 25). However the absence of any morphological evidence for the existence of a comparable river valley makes this less likely. The rock platforms in which the basins are found can also be compared with marine abrasion platforms in which comparable basins occur. In this case the flat denudational plains of the interior may be the remnants of a raised marine abrasion surface. The fresh nature of the rock basins suggests that this event was not followed by intense tropical rock weathering. Therefore, a correlation with the Plio-Pleistocene incursion of the sea is the most likely possibility. The postulation of a marine cause for the denudation of the eastern part of the denudational plains may also explain the extreme flatness of the Buchuma level in contrast to the undulating nature of the Mtito Andei level. Furthermore it explains the abnormal distribution of rock fragments far upstream their present-day outcrop.

Stream valleys

The stream valleys occur in the dissected parts of the denudational plains. They commonly consist of four components (Table 27).

- The valley heads are represented by spoon shaped erosion hollows at the beginning of the valleys. They form part of the areas where active sheetwash is lowering the surface (Kadomura, 1970, p. 14).
- The valley slopes are represented by the sloping surfaces connecting the plain platforms or interfluve summits with the centre or bottom of the valleys. They are often found to have a slightly concave shape with shallow soils at the upper part.
- The valley bottoms are represented by the flat alluvial accumulation surfaces at the centre of the valleys. They are commonly characterised by a newly formed stream channel. This indicates that under the present conditions stream incision predominates over the in-filling of valleys by sheetwash deposits. Consequently still drier conditions would be expected to have been related to the sedimentation of the valley bottoms.

3.2.1.2.2 Denudational hills and plateaus

The elevated denudational areas are characterised by a faint to moderate relief. They usually have a cover of residual deposits of saprolite or rock fragments derived from the substratum.

The denudational hills and plateaus enclosed in the coastal region includes the residuals of the Coastal Range and further inland the isolated hills known as Kilibasi, Taru, Lali, Dakadima and Dakadakatha hills. The hills have been divided into two groups according to their elevation above their surroundings. This means in practice the distinction of two general summit levels. They have been called the Majimboni and Shimba levels during the present study.

- The Majimboni level is formed by the summits of hills and plateaus at approximately 50 to 150 m above the highest coastal levels. The residuals are mainly underlain by Triassic-Jurassic sandstones of the Mariakani and Mazeras Formations. An exception is the Irima Hill which consists of Late Cretaceous syenites and associated rocks of the Jombo Complex. The summit of this hill, like most of the others at the Majimboni level, is characterised by the occurrence of iron-manganese boulders and nodules. (Caswell, 1953, p. 55). This indicates that the summits of the Majimboni level are the remnants of an old land surface.
- The Shimba level is formed by the summits of hills and plateaus at approximately 200 to 400 m above the highest coastal level. The residuals lack a deep saprolite or other features which are linked to the presence of an old land surface. Caswell (1953, p. 52) suggested that the Shimba Hills, which form the type area of the Shimba level, may represent a remnant of the Miocene surface. In Section 3.2.1.3.2 more attention is paid to the possible ages of the summit levels.

Fig. 26 Residual hills of the Coastal range west of Kilifi

The residuals of the Coastal Range are associated with the rocks of the Middle and Upper Mazeras Formation (Appendix I). The abundance of gravel and boulder beds in these members over the clayey beds of the Lower Mazeras Formation is believed to have caused the development of a cuesta ridge. The present hills and plateaus of the Coastal Range are probably the remnants of this cuesta which has been dissected and partly removed by surface lowering (Fig. 26).
Mangea Hill is one of the most prominent residuals on the interfluve area between the Galana and Voi rivers. It consists of Early Jurassic sandstones of the Middle Mazeras Formation and rises approximately 300 m above the level of the Early Pleistocene Sokoke/Mtsengo level. Accepting a geological age of 195 to 178 my for the Early Jurassic (Faure, 1977, Appendix II), the elevation of Mangea Hill implies a mean surface lowering rate of approximately 1.6 to 1.7 m/my. Irima hill which is made up of the Late Cretaceous agglomerates of the Jombo Complex, rises approximately 150 m above the Early Pleistocene coastal levels. Accepting a geological age of about 100 to 65 my for the Late Cretaceous (Faure, 1977, Appendix II), implies a mean surface lowering of around 1.5 to 2.3 m/my. The elevation of the subvolcanic syenites of the Late Cretaceous Jombo complex show that the surface lowering in the Mazeras sandstones took place with a mean rate of approximately 3 to 5 m/my. Continuous erosion since the Early Cretaceous would imply that 500 to 900 m of sandstones have been removed to form the present surface of plateau on the Shimba hills. The exposed Upper Mazeras deposits, however, clearly indicate the end of the deltaic deposition. Therefore, a continuous erosion of the Early Jurassic sandstones of the Upper Mazeras Formation is unlikely. Consequently the residuals of the Coastal Range most probably have been covered by later deposits which were subsequently removed, exhuming the Upper Mazeras rocks.
A comparable situation seems to occur further inland where the residuals are found near the contact of the metamorphic rocks of the Mozambique Belt and the sedimentary rocks of the Taru Formation. Kilibasi hill is the highest of this second coastal range. It rises about 400 m above the surrounding Early Pleistocene Taru level and is made up of Early Permian sandstones of the Middle Taru Formation which are down faulted against the metamorphic basement rocks. Accepting a geological age of 280 to 240 my for the Early Permian(Faure, 1977, Appendix II), this suggests a mean surface-lowering rate of 1.4 to 1.7 m/my in the area underlain by the sedimentary rocks of the Taru Formation. Compared with the surface lowering rate of about 10 m/my for moderately uplifted areas (Finkl, 1982, p. 146), the found figures are low and resemble those given for denudation rates of cratonic margins.

From the above it is concluded that the process of surface lowering can not have been continuous throughout the Mesozoic and Cainozoic. Either long periods of standstill have occurred or large parts of southeast Kenya were once overlain by sedimentary covers younger than that of the Karroo System exposed at present. Late Jurassic and Cretaceous covers are known to occur high on the eastern flank of the Ethiopian dome (Pulfrey, 1969; Kazimin, 1972). In the Lamu embayment the most westerly outcrop of Middle Jurassic limestones and sandstones occurs at Matasada hill (Walters & Linton, 1973, p. 140). The present elevation of this exposure is approximately 400 m +MSL. This shows that the Middle Jurassic sea might well have covered large parts of southeast Kenya. This implies that later erosion must have removed the cover of marine sediments. A comparable situation is known in the Ardennes in Europe (Lucius, 1948; 1957)

The residual hills of the interior have been grouped into three categories according to their elevation above the surrounding plains and their morphological characteristics. Consequently the hills are considered to indicate the existence of three different summit levels. As the relationship to the two levels of the residual hills and plateaus at the coast is uncertain, they have been kept separate and given different names (Appendix 1).

- The Zagatisi level occurs at approximately 50 to 150 m above the denudational plains of the Buchuma level. The related residuals embrace most of the higher limestone ridges and granitoid whalebacks. The soils are generally shallow and no deep saprolite is found. Saggerson (1962b, p. 5, 6) considered most of the residuals to represent the Sub-Miocene peneplain. Van Wijngaarden (1978, p. 56) correlated the summits with the Kithioko (Miocene) level.
- The Sagala level occurs between about 150 and 500 m above the plains of the Buchuma level. The residuals which have been formed in various metamorphic rocks, are characterised by the presence of either a deep regolith or by steep bare hill-slopes with caves and flared surfaces. The summit level correlates in general with the Maungu surface and the End-Cretaceous peneplain of Saggerson (1962b, p. 5) and the Sagala (end-Cretaceous) level of Van Wijngaarden (1978, p. 56). The date of End-Cretaceous is based on correlation with comparable residuals outside the study area and is not confirmed by datings.
- The Taita level occurs at approximately 900 to 1200 m above the surrounding plains of the Buchuma level. It consists mainly of residuals with shallow soils or bare rock surfaces. The summit level correlates with the Gondwana (Jurassic) and Post Gondwana (Early Cretaceous) levels distinguished by Van Wijngaarden (1978, p. 56). As a result of strong erosion the soil pattern is complex and varies with the character of the underlying rock type.

Around the residual hills of the interior region extensive aggradational surfaces are found (Fig. 27). They have been indicated as foot slopes and piedmont plains on the geomorphological map (Appendix I). Their formation has been studied by Kadomura (1970, p. 11) but got no further attention during the present work.

In general it must be said that for many residual hills the possible relationship with old planation surfaces is uncertain. When a residual hill has been denuded of its soil or saprolite cover it has lost its identity. The recognition and reconstruction of planation levels from their summits then becomes speculative. However, if regional rates of surface lowering can

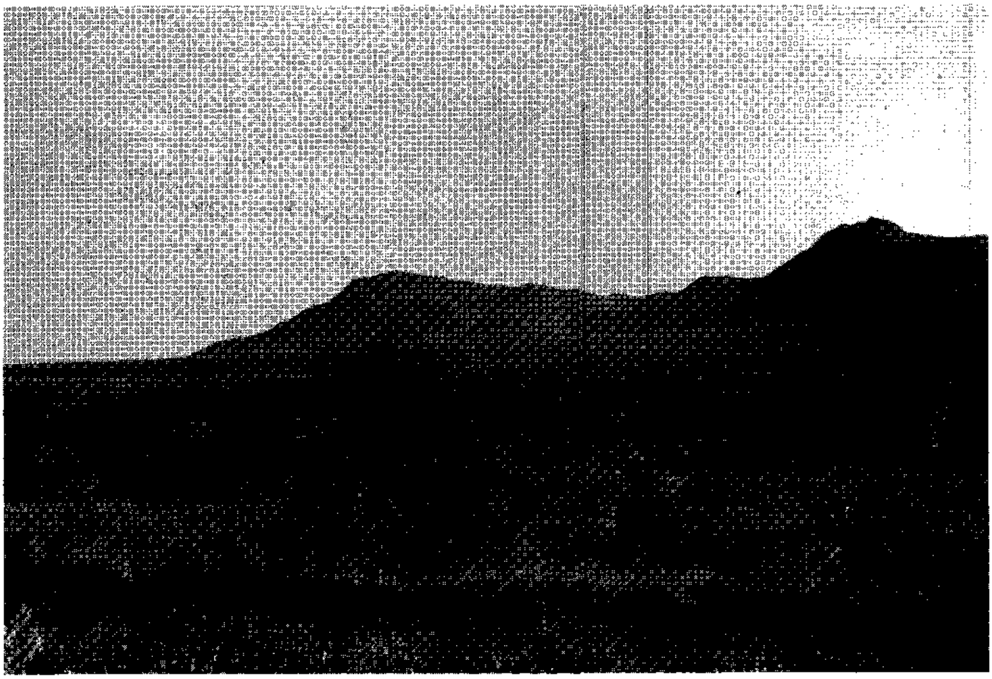


Fig. 27 Piedmont plain at the foot of Sagala Hills

be deduced with greater certainty (e.g. from the relief inversion of dated lava flows) it is possible to check the validity of the supposed presence of old land surfaces at the summits and shoulder levels of residual hills.

3.2.1.3 Origin and development

From the description and discussion of the morphological structure of the denudational areas it has been shown that several episodes of surface lowering occurred during the geological past. A major problem remaining is to identify and date the land surface remnants.
In the following sections a relative sequence of events in the denudational areas is presented. It is followed by a provisional stratigraphical correlation and a review of the tectonic and climatic effects which may have influenced the genesis and later development of denudational areas of the interior.

Table 28 Subdivision of the Tsavo and Pre-Tsavo/Nyika periods in the denudational areas

period	surface	denudational level	main event	lithostratigraphical record	period/surface
Tsavo	lower	Buchuma	soil formation denudation dissection	Plio-Pleistocene deposits	
	upper	Mtito Andei	soil formation denudation ? dissection	Marafa Formation ?	Late Pre-Nyika
Late Pre-Tsavo		Zagatisi	soil formation denudation	Baratumu Formation ?	Early Pre-Nyika
Middle Pre-Tsavo		Sagala	soil formation denudation	Late Cretaceous to Eocene	
					?
Early Pre-Tsavo	lower ?	Taita	denudation	Mtomkuu Formation ?	
	upper ?		denudation	Kambe Formation ?	

3.2.1.3.1 Sequence of events

The origin and development of the denudational areas of the interior spans a long period of time starting in the Middle Precambrian with the folding and metamorphosis of the Usangaran deposits of the Mozambique Belt. The fold mountains which resulted from this major orogenetic event are the basic landforms from which the configuration of the present-day denudational areas have developed. The events of the first half of the period which elapsed after the last phase of deformation in the Mozambique Belt around 500 my ago (Horkel et al., 1979, p. 19) are obscure since no sedimentary record remains in southeast Kenya. The Duruma sandstones and later sediments at the coast and in the Lamu embayment illustrate the geological history from the Paleozoic to the Cainozoic periods.

Tsavo period

The Tsavo period embraces the events related to the formation of the Buchuma and Mtito Andei levels. The upper and lower division of the land surface which developed in that time corresponds with the Mtito Andei and Buchuma levels, respectively.

Pre-Tsavo period

The Pre-Tsavo period embraces the events related to the formation of the residual hills. The three levels which have been distinguished may reflect three different age groups. However a more detailed study of the soils and superficial deposits has to made for confirmation.

3.2.1.3.2 Chronological correlations

The correlation of the sequence of events in the denudational areas with other geological chronologies is seriously hampered by the lack of dateable events. Nevertheless there are some morphological features which enable the establishment of approximate fixed points.
The first important fact is that the Buchuma and Mtito Andei level occur in the western part of the study area about 100 m below the Yatta Plateau. The phonolites on top of this inverted lava flow have been K/Ar dated at 13.2 my (Evernden, 1965, p. 363). Hence the post-Miocene of the two levels is certain. The remnants of the Zagatisi level rise roughly 100 to 150 m above the plains of the Buchuma level. Thus their age may be similar to that of the lavas on the Yatta plateau.
A second remarkable feature is the deep, rotten rock found at the summits of the larger hills of the Sagala level. This may be used to assign the level to the period of the Late Cretaceous to Late Oligocene. During this long interval of time tectonic quietness is supposed to have reigned over vast areas resulting in a planation of extraordinary smoothness and deep soils profiles (King, 1976, p. 139).
In Table 29 these fixed points have been used to correlate the sequence of events in the denudational areas with the table of global geomorphic planations described by King (1976, p. 138, Table 1). The main lithostratigraphical units in the NW part of the Lamu embayment and in the study area have been added to illustrate the possible relationship between the sedimentary and erosional history of southeast Kenya. The sedimentation rates are based on the data provided by Walters & Linton (1973) and Karanja (1983) on the thickness and age of the various formations. This correlation is provisional and requires further refining.

3.2.1.3.3 Tectonic and climatic effects

Several tectonic events are known from the sedimentary successions at the coast (Cannon et al. 1981a) and the Lamu embayment (Walters & Linton, 1973;; Karanja, 1983). They apparently have been a major factor in controlling the Paleozoic and Mesozoic erosional and sedimentary history of the area. The low fault scarps present on the denudational plain show that minor tectonic activity continued up to the Pleistocene period.
Insufficient data are available to reconstruct the climatic conditions during the denudation of the interior.

