The Landforms in the Tsavo-Voi Area, Southern Kenya: An Interim Report on the Geomorphology in the Basement System Rocks in a Tropical Semi-Arid Region of East Africa

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SUMMARY

The nature and evolution of landforms which are formed on the Basement System rocks in the semi-arid region of southern Kenya are examined on the basis of field reconnaissance surveys and aerial photo interpretation. The occurrence of inselbergs, bornhardt domes, ribs and pediments is primarily controlled by the structures of bedrock. Pediments having a smooth surface slope are preserved only on the non-dissected plains of the end-Tertiary erosion surface, and are found around the inselbergs which stand abruptly over the plain with a relative height of 100 - 350 m, as observed in the vicinity of Voi town. On the other hand, in the area of dissected plain pediments have almost been destroyed by river incision, and rock outcrops of gneisses form bornhardt domes and ribs as in the Tsavo area are evident. The anual rainfall in the Tsavo-Voi area is somewhat less than 500 mm.

The dissection of pediments and pediplains by gullies and rills is more distinct in the peripheral zone of the higher hill masses such as the Taita and Sagala Hills where annual rainfall exceeds 750 mm. Within the area along the Nairobi-Mombasa Road the typical examples of pediments being dissected are found at the southern foot slopes of the Mbatini and Mbitini Hills, north of Sultan Hamud. In general, the dissection both of pediment slopes and of end-Tertiary peneplain is distinguished in the area along the Athi-Galana River system and in the scarp-foot zone of high and large hill masses receiving a larger amount of precipitation.

Though the smoothly curved pediment slopes are recognized on the non-dissected plains as in the vicinity of Voi town, pediment surfaces have been slightly modified by gullying and sheetwash erosion under the present climatic condition. These processes caused only minor changes to the surface, and the movement of surface materials is not pronounced. However, they are the most important active processes that modify the surface of pediment slopes at the present time. It seems probable that most of the pediments and pediplains in the area surveyed appear to be in the stage of gradual destruction under the present climatic condition rather than being formed. Rill incision in the scarp-foot zone is thought to be a significant process that maintains the abrupt transition of slopes from the pediment slopes, even of dissected slopes, to the hills. This process is remarkable in the scarp-foot zone of the Taita and Sagala Hills.

Gullying and sheetwash erosion in the semi-arid savanna region of southern Kenya have been accelerated due to both over-grazing and to engineering activities by man as construction of roads. Morpho-conservation should be necessary for future environmental conservation of savanna ecosystem.

INTRODUCTION

The author was in Kenya during the period of December, 1969 - January, 1970, and made a reconnaissance geomorphological survey of the area in the Basement System rocks between Nairobi and Mackinnon Road along the Nairobi-Mombasa Road. In many parts of the area surveyed climate is semi-arid and savanna type vegetation is dominat, apart from high and large hill masses such as the hilly country of the Machakos District and the Taita Hills. Within the area along the Nairobi-Mombasa Road the Kapti Plain in one of the areas where inselbergs and pediment landforms are typically developed (Toya 1967; Ojany 1969).

The area between Mtito Andei and Maung, some 30 km southeast of Voi town, i. e. the Tsavo-Voi area, is another area where inselbergs and pediments are also typically developed on the Basement System rocks. Most of the area fall within the Tsavo National Park, and field survey outside of a car is prohibited. In spite of such a limitation, typically developed semi-arid landscape in this area was very attractive to the author in the geomorphological study of tropical Africa. He, therefore, atempted to study landforms in this area based mainly on aerial photo analysis and interpretation. Aerial photographs on a scale of 1 : 50,000 were obtained from Survey of Kenya, Nairobi. Topographical maps on a scale of 1 : 50,000, with 50 foot contour interval cover only the southern part of this area.

In order to clarify the nature and distribution of landforms characterizing the semi-arid landscape, the landforms in this area are analyzed and classified from their shapes, geneses, composing materials and ages, and geomorphological maps were compiled using aerial photographs (Figs 3 - 5). The main geomorphological land units consisting of the semi-arid landscape are plains, inselbergs, bornhardt domes, ribs, pediments and pediplains as in the other tropical semi-arid region of Africa where bedrocks consist of the Basement System rocks.

The nature, evolution and recent modification of these landforms are described and examined in this paper. The problems on the conservation of the savanna ecosystem are discussed briefly in relation to gullying and sheetwash erosion. In the concluding chapter some problems on climatic geomorphological study of semi-arid regions are pointed out.