Table 29 Correlation of the denudational levels

Geological time					Sedimentation rates (cm/ky)				Geomorphological levels	
Per.	Epoch		Stage	Age (my)	NW Lamu emb. 10 20 30	SE Kenya 10 20 30	Formation		Denudation levels SE Kenya	Global planations (King, 1976)
Q	Holocene				#	#				
				-.01-	#	#	Reef Complex			
U		Late			#	#				Youngest
				-.13-	#	#	Changamwe			
A		Middle			#	#				Landscapes/Cycle
	Pleis-			-.75-	#	#				
R					#	#		U		
	tocene			-1.7-	#	#			?-	
T.		Early			#	#	Magarini			Active Episode E
				-2.0-	#	#		L	Buchuma level	
					#	#				Widespread II
				-2.3-	#	#				
	Plio-	Late			#	#			Mtito Andei level	Planations I
				-3.3-	#	#	Marafa			
	cene	Early			#	#			Majimboni level ?	Active Episode D
				5-						
T		Late			##	##				
	Mio-			11-					Zagatisi level	
E		Middle			##########	##########	Baratumu			Rolling Surface
	cene			14-						
R		Early			##	##			Shimba level ?	
				22-						
T	Oligo-	Late								Active Episode C
				32-						
I	cene	Early								
				37-						II
A		Late				##				
				43-						Moorland
R	Eocene	Middle			#######	#######				
				49-						B'
Y		Early				#############	(not exposed)			Planation
				53-						
	Paleo-	Late				#				
				57-		#			Sagala level	I
	cene	Early				#				
				65-						
C			Maastrichtian							
				70-						
R		Seno-	Campanian		##					
				76-						Active Episode B
E		nian	Santonian		#					
	Late			82-						
T			Coniacian							
				88-						
A			Turonian		##					
				94-						
C			Cenomanian		###	#				
				-100-		#				
A			Albian		#######	#				Kretacic or
				-106-		#				
C			Aptian		##	#				Post-Gondwana
				-112-				U		
E			Barremian							
	Early			-118-					Lower	Planation
O			Hauterivian		##					
				-124-	##				?	
U		Neoco-	Valanginian		##		Mtomkuu			
				-130-	##				Taita level	
S		mian	Beriassian		##	#				
				-136-						
			Portlandian							
				-146-						
			Kimmeridgian							Active Episode A
J	Late	Malm		-151-		#########		M		
			Oxfordian		#					
U				-157-						
			Callovian			####		L		
R				-162-						
			Bathonian			#				
A	Middle			-167-		#	Kambe			Gondwana
		Dogger	Bajonian			#				
S				-172-						
			Aalenian						upper	Planation
S				-176-						
			Toarcian						?	
I				-178-						
			Pliensbachian							
C	Early			-183-					-------?-?-------	--------?-?-------
		Lias	Sinemurian			###		U		
				-188-		###				
			Hettangian			###	Mazereas	M		
				-195-		###				
			Rhaetian			###		L		
	Late		Norian			#######		U		
TRIAS						#######				
			Carnian			#######	Mariakani	M		
				-205-		#######				
-SIC			Ladinian			#######		L		
	Middle									
			Anisisan			#####		U		
				-225-			Maji ya			
	Early		Scytian			###		M		
				-230-			Chumvi			
			Tatarian			#####		L		
	Late									
PER-			Kazanian			######		U		
				-251-		######				
MIAN			Kungurian			######		M		

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U		Late			#	#				Youngest
				-.13-	#	#	Changamwe			
A		Middle			#	#				Landscapes/Cycle
	Pleis-			-.75-	#	#				
R					#	#		U		
	tocene			-1.7-	#	#			?	
T.		Early			#	#	Magarini			Active Episode E
				-2.0-	#	#		L	Buchuma level	Widespread II
				-2.3-	#	#				
	Plio-	Late		-3.3-	#	#	Marafa		Mtito Andei level	Planations I
	cene	Early		5-	#	#			Majimboni level ?	Active Episode D
T	Mio-	Late			##	##			Zagatisi level	
E		Middle		11-	##########	##########	Baratumu			Rolling Surface
	cene			14-						
R		Early			##	##			Shimba level ?	
				22-						
T	Oligo-	Late								Active Episode C
				32-						
I	cene	Early								
				37-						II
A		Late				##				
				43-						Moorland
R	Eocene	Middle			#######	#######				
				49-						B'
Y		Early				#############	(not exposed)			Planation
				53-						
	Paleo-	Late				#				
				57-		#			Sagala level	I
	cene	Early				#				
				65-						
C			Maastrichtian							
				70-						
R		Seno-	Campanian		##					
				76-						Active Episode B
E		nian	Santonian		#					
	Late			82-						
T			Coniacian							
				88-						
A			Turonian		##					
				94-						
C			Cenomanian		###	#				
				100-		#				
A			Albian		#######	#				Kretacic or
				106-		#				
C			Aptian		##	#				Post-Gondwana
				112-				U		
E			Barremian							
	Early			118-					lower	Planation
O			Hauterivian		##					
		Neoco-		124-	##				?	
U			Valanginian		##		Mtomkuu			
		mian		130-	##				Taita level	
S			Beriassian		##	#				
				136-						
			Portlandian							
				146-						
			Kimmeridgian							Active Episode A
J	Late	Malm		151-	#	#########		M		
			Oxfordian		#					
U				157-						
			Callovian			####		L		
R				162-						
			Bathonian			#				
A	Middle			167-		#	Kambe			Gondwana
		Dogger	Bajonian			#				
S				172-						
			Aalenian						upper	Planation
S				176-						
			Toarcian						?	
I				178-						
			Pliensbachian							
C	Early			183-					?-?	?-?
		Lias	Sinemurian			###		U		
				188-		###				
			Hettangian			###	Mazereas	M		
				195-		###				
			Rhaetian			###		L		
	Late		Norian			#######		U		
TRIAS						#######				
			Carnian			#######	Mariakani	M		
				205-		#######				
-SIC			Ladinian			#######		L		
	Middle									
			Anisisan			#####		U		
				225-			Maji ya			
	Early		Scytian			###		M		
				230-			Chumvi			
			Tatarian			#####		L		
	Late									
PER-			Kazanian			######		U		
				251-		######				
MIAN			Kungurian			######		M		
	Early						Taru			
			Sakmarian			#				
				280-		# ?		L		
CARB.	Late		Stephanian			#				

2 *Volcanic and lacustrine areas*

Volcanic and lacustrine sedimentary areas occur in the northwestern part of the study area. The most well known physiographical features are formed by the Yatta Plateau and the Chyulu Hills. More extensive volcanic areas occur further to the west and northwest, Mt. Kilimanjaro, the Kapiti Plains and Mt. Kenya being the most important features. Since the volcanic rocks have preserved old land surfaces and are datable by radiometric methods, the areas are of importance in the reconstruction of the geological history of southeast Kenya.
In the next sections, the stratigraphy of the deposits is summarised, followed by a description of the morphological structure of the volcanic and lacustrine landscapes and their developmental history.

3.2.2.1 Stratigraphical record

The rocks of the volcanic areas of the Yatta Plateau consist of phonolites. They are commonly known as the Yatta phonolites (Sanders, 1963, p. 35), Yatta Plateau phonolites (Walsh, 1963, p. 23) and Kapiti phonolites (Fairburn, 1963, p. 21). They are known to have a K/Ar age of 13.2 my (Evernden & Curtis, 1965, p. 363). The Chyulu volcanites have been referred to as Pleistocene and Recent Lavas (Walsh, 1963, p. 23) or Quaternary volcanic rocks (Searl, 1954, p. 20). They accumulated as a result of the extrusion of olivine basalts and pyroclastics from numerous eruption centres. Various lacustrine deposits occur in association with the Tertiary and Quaternary volcanic rocks (Fairburn, 1963, p. 23). Those found in the study area are related to the Chyulu volcanic events.

3.2.2.2 Morphological structure

The differing characters and ages of the materials in the volcanic areas of the Yatta Plateau and the Chyulu Hills appear to be the dominating factors in the landscape formation. They have resulted in the development of typical sceneries. Although hills and plateaus can be distinguished in both landscapes, these are essentially different in origin. Their land units are described and discussed in the following sections.

3.2.2.2.1 The Chyulu hills and plateaus

The multicentre volcano known as Chyulu is formed by the accumulation of mainly basaltic rocks. Its landforms are well preserved because of their relative young age (Fig. 28). In Table 30 a synopsis is given of the land units which can be distinguished.

Fig. 28 Panorama of the Chyulu Range

Table 30 Land units of the Chyulu hills and plateaus

land type	land components
ash and cinder cones	crater pits cone slopes
ash and lapilli fields	volcanic plains
lava fields	lava flows
former lava-dam lakes	lake plains lake terraces

Ash and cinder cones

Fifteen of the approximately 170 ash and cinder cones of the Chyulu Range fall within the study area. The Five Sisters south of the Kilaguni Lodge are examples of relatively old cones as seen from their soil formation and more eroded forms. The volcanic cone known as Kyaimu (Fig. 29) is a more recent

Fig. 29 Recent volcanic centre at Kyaimu (Tsavo West National Park)

example, being bare and consisting of unweathered basaltic cinders.
The cones in the centre of Chyulu Range are lined up in an approximate NNW-SSE direction. This corresponds to the main fold-trend in the underlying metamorphic basement and indicates that the volcanic activity is connected with an old zone of weakness in the crust.
Most cones can be divided into two components (Table 30).

- The craters are represented by the basin-like, rimmed structures at the summit of the pyroclastic cones. They can be circular or horseshoe shaped. A good example of the latter is found on the cone known as Malembwa.
- The cone slopes are made up of the often straight, inclined surfaces between the crater rim and the surrounding plains or lava fields. They consists mainly of lapilli and volcanic bombs. The soils have an A(B)C-horizon sequence with gradual transitions. The B-horizons are dark, reddish brown to brown and have a very weak, subangular, blocky structure. They have been classified as Mollic Andosols (Touber, 1979, p. 31). A petric or stony phase occurs in places due to the presence of volcanic bombs. On the reconnaissance soil map of the Mtito Andei area they have been mapped as soils developed on pyroclastic deposits (Van Wijngaarden &

Van Engelen, 1985, Appendix 1a, unit HPC).

Ash and lapilli fields

The ash and lapilli fields are made up of gently sloping plains made up of pyroclastic deposits. They occur immediately around the Five Sisters. On the geomorphological map this unit has been called the Kilanguni Plain. The position of the ash and lapilli deposits is southwest of the eruption points. This shows that the pyroclastics accumulated during a relatively short period when the northeast monsoon prevailed. The soils are characterised by an ABC horizon sequence with gradual transitions. The B horizons are dark brown and have a weak, subangular, blocky structure. The soils have been classified as Mollic Andosols with a petric phase (Van Wijngaarden, 1978, p. 157).

Lava fields

The lava fields form the greater part of the long, slightly concave slopes of the Chyulu Range. On the MSS Landsat imagery various different flows can be distinguished. They often start at the base of the cinder cones or at their centres where a horseshoe crater is present. The outflow of lava at the base of the cinder cones caused the undermining of part of the cone slopes, which in an advanced stage led to the opening up of the crater rim and the formation of the horseshoe crater.

The lava flows are clearly of different ages. Older ones, such as those of the Five Sisters, are grey due to a slightly weathered crust. Those of the Shetani are known to be approximately 120 y old (Nyamweru, 1980, p. 70). The rocks at the surface are black and almost completely bare, while inside lava tunnels are found.

Of interest are the flows near Mangelete which filled in the valley of the Mtito Andei River. Relief inversion has not yet taken place, but river incision has been of the order of 10 to 15 m. Similar lava-filled valley can be seen at the Kambu, Masongaleni and Kibwezi Rivers. These were studied by Temperley (1956, vol. II, p. 64-122), who recognized three superimposed flows without evidence for a considerable lapse of time between the successive extrusions. The unweathered surface caused Walsh (1963, p. 11) to conclude that they were probably not older than 1000 years. From organic material below a basalt flow in the Shimba-Kibwezi area, Saggerson (1963, p. 31) reported a 14C date of 480 ($\pm$200) y BP.

Former lava-dam lakes

The former lava-dam lakes north of the Kilimanjaro volcano are well known in the Amboseli area, Their lacustrine deposits have been mapped and described by Williams (1972, p. 49-63). A much smaller, but similar feature is found between the Kilaguni volcanic cone and Mzima Springs. Lacustrine limestones are exposed near the Kyulu gate and also near Mzima Springs where they appear to be overlain by younger lava flows. Two units have been distinguished during the present study (Table 30).

- The lake plains are seen as the flat plain surfaces in the Kyulu and Mzima Springs area. On the geomorphological map (Appendix 1) they have been called the Kyulu plains. They partly correlate with the volcanic plains on the soil map of the Mtito Andei area (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, unit PvV2P).
  The soils of these plains have an A(B)R-horizon sequence with gradual and abrupt transitions. The B-horizons are very dark, greyish brown and have moderately thick clay cutans and a fine subangular to angular blocky structure. They have been classified as Lithosols and Haplic Chernozems with partly a lithic phase (Van Wijngaarden, 1978, p. 158).
- The lake terraces seen as the higher edges of the lake plains. They are underlain by lacustrine limestones showing that the former lake once stood far above the level of the Kyulu plain. The limestones contain abundant macro and micro fossils. Stone Age implements are also present. Further investigations of the area is important in order to unravel the details of the Quaternary history of southeast Kenya.

The initial damming of the depression between the denudational plains and the lower slopes of the Chyulu lava fields was apparently caused by the outflow of lava from the Five Sisters in the east and the Kitani volcanic cone in the west. The fact that lacustrine limestones are also found between Mzima Springs and the Tsavo River shows that another barrier must have existed further to the southeast. This may be associated with a tectonic sinking of the whole area of the Chyulu Range. That such a displacement took place can be deduced from the position of the Chyulu lavas which are below the level of the denudational plains to the east.

3.2.2.2.2 Yatta hills and plateaus

The outstanding features of the Yatta Plateau have attracted attention for many years. Fairburn (1963, p. 21) summarised the theories about their origin. These vary from a lava flow which filled a valley at the time of its extrusion (Gregory, 1921, p. 186) to extrusion along a series of feeding fissures (Dodson, 1953, p. 5). Later studies and surveys have added little or no new evidence for either of these two contrasting origins and no conclusive explanation exists for this extraordinarily long lava plateau (Fig. 30). During the present study attention was paid to the land units which can be recognized (Table 31). They are described and discussed in the text below.

Volcanic plateaus
The volcanic plateaus are primarily formed by the main segments of the Yatta Plateau. From Fig. 31 it can be seen that the segmentation is probably connected with regional faulting. The vertical displacements are

Table 31. Land units of the Yatta hills and plateaus

land type	components
volcanic plateaus	plateau plains plateau depressions plateau gaps plateau slopes
volcanic buttes	butte summits butte slopes

approximately 10 to 30 m and took place partly along old strike-faults in the metamorphic basement rocks. Nowhere were they associated with volcanic activity, making a possible fissure eruption origin for the Yatta phonolites more likely.

Isolated landmasses in the form of mesas are associated with these large segments. In the central part of the Yatta, large mesas are found near Nthwaiani, Wathoni and Kitaani kia Ndundu. Many more are present along its southern part. Those near Atta and Sangaya are the most prominent. Their position indicates that at these places the Yatta had spurs which extended from the main plateau. A clear example can be seen near Kyandula, where the mesas and spurs occur opposite the confluence of the Kibiko and Athi rivers. Thus during the outflow of the Yatta phonolites in the Middle Miocene a paleo-Kiboko valley did exist. The Nthwaiani mesa also seems to indicate the position of a paleo-Tiva valley. The Wathoni mesa occurs near the abrupt eastward turn of the present Tiva River and may be associated with the presence of a valley system during the outflow of the phonolite lava in the Middle-Miocene period. Along the northwesterly part of the Yatta Plateau, spurs and mesas near present-day river confluences are known (e.g. near the Thwake-Athi confluence).

This coincidence of spurs and mesas near the major branch streams of the Athi and Tiva rivers show that the Yatta phonolite probably filled a main valley of the Middle-Miocene landscape. This is further evidenced by the flow direction of the lava which is indicated by the orientation of large anorthoclase phenocrysts. The question of whether the lava erupted along a series of fissures in this major valley, or came from the flood-lava area of the Kapiti plains, has not yet been satisfactorily answered. However, as yet no feeders have been found to sustain the fissure eruption origin (Fairburn, 1963, p. 21, Walsh, 1963, p. 7) is suggesting that the lava flow origin is more likely.

Whatever their origin, the Yatta lavas covered parts of the Middle-Miocene landscape and preserved them. In the northwestern part of the study area, the stream bed of the present Athi river lies about 240 to 180 m below the Yatta plateau. Near the Atta mesa the position of the same river is at about 150 m below the Middle Miocene land surface. This shows that river incision into the metamorphic rocks of the Mozambique Belt System took place with a mean rate of about 18 to 11 m/my. For the Tiva River this figure increases to about 22 m/my. In the most northeasterly part of the study area the Yatta

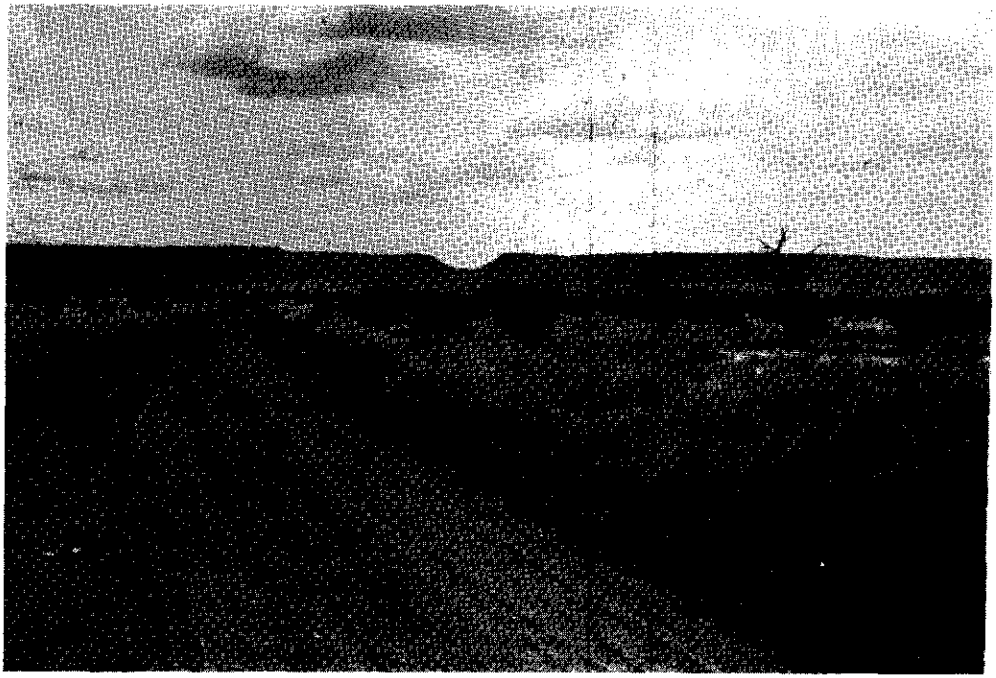

Fig. 30 Panorama of the southern end of the Yatta Plateau

Plateau rises to about 160 m above the plain surface of the Buchuma level. This suggests a mean denudation rate of at least 12 m/my for the surrounding metamorphic areas. The influence on the rate of denudation of different rock types and their stage of weathering is clearly shown by the fact that the Yatta phonolites survived the intense erosion. This leads to the conclusion that the metamorphic rocks of the Middle-Miocene landscape were probably deeply weathered.