This paper is an interim report on the climatic gemorphological study in East Africa that was conducted by the Tokyo Metropolitan University Scientific Research for East Africa in 1969 - 1970. This research was supported by a Research Fund granted by the Ministry of Education, Japan.

GENERAL PHYSIOGRAPHY

The area surveyed, the Tsavo-Voi area, is situated in the middle of the Nairobi-Mombasa Road, and lies on a part of the vast inland plateau of East Africa. The principal geology in this area is crystalline rocks of the Basement System, which is considered Archean in age (Fig. 1). Gneisses, schists, amphibolites and crystalline limestones are the main rocks that make up the Basement System in this area (Parkinson 1947; Sanders 1963). Most of this area is occupied by a plain, the elevation of which is 1000 - 3000 feet (c. 300 - 900 m), sloping gently coastward. The plain surface is recognized as the end-Tertiary peneplain (e. g. Saggerson 1962), equivalent to King's Post African surface (King 1962). Ojany (1966) called the plain in this area 'Low Foreland Plateau .

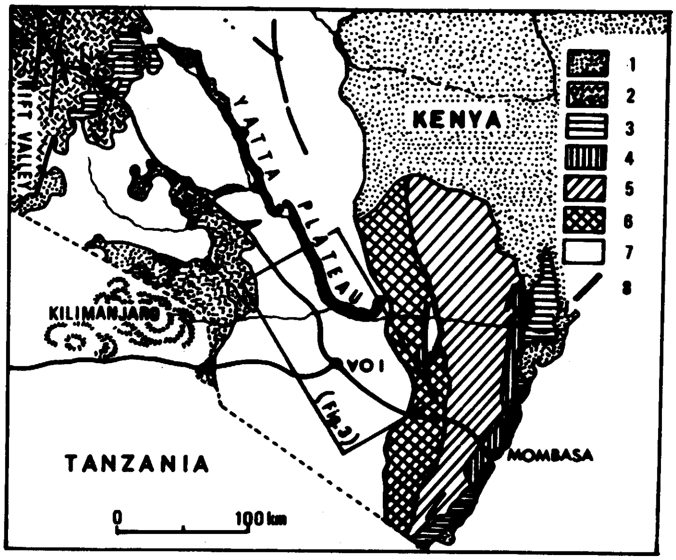

Fig. 1 General geology of southern Kenya (After Atlas of Kenya, 1962)
1 : Quaternary sediments 2: Quaternary to Tertiary volcanics
3: Tertiary sediments 4: Jurassic 5: Triassic 6: Carboniferous ? - Permian
6: 7: Basement System 8: Fault.

In the area west of the Nairobi-Mombasa Road there are two large and high hill masses, the Taita and Sagala Hills. The summits of these hills rise over 4000 feet (c. 1200 m), and highest peak of the Taita Hills, Vuria, reaches 7234 feet (c. 2170 m). The Voi, Irima, Manga, Mbulia and Nyangala are the other main hills scattered in the area along the Nairobi-Mombasa Road (Fig. 3). All of these hills stand sharply over the plain as inselbergs, with an elevation of 2500 - 3500 feet (c. 750 - 1050 m.). These hills are considered to be a residuals from Cretaceous erosion surface (Sanders 1963).

The Yatta Plateau, extending from east of Nairobi to east of this area with an entire length of some 400 km, appear in the northeastern part of this area. This plateau rises 75 - 100 m above the plain. The surface of the plateau is composed of phonolite lava 7 - 12 m in thickness overlying the Basement System rocks. The erosion surface under lava is considered to be of sub - Miocene surface (Dixey 1948), older and higher than the end-Tertiary surface. It seems probable that the capping of lava, which is more resistant to erosion than gneisses, resulted in the conversion of topography, forming a plateau with steep escarpments on both sides.

Most of the area, excluding the higher hill masses such as the Taita and Sagala Hills, is semi-arid. The rainfall pattern is biannual, with rainy seasons in November / December and March/ April (Fig. 2). The mean annual rainfall in most of the plain is less than 500 mm, and decreases toward the east and to the north. In the higher hill masses, however, precipitation increases abruptly with elevation, exceeding 1000 mm. The mean annual rainfall at selected locations is shown in Table 1. Due to higher temperature (mean temperature 24.9^{o}C, mean maximum temperature 30.5^{o}C at Voi Met. Sta.), evaporation is very high (average evaporation measured by a 15" pan was 2148 mm at Voi). Potential evapotransipiration based on the Thornthwate's Method is greater than rainfall throughout the year, and the total deficency of water balance at Voi is over 34 ins. (c. 850 mm) (Sansom 1954).