Near the Atta mesa the general plain surface of the Buchuma level lies about 100 m below the Yatta plateau. At the easterly end of the Yatta Plateau, the elevation decreases further to about 20 or 30 m showing that during the post Middle Miocene denudation of the interior, the erosion base was situated near the present end of the Yatta Plateau. Further evidence is given by fact that the Yatta phonolite extend below the Plio-Pleistocene deposits of the Lamu embayment. This is shown by an outcrop of the Yatta lava about 10 km east of the main plateau surface near Sangayaya (Dodson, 1966, p. 7) where phonolites occur near the surface of the Early Pleistocene Taru level. Thus it may be concluded that the inversion of the Yatta Plateau mainly took place during the Late Miocene and Pliocene periods.

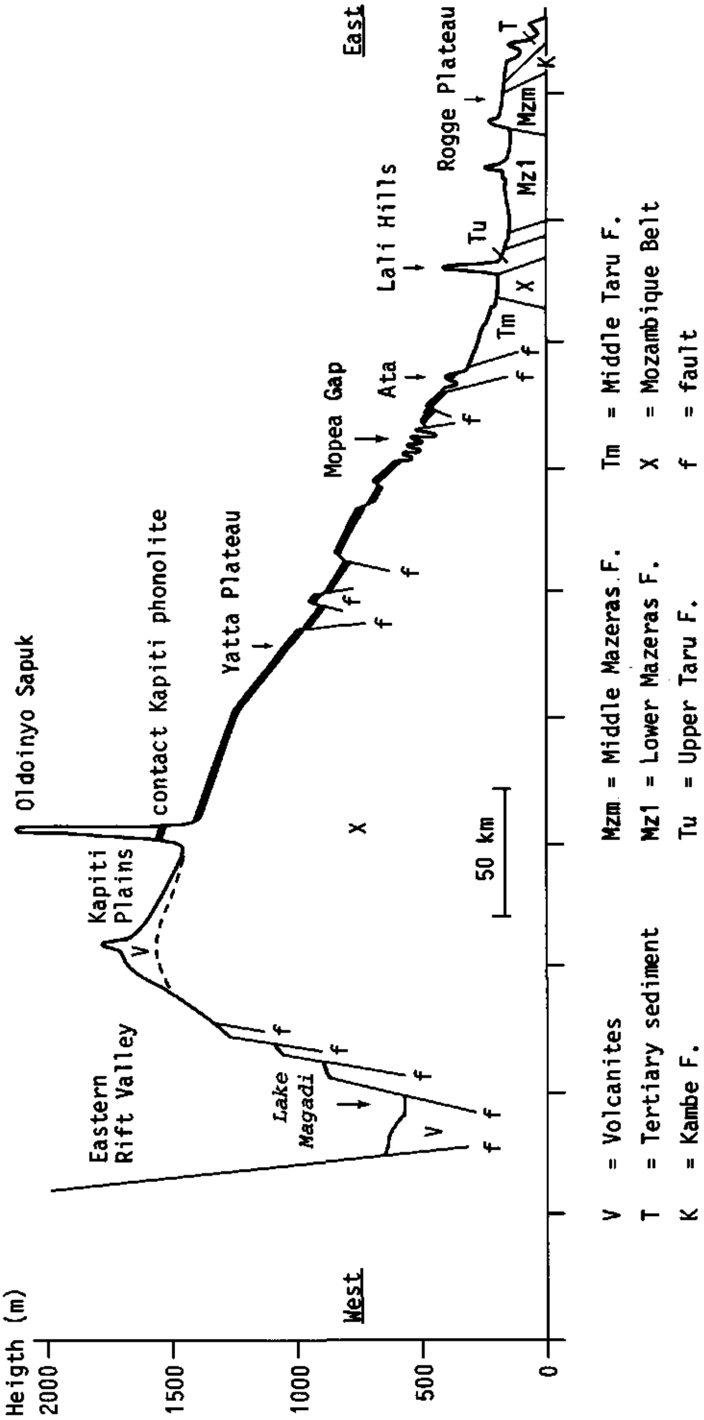

Fig. 31 Longprofile of the Yatta Plateau.

During the present study four components of the volcanic plateaus have been distinguished (Table 31).

- The plateau plains are represented by the flat and higher parts of the plateau and mesa summits. They are overlain by clayey, superficial deposits of approximately 1 to 2 m thick. The presence of metamorphic fragments in the sand and gravel fraction is noteworthy. This shows that the present-day plateau plain was once situated below the general surface of the surroundings.

  The soils which developed on the plateau plains have an AB(C)R-horizon sequence with diffuse boundaries. The B-horizons are dark red and porous massive or have a fine to medium subangular blocky structure. They have been classified as Rhodic Ferralsols and Ferralic Cambisols with in places a lithic and stony phase (Van Wijngaarden, 1978, p. 97, Appendix 1a,1b, unit LIC).
- The plateau depressions are represented by flat areas surrounded by higher ground and with evidence of poorly drained conditions. They are of various sizes as on the denudational plains. The large depressions are found mainly on the northwestern section of the Yatta Plateau and lie outside the study area. They have been recorded as bottomlands on the reconnaissance soil map of the Makueni area (Muchena et al., 1978, Appendix 1, unit BLd). Their soils appear to consist of calcareous, Pellic Vertisols with a saline and sodic phase. Comparable dark grey to black clay soils have been found in large stretches on the lava plateau in the Nairobi-Machakos area by Scott & Bellis (1963, p. 12, map sheet east) who argued for the presence of former lakes on the lava plains and plateaus in order to explain their occurrence. Lacustrine sediments are known on the Kapiti plains (Fairburn, 1963, p. 23) as The Athi tuffs and Lake Beds. Their Pliocene age (5.5 to 5.2 my BP) is indicated by radiometric datings of the underlying Simbara Series and the overlying Nairobi phonolites (Baker et al., 1971, p. 198, 206).

  Many smaller depressions, indicated on topographical maps as waterholes, are also present. Like the waterholes on the denudational plain, they are imperfectly drained. A great increase in the number of depressions at the southeastern end of the Yatta plateau is striking. Sanders (1963, p. 25), who mapped the geology in this area, called these depressions craters. In some he recorded the presence of a central plug rising about 10 m above the floor. From their distribution Sanders concluded that the lava poured out from points on several 'en echelon' fissures in the basement rocks. However, these same features can be explained by gas or steam explosions which occurred as a result of the outflow of hot lava over a water-saturated surface. The marked vesicularity east of the Mopea Gap (Sanders, 1963, p. 25) indicates that from this point the rapid outflow of the phonolite started to cool down and retard. The widening of the main plateau platform of the Yatta at this site evidences the presence of a flat area at the time of outflow of the lava. A divergence in the places where the lava accumulated is shown by the position of the mesas in this area. This may indicate the presence of an old delta at the mouth of the paleo-Athi river. On the Rogge Plateau, Middle Miocene marine limestones of the Baratumu Formation are exposed at elevations of up to about 150 m +MSL. It may well be possible that the coastal deposition in the Middle Miocene period reached the place where the Yatta Plateau broadens and becomes characterised by the numerous waterholes. A detailed mapping of the contact zone between the Yatta phonolite and the underlying Precambrian metamorphic rocks is needed for further clarification. The well rounded quartz pebbles found under the phonolite west of the Mopea Gap show that rolled materials are present. However, they alone do however not prove the presence of a former fluvial or coastal depositional environment. Like the rounded pebbles on the Buchuma plain level, they may also represent residual deposits derived from a previous cover of sedimentary rocks.

- The summit gaps are represented by the narrow passes through the plateau plain. The most well known are the Yatta and Thabangunji-Mopea gaps. They occur some distance downstream from the confluence of the Athi with the Kibiko and Tsavo rivers, respectively. Tectonic displacement has been shown in connection with the Yatta and Thabangunji Gaps (Walsh, 1963, geological map of Ikutha area; Sanders, 1963, geological map South Yatta area). So it is likely that the areas where gaps did develop were in these zone of weakness. Fluvial influence on their incision is evident. In the centre of the Thabangunji gap abundant rounded gravel is found which has metamorphic and volcanic components (Fig. 32).

From this it is concluded that, after the outpouring of the Yatta phonolite, the paleo-Kiboko and Tsavo rivers attempted to flow to the centre of the Lamu embayment in the northeast. They succeeded by cutting gaps in the lava surface in order to join the stream valley which developed on the northeastern side of the phonolite flow.

The depth of the Yatta gap is about 70 m which is roughly one third of the distance between the plateau summit and the present Athi river bed. Using a mean rate of fluvial incision of 18 m/my, this means that at about 9 my BP the gap was abandoned. This was before the end of the first phase of rifting at 12 to 8 my BP (Baker et al.,1978, p. 33).

The bottom of the Mopea gap lies at about 80 m below the summit platform, while the Galana River flows roughly 100 m lower. Thus at about 7.6 my BP the Mopea Gap was abandoned if it is assumed that river incision started to act immediately after the outpouring of the lava at about 13.2 my BP.

Other low passages across the Yatta plateau are known to occur near the confluence of the Athi with the Kibwezi and Kenani rivers. The fluviatile erosion did not cause gaps but lowered the lava outcrop considerably.

Remnants of an abandoned valley at the northeastern side of the Yatta were recorded by Sanders (1963, p. 8).

On the reconnaissance soil-map of the Mtito Andei area they have been indicated as Bottomlands and Alluvial Valleys (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, unit Bxd, AAv1 and AAvsK). However they are considerably younger than the gaps as they occur below the plain surface of the Buchuma level.

Fig. 32 Fluvial deposits on phonolite block in Thabangunji gap

- The plateau slopes are represented by the inclined surfaces between the summits of the plateau plains and the surrounding denudational areas. Their often perpendicular upper parts consist of the Yatta phonolites. Below these scarps are the long straight to slightly concave erosional slopes underlain by various Precambrian metamorphic rocks. At their lower parts colluvium has accumulated. The transition towards the lower plains consists of long gently sloping piedmont surfaces. On the soil map of the Mtito Andei and Tsavo areas they have been indicated as foot slopes (Van Wijngaarden & Van Engelen, 1985, Appendix 1a,1b, unit FXr2). Their soils have an AB(C)-horizon sequence with gradual to clear transitions. The B-horizons are dark red and have common moderately thick clay cutans and a medium to coarse subangular to angular structure (Van Wijngaarden, 1978, p. 94). Active incision has in many places destroyed these accumulation surfaces.

Volcanic buttes

The volcanic buttes are represented by the small and lowered isolated remnants of the Yatta Plateau. Their summits are often strewn with fragments of the Yatta phonolites. Their slopes are comparable to those of the volcanic plateaus.

3.2.2.3 Origin and development

From the morphological structure of the Tertiary and Quaternary volcanic areas it is clear that their development was essentially different. The source of the Yatta lava-flow was most probably situated in the Kapiti plains far beyond the western boundary of the study area. Its emplacement seems to have been a unique event. In contrast the Quaternary volcanic field of the Chyulu Range was clearly created in situ as a result of repeated eruptions from numerous vents, the most recent of which are known to be not older than 120 y. In the following paragraphs the sequence of events is summarized and followed by a chronological correlation with other events in the region. In the closing section on the developmental history some tectonic and climatic effects are reviewed.

3.2.2.3.1 Sequence of events

Before the extrusion of the Yatta phonolites in the Middle Miocene, the western part of the study area formed part of a dissected landscape. Valleys and interfluve ridges occurred in association with residual hills. The position of the Yatta Plateau shows that the direction of the main drainage ways was associated with the regional trend of the Precambrian basement structures. The northward turn at the downstream end of the Yatta Plateau coincides with the transition towards the sedimentary rocks of the Duruma Group. The rocks of the Taru Formation probably formed an obstacle for the southeastern flowing streams. This shows that cuesta ridges may have existed in the coastal area at the time the lava flowed down the paleo-Athi/Galana valley. The lava flow came to a halt in a swampy and flat area in the Atta/Sangayaya area which probably formed part of the coastal plain of the Middle Miocene period.

The event which caused the out flow of the phonolite lava over a distance of more than 300 km from the source area is not exactly understood. As a new hypothesis the burst of a lava dam at the old watershed east of the Kapiti Plains is suggested. Evidence for this is derived from the difference in elevations of the contact of the phonolites with the basement rocks. At the foot of the Ol Doinyo Sapuk and Matuu Hill the lava contact occurs approximately 200 m above that in the passes of the Kanzalu Range through which the phonolite flowed in the paleo-Athi valley (Fairburn, 1963, Geological map of the North Machakos-Thika area. The confinement of the Kapiti phonolite west of this old watershed of the Naivaisha depression has

been advocated by Williams (1978, p. 111-3). However to make an in-fill possible which reached 200 m above the bottom of the eastern passes, these low places must have been dammed up by lava. A burst of such a barrier may have given enough speed and supply to fill the whole paleo-Athi valley with a phonolite flow. As a consequence of this event the level of the lava surface in the Naivasha depression will have fallen. This may explain why the lava around the residuals is found far above that in the plains.
After the deposition of the Simbara Volcanic Series during the first eruptions of the Aberdare volcano, lacustrine sediments accumulated in this depression on the Kapiti plains (Fairburn 1963, p.22). The same took probably place on the lava surface of the present Yatta Plateau. The black clays in the large depressions are to believed the remains of this event. While volcanic eruptions went on in central Kenya, the Yatta phonolite flow underwent relief inversion.

The accumulation of the Kilimanjaro volcanic rocks was a major event. It was probably associated with the formation of the depression in which most of the basaltic lavas and pyroclastics of the Chyulu Range later accumulated. The actual start of the volcanic activity in the Chyulu Ranges is uncertain.

3.2.2.3.2 Chronological correlations

The rock type, physiographic position and radiometric dating of the Yatta phonolite clearly show its connection with the Miocene volcanism in the Naivasha trough or depression (Baker et al., 1971, p. 196; Williams, 1978, p. 113). The Quaternary age of the volcanic rocks of the Chyulu Hills is generally accepted (Nyamweru, 1980). However, little is known about the stratigraphy of the rocks and so a chronological correlation of the lacustrine succession near Kyulu Gate in Tsavo West National Park is not yet impossible. A lithological correspondence with the Pleistocene Sinya beds in the Amboseli area (Williams, 1972, p. 51) seems likely, but more study is needed to prove this suggestion.

3.2.2.3.3 Tectonic and climatic effects

The presence of low fault scarps on the Yatta Plateau (Walsh, 1963, geological map Ikutha area) shows that tectonic movement influenced the morphology of the region. The faulting probably corresponds with the formation of the Pleistocene scarps in the denudational areas. This is shown by the continuity between some fault scarps in the denudational plains and the Yatta Plateau (Sanders, 1963, p. 30).
Whether tectonic activity controlled the outpouring of the Chyulu lavas is not certain. The volcanic lineaments of the eruption points (Williams, 1978,

p. 4), suggest a relation with old basement structures and Cainozoic faults associated with rift formation.
The occurrence extensive former lakes in the Quaternary volcanic areas witness the presence of wetter climates in the past. More stratigraphic work is needed before a correlation can be made with the coastal chronology.

3.2.3 Fluvial areas

Large parts of the interior and the coastal plains of southeast Kenya have been dissected and remodelled by the action of water running through relatively narrow channels. This has resulted in the formation of many stream valleys which have been indicated as fluvial areas during the present study. As literal application of this definition is unpractical for the preparation of a 1 : 500 000 geomorphological map, only the main fluvial areas were taken into account. The smaller stream valleys have been described together with the land units of the surrounding coastal and interior areas. In the following sections of this report the fluvial areas are described and discussed in more detail.

3.2.3.1 Stratigraphical framework

The sedimentary deposits of the fluvial areas in southeast Kenya are little known. In most of the available geological reports they are mentioned but not described in detail.
In the Kwale area Caswell (1953, p. 30) called them alluvia. In the Kilifi area the fluvial deposits were included in the Recent Deposits. Most of the alluvium which fills the flat-bottomed valleys was considered to have accumulated during Pleistocene times (Caswell, 1956, p. 35).
In the Malindi area alluvium has been indicated on the geological map (Thompson, 1956). The deposits includes part of the sediments of the Sabaki and Koromi rivers, but were not further described in the adjoining report.
Williams (1962, p. 48) distinguished the silt of the Tana delta and the muds of the Tana alluvial plain. Both deposits were described as Recent Deposits without further evidence for their age being given.
In the Mid-Galana area, Sanders (1959, p. 36) reported the occurrence of Post-Miocene Beds at several points along the Galana river. They were described as yellow and brown, coarse, poorly consolidated, cross-bedded sandstones containing abundant pebbles of the Yatta phonolites. From the given site location it is deduced that he was referring to the terrace deposits of the narrow alluvial strip along the Galana river. To the west fine silts and sands are described as the materials bordering the present-day river bed.
Along the Galana river in the Voi and South Yatta area, Sanders (1963, p.

26) reported Pleistocene to Recent scrolls of cross-bedded sand and gravel containing pebbles of gneiss and lava. No evidence for his dating is given. Along the course of the lower Tiva river, red, brown and dark grey alluvial earths have been identified. Neither fluvial deposits was described in more detail.
In the Ndiandaza area Rix (1964, p. 18) mapped these deposits as Sandy alluvium. In his report he described them as dark alluvial muds.
Alluvium along the Tsavo river west of the Yu-Uni Falls has been reported by Bear (1955, p. 35). He included them in his Pleistocene and Recent deposits and mentioned the black cotton soils developed on them. Likewise, sandy alluvium along the Voi, Bura and Mwatate river has been reported in the area south of the Taita hills by Walsh (1960, p. 17).
In the Kasigau-Kurasse area the deposits bordering the Mwatate river have been indicated as Grey alluvial soils (Saggerson, 1962b, p. 40). Similar sediments have also been seen in other stream courses associated with the broad flat floored valleys occurring in the denudational plains of the Buchuma level. In the Taita Hills alluvial gravels, silts and clays has been reported along the main rivers (Horkel et al., 1979, p. 15).
During the reconnaissance soil surveys various stream deposits have been distinguished. In the Kwale-Mombasa-Lungalunga area they are indicated as River deposits which consist of layered sands, silts and clays (Michieka et al., 1978, p. 29). In the Voi area they have been called Fluviatile deposits (Van Wijngaarden, 1978, p. 48) and occur along the Tiva, Athi-Galana and Voi rivers. The deposits of the valley floors and the depressions have been described as subrecent-alluvial sediments. In the Kilifi area stratified sands and silts occurring in the floodplains of the major streams have been reported under the heading of Recent alluvial and unconsolidated deposits (Boxem et al., 1987, p. 24).

From the above it is clear that a well defined stratigraphy has yet to be established. There is clear evidence for the existence of older and younger deposits, but their exact age is uncertain. If a correlation between the fluvial deposits and the sediments in the littoral zone could be made, then a more detailed stratigraphy would emerge.
In the following sections, descriptions are given of the various fluvial levels which have been distinguished during the present study. The picture remains incomplete since the fluvial areas only received superficial attention. More detailed fieldwork will be needed to reveal the full history of the rivers and streams in southeast Kenya.

3.2.3.2 Morphological structure

From previous studies and surveys the existence of several river terraces is known. Toya et al. (1973, p. 88) reported the presence of four terrace-like steps along the Sabaki river near Jilore. They tried to correlate them with

the Ganda or Kilifi (=Majaoni or Mtondia), the Malindi (=Mackenzie-I) and the Shelly Beach Terraces (=Uhuru), respectively. Michieka et al., (1978, p. 31) also reported the existence of three terraces along the Mkurumuji river in the Kwale area. In the north, Higher terraces were distinguished from the Tana floodplain by Stolp & Vleeshouwer (1981, p. 8).
On the present geomorphological map (Appendix I) the various remnants of former floodplains and valley floors have been subdivided into lower, middle and upper fluvial levels. The criteria used for this subdivision were their relative position with respect to the various levels of the coastal plain and their height above the present-day river bed. Thus the lower, middle and higher fluvial levels correlate with the lower, middle and higher paralic and littoral levels of the coastal plain. Since accurate topographical data in the form of ground level measurements are lacking the correlation is often tentative. More work is required before a firm sequence and correlation of the stream terraces can be established.
In the following sections the land units of the various terraces distinguished during this study are described and discussed.

3.2.3.2.1 Lower fluvial levels

Remnants of former floodplains can be found between 0 and 10 m above most present-day majors streams. The remnants are commonly characterised by stratified deposits and relatively young soil profiles. The levels of these fluvial areas are indicated as the lower fluvial levels as they merge with the lower littoral levels at the coast.
Most streams run in a approximate west-east direction and their older terraces are positioned above the younger ones. This illustrates the continuing uplift of most of the study area. By contrast the terraces along the lower Tana river show hardly any difference in elevation. Near the Tana delta, the older terraces on the eastern bank of the river even seem to pass under the younger ones. This points to a relative down warp of the Tana basin east of the present-day river course. As a consequence, correlation of terraces in different major drainage areas on the basis of relative elevation above the stream bed is hazardous. This requires a separate

Table 32 Land units of the lower fluvial levels

Land type	Land component
floodplains	stream beds levees crevasse ridges back swamps
stream terraces	former stream-beds former levees former back-swamps

treatment for each of the main catchment areas and a description of the terraces based on other characteristics as well as height above the river bed alone. Minor landform associations and soil development are important additional criteria for distinction and correlation.
Table 32 gives a synopsis of the land units which can be distinguished on aerial photographs and in the field. Their occurrence and characteristics in the various drainage areas are described below.

Tana-Tiva basin

The alluvial valley of the Tana river is one of the most prominent fluvial areas of Kenya and is characterised by the presence of a recent floodplain and several stream terraces. The upper course of the river lies west and north of the study area, where it cuts through Tertiary and Quaternary volcanites and Precambrian metamorphic rocks. In this region the position of the river bed is structurally controlled and the stream pattern is mainly braided. Apparently no older terraces have been formed or were recently eroded away (Veldkamp & Visser, 1986, p. 74) and this may well reflect the Pleistocene uplift of the East Kenya-Somalia block. It further shows that under the present climatic conditions stream bed incision predominates in that area.
The middle and lower Tana-valley runs through the Plio-Pleistocene sediments of the Lamu embayment. At the transition from the Precambrian metamorphic area to the sedimentary area, the stream pattern changes to meandering and a broad alluvial valley has been formed. Extensive recent splay deposits have been reported in this area and it is suggested that they are related to recently increased erosion (Sombroek et al., 1974, p. 3). Further study of the river valley is required in order to connect these deposits with the phase of terrace dissection and removal in the upper course.
The presence of several terraces along the middle and lower Tana valley is known from several soil and irrigation feasibility studies. In the report of Ilaco/Acres (1967) the occurrence of a Middle terrace is described. The unit correlates with the Low-terrace land reported by Sombroek et al. (1974, p. 3) which occurs a few metres above the flood level (about 5 m above stream bed) of the Tana river. The terrace is characterised by the presence of a hardpan at around 80 cm depth (Sombroek et al., 1974, p. 7).
Near the fluvial delta plain of the Tana river a Lower terrace and Upper terrace have been reported at about 2 to 3 and 5 m above flood level (Sombroek et al. 1973, p. 5).
On the geomorphological map this Lower terrace has been included in the floodplain areas for the convenience of map compilation and indicated as the Tana-III plain. On a larger scale the older or upper parts of the Tana floodplain are easy to distinguish from the younger parts by the fact that the surfaces of the former show evidence of earlier dissection. The valleys which were formed have subsequently been blocked by the deposits of the younger parts of the Tana flood plain resulting in many small lakes can be

found in these former valleys. This clearly shows that two separate stages of landscape formation are involved.
The younger fluvial surface has been defined and indicated as the Tana-II level. It consists of the vegetated meander-terraces at about 1 to 2 m above the bare point-bar deposits. These form part of an abandoned meander belt in which the Tana river cuts the present bedding. When studied in detail it seems that the Tana-II level can be subdivided in an older and younger sub-level.

Tana Floodplain

The floodplain of the Tana river has been subdivided into four components (Table 32).

- The levees are seen as long broad ridges along the stream channel. They are made up of stratified, non-calcareous fine sands to loams.
  Insufficient detail is known to enable differentiation between the levee deposits of the various lower fluvial levels.
  The soils of the younger levees are characterised by an A-C-horizon sequence and have been classified as Eutric Fluvisols (Stolp & Vleeshouwer, 1981, p. 15, mapping unit FR11). The soils on the levee aprons towards the backswamps show vertic properties and have therefore been classified as Vertic Fluvisols (Stolp & Vleeshouwer, 1981, p. 17, mapping units FRb1,2).
- The crevasse splays are seen as tongue-shaped masses of stratified sediments near water-cut channels through the levees. Examples can be found near Wema and Kulesa. Their deposits and soils are similar to those of the levees.
- The backswamps are made up of the low lying land on both sides of the river beyond the levees. Their deposits consist of strongly cracking, non-calcareous clays. The soils which developed in the sediments classify as Vertic Fluvisols (Stolp & Vleeshouwer, 1981, p. 19, mapping unit FRb3).

Tana terraces

The terraces of the lower levels of the Tana river appear to consist of only one component (Table 32).

- The former backswamps are made up of the remnants of abandoned flood basins. Their sediments consist of cracking, calcareous and sodic clays. The soils have an ABC-horizon sequence and are characterised by clay illuviation. They have been classified as vertic Solonetz (Stolp & Vleeshouwer, 1981, p. 24, mapping unit TOu).

The Tiva river has, like the Tana river, a structurally controlled upper course, deeply incised into Precambrian metamorphic rocks. After its sudden eastward bend near Wathoni, the river meanders until it reaches the area where Plio-pleistocene deposits are overlying the consolidated subsurface rocks. In this section two high terraces and an active floodplain have been recorded (Van Wijngaarden, 1978, p. 52). The terraces are further discussed in Section 3.2.3.2.3. The floodplain is too narrow to be mapped on a 1 : 500

000 scale. Still further east, the Tiva has a braided stream pattern. Numerous streams cut their channels through the remnants of the middle fluvial levels. They have not been indicated on the geomorphological map because of their size.

Athi-Galana/Sabaki basin

The composition of the lower fluvial levels along the Athi-Galana/Sabaki river and its tributaries is similar to that of the Tana river, but differences included the smaller width of the floodplain and clearer height differences between the various fluvial levels. This illustrates the stronger uplift of the Athi-Galana/Sabaki basin.
In its upper course the river is again deeply incised in Precambrian metamorphic rocks. This has resulted in a stream valley of about 70 to 100 m deep, calculated from the surface of the surrounding plains at the Buchuma or Mtito Andei level. In this section the position of the river is again structurally controlled. In the floodplain terrace remnants at 1 to 2 m above the levels of active point-bar deposits occur but they are too small to be mapped on a 1 : 500 000 scale.
Further east the floodplain broadens and the river starts to meander. The influence of the subsurface rock structures is, however, still recognizable. East of the narrow passage through the Jurassic limestones of the Kambe Formation the Sabaki river has filled in a large river estuary. Here the fluvial areas of lower levels reach a width similar to these of the Tana river.

Galana/Sabaki floodplain

Within the floodplain of the Galana/Sabaki river three Lower levels can be distinguished.

- The Galana/Sabaki-I level, formed by the active river bed with its sandbanks and point bars;
- The Galana/Sabaki-II level, made up of vegetated point-bar terraces and abandoned meanders at about 1 to 2 m above the active sandbanks;
- The Galana/Sabaki-III level, consisting of vegetated levees and backswamps at around 5 m above the active sandbanks.

This last level correlates with the Madungoni surface described by Toya et al. (1973, p. 88). It has been formed by fluvial sedimentation in a formerly eroded river valley. This is evidenced by the blocking of the branch valleys by levee and backswamp deposits. As in the Tana valley, small lateral lakes are found. The floodplain appears to be made up of two components.

- The levees of the Galana/Sabaki river consist of non-calcareous, stratified fine sands to sandy clay loams. They are characterised by dark brown to dark yellowish brown soils with an AC-horizon sequence and classify as eutric Fluvisols (Van de Weg & Sombroek, 1976, p. 14, mapping unit AA1, Sombroek et al., 1982, p. 36, mapping unit A5).

- The backswamps consist of stratified, cracking clays. Their soils classify as vertic Fluvisols.

Galana/Sabaki terraces

The terraces of the lower levels of the Galana/Sabaki river, have not yet been recognized. They may well be present and have probably been included in the terrace remnants of the middle levels.

Voi-Vitengeni-Rare basin

In the upper and middle courses of the Voi river the lower fluvial levels have not been recognized. The absence of lower fluvial levels along most of the course of the Voi/Vitengeni river may be associated with the seasonal character of the stream. Another factor has probably been the stronger uplift of the central part of the study area.
Only in the littoral zone between Rare and the mouth of the river in the Bandari ya wali, the lower terraces have been recognized The most prominent feature is a floodplain with narrow levees and backswamps. It has been mapped as the Rare-III level and correlated with the wide floodplain areas of the Tana and Sabaki river.

Other drainage basins

A similar situation to the Voi basin occurs in the other catchments of the central part of the study area. They all have a predominantly erosive character in the upper courses and a broadening flood plain when passing through the littoral zone.

In conclusion it can be said that the lower fluvial levels are well developed along the middle and lower courses of the perennial Tana, Athi/Galana/Sabaki rivers. The intermittent rivers of the central and southern sections of the study area have relatively small floodplains and lower terraces when passing through the littoral zone.

Table 33 Land units of the middle fluvial levels

land type	land component
stream valleys	valley floors stream terraces
fault sags	sag ponds

3.2.3.2.2 Middle fluvial levels

Between about 5 and 40 m above the present-day stream beds two other terrace levels have been recognized. Near the mouth of the Tana and Sabaki rivers, they merge with the Mtondia and Majaoni levels of the littoral zone. Therefore these stream terraces have been shown on the geomorphological map as remnants of the middle fluvial levels. As far as could be observed the related deposits have lost most of their sedimentary structures. In the central part of the study area the fluvial areas of the middle levels are mainly represented by alluvial valley-fills. They are found in the form of incised valley floors or as local valley shoulders. Their identification as middle fluvial areas is partly based on the fact that they occur below the summit level of the Mitangani or Tezo plain. Therefore the valley floors and shoulders must be younger than the higher levels of the paralic and littoral zone. Table 33 gives a synopsis of the land units which have been described during the present study. Their main characteristics are described and discussed below.

Tana-Tiva basin

On both sides of the Tana river remnants of stream terraces are found at about 5 to 7 and 8 to 12 m above its present stream bed level. On the geomorphological map (Appendix I) they are indicated by the map symbols 334 and 335. These remnants form part of two former floodplains, which have been correlated with fluvial level IV and V.

Tana-IV level

The level of the Tana-IV plain correlates approximately with that of the Upper Terrace distinguished by Sombroek et al. (1973, p. 5). Compared with the flood plain of the lower fluvial levels, it lacks the characteristic landforms of a meandering stream. The terrace treads consist of sandy clays without sedimentary structures. More stratigraphical work is needed to distinguish these deposits from the littoral deposits of the corresponding Mtondia level. The deposits underlying the terraces of the Tana-III level may be found to consist of littoral sediments of which the upper part has been reworked since in the present fluvial areas coastal sand bars are absent.

Many of the sag ponds found in the littoral area of the Majaoni level appear to be connected with the terrace of the Tana-IV level. Therefore they also have been included in the fluvial areas of mapping unit 334 (Appendix I). The ponds may have been flooded during times of high river discharge when the Mtondia level was being built up. More data has to be collected from these sag ponds in order to unravel their history.

The soils of the terrace remnants of the Tana-III plain have an ABC-horizon sequence with gradual transitions. The B-horizons are often very hard and have a texture of sandy clay to clay loam. They are further characterised by a moderate salinity and a moderate to strong sodicity (Sombroek et al. 1973, p. 5). The soils are classified as Orthic and Gleyic Solonetz with a saline phase. They tend towards Gleyic and Luvic Phaeozems with a saline and sodic phase where the high sodium content occurs too deep to be diagnostic for an natric B-horizon. At the bottoms of the sag ponds, clays with vertic properties occur in the subsoils. The soils which developed at these sites are mostly vertic intergrades of the Solonetz and Phaeozems. However, if a light textured topsoil is present, then the soils have to be classified as Solodic and Humic Planosols. On the exploratory soil map of Kenya (Sombroek et al., 1982, Appendix 1) the terraces are included in the coastal plains (mapping unit Pc5). This underlines the uncertainty which exists about the correct classification of these terraces.

Tana-V level

A still higher terrace occurs along the Tana river at about 8 to 12 m above the present-day stream bed. The treads of the terrace appear to merge with the Majaoni level of the littoral zone. The level of the terrace remnants correlates with that of the lowest Upper River Terrace described by Sombroek et al. (1982, Appendix 1, unit Pt4). Morphologically, it differs from the surrounding littoral terraces by the absence of sand bars parallel to the coast. As on the Tana-IV plain, the lithological characteristics resemble those of the corresponding littoral Majaoni terrace. Part of the fault sags of the Tezo level east of the Tana are connected with the terrace tread of the Tana-V plain. The deposits in the former sag ponds consist mainly of heavy, cracking clays.

The soils of the terraces and sag ponds in the study area usually have an ABC-horizon sequence with clear transitions. The B-horizons vary in colour from very dark, greyish brown to dark reddish brown and show signs of clay illuviation. They are moderately saline and moderately to strongly sodic. The soils are classified as Orthic Solonetz with a saline phase and tend to Vertic Luvisols with a saline and sodic phase. On the exploratory map of Kenya (Sombroek et al., 1982, Appendix 1) they included in the mapping units Pc3 and Pt4.

The soils of the sag ponds are characterised by an A(B)C-horizon sequence with gradual transitions. The colours of the subsoils vary from light, brownish grey to brown. In places the soils are sodic but the salinity is usually low. They are classified mainly as Gleyic Phaeozems and pellic Vertisols with a sodic phase (Sombroek et al., 1982, Appendix 1, unit B15)

Tiva and other Tana tributaries

Along the lower course of the Tiva river and other tributaries on the western bank of the Tana river, several abandoned floodplains or incised valley bottoms are observed on aerial photographs. The former floodplains are situated below the level of the surrounding paralic areas. They often start from relatively narrow beds and widen towards the coast. Their identification as correlatives of the Mtondia and Majaoni levels is based on the fact that they appear to merge with those levels and the related Tana-IV and Tana-V plains. No details of their sediments are known. The numerous abandoned stream beds which can be seen on aerial photographs show that the middle terraces of the lower Tiva course were once part of a braided system. On the exploratory soil map these fluvial areas are part of the Sedimentary plains of large alluvial fans (Sombroek et al., 1982, p. 35, unit Pf3). The deposits mainly consist of reworked material from unconsolidated subsurface deposits. During periods of high rainfall the areas are sometimes flooded and as a result the surface is in places covered by wash deposits of fine sands and silts. Thus the soils of the middle Tiva terraces show a wide variation. On the exploratory soil map of Kenya they have been shown as Orthic Solonetz with a saline phase in association with Solodic Planosols with a saline phase and Chromic Vertisols with a saline and sodic phase. The soils which developed in the more recent superficial wash have been classified as Cambic Arenosols.

On the other tributaries the fluvial areas which correlate with the middle terraces of the Tana river exist as incised valley floors. They reflect the multicycle history of the valleys cut into the deposits which underlie the paralic areas of the Mitangani and Samburu plain levels. Their correlation with the Tana-IV and Tana-V plain is again based on the fact that the levels of the valley floors merge with those of the middle Tana terraces.