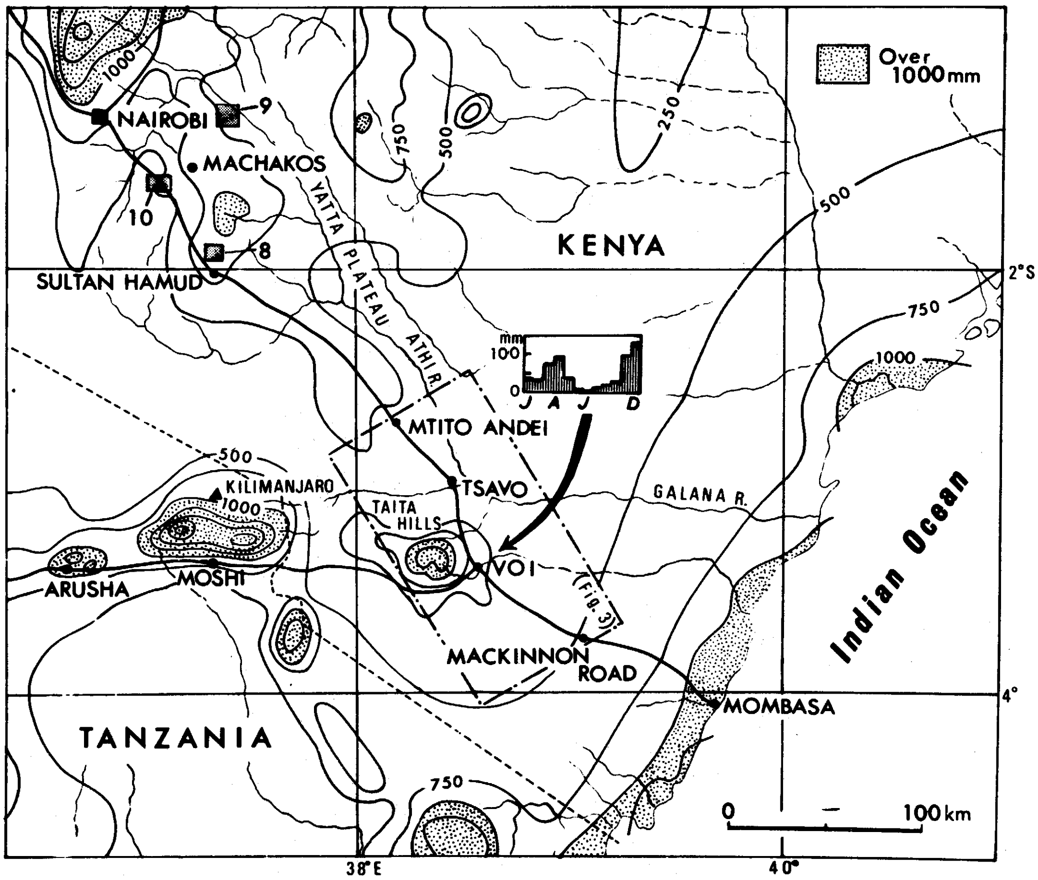

Fig. 2 Annual rainfall in southern Kenya (After Mean Annual Rainfall Map of East Africa, 1955)

Table 1 Rainfall at selected stations

Station	Altitude	Period	Average	Maximum	Minimum
Voi, Met. Sta.	1837 ft	1904-62	538 mm	1201 mm	184 mm
Voi, Wundanyi Estate	4800	1929-62	1329	2192	917
Mtito Andei, Tsavo N.Park	3000	1951-62	616	908	387

Source: East Afr. Met. Dept., 1964.

In spite of the meager rainfall, rainfall intensity is rather strong, and heavy showers have occasionally occurred within a short period (Table 2). The maximum 24 hours-rainfall recorded at Voi was 254.0 mm (Dcember 26, 1927). The impact of such showers after a long dry season is an important geomorphic process in this semi-arid region. As will be mentioned later, fluvial processes resulting from such showers, gullying and sheetwash erosion have played the most important role in changing the landforms at the present time.

Because of the higher evaporation, surface run-off usually disappears shortly after the rain stops, except for large exotic rivers that originate in the Kilimanjaro area and the Taita Hills such as the Tsavo, Voi and Mbololo Rivers. Among the tributaries of the Athi-Galana River, the only river entering directly into the Indian Ocean in southern Kenya, the Tsavo is the only permanent river.

Most of the plains and pediment slopes, dissected and non-dissected, are covered by grass with bush vegetation consisting mainly of Acacia and Commiphora species representing a savanna landscape. Baobab and Euphorbia are occasionally found. The density of bush vegetation varies from dense to light, and the area which is liable to flooding during shower periods are evidenced by grasslands without bushes. Outside of the Tsavo National Park, some parts of the plains and pediments are used as sisal estates and farmland. Termites 1 - 2 m in height are numerous in the red sandy soils covering the Basement System rocks, characterizing the savanna landscape. In the national park there are numerous waterholes for game.

Table 2 Maximum rainfall in 24 hours at Voi Met. Sta. (1904-62)

Month	Max. fall in 24 hours	Date / Year
January	50.8 mm	15 1928
February	126.0	21 1943
March	88.9	17 1927
April	147.3	21 1948
May	59.9	6 1946
June	41.1	11 1936
July	18.0	10 1949
August	26.4	12 1935
September	43.7	26 1961
October	51.8	24 1960
November	106.7	24 1951
December	254.0	26 1927
Year	254.0	Dec. 26 1927

Source: East Afr. Met. Dept., 1964.

LAND CLASSIFICATION AND GEOMORPHOLOGICAL MAPPING

Land classification, together with geomorphological mapping are necessary steps in regional geomorphological studies. There are many land classification systems (Nakano 1955; Klimaszewski 1957, 1962; Mabbutt 1962; Christian and Stewart 1968; Thomas 1969; Verstappen 1970; Webster and Beckett 1970). Though most of these systems aim at applied purposes such as land development and conservation projects, they basically include geomorphological purposes and are based on geomorphic principles. The results of land classification are usually presented in a geomorphological map. Verstappen (1970) differentiated 'general purpose (pure)' geomorphological maps from applied or 'special-purpose' geomorphological maps such as morpho-conservation maps and hydro-morphological maps.

All of the above-mentioned classification systems adopt morphographical, morphogenetical, morphometric and morphochronological information in order to recognize unit landforms. In other words, the criteria for classifving unit landforms are similarity and homogeneity of shapes, geneses, composing materials and ages of landforms. The author tries to analyze and classify the landforms in the Tsavo-Voi area in applying these criteria using aerial photographs.

With land classification and land systems in tropical Africa, Thomas (1969) proposed a comprehensive system. Webster and Beckett (1970) recently reported on the land system of the Ngapoi area in Western Kenya. These systems of land classification and hierarchial arrangement of unit landforms classified are useful in recognizing and mapping the landforms in this area under tropical semi-arid climatic conditions.

Land Systems

The landscape in this area is divided into the following three major land systems (Fig. 3):

(a) The Taita and Sagala Hills, consisting of the Basement System rocks, residuals from the Cretaceous erosion surface.
(b) The Yatta Plateau, consisting of phonolite lava overlying the sub-Miocene erosion surface of the Basement System rocks.
(c) The Tsavo-Voi Plain, formed on the Basement System rocks overlain by reddish sandy soils, a part of the end-Tertiary erosion surface.

The Tsavo-Voi Plain is subdivided into three subsystems by degree of dissection. The first is the Voi Plain and the Kalinzo Plain of non-dissected surface, and the second is the Tsavo Plain, composed of a dissected surface. These may correspond to etchplain and dissected etchplain respectively. The third is the Mtito Andei Plain, a partly dissected plain that shows an intermediate nature between the above two.

Classification of Unit Landforms

Detailed analysis and classification are made only on the plain land systems because they are in a semi-arid climatic conditions and include typical semi-arid landforms such as inselbergs and pediments. The results of land classification are presented in a synoptic geomorphological map (Fig. 3) originally plotted on topographical maps at a scale of 1 : 250, 000, and in two detailed geomorphological maps (Figs. 4 - 5) originally plotted from aerial photographs at a scale of approximately 1 : 50, 000. In presenting unit landforms on detailed maps minor landforms being formed by active processes under the present climatic condition are emphasized.