The soils of these incised valley-floors have not been studied. On the reconnaissance soil map of Kenya they are shown as Chromic Vertisols with a saline sodic phase (Sombroek et al., 1982, p. 36, mapping unit A12). No information about the differences between the higher and lower parts of the valley floors is available.

Athi-Galana/Sabaki basin

In the central part of the study area, terraces and remnants of valley floors which correlate with the middle levels of the littoral zone are found. Along the Sabaki river they are present in the lower course east of the Lali hills. Two middle fluvial levels have been recognized. The terraces which occur at about 20 to 25 m above the present-day stream bed have been identified as remnants of the Sabaki-IV level. At about 30 to 35 m terrace remnants of another level are present. Near the Lali Hills fluvial deposits with phonolite pebbles help in identifying the flat areas along the valley side slopes of the Sabaki river as terrace remnants. Further east the fluvial nature of the superficial deposits at this level is less convincing. Therefore the flat remnants have been included in the terrains mapped as dissected parts of the paralic Mitangani plain. However, when more detailed fieldwork can be carried out the flat areas on the higher parts of the valley side are likely to be established as true river terraces.

The greater elevation of the middle Sabaki terrace compared to those of the Tana basin is remarkable and seems to reflect the stronger uplift of the central parts of the study area.

Typical soils of the Sabaki middle terraces are not known.

Other drainage basins

The fluvial areas of the middle level in the drainage basins in the central and southern parts of the study area are made up of valley bottom plains and valley shoulders. Their sediments have been shown to consist of clays and fine silts. The distinction of the two middle levels in these areas is provisional and based upon their differing topographical positions.
On the soil maps these fluvial areas have been mapped as Bottom Lands and Alluvial Valleys (Van Wijngaarden & van Engelen, 1985, Appendix 1b) or River Terraces and Floodplains (Michieka et al, 1978, Appendix 1a, 1b). The soils appear to consist of a complex of Vertisols, Solonetz and Luvisols. Around the eroding stream beds Fluvisols are usually found.

3.2.3.2.3 Higher fluvial levels

Between about 10 m and 50 m above the present-day stream beds in the interior region two other terrace levels have been recognized. Near the transition towards the coastal region, these terraces widen and then merge with the paralic plains. The land units are similar to those of the middle fluvial levels.

Tana-Tiva basin

Along the middle course of the Tiva river remnants of three higher fluvial levels occur. They were first recognized during the reconnaissance soil survey of the Mtito Andei area (Van Wijngaarden, 1978, p. 52). The highest terraces occurs at about 20 to 25 m above the floodplain level and are characterised by Chromic Luvisols in the well drained parts and Pellic and Chromic Vertisols in areas of poor drainage (Van Wijngaarden & Van Engelen, 1985, Appendix 1a, mapping units AAr1 and AAr2). Further east the terraces merge with the paralic plains of the Taru level.
The second terrace which was recognized in the Tiva valley occurs at about 5 to 10 m above the floodplain. More to east it appears to merge with the Samburu level of the paralic zone. The soils of this second higher terrace mainly consist of Calcic Luvisols with a petric phase caused by the abundance of pisocalcic material in the subsurface (Van Wijngaarden & van Engelen, 1985, Appendix 1a, mapping unit AAr3).
The 2 to 5 km wide valley bottom plain of the middle course of the Tiva appears to be connected with the Mitangani level of the paralic zone. It is characterised by Chromic Vertisols (Van Wijngaarden & van Engelen, 1985, Appendix 1a, mapping unit AAr5). To the east, this valley bottom plain has been incised by the Tiva river and a younger floodplain occurs.

Athi-Galana basin

The higher fluvial levels of the Athi-Galana basin occur as valley bottom plains in the branch streams and strongly dissected terraces along the main stream. That the strongly dissected areas along the Athi-Galana river do indeed consist of former terraces is shown by the presence of well rounded phonolite pebbles which are found in the gravel deposits on the metamorphic rocks. The boundaries between the terrace levels are provisional as they are based mainly on aerial-photo interpretation.
On the soil maps of the Mtito Andei and the Voi area the strongly eroded fluvial terraces are included in the dissected erosional end sedimentary plains (Van Wijngaarden & van Engelen, 1985, Appendix 1a, 1b). The soils of the valley bottom plains in the minor side branches correlate correspond to those of the higher Tiva terrace.

Other drainage basins

The valley bottom plains of the remaining drainage basins of the interior have been included in the fluvial areas and provisionally correlated with the highest level. In the depositional areas at the foot of the residual hills, sedimentation of alluvium may have continued considerably longer than in the valley plains which have an incised stream bed.
On the soil maps of the Mtito Andei and the Tsavo areas the valley bottom plains are indicated as Bottomlands and Broad Alluvial Valleys. They are characterised by Vertisols, Luvisols and Solonetz often with large amounts of calcium carbonate, sodium and soluble salts (Van Wijngaarden & van Engelen, 1985, Appendix 1a,1b).

3.2.3.3 Origin and development

The morphological structure of the fluvial areas shows that their and genesis later development in the middle and lower courses of major streams is associated with the paralic and littoral areas. Changes in erosion base level and climatic conditions both played a role.

3.2.3.3.1 Sequence of events

The merging of the various fluvial levels with the main paralic and littoral levels shows that the events leading to the formation of all these areas are related. Therefore the same terminology for the subdivision of the time during which the coastland developed has been used again here. A synopsis of the main events in the coastal region and the fluvial areas is given in Table 35.

Table 35 Subdivision of the Nyika period in the fluvial areas

period	surface	littoral level	sea level	paralic level	fluvial level	fluvial event	lithostratigraphical record
Late Nyika	lower	Bofa	high		I	dissection	
	middle	Uhuru-II	? high		II	sedimentation dissection	Alluvium
		Uhuru-I	? high				
					?? ??		
	upper	Mackenzie-II	? high low		III	sedimentation dissection	Alluvium
		Mackenzie-I	? high				
Middle Nyika	lower	Mtondia-II	? high		IV	sedimentation dissection	Alluvium
		Mtondia-I	? high low				
	upper	Majaoni-II	? high		V	sedimentation dissection	Alluvium
		Majaoni-I	? high low				
Early Nyika	lower	Tezo-II	? high	Mitangani	VI	sedimentation dissection	Alluvium
		Tezo-I	? high low				
	middle	Cambini-II	? high	Samburu/Bore	VII	sedimentation dissection	Alluvium
		Cambini-I	? high low				
	upper	Sokoke-II	? high	Taru/Mtsengo	VIII	sedimentation dissection	Alluvium
		Sokoke-I	? high low				

3.2.3.3.2 Chronological correlation

No radiometric or other datings of the various terrace levels are available. Therefore their ages remain provisional and chronological correlation is only possible through the proposed connection with the dated coastal levels.

3.2.3.3.3 Tectonic and climatic effects

The smaller elevations of apparently contemporary middle and lower terraces in the Tana basin compared to those of the drainage basins of the central part of the study area reflect the influence of differential uplift. This tectonic movement is believed to have been connected with the formation of the Maktau dome.

The development of the fluvial areas also reflects the presence of changing periods of erosion and sedimentation. However, too little detail is known to be able to derive a dated sequence of wetter and dryer climatic conditions from the geomorphological structure of the fluvial areas. In the Tana and Athi-Galana rivers, moreover, the volume of sediment did not only depend on the amount of erosion in the denudational areas. The deposition of large amounts of fluvial sediments during the Holocene sea-level rise suggests that materials from melting glaciers on Mt. Kenya and Mt. Kilimanjaro were another important source.

A warmer climate and wetter climate, as is likely to have occurred during the periods of high sea-level (Van Zinderen Bakker & Mercer, 1986, p. 230), will generally have led to a lessening of sheetwash erosion. Incision of the valley floor plains is likely to have occurred during these periods, just as it does today. In the Tana and Athi-Galana rivers, Pleistocene the aggradation of the floodplain is most likely to have place during the onset of the warmer and wetter episodes because of their connection with the glaciated areas of the interior.

4 CONCLUSION AND DISCUSSION

The analysis of the morphology of southeast Kenya has shown that most of the landforms of the present-day landscapes were formed during the Plio-Pleistocene period. Few remnants of earlier landscapes have been left which can be identified from old surface crusts and soils.
In this chapter the geomorphological history of southeast Kenya is reviewed and updated by the conclusions reached in the present study. Suggestions for possible continuation of this research are made in the final section.

4.1 Geomorphological history

The morphological genesis and later development of the coastal and interior region of southeast Kenya occurred over a vast period of time. The starting point of the current review of the geomorphological history has been taken at the orogenic episode of the Middle to Late Precambrian, which led to the folding and metamorphosis of the Usangaran sediments of the Mozambique Belt geosyncline. In the following sections the successive changes in the morphology of the study area are reviewed and discussed.

4.1.1 Precambrian era

From the results of geological surveys (Bear, 1955; Walsh, 1960; Saggerson, 1962b; Sanders, 1963; Horkel et al. 1979; Pohl & Niedermayr, 1979) it is clear that during the Early to Middle Precambrian time the whole of southeast Kenya was part of a vast depressional structure, known as the Mozambique geosyncline. This was gradually filled in with a series of sedimentary rocks and volcanic intercalations, which correlate with the Usagaran sediments of Tanzania (Pohl & Niedermayr, 1979, p. 8; Horkel et al. 1979, p. 4). During three phases of deformation the rocks were folded, metamorphosed and rejuvenated. This took place in the Late Precambrian and continued into the Cambrian period. The orogenic events led to the formation of what is now seen as the metamorphic basement mainly composed of the gneisses of the Mozambique belt. The NNW-trend in the metamorphic basement originates from the first period of folding. This direction can be observed in the present-day landscape by the direction of the Yatta Plateau and the low ridges of the Tsavo area. The higher residual hills are also positioned in line with the direction of the fold structures in the Precambrian rocks (e.g. the Pare-Usambara mountains and the Kasigau-Sagala-Taita-Ngulia hills). The morphological result of the early orogenic events was that at the end of the Precambrian/Cambrian times the landscape consisted mainly of fold mountain areas with a high relief intensity.

4.1.2 Paleozoic era

After the third deformation phase at the end of the Cambrian period (Horkel, 1979, p. 19), there followed a period of approximately 200 my in which nothing is known from southeast Kenya. It was when extensive platform covers were deposited over the northern part of Africa (Choubert & Faure-Muet, 1976). This suggests considerable erosion of the mountain belts of central Africa. A similar erosion is expected to have occurred in the mountains of southeast Kenya assuming that the climatological conditions were not considerably different. That the correlative deposits of this period are not found in the area shows that, during the Ordovician, Silurian, Devonian and most of the Carboniferous, southeast Kenya probably existed as a large denudational region.

It was not until the end of the Carboniferous that deposition took place within the area of the present study. The stratigraphy and reconstruction of the sedimentary paleo-environment of the rocks of the Duruma Group related to this event have been recently updated by Cannon et al. (1981b). They show that, at the end of the Carboniferous or beginning of the Permian, the deposition was initiated by major rift faulting. This resulted in the formation of linear troughs in which the mainly fluvial deposits of the Taru Formation were deposited. The arkosic nature of the sandstones show that what remained of the original fold-mountain landscape was again intensely eroded. It is likely that the interior area was completely stripped of its soils and regolith, in order that fresh metamorphic materials could become the major component in the sediment load of the rivers. The predominant north-northeastwardly directed paleocurrents known from the Kilifi area (Cannon et al., 1981b, p. 422) show that the region of the present-day Pare mountains and the Kasigau-Sagala-Taita-Ngulia hills probably acted as main watershed areas.
Several residual hills consisting of Permian sandstones of the Taru Formation (e.g. Kilibasi, Taru and Lali hills) presently rise approximately 200 to 450 m above the denudational plain level which is underlain by Precambrian metamorphic rocks of the Mozambique Belt. This indicates that large parts of the flat and featureless plains in the Tsavo-East area may once have been overlain by sedimentary rocks of the Duruma Group. Blocks of sandstones found up to about 40 km west of the present-day most westward outcrop (Saggerson, 1962b, p. 35) are probably the remains of this former

Permian-Triassic sedimentary cover. The widespread occurrence of well to very well rounded quartz gravel throughout the Tsavo plains may also be related to the presence of Duruma rocks west of their present outcrop. From the partly lacustrine nature of rocks of the subsequent Maji ya Chumvi Formation it is clear that at the end of the Permian period extensive lakes existed in the region. Abundant plant remains (Karanja, 1983, p. 6) indicate the presence of associated vegetation cover.

In conclusion, it can be said that at the end of the Permian the landscape in the most southwesterly part of the study area consisted of a strong dissected hill or mountain region. As in the present-day dissected metamorphic areas of central Kenya, the major direction of the drainage pattern was probably parallel to the fold-trend in the basement rocks. The position of the present old upland massifs seems to indicate the watershed areas of that time. The flat fluviolacustrine area in the central and eastern part of the study area must have been a swampy monotonous region. The mud cracks and salty horizons indicate an arid climate at the end of this period (Karanja, 1983, p. 6).

4.1.3 Mesozoic era

Considering the sedimentary record, the geomorphological history of the Mesozoic era can be divided into six different periods. Remnants of the Late Mesozoic landscape are believed to be present on the summits of the residuals of the Taita and Sagala levels.

4.1.3.1 Early to Middle Triassic period

At the turn of the Triassic period a marine incursion is believed to have taken place in southeast Kenya (Cannon et al. 1981b, p. 423). The paleocurrent direction suggests that the transgression reached the area from the northeast and the shallow marine to lagoonal environment is evidenced by fish-fossils at the bottom of the Middle Maji ya Chumvi Formation (Cannon, 1981b, p. 423). This event changed the landscape of most of the present study area. Beside the mainly fluvial erosion and fluviolacustrine deposition, marine abrasion and sedimentation started to play a role. The presence of a disc-shaped nodule comparable to those of the Middle Maji ya Chumvi fish-bed among the gravel found in the Buchuma rock basins, may indicate that this transgression reached the present interior areas. Consequently the planation and denudation of the metamorphic areas may have been partly marine in character during the Triassic period.
After the regression of the Triassic sea the lacustrine sedimentation continued. The predominance of shales deposited in shallow water show that

fairly stable conditions occurred. Whether the interior was vegetated and deep soil formation took place is unknown, but around the lakes there was enough food for reptiles to live (Harris & Caroll, 1977). Arid conditions are known to have also existed, as evidenced by the mud cracks and salty layers found in the rocks of the Maji ya Chumvi Formation. The lacustrine sedimentation became more sandy towards the Middle Triassic. It heralded the second major faulting related to the development of the Karroo deposition. This tectonic event led to a renewed intensification of the deposition and the sedimentary environment changed from lacustrine into more deltaic (Cannon et al, 1981a). Large parts of the present study area came under influence of coastal processes once more. The extent to which the sandstones of the related Mariakani Formation have overlapped the older deposits is unknown and consequently it is uncertain whether the coastal conditions did occur in the present interior areas.
It may be concluded that towards the end of the Triassic period the landscape of southeast Kenya consisted of relatively small, dissected remnants of the old fold mountains in the metamorphic areas of the southwestern interior, extensive fluvial and lacustrine plains in the central area and vast lakes with deltaic border plains further east.

4.1.3.2 Late Triassic to Early Jurassic period

A phase of major faulting affected the landscape at the end of the Triassic. It led to a slight folding of the Taru, Maji ya Chumvi and Mariakani Formations and was followed by a re-activating of the erosion of the metamorphic basement rocks and the deposition of the arkosic sandstones of the Mazeras Formation (Cannon et al., 1981b, p. 424). The intensified erosion probably also acted on the now slightly folded and tilted sedimentary plains. Caswell (1953, p. 8) suggested a semi-arid climate with periods of increased aridity during the Triassic period. This would mean that sheetwash processes probably dominated the erosion of the interior at this time. A partial exhumation of the metamorphic basement by the stripping-off of the sedimentary cover may have taken place and to the east a cuesta landscape probably started to develop. Further east the landscape consisted of extensive deltaic swamps and lakes. During the end of the Triassic and the beginning of the Jurassic the deposition of the Mazeras sediments shows that the environment was sufficiently wet to sustain extensive Dadoxylon and Cedroxylon forests.
Sometime during the Early Jurassic a fourth episode of faulting led to renewed erosion of the metamorphic rocks in the interior and a deposition of arkosic sediments related to the Upper Mazeras Formation. The presence of abundant pebble horizons shows that the rivers transporting the erosional waste had considerable more energy than those in the same area today. The predominant eolian nature of the sands toward the top of the Upper Mazeras Formation shows that the Early Jurassic lakes were gradually drying up and that dunes were formed at the borders.

4.1.3.3 Middle Jurassic period

The depositional episode which led to the formation of the Duruma Group was followed by a period of approximately 10 my years from which no deposits have been found in southeastern Kenya. In coastal Tanzania a similar stratigraphic break is known (Kent et al., 1971, p. 89, Fig. 39). This may reflect a period of stability during which soil formation took place.
The elevation of the Shimba and Mangea hills shows that, in the east of the present study area, remnants of this Early Jurassic sedimentary land-surface could be found approximately 250 to 300 above the level of the present Sokoke littoral plain. However, since the summit plateaus of the Shimba and Mangea Hills are not characterised by a deep regolith it is unlikely that they do represent the original Jurassic surface. The elevation of the subvolcanic syenites of the Late Cretaceous Jombo complex shows that the surface lowering in the Mazeras sandstones took place at a mean rate of approximately 3 to 5 m/my. From this it is clear that the Early Jurassic sandstones of the Upper Mazeras Formation are unlikely to have been subject to continuous erosion. Consequently they most probably have been covered by later deposits which were subsequently removed, exhuming the Upper Mazeras rocks.

The first period which might be related to a deposition over the Mazeras Formation is the Middle Jurassic during which a marine transgression started to encroach from the north. According to fossil evidence this shallow, continental sea was connected with the Tethys ocean (Cannon, 1982b, p. 423). In northeastern Kenya the related deposits formed the Daua Limestone Series with an estimated maximum thickness of approximately 580 m (Thompson & Dodson, 1958, p. 5). These rocks form the substratum of the Derkali Plateau, which reaches a maximum height of approximately 975 m in north Kenya.
In southeastern Kenya contemporaneous limestones of the Kambe Formation occur with an estimated thickness of 600 m (Walters & Linton, 1973, p. 139). In the central part of the coast the rocks have been downfaulted and tilted against the Mazeras Formation.
Considering their tilt and throw it is not unlikely that the Middle Jurassic sea once stood more than 300 m above the present plateau surface of the Shimba Hills. In this case the Middle Jurassic shore line presently occurs above approximately 800 m +MSL which is an elevation similar to that found in northeast Kenya.

4.1.3.4 Late Jurassic to Early Cretaceous period

The deposition of the limestones of the Kambe Formation was terminated by renewed uplift of the interior and down faulting of the coast. This was followed by the deposition of the shales/siltstones and sandstones of the Lower Mtomkuu Formation (Cannon et al, 1981a). No deposits are known from

the late Callovian and lower Oxfordian stages. In the El Wak/Mandula area in northeast Kenya a stratigraphic break at this time is marked by the presence of a thin calcrete (Baker & Saggerson, 1958, p. 19). This is an indication that there was a relatively short period of weathering and soil formation. A subsequent phase of faulting initiated deep marine conditions in southeast Kenya and led to the deposition of the Middle Mtomkuu shales during the beginning of the Late Jurassic. Evidence for a far westward transgression of the Late Jurassic sea comes from the centrum of the Lamu embayment. Here the isolated hills known as Matasade, Dogogigicha and Kubi Dakhara are reported to consist of Oxfordian limestones, sandstones and siltstones (Walters & Linton 1973, p. 140). The residuals are situated at an elevation of about 405 m +MSL (Dogogicha hill).
The height of these residuals provides a minimum for the elevation of the Late Jurassic shoreline on the flanks of the Kenyan and Ethiopian domes.

No deposits from the last 10 my of the Late Jurassic period are found in southeast Kenya. A similar hiatus is known to occur in northeast Kenya where in the deposition centre of the Mandera-Damassa area the sedimentation continued up to the Portlandian. The rocks are known as the Mandera sandstones and are considered to represent the regressive phase of the Late Jurassic sea (Joubert, 1960, p. 39). The transition of these deposits into the overlying Danissa beds in the Hegalu Hills is marked by thick ferricrete (Joubert, 1960, p. 43). It is as yet the only known spot in east Kenya where a well preserved residual of the Late Jurassic surface can be found. The ferricrete proves that tropical soil formation took place at the end of the Jurassic period. When correlated with the global geomorphic planations of King (1976, p. 138), this ferricrete marks the land surface of the Gondwana planation. Its presence on the Late Jurassic littoral deposits show that the planation of the Gondwana in northeast Kenya is likely to have been associated with marine abrasion. The same may apply in southeast Kenya. The upper summit level of the Taita Hills which have been related to this planation (Van Wijngaarden, 1978, p. 56) lack evidence of deep soil formation. Their connection with the Gondwana Planation is therefore tentative.

4.1.3.5 Early Cretaceous period

During the Early Cretaceous period, approximately 1500 m of Neocomian deltaic sandstones, siltstones and shales were deposited in the Lamu embayment (Walters & Linton, 1973, p. 140). In contrast only 80 m of shallow marine deposits are known in southeast Kenya. Here the Early Cretaceous deposits consist of Berriasian shales overlain by Aptian clays and Albian to Cenomanian shales and limestones (Freretown limestones), separated by a stratigraphic break of approximately 20 my. In the provisional stratigraphy of Cannon et al. (1981b, p. 421) the rocks belong to the Upper Mtomkuu Formation.

In northeast Kenya shallow marine or deltaic conditions prevailed during the Neocomian. This is evidenced by the Danissa Beds (Saggerson & Miller, 1957, p. 25; Baker & Saggerson, 1958, p. 26; Joubert, 1960, p. 39). They are conformably overlain by the Early to Late Cretaceous Maheran sandstones. The massive sandy nature of these rocks point to increased erosion in the interior at the end of the Early Cretaceous probably due to uplift (Baker & Saggerson, 1958, p. 32). Correlated with the global geomorphic planations of King (1976, p. 138), these mainly Early Cretaceous deposits are the products of the dissection and lowering of the Gondwana landscape. The newly developed land surface in east Kenya correlates with King's Kretacic or Post Gondwana landscape. In the northeastern and central parts the surface was probably extremely flat as it consisted of sedimentary plains. Exhumed or eroded remnants of this landscape are now found at the summits of the Tifo and Garri Hills in northeast Kenya.
The lack of a clear record of this Early Cretaceous planation in the coastal succession of southeast Kenya is interesting and may reflect the fact that the main rivers from the interior were forced to discharge their sediment load in the Lamu embayment to the northeast. The presence of NNE-SSW directed cuestas of the Taru and Mazeras Formation may have been the reason for this.
The question as to how far the Early Cretaceous deposition reached into the interior of southeast Kenya remains unanswered. The maximum elevation of the Early to late Cretaceous Maheran Series in northeast Kenya is approximately 850 m. If a similar height is assumed for southeast Kenya the shoreline would probably have reached even beyond the limits of the study area.

4.1.3.6 Late Cretaceous period

The final separation of Madagascar and East Africa probably took place after the deposition of the Early to Late Cretaceous Mtomkuu Formation (Cannon et al. 1981b, p. 424). This created a new base level and probably changed the direction of drainage systems in east Kenya. In the chronology of global planations (King, 1976, p. 139), the occurrence of this major tectonic event coincides with Active Episode B. In the study area, this event is believed to have been marked by the intrusion of the Jombo igneous complex.
In neither northeast nor southeast Kenya are there any sedimentary rocks known from the final part of the Late Cretaceous. Approximately 450 m of Campanian mudstones with thin bands of argillaceous sandstones and limestones were deposited in the Lamu embayment (Walters & Linton, 1973, p. 142). This shows that the deposition centrum had now shifted from the north towards the Lamu embayment, probably as a result of the tectonic changes at the beginning of the Late Cretaceous. The deposition of the Late Cretaceous beds was followed by a general tectonic activity which led to the formation of several uplifted blocks in the Lamu embayment (Walters & Linton, 1973, p. 153; Karanja, 1983, p. 12).

The surface which developed during the episode may be correlated with the Moorland (African or End-Cretaceous) planation surface which is known to have been encrusted in many places by thick laterite, calcrete or bauxite profiles (King 1976, p. 139). However, in southeast Kenya, such features seem to be totally absent. The only evidence for prolonged weathering and soil formation is found on residual hills of the Sagala level at approximately 300 to 500 m above the surrounding plains. Consequently only the residuals at or above this level may be considered as relics of the Cretaceous and earlier landscapes.

4.1.4 Cainozoic era

The Cainozoic era is characterised by major tectonic movements and widespread volcanism in central Kenya. These events culminated in the formation of the East African Rift system. Landscape formation in the interior region of the study area is seen to be closely related to what happened in central Kenya. In the coastal region eustatic sea-level changes occurred in addition to the tectonic movement of the eastern flank of the rift valley.

4.1.4.1 Tertiary period

It is known from the sedimentary succession in the Lamu embayment that, during the Paleocene epoch, stable conditions occurred in east Kenya. Some 75 m of limestones with interbedded shales and fine sandstones have been found only at its southeastern end. (Walters & Linton, 1973, p. 142). However, with the onset of the Eocene, the embayment started to be uplifted in the west and down-warped at the coast. The erosion that followed involved the stripping of soils and regolith in the surrounding areas. This is reflected by 1500 m of limestones interbedded with fine grained argillaceous sandstones and shales found at the coast and a large sedimentary hiatus in the northwestern part of the embayment. During the Middle Eocene period the deposition in the Lamu embayment intensified and became more coarse grained and feldspatic. This show that in the surrounding areas erosion was acting on newly exposed basement rocks (Walters & Linton, 1973, p. 141). Towards the end of the Eocene the deposition rate decreased.

Oligocene epoch

During the Oligocene only 50 m of limestones are known to have been deposited at the coastal end of the Lamu embayment. This probably means that the whole of eastern Kenya experienced a period of stability during which soil formation occurred. The surface of the landscape probably correlates with one of the sub-phases of the Moorland planation of King (1976. p. 139).

This shows that in East Africa there is sedimentary evidence for the distinction between a Late Cretaceous and an Early Tertiary surface. Considering the intense erosion which took place during the Early and Middle Eocene, the landscape in southeast Kenya is likely to have consisted of residual hills and plains in the west and a more cuestalike landscape with residual hills towards the coast. The erosion seems to have been of such an intensity that the Late Cretaceous surface was almost completely destroyed.

Miocene epoch

Uplift and warping at the end of the Late Oligocene initiated a new cycle of deposition in the Lamu embayment (Walters & Linton, 1973, p. 154). The events are believed to be the regional representatives of the Active episode C described by King (1976). They involved the formation of the Turkana depression on the northwest flank of the Kenyan dome (Baker et al., 1972, p. 9). The sedimentation in this basin was followed by the outflow of the Turkana basalts which have been radiometrically dated at about 32.2 to 14.0 my BP (Baker et al., 1971, p. 195). In western Kenya large lakes were formed and their deposits are found under and between the Kisingiri volcanites (22 to 16.5 my). Terrestrial limestones underlying the Middle Miocene flood-lavas at the western edge of the Lamu embayment (Brotzu et al., 1984, p. 82) are likely to have been formed during the same period.
The Early Miocene landscape of southeastern Kenya was probably completely under tropical forest (Van Zinderen Bakker & Mercer, 1986, p. 121-124). This means that dissection would have been the dominant process with no or little surface wash. However, due to the gradual uplift of the Kenyan dome, climatic conditions already started to resemble those of today and a woodland or savannah type of vegetation between coastal and inland forest is likely. Evidence for the contemporaneous existence of dry-adapted forests and savannas during the Early Miocene has been reported by Bonnefille (1984). This may be one of the reasons for the relative greater lowering of the landscape between the coastal hills and plateaus and the dissected plains of the Mtito Andei area.

In the Miocene period deposition took place in the whole Lamu embayment. During the Middle Miocene the rate of sedimentation was especially high (Walters and Linton, 1973, p. 142). In southeast Kenya it is seen in the deposition of the marine sediments of the Baratumu Formation. The accelerated erosion of the interior may be connected with the known cold episodes of the Middle Miocene and the resulting expansion of a woodland vegetation (Van Zinderen Bakker & Mercer, 1986, p. 219-220).

The outpouring of extensive flood lavas in central Kenya at about 12-13 my BP changed the landscape drastically. In the study area this event led to the outpouring of the Yatta phonolites. The position of the lavas is believed to reflect the position of a major Middle Miocene drainage system. The diverging eastern termination of the flow probably marks the position of the Middle Miocene coastline. The relief inversion which has taken place

since its outpouring amounts at least 100 to 150 m. in the central part of the study area. This means a surface lowering of 7.5 to 11 m/my. This is twice the value estimated from the inversion which took place at Jombo Hill since the Late Cretaceous.
The land surface which existed at the end of the Miocene can be correlated with the Rolling Surface defined by King (1976, p. 139). In the study area the landscape may have existed as a sedimentary plain in the north east and a dissected terrain in the interior. West of the study area extensive, flat lava plains existed on which lakes started to be formed.

The first phase of rift faulting at approximately 12 to 8 my BP (Baker, 1978, p. 33) marks the end of the Miocene landscape formation. This tectonic event correlates with the Active episode D of King (1976, p. 140). The first phase of rifting involved the formation of a half-graben in the southern part of Kenya with an upheaval of its western flank only (Baker et al. 1978, p. 33).
At approximately 5.5 my BP the Aberdare volcano became active. Its eastern slopes form part of the catchment area of the Athi and Tana rivers and therefore this event must have brought about a change in the composition of the deposits of the Lamu embayment. The landscape formation of this period can be correlated with the first phase of the Widespread Planation described by King (1976, p. 140).

Pliocene epoch
The Late Miocene morphogenesis was terminated by the second phase of rifting which took place between approximately 5 and 3 my BP (Baker et al., 1978, p. 35). This led to the formation of a true rift valley in central Kenya and involved a vertical displacement of approximately 500 m along the eastern fault in the southern part. On the eastern flank the volcano of Mt. Kenya erupted large quantities of lavas and pyroclastic materials. This major Late Pliocene eruption phase occurred between about 3.1 and 2.6 my BP.

At the coast of southeast Kenya the sediments of the Marafa Formation were deposited during this time, showing that the interior uplift went hand in hand with the coastal down-warp as suggested by Baker et al. (1972, p. 9). The Marafa Formation south of the Rogge Plateau apparently lacks any volcanic component indicating that the headwaters of the Athi/Galana River probably ended in the Lamu embayment north of the Rogge Plateau.

Before the third phase of rifting which disrupted the drainage system and drastically changed the landscape, a period of stability occurred. At the coast of southeast Kenya this led to the formation of a thick ferricrete on the deposits of the Marafa Formation. The laterite cap on Mrima Hill (Caswell, 1953, p. 44) was also probably formed during this period. The lower foot-plateaus of Mt. Kenya are likewise encrusted by a thick ferricrete as are the Nairobi trachites (3.2 to 3.5 my BP).
The younger lavas and tuffs known as the Limuru Trachites (1.5 to 1.7 my

BP), apparently, have not developed such a pedogenetic crust. This indicates that after the Late Pliocene, climatic conditions in east Kenya may have been too dry for their formation.
In most parts of the study area the laterite profiles have been complete truncated, reworked or covered by gravel and other deposits. This shows that the Pleistocene was a very active period at the coast as well as in the interior. This is also illustrated by the relief inversion of the older lahars of Mt. Kenya which amounts to than 100 m (Veldkamp & Visser, 1986, p. 54). The deposition of these volcanic mud flows is most likely to have taken place during the main active phase from 3.1 to 2.6 my BP. This suggests a surface lowering of about 30 to 40 m/my since the Late Pliocene period. The first savannah vegetation in East Africa is believed to have developed in this same period due to climatic cooling around 2.5 my BP (Van Zinderen Bakker & Mercer, 1986, p. 227). This indicates that the Pleistocene rate of surface lowering under still drier savannah conditions is likely to have been still more. Consequently, it is incorrect to consider the widespread plains of southeast Kenya to be representatives of the End-Tertiary Surface. Most of the plain areas of the interior and correlative hills and plateaus in the coastal region are true Pleistocene landforms with Pleistocene deposits and Pleistocene soils.

In the classification of King (1976, p. 140) the development of the Late Pliocene surface correlates with the second sub-phase of the Widespread Planations. In southeast Kenya, the landscape of the interior probably resembled that of today, except that Mt. Kilimanjaro and the Chyulu Range did not exist.
Further towards the coast a deep dissection of the ferricreted land-surface took place at the transition of the Pliocene and Pleistocene periods. This erosive action was apparently initiated by the low sea-levels related to a cold period, known as the Pretiglian in NW Europe, at around 2.3 to 2.1 my BP.

4.1.4.2 Quaternary period

The third phase of rifting in central Kenya marks the beginning of the Pleistocene landscape formation. This major tectonic event occurred between 2 and 1.7 my BP (Baker et al., 1978, p. 35) and involved a further uplift of the rift flanks and the formation of the rift plateaus. The second active phase of Mt. Kenya which involved mainly fissure eruptions and the formation of lahars (Baker, 1967, p. 15; Veldkamp & Visser, 1986, p. 62) is likely to have taken place as a result of this event. In east Kenya coastal downwarp occurred and large parts not only of the Lamu embayment but also the present study area submerged. In King's classification this Plio-Pleistocene phase of uplift and downwarp correlates with Active Episode E (King, 1976, p. 140).

Early Pleistocene epoch

The denudation and dissection of the Late Pliocene (=End-Tertiary) surface which followed the third phase of rifting resulted in the deposits of the Lower Magarini Formation in the coastal succession of southeast Kenya. In the Lamu embayment, the correlative sediments are known as the Plio-Pleistocene bay deposits. The coincidence of the coastal downwarp and the occurrence of high sea-levels led to a far inland reaching incursion of the sea. The extensive flat denudational plains of the Buchuma level in the interior are believed to be related to this event.

During the Eburonian of NW Europe (approximately 1.7 to 1.4 my BP), low sea-levels occurred along the coast of southeast Kenya. The deposits of the Lower Magarini Formation were partly eroded and denudation is likely to have taken place in the interior.

A period of relatively high sea-levels lasted approximately from 1.4 to 1.2 my BP and is believed to have coincided with the Waalian in NW Europe. Along the coast the littoral sands of the Upper Magarini Formation were deposited and to the west paralic conditions prevailed, under which the fluvial and sheetwash deposits of the interior accumulated. The whole Giriama hill country appears to have been covered by these Early Pleistocene paralic and littoral deposits. The residuals of the Upper Mazeras cuesta, known as the Coastal Range, are likely to have protruded as islands above the submerged areas. The transgression by the sea involved at least two phases and resulted in the formation of the oldest coastal plains and terraces of the Taru/Mtsengo/Sokoke levels.From the reconstruction of the most probable uplift rate of the coast it appears that the formation of the highest coastal terrace (Sokoke-I level) may have been connected with the first warm Waalian-A and its emergence from the sea with the cool Waalian-B episodes. The formation of the Sokoke-II level may then have coincided with the warm Waalian-C episode in NW Europe. In the interior region soil formation took place.