Because of limited field survey, detailed information on unit landforms, especially on the nature and the thickness of surface materials and chronological data were not obtained. Therefore, the nature of some unit landforms is not fully exlained. The description and discussion of some important unit landforms are made in the following sections.

INSELBERGS, PEDIMENTS AND RELATED LANDFORMS

Inselbergs and Pediments

Scattered inselbergs and bornhardt domes tower over the plain within a zone 15 - 20 km wide, almost parallel to the Nairobi-Mombasa Road (Fig. 3). The relative height of inselbergs is generally 100 - 350 m above the re-entering angle between scarps and pediment slopes. The main rocks that make up the inselbergs and bornhardt domes are hornblend biotite gneiss, hornblend garnet gneiss, garnetiferous biotie gneiss and granitoid gneiss (Sanders 1963). These gneisses are strongly exfoliated with a steep dip, forming steep-sided hillslopes with a convex profile (Plate 1 & 2). The slope angle of the hillslopes ranges from 30° to near vertical.

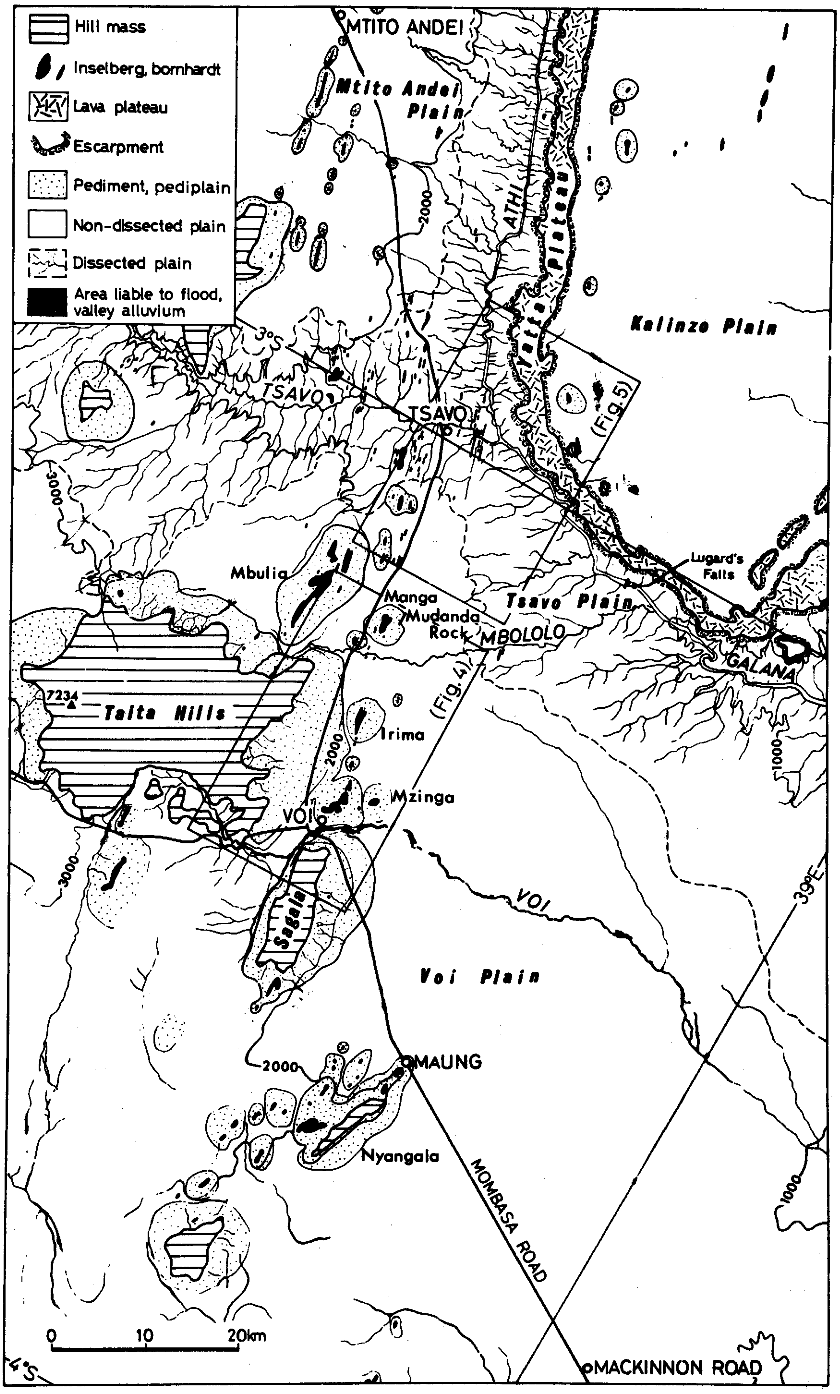

Fig. 3 Synoptic geomorphological map of the Tsavo-Voi area. Contours in feet

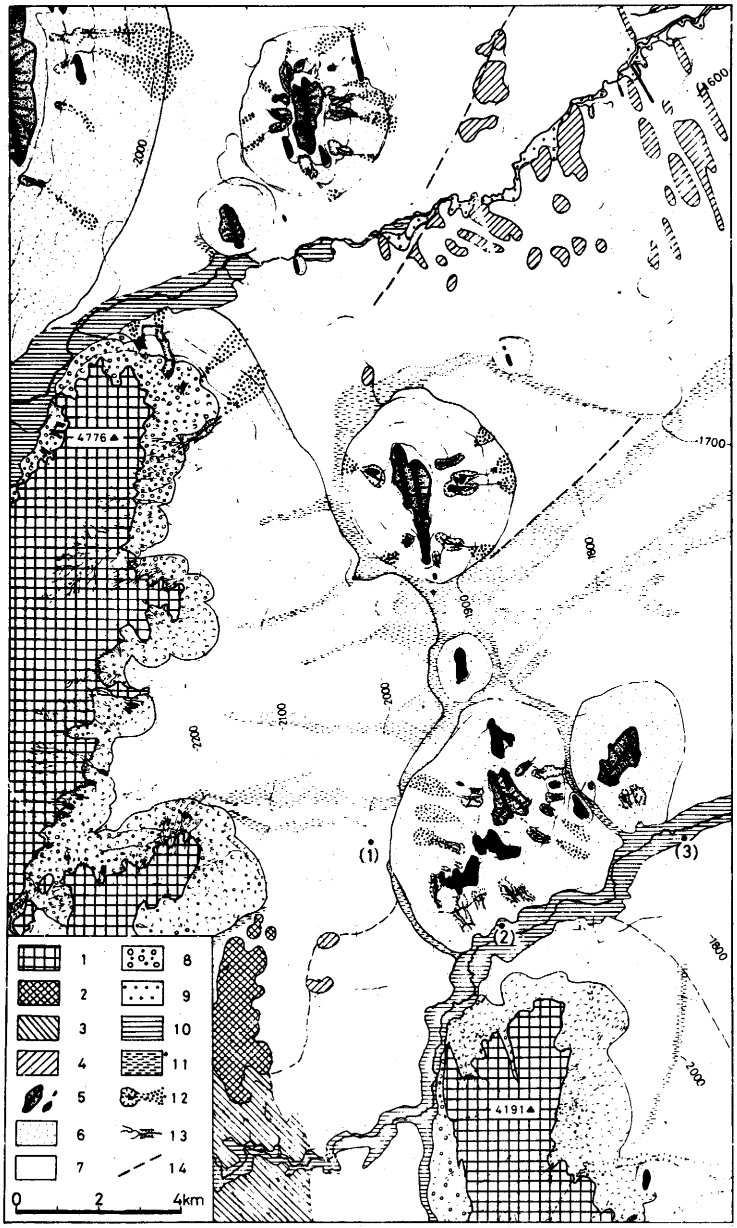

Fig. 4 Geomopphological map of the Voi area. Contours in feet

1: Higher relief hill mass, 2: Moderate relief hill mass 3: Undulating hills

4: Slight height on plainland 5: Inselberg, bornharbt dome and rib 6: Pediment and pediplain

7: Flat to gently sloping plain surface, including convex top slope 8: Alluvial cone and fan

9: Concave valley side slope and saucer-shaped valley 10: Valley flat alluvium

11: Depression and area liable to flood 12: Spoon-shaped erosion hollow and recent sedimentation

13: Rill, gully, groove-shaped gully and scarp-foot incision 14: Fault

(1) - (3): Location of geological columnar sections shown in Fig. 7.