A period of predominately low sea-levels occurred at around 1.2 to 1.0 my BP and has been correlated with the Menapian in NW Europe. In the coastal region of southeast Kenya the paralic and littoral areas emerged. Soil formation started on the newly formed surfaces, while rivers and streams had to find new ways through the flat sedimentary plains to the new shore. Near the coast, dissection took place resulting in a valley system with a relief intensity of approximately 100 m. This shows that the sea level had fallen considerably.

In the interior, new volcanic activity began, building up Mt. Kilimanjaro. The volcanic rocks of the earliest phase are known as the Lower olivine basalts and have been dated as approximately 1.1 to 0.85 my BP. The lava flowed over the Early Pleistocene surface and blocked off the old drainage way between the Taita-Ngulia-Kilungu-Mua and the Pare-Ol Doinyo Orok-Meto watersheds. This led to the formations of important lava-dam lakes in which limestones with silts and clays accumulated. Lake Amboseli is probably the most well known example.

The next phase with periods of relatively high sea-levels lasted from approximately 1.0 to 0.75 my BP and may be correlated with the Bavelian in NW Europe. The littoral zone of southeast Kenya was gradually submerged and the correlative deposits are believed to be the Changamwe/Kipevu Beds. Parts of the Upper Magarini Formation were redeposited and the inclusion of coral limestone in these sands (Kajita, 1982, p. 10) shows that a coral reef started to develop. It was most likely a barrier reef behind which the beach sands and lagoonal clays accumulated. The almost complete disappearance of this Early Pleistocene reef is probably due to later downfaulting of the littoral zone. Towards the central and western part of the paralic zone fluvial and sheetwash deposits accumulated and partly filled in the dissected terrains of the previously formed Taru/Mtsengo levels.
The paralic and littoral plains of the Taru/Bore/Cambini levels are thought to have been formed at this time. Two phases have been recognized from the presence of two sub-levels in both the littoral and paralic zone. The first is connected with the Cambini-I level the formation of which has been provisionally linked with the Bavel interglacial and the subsequent Linge glacial in NW Europe. The submergence and emergence which led to the formation of the Cambini-II level has been correlated with the Leerdam interglacial and Dorst glacial of the Bavelian period.
The beaches and dunes in the littoral zone underwent an intense soil formation. This is reflected by the deep, dusky red Ferralsols found on the Sokoke and Cambini levels. On the paralic plains an association of mainly red to brown Luvisols and Solonetz developed. The soils with the high sodium exchange percentage probably reflect the original presence of abundant volcanoclastic material in the paralic sediments and may be related to the contemporaneous volcanic activity at Mt. Kilimanjaro and in the Nyambeni Range during the time of deposition. On the denudational plains of the interior the multi-cyclic development of the soils continued which finally led to intergrades between Luvisols and Ferralsols found today.
Dissection of the coastal area took place after the sea level dropped. The coastal hills and plateaus were further sculptured and assumed their present-day configuration. This is indicated by the presence of still undissected valley-floors that correlate with the next period of deposition and in-fill of the dissected landscape.

Middle Pleistocene epoch

The next period, during which the sea-levels have fluctuated, lasted from approximately 0.75 to 0.55 my BP. The episode has provisionally been correlated with the Early Cromerian in NW Europe which includes the Waardenburg interglacial and the Glacial A. During this interval the littoral and paralic plains of the Tezo/Mitangani levels are believed to have been formed. From the sedimentary succession at the coast it has been concluded that the formation of these levels took place in at least two phases. This is also reflected by the valley and plain morphology of the paralic zone but only one littoral terrace can be recognized since the younger probably overlies the older.

The first stage in the formation of the Tezo/Mitangani plains has been correlated with the high sea-levels which are supposed to be associated the Waardenburg interglacial in NW Europe. This episode lasted approximately from 0.75 to 0.68 ky BP and led to a renewed submergence of the coast in southeastern Kenya. The area of submergence was smaller than when the Taru and Samburu levels were formed showing that there was a continuing uplift of the interior during this part of the Pleistocene.
The first emergence of the Tezo level probably coincided with the next cold phase of the Early Cromerian in northwestern Europe.
The Mitangani level was formed in the paralic zone. In the central and southern section the remnants of this paralic plain are only present on the main watershed areas. Further north the Mitangani level occurs as a continuous surface and correlates with the higher parts of grey clay plains on the exploratory soil map of Kenya. Middle Stone Age artefacts are found, scattered over the whole area, in a gravel layer under the deposits of the second phase of deposition. The presence of a desert varnish, on many of these artefacts and on the gravel, shows that they suffered a period of aridification. The dating of this culture at approximately 700 to 625 ky BP by the results of the present study contradicts the generally accepted 40 to 60 ky BP (Hamilton, 1982, p. 254). If the 14C dated terrace-sequence in coastal Kenya were acceptable this 40 to 60 ky BP would indeed have been correct but, as it is inconsistent with the 230Th/234U dated reconstruction of the Pleistocene paleosea-levels and coastal uplift rate, the young age is unlikely.

During the period of high sea-level which followed the Tezo level was re-submerged. This led to the deposition of beach and lagoonal deposits in the eastern part of the coast. The coarser grain-size of the sands compared to those of the Magarini Formation shows that in the interior erosion took place which may have been connected with renewed tectonic activity. In the Kenya Rift Valley an intense grid faulting of the rift floor occurred during the period between approximately 0.9 and 0.4 my BP and its influence may have been felt over a large area.
The final emergence of the Tezo/Mitangani levels is believed to correlate with the lowering of sea levels during the Glacial A of the Cromerian in NW Europe. This period occurred between approximately 600 and 550 ky BP and has provisionally correlated with oxygen-isotope stage 16 known from the cores V28-238 and 239 (Shackleton & Opdyke, 1973). In the central section of southeastern Kenya it was accompanied by faulting which led to the separation of the littoral Tezo level from its correlative paralic Mitangani level. As a consequence the Mazeras fault-scarp was formed in which the main rivers eroded deep gorges. The tectonic activity is believed to have been the result of isostatic pressure caused by the weight of the volcanic cone of Mt. Kilimanjaro. The crustal movement resulted in the formation of the Maktau dome and explains the difference in elevation between the paralic levels of the central and northern coastal sections.
Soil formation on the littoral plains of the Tezo level resulted in the

development of red Luvisols and Acrisols. In the paralic areas of the Mitangani level mainly greyish brown to grey Solonetz and Luvisols were formed.

Since this phase of soil formation in the paralic zone did not result in ferrugination of the soils it is believed that the climate gradually became drier. The high sodium and calcium contents in the upper part of the soil profiles also points to this. The presence of abundant sodium and calcium in the paralic deposits may be connected with a renewed influx of volcanoclastic materials. The Marsabit and Nyambeni multicentre volcanos supplied abundant pyroclastic materials in the Lamu embayment. In the study area, the volcanic material were probably derived from the Chyulu Range. The provisional age setting for the paralic levels appears to be confirmed by the dating of the Marsabit volcanites at approximately 0.6 my (Brotzu et al., 1984, p. 81). In the northwestern part of the Lamu embayment the lavas overly the sedimentary plains which correlate with the paralic plains of southeast Kenya. The volcanic activity around Marsabit resulted in the formation of a large lava-dam lake known as Lake Chalbi. The lacustrine limestones found within the study area near Kilaguni Gate and Mzima Springs in the Tsavo-West National Park accumulated in similar lava-dam lakes. The origin of these lakes is linked with the volcanic activity which gradually formed the Chyulu Hills. The limestones probably accumulated during subsequent warm and probably more humid periods and hold a wealth of information in the form of pollen, fossils and Stone Age implements. More details of the Pleistocene environmental development may be obtained from further studies at these sites.

During the following period of high sea-levels the upper Majaoni terrace was formed. This event which lasted from approximately 540 to 475 ky BP has been provisionally connected with the Westerhoven interglacial of the Cromerian in NW Europe and oxygen isotope stage 15. There is no direct evidence that in southeast Kenya the climate was more humid during this period of high sea-level. However the formation of large dune complexes in the Tana delta shows that there was a considerable influx of fresh, coarse materials at that time. This may due to a partial or complete reduction of the glaciers which are likely to have been present on Mt. Kenya. Coral-reef building took probably place in the central part of the coast and closed the wide river valleys near Mombasa, Kilifi and Malindi initiating the present-day embayments.

A stage of predominantly low sea-levels preceded the formation of the terrace of the Majaoni-II level. This interval has provisionally been connected with the cold periods of the Cromerian Glacial B in NW Europe at approximately 475 to 355 ky BP. Due to the low sea-levels erosion took place at the coast resulting in the dissection of the coral reef in front of the major river outlets. The central section of the paralic zone underwent further dissection which led to the multi-cycle valleys found at present. To the north and west stable conditions may have prevailed with the exception of areas alongside the major rivers where continuous incision is likely to have taken place.

On Mt. Kilimanjaro the first and second glaciation of its summit took place during this time (Evernden & Curtis, 1965, p. 362).
Next, an episode of predominantly high sea-levels led to the formation of the lower Majaoni terrace. This period has been provisionally correlated with the Rosmalen Interglacial of the Cromerian in NW Europe at approximately 355 to 325 ky BP. Renewed reef building in the central section resulted in the deposition of the Mtwapa limestones which closed or nearly closed the major river outlets.
In the northern section large barrier and dune ridges were formed in front of the Tana delta. This indicates that there was again an abundance of sediment in the Tana delta which may reflect the partial or complete melting of the glaciers on Mt. Kenya. This continued during the first part of the regression when a complex of sand bars and lagoon plains was formed at the eastern periphery of the Tana delta. In front of the Sabaki river a large dune complex also developed, the first since the deposition of the Upper Magarini Formation. This confirms the provisional age setting of the terrace sequence since the period related to the Majaoni-II level was the first warm episode after the early glaciations of Mt. Kilimanjaro.
Soil formation initiated red Luvisols on the Majaoni terraces of the central section of the coast and grey brown Solonetz in the northern and southern lagoon plains.
The final emergence of the lower Majaoni level has been provisionally correlated with the Cromerian Glacial C in NW Europe at approximately 325 to 300 ky BP. After emergence, the terrace was exposed to dry climatic conditions. This is evidenced by alluvial fans, ablation pans and sand-drift complexes occurring on the terrace tread.
The formation of the terrace at the Mtondia-I level has been provisionally connected with the high sea-levels at approximately 300 to 260 ky BP. The period correlates with Noordbergum Interglacial of the Cromerian in NW Europe and oxygen isotope stage 9. In the central section of the coast the submergence led to the formation of a terrace with sandy beaches and dune ridges over abraded coral limestones. In the northern and southern sections more lagoonal conditions prevailed and led to the formation of a different landscape of lagoon plains and sand bars.
The next period of low sea-levels has provisionally been correlated with the Elsterian of NW Europe. This occurred at approximately 260 to 225 ky BP and can be connected with oxygen isotope stage 8. Dry condition are known to have occurred after the emergence of the upper Mtondia level from the evidence of alluvial fans with peripheral dune complexes along the whole coast. They are tentatively considered to be contemporaneous with the Younger Fans indicated on the Exploratory Soil Map of Kenya.
The terrace of the Mtondia-II level is believed to have been formed as a result of high sea-levels during the Holsteinian of NW Europe. This occurred at approximately 225 to 175 ky BP and is most likely to be connected with oxygen isotope stage 7. In the central section the submergence resulted in a reoccupation of a former abraded, raised reef platform. In the northern section barrier and dune ridges were formed. In the southern part of the

coast the sedimentation mainly resulted in the formation of sand bars.
During the period of low sea-level which followed dry conditions probably prevailed again. This is evidenced by local sand-drift complexes on the Mtondia-II level. The cool and dry episode has been provisionally correlated with the Saalian of NW Europe. This occurred at approximately 175 to 130 kg BP and may be connected with oxygen isotope stage 6.
Soil formation was only slight and led to reddish brown or yellow Cambisols and Arenosols in the central section. Inclusion of materials from paleosols means that the soils on the terrace platforms classify partly as Ferralsols.
In the northern and southern sections, the majority of the soils are clayey and classify as Solonetz and Luvisols. On the sandy ridges albic and Cambic Arenosols developed.

Late Pleistocene epoch

The high sea-levels between approximately 130 and 110 ky BP have been provisionally correlated with the formation of the Mackenzie terraces and the present-day reef platform. The period correlates with the Eemian of NW Europe. All possible terrace remnants of Weichselian paleosea-levels of approximately 85, 60, 40 and 30 ky BP are believed to be submerged at present.
A neotectonic activity caused the formation of small fault scarps in the sandbars of the Tana embayment. Since they are approximately parallel to the outline of the present-day delta, it is concluded that the location and form of the Tana delta is structurally controlled.

Holocene epoch

After its lowest minimum at around 14 ky BP the sea started to rise till it reached its present level at approximately 0.6 ky BP (Fairbridge, 1971). In southeast Kenya this Holocene rise is marked by the filling in of the estuary of the Sabaki river and the development of the present Tana delta by the deposition of beach sands and lagoonal muds. The abundance of sediments in these two areas again reflects the relationship with the melting glaciers on Mt. Kenya and Mt. Kilimanjaro. The Uhuru levels at 3 to 5 m +MSL and at 2 to 3 m +MSL were formed during this period. They represent two Holocene sea-level fluctuations which are 14C dated at 5.2 ky BP and 2.8 to 2.6 ky BP. The mean uplift rate of the Kenyan coast has been shown in the present study to be approximately 0.1 m/ky. This means that at around 5000 y BP the sea-level was about 2.5 m above that of today. During the second Holocene maximum the sea level may have 0.5 m higher than the one of today. The active erosion of the shoreline by wave attack may indicate a slight rise in the sea level at present.
There may have occurred a wet period between the formation of the upper and lower Uhuru level. This is evidenced by the peat deposits found at the Uhuru Farm and probably corresponds with the very wet conditions and the temperature optimum on Mt. Kenya reported by Coetzee (1967).
Next there followed an important drier episode during which old beach ridges were attacked by eolian activity. Along the central coast they were blown

into parallel dunes and at Nyali Beach reach an elevation of about 4 m above the raised beach surface of the upper Uhuru level. At Shelly beach their height is not more than 3 m. A possible date of 2.2 ky BP for this episode is derived from a 14C determination for shells found in this dune ridge at Shelly Beach (Åse, 1978, p. 218).
Along the northern section of the coast, the beach ridges were blown into high, parabolic-dunes with a maximum height of around 50 m. This difference may well be due to the larger extent of beach ridge complexes and the fact that the original beach ridges were more perpendicular to the southeast monsoon winds. A similar age between the dunes of the central and northern sections of the coast is likely but not proven. Actual dune formation leads to the formation of foredune ridges which have no soil formation.
Further evidence for a dry period after the genesis of the lower Uhuru level is seen in the gypsum beds of a former arm of the Mida creek. Their occurrence behind Recent wind-blown sands has been reported already by Thompson (1956, p. 37). The occurrence of CaCO3 concretions in the interdistributary deposits of the Tana delta (Stolp & Vleeshouwer, 1981, p. 18) may also indicate conditions of desiccation.
The drier episode seems to correspond with the cooler and drier conditions found on Mt. Kenya (Coetzee, 1967). Although cooler conditions at the coast can not be proven, the decrease in rainfall after about 2500 y BP (Subatlantic in NW Europe) seems to be evident.
In the paralic zone of the coast relatively little is known of what happened during the Holocene. However, in the interior human settlement may have been responsible for the accelerated erosion of the Taita and Sagala Hills. The erosion of the foot plains around these and other residual hills is also attributed to this settlement (Kadomura, 1970, p. 18). The volcanic activity around the Chyulu multi-centre volcano continued until 150 y ago. Dissection of valley floors, river-bank erosion and sheetwash are the most important active geomorphological processes at present.

4.2 Future research

Several recommendations for future research can be made as a result of this study of the geomorphology of southeast Kenya

The Pleistocene coastal stratigraphy requires a detailed study. The exposures in the erosion alcoves and in the cliffs around the embayments of the coast have not been fully investigated. A radiometric dating programme of the coral limestones is needed and the use of the 4He isotope method is recommended since the range of the 230Th/234Ur method is limited.

The sedimentary succession in the paralic zone needs also further study since exposures are scarce the research would require a drilling programm. In the Lamu embayment additional dating evidence may be derived from the volcanic rocks around the Mt. Marsabit and a mineralogical study of the sediments may find a link with the dated volcanic succession on the eastern flank of the Kenyan Rift Valley.

The lacustrine deposits around Mt.Kilimanjaro are still unexplored. Together with those known in the Chalbi Desert they could form the subject of a combined sedimentological and archeological research programme which would undoubtedly reveal abundant information about the Middle to Late Pleistocene environment of east Kenya.

Finally, a national geomorphological mapping programme is proposed. This would provide detailed data for geographical reference systems which will function in the near future as a major source of information.
The present study has shown that the spacial variation of soils can be better understood if relationships with the geomorphological position in time and place is known. More information on the geomorphological history will therefore be of value for the current soil mapping programme in Kenya.

SUMMARY

The landscape of southeast Kenya forms part of two geomorphological regions which have been called coastland and inland in this study.