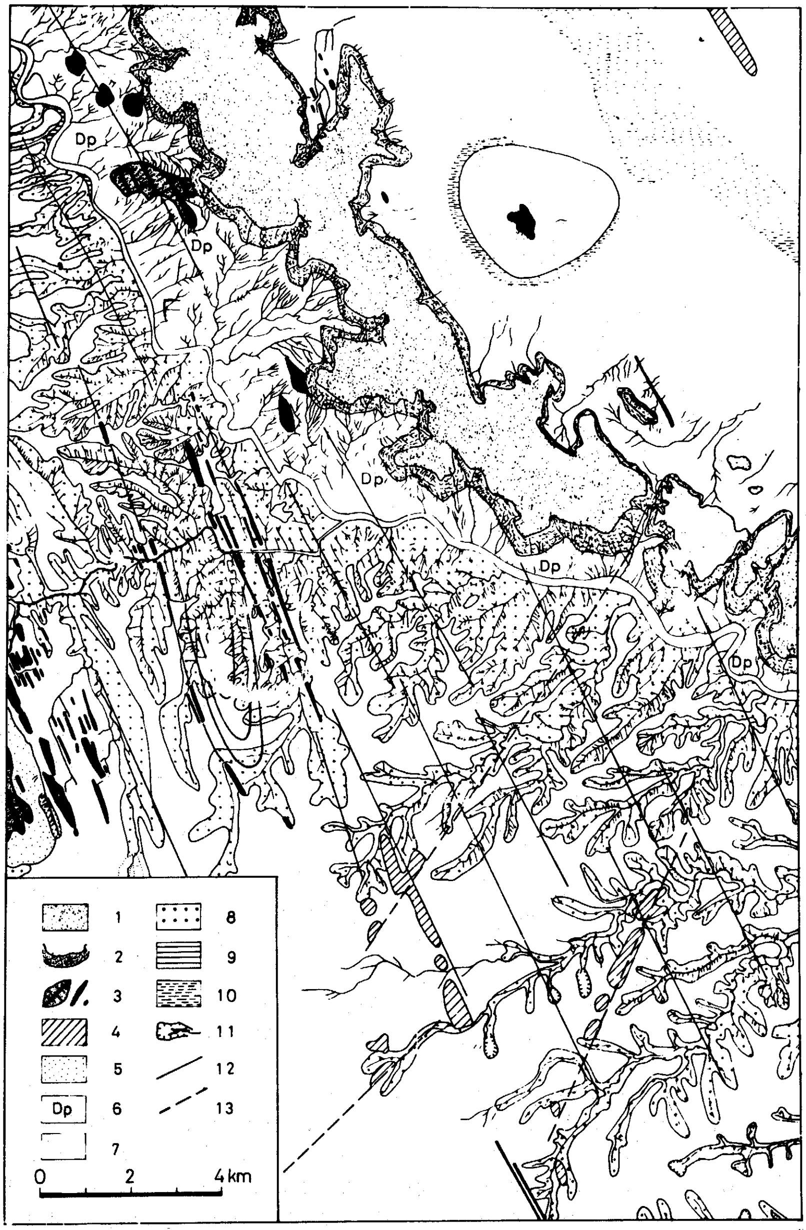

Fig. 5 Geomorphological map of the Tsavo area

1 : Lava plateau 2: Escarpment 3: Inselberg, bornhardt dome and rib

4: Slight height on plainland 5: Pediment 6: Dissected pediment

7: Flat to gently sloping plain surface and convex top slope 8: Concave valley side slope and saucer-shaped valley 9: Valley flat alluvium

10: Depression and area liable to flood 11: Spoon-shaped erosion hollow

12: Structural trend of the Basement System 13: Fault

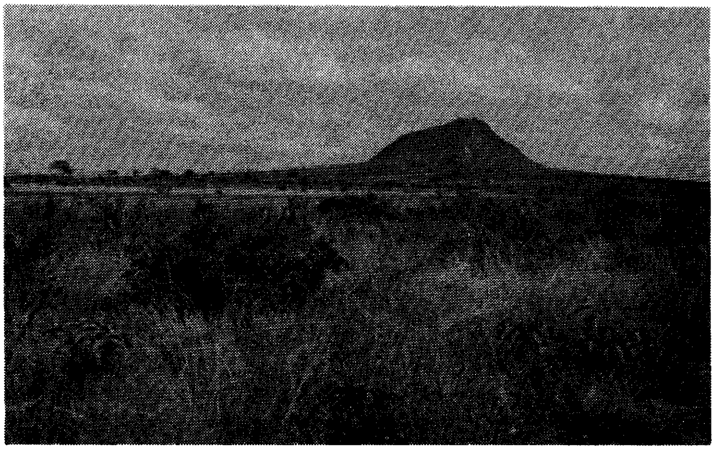

Plate 1 Irima Hill and pediment viewed from south. Hillslopes are composed of hornblend-garnet gneiss

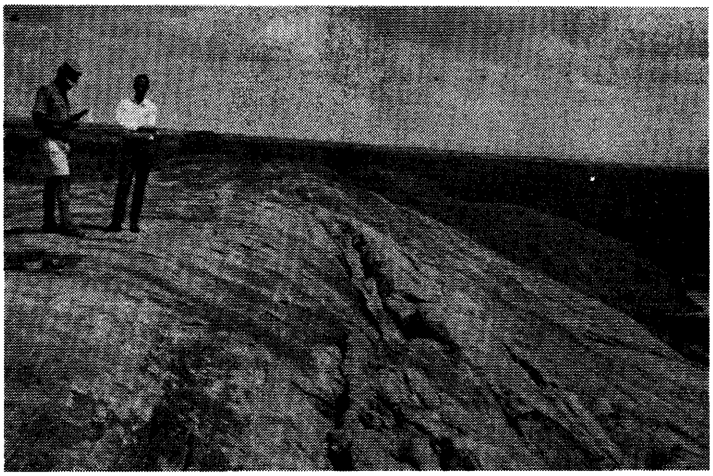

Plate 2 Domed rock ridge, Mudanda Rock

The main crest lines of the inselbergs and bornhardt domes are elongated to the NNW direction which follows the regional structural trend of the gneisses. The occurrence of these landforms is basically controlled by the structure of the Basement System rocks. Banded outcrops of bare rocks are clearly observed among vegetated hillslopes. Boulders derived from exfoliated gneisses are found accumulated at the base of scarps to form debris talus, and are not transported to the gentle pediment slopes. The dissection of hillslopes by rills are rare in the inselbergs having a relief of 100 - 350 m.

Many bornhardt domes and ribs consisting of outcrops of bare rocks are distributed in the area north to Ndi Station, especially in the dissected plain in the vicinity of Tsavo. Mudanda Rock and Mbololo Hills are typical examples (Plate 2). These landforms are controlled strictly by the structure of gneisses, mostly granitoid and migmatic rocks (Sanders 1963), and steeply dipping foliation is dominant to form parallel narrow rock ridges, corresponding to the regional structural trend

(Fig. 5). The relative height of these landforms is 5 - 20 m. No distinct pediments are formed at the foot of these outcrop landforms. The development of outcrop landforms is thought to be related to the dissection of former erosion surfaces. Most of outcrop domes and ribs stand on the dissected end-Tertiary peneplain in the Tsavo Plain. This may indicate that such outcrop landforms originated from core rocks consisting of harder rocks as granitoid gneiss, by stripping of etched erosion surfaces as suggested by Ollier (1960), Thomas (1965) and others. In this sense, some of the higher inselbergs standing on the non-dissected end-Tertiary surface possibly originated from older etched erosion surfaces by stripping of weathered mantle. These considerations can support the theory of 'Doppelten Einebnungsflächen' (double surfaces of levelling) of Büdel (1957), as well as the theory of 'savanna planation' of Cotton (1961).

Pediment landforms having a smooth surface are found only around the inselbergs which stand on the non-dissected plain and have a relative height of 100 - 350m. Their plane geometry is usually circular or elliptical in proportion as the geometry of inselbergs. In the area mapped in Fig. 4 pediments surrounding the Voi, Mzinga, Mwakigali, Irima, Manga and Mbulia Hills are such cases. These kinds of pediments are also found in the vicinity of Maungu, in the area north ot Mtito Andei (Mtito Andei Plain), and on the non-dissected plain east of the Yatta Plateau (Kalinzo Plain). All of these smoothly curved pediments are developed on the non-dissected end-Tertiary peneplain.

Fig. 6 Inselbergs and pediments north of Voi town, viewed from south

The length of pedimencs ranges from 200 m to 3000 m, and is related to the relief and the size of inselbergs. In general larger