The coastal region is characterised by landforms and superficial sediments which have originated from marine processes. The subsurface mainly consists of slightly folded and tilted Paleozoic and Mesozoic sandstones, shales and limestones. In the north and east these rocks are overlain by Cainozoic sands, clays and soft limestones. The present study shows that the coastal area is wider than previously assumed and is to be subdivided in a littoral and paralic zone.

The littoral zone includes the seaward part and consists of a sequence of active and raised sandy beaches, coral reefs and lagoons. Depending on their position and form, they occur as plateaus, terraces or plains in the present landscape. In the land surfaces of these units 8 major levels occur, each of which can be divided into two sub-levels.

The surfaces of the lower levels are relatively small and have small differences in elevation. They have been called: Bofa (-10 to 2 m +MSL), Uhuru-II (2 to 4 m), Uhuru-I (4 to 6 m), Mackenzie-II (6 tot 8 m) and Mackenzie-I (8 to 10 m).

The surfaces of the middle levels are seen in relatively broad terraces with moderately large differences in height. They have been called: Mtondia-II (10 to 15 m), Mtondia-I (15 to 25 m), Majaoni-II (25 tot 35 and Majaoni-I (30 tot 50 m).

The surfaces of the higher levels mainly occur as terrace remnants or isolated plateaus. The have been named: Tezo (50 to 80 m), Cambini-II (70 to 90 m), Cambini-I (80 to 130 m), Sokoke-II (130 to 150 m) and Sokoke-I (140 to 175 m).

The analysis of the landscape and available radiometric data shows that the terrace sequence probably developed throughout the Pleistocene. The approximate ages of the littoral levels have been determined through a provisional correlation with the bioclimatic chronostratigraphy of The Netherlands and NW Europe (Zagwijn et al., 1985, Zagwijn, 1985) and the oxygen-isotope stages known from ocean cores (Shackleton & Opdyke, 1973; 1976). From this it appears that the uplift rate of the coast has been fairly constant at approximately 0.11 m/ky.

The Sokoke (1,4 to 1.0 my BP) and Cambini levels (1.0 to 0.75 my BP) have an Early Pleistocene age and probably correlate with the relatively high sea-

levels of the Waalian and Bavelian. The terraces and plateaus are characterised by deep developed, dark red Ferralsols. The Tezo (0.75 to 0.55 my BP), Majaoni (0,55 tot 0,30 my BP) and Mtondia levels (0,30 tot 0,13 my BP) have a Middle Pleistocene age and probably correlate with the relatively high sea-levels of the Cromerian and Holsteinian. The terraces are characterised by red and brown Acrisols, Luvisols and Cambisols. The Mackenzie levels (130 to 115 ky BP) and the present reef-platform (115 to 100 ky BP) have a Late Pleistocene age and correlate with the high sea-levels of the Eemian. The terraces which possibly developed during the sea level maxima of the Weichselian are at present submerged because of the Holocene transgression. The terraces of the Mackenzie levels are characterised by brown and yellow Cambisols. The Uhuru levels have a Holocene age and point to sea-levels slightly higher than those of today at around 5000 y BP and 2800 y BP. These youngest terraces are characterised by grey and white Regosols.
Alluvial fans and sand-drift complexes are evidence of several dry episodes in the past. The soil sequence marks a change from a humid tropical climate to a savannah climate at around 800 ky BP. Severe dry conditions probably occurred between 725 and 625 ky BP.

The paralic zone comprises the landward part of the coastal region and consists of several sedimentary surfaces unconformably overlying the rocks of the subsurface. The landscape is made up of hills, plateaus and plains. In the surfaces of these units, three main levels have been distinguished. The Mitangani level occurs between 50 and 300 m and is associated with the Tezo level (0.75 to 0.55 my BP) of the littoral zone. The original surface of the Mitangani level is characterised by grey Solonetz. The provisional Middle-Pleistocene age appears to be confirmed by the dating of basalts (0.6 ky BP) overlying a similar sedimentary plain near Mt. Marsabit in north Kenya.
The Samburu/Bore levels (85 to 400 m) are associated with the Cambini levels (1.0 to 0.75 my BP) of the littoral zone. The original surface is characterised by brown and yellowish red Acrisols, Luvisols and Solonetz. The Taru/Mtsengo levels (150 to 500 m) are associated with the Sokoke levels (1.4 to 1.0 my BP) of the littoral zone. The original surface is characterised by red Acrisols and Luvisols. The provisional Early-Pleistocene age of these two higher paralic levels has as yet not be confirmed by radiometric datings.
The differential uplift of the paralic plains is suggested to be the result of isostatic pressure caused by the weight of the volcanic cone of Mt. Kilimanjaro which was mainly built up between 1.1 and 0.42 my BP.

The interior of southeast Kenya is characterised by landforms and deposits which are associated with terrestrial processes. The subsurface mainly consists of Precambrian metamorphic rocks and Paleozoic to Mesozoic sedimentary rocks. The region has been subdivided into denudational, volcanic, lacustrine and fluvial areas.

The denudational areas are made up of extensive plains with scattered residual hills and structural ridges. In the land surfaces of the plains, two denudational levels have been distinguished. In the study area they have been described as: Buchuma level (250 to 1000 m) and Mtito Andei level (800 to 1000 m).
The denudation of the Buchuma level appears to be associated with the deposition of the Plio-Pleistocene sediments in the Lamu embayment and at the coast. Especially in the Lamu embayment, this event is known to be related with a far inland reaching incursion of the sea caused by coastal downwarp (Baker & Saggerson, 1965). This tectonic movement probably was associated with the third phase of rifting (2.0 to 1.7 my BP) in central Kenya and coincided with the occurrence of high, Tiglian sea-levels. Considering the later sheetwash erosion it is unlikely that the present outcrop of the Plio-Pleistocene deposits mark the original shoreline. It is suggested, therefore, that the flat character of the plains at the Buchuma level may be the result of marine denudation processes. The provisional Early Pleistocene age of the Buchuma level appears to be confirmed by the absence of deep soils with laterite formation characteristic for the Pliocene surfaces in eastern Kenya.
The Mtito Andei level correlates with the Pliocene Mulango Surface distinguished in the provisional denudation chronology of Kenya (Ojany, 1978). The landscape is dissected and consists of valleys and interfluves.
The residual hills and plateaus have been subdivided into five units on the basis of differences in elevation an morphological characteristics. A firm identification of old land surfaces often is impossible as the soils and regolith have been eroded in most places.

The volcanic and lacustrine areas of the interior are associated and comprise the Yatta Plateau and the Chyulu Hills.
The formation of the Yatta Plateau is linked with the extrusion of flood lavas in the Naivasha depression during the Middle Miocene. The plateau is covered by phonolites (13,2 my BP) and received its present inversed relief by differential erosion. The summit of the Yatta Plateau occurs approximately 100 to 150 m above the plains of the Buchuma level. This shows that the mean denudation rate since the Middle Miocene amounted roughly 10 m/ky. The decrease in relief inversion at the southeasterly end of the Yatta Plateau suggests that the erosion base level was near this site during the Midden Miocene and Pliocene times.
The volcanic areas of the Chyulu Hills are mainly made up of basaltic ash and cinder cones with associated lava flows. Their maximum age is as yet not confirmed, but it is generally assumed that they erupted during the Late-Pleistocene and Recent times. Lacustrine deposits occur in former lava-dam lakes and are related to wetter episodes.

The fluvial areas are mainly made up of floodplains, terraces and valley floors. A provisional division in lower, middle and upper terraces is proposed analogue to the terrace sequence in the littoral zone.

SAMENVATTING

Het landschap van zuidoost Kenia maakt deel uit van twee geomorfologishe gebieden die in deze studie als kustland en binnenland worden aangeduid.

Het kustgebied is gekenmerkt door de aanwezigheid van vormen en oppervlakkige afzettingen die zijn ontstaan onder de wisselende invloed van ondiep marine en terrestrische omstandigheden. De gesteenten in de ondergrond bestaan voornamelijk uit zwak geplooide en scheef gestelde paleozoische en mesozoische zandstenen, schalies en kalkstenen. In het noorden en oosten zijn deze overdekt door Cainozoische zanden, kleien en kalken. De huidige studie toont aan dat het kustgebied breder is dan voorheen werd aangenomen en kan worden onderverdeeld in een litorale en een paralische zone.

De litorale zone omvat het kust-nabije deel en bestaat uit een opeenvolging van actieve en opgeheven zandstranden, koraalriffen en lagunes. Afhankelijk van hun ligging en vorm komen zij in het huidige landschap voor als plateaus, terrassen of min of meer aaneengesloten vlakten. In de landoppervlakken van deze eenheden zijn 8 hoofdniveaus te onderscheiden die veelal weer verder zijn te verdelen in twee onderniveaus.
De oppervlakken van de lagere niveaus zijn relatief smal en hebben geringe hoogte verschillen. Zij zijn nader aangeduid als: Bofa (-10 tot + 2 m), Uhuru-II (2 tot 4 m), Uhuru-I (4 tot 6 m), Mackenzie-II (6 tot 8 m) en Mackenzie-I (8 tot 10 m). De oppervlakken van de middelste niveaus maken in het algemeen deel uit van bredere terrassen met matig grote hoogte verschillen. Zij worden in deze studie aangeduid als: Mtondia-II (10 tot 15 m), Mtondia-II (15 tot 25 m), Majaoni-II (25 tot 35 m) en Majaoni (30 tot 50 m). De oppervlakken van de hogere niveaus komen voornamelijk voor als terrasresten of geïsoleerde plateaus. Zij zijn nader aangeduid als: Tezo (50 tot 80 m), Cambini-II (70 tot 90 m), Cambini-I (80 tot 130), Sokoke-II (130 tot 150 m) en Sokoke-I (140 tot 175 m).
De geomorfologische analyse toont aan dat deze terrasopeenvolging zich waarschijnlijk heeft ontwikkeld gedurende de laatste 1,4 my van het Pleistoceen. Door middel van een voorlopige correlatie met de chronostratigrafie van het Kwartair in Nederland en NW Europa (Zagwijn et al., 1985: Zagwijn 1985) en de zuurstof-isotopengegevens uit diepzeekernen (Shackleton en Opdyke, 1973; 1976) is de ouderdom van de terrassen bij benadering vastgesteld. Hieruit kan verder orden afgeleid dat de opheffingssnelheid van de litorale zone tamelijk constant is geweest en

gemiddeld 0,11 m/ky bedraagt.
De Sokoke (1,4 tot 1,0 my BP) en Cambini niveaus (1,0 tot 0,75 my BP) hebben een vroeg-pleistocene ouderdom en correleren waarschijnlijk met de hoogste zeestanden in het Waalien en het Bavelien. De terrasniveaus zijn gekenmerkt door diep-ontwikkelde, donkerrode Ferralsols. De Tezo (0,75 tot 0,55 my BP), Majaoni (0.55 tot 0.30 my BP) en Mtondia niveaus (0,30 tot 0,13 my BP) hebben een midden-pleistocene ouderdom en correleren waarschijnlijk met de hoogste zeestanden in het Cromerien en het Holsteinien. De terrasniveaus zijn gekenmerkt door voornamelijk rode en bruine Acrisols, Luvisols en Cambisols. De Mackenzie niveaus (130 tot 115 ky BP) en het huidige rifplatform (115 tot 100 my BP) hebben een laat-pleistocene ouderdom en correleren met de hoge zeestanden in het Eemien. De eventuele terrassen die zich in het Weichselien hebben gevormd zijn tengevolge van de Holocene zeespiegelrijzing ondergelopen. De terrassen van de Mackenzie niveaus zijn gekenmerkt door bruine en gele Cambisols. De Uhuru niveaus hebben een holocene ouderdom en wijzen op zeespiegelmaxima rond 5000 BP en 2800 BP. Deze jongste terrasniveaus zijn gekenmerkt door grijze en witte Regosols.
De vormen en de bodems op de terrassen vertonen de sporen van de afwisseling van nattere en drogere klimaats omstandigheden. Vooral de bodemsequentie van oud naar jong lijkt een geleidelijke droger worden van het klimaat aan de kust aan te geven. Uitgesproken droge omstandigheden moeten zijn voorgekomen tussen 625 en 725 ky BP.

De paralische zone omvat het landinwaarts gelegen deel van het kustgebied en bestaat uit een opeenvolging van sedimentaire oppervlakken die discordant voorkomen over de gesteenten in de ondergrond. Het landschap bestaat uit heuvels en plateaus of vlakten. In de landoppervlakten van deze eenheden zijn drie hoofdniveaus onderscheiden.
Het Mitangani niveau (50 tot 300 m) blijkt met name in het noorden te zijn verbonden met het Tezo niveau (0,75 tot 0,55 my BP) in de litorale zone van het kustgebied. De voorlopige midden-pleistocene ouderdom lijkt te worden bevestigd door de datering van de olivijn basalt (0.6 my BP) die een vergelijkbare sedimentaire vlakte overdekt bij Mt. Marsabit. Het oorspronkelijke oppervlak van het Mitangani niveau is vooral gekenmerkt door grijze Solonetz.
De Samburu/Bore niveaus (85 to 400 m) zijn te correleren met de Cambini niveaus (1,0 tot 0,75 my BP) in de litorale zone. Het oorspronkelijke oppervlak is gekenmerkt door bruine en geel-rode Acrisolen, Luvisolen en Solonetz. De Taru/Mtsengo niveaus (150 to 500 m) zijn te correleren met de Sokoke niveaus (1,4 tot 1,0 my BP) in de litorale zone. Het oorspronkelijke oppervlak is gekenmerkt door rode Acrisolen en Luvisolen. De vroeg-pleistocene ouderdom van deze twee laatste niveaus in de paralische zone is vooralsnog niet bevestigd door andere dateringen.
De differentiële opheffing van deze sedimentaire vlakten is het grootst in het middenstuk van het kustgebied. Als mogelijke oorzaak wordt gedacht aan isostatische druk tengevolge van het gewicht van het vulkaanlichaam van Mt. Kilimanjaro dat zich vormde in de periode van 1.1 tot 0.42 my BP.

Het binnenland van zuidoost Kenia is gekenmerkt door vormen en oppervlakkige afzettingen die zijn gevormd door bij het land behorende processen. De gesteenten in de ondergrond bestaan voornamelijk uit precambrische gneizen en zandstenen uit het Paleozoicum en Mesozoicum. Het landschap kan worden onderverdeeld in denudatieve, vulkanische, lacustrine en fluviatiele delen.

De denudatiegebieden bestaan uit uitgestrekte vlakten met verspreid-voorkomende restheuvels en structurele ruggen. In de landoppervlakken van de denudatievlakten zijn twee hoofdniveaus te onderscheiden. In het studiegebied zijn zij aangeduid als het Buchuma niveau (250 tot 1000 m) en het Mtito Andei niveau (800 tot 1000 m).
De denudatie van het Buchuma niveau lijkt verbonden te zijn met de afzetting van de plio-pleistocene sedimenten in de Lamu baai en aan de kust. Met name in de Lamu baai ging deze gebeurtenis gepaard met het ver landinwaarts binnendringen van de zee tengevolge van het neerdrukken van de kust (Baker en Saggerson, 1965). Deze tectonische beweging hangt samen met de opheffing van de oostelijke flank van de Rift Valley in midden Kenia tijdens de derde fase van rifting (2.0 to 1.7 my BP). Het ver binnendringen van de zee is nader te verklaren doordat het neerdrukken van de kust samen viel met de relatief hoge zeestanden van het Tiglien. Gelet op de huidige processen van vlakspoeling, geven de plio-pleistocene baai afzettingen slechts bij benadering de positie van de toenmalige kustlijn aan. Het is daarom niet onmogelijk dat het extreem vlakke karakter van het Buchuma niveau het gevolg is van marine denudatie. De in deze studie afgeleide vroeg pleistocene ouderdom van het Buchuma niveau is voorlopig maar lijkt te worden bevestigd door de afwezigheid van diepe bodems met lateriet, welke kenmerkend zijn voor de pliocene landoppervlakken in Oost Kenia.
Het Mtito Andei niveau correleert met het Pliocene Mulango Surface in de voorlopige denudatie chronologie van Kenia (Ojany, 1978). Het landschap is versneden en bestaat uit dalen en waterscheidingsruggen.
De restheuvels en plateaus zijn onderverdeeld in vijf groepen op grond van verschillen in hoogteligging en morfologische kenmerken. Het veelal ontbreken van oude bodems op de toppen maakt een juiste identificatie onmogelijk.

De vulkanische en lacustrine gebieden van het binnenland zijn met elkaar verbonden en omvatten het Yatta Plateau en het gebied van de Chyulu Hills. Het door differentiele erosie ontstane Yata Plateau is overdekt door phonoliet lavas (13.2 my BP). De huidige top van het plateau ligt ongeveer 100 to 150 meter boven de grote denudatie vlakken en geeft een maat voor de gemiddelde denudatiesnelheid vanaf het Midden Miocene. Sterke afname van de inversiehoogte aan het zuidoostelijke uiteinde van het Yatta Plateau wijst erop dat de erosie basis gedurende het Midden Miocene en het Pliocene nabij moet zijn geweest.
De vulkanische gebieden van de Chyulu Hills bestaan voornamelijk uit basaltische as- en slakken kegels en lavastromen. De ouderdom is niet

definitief vastgesteld, maar algemeen wordt aangenomen dat de vulkanische activiteit plaats vond vanaf het Laat Pleistoceen tot heden. Lacustrine afzettingen komen voor in oude lavadam-meren en wijzen op nattere omstandigheden dan de huidige.

De fluviatiele gebieden bestaan voornamelijk uit overstromingsvlakten, terrassen en dalbodems. De voorgestelde indeling van laag, midden en hoogterrassen is overeenkomstig de opeenvolging van litorale en paralische niveaus in het kustgebied.

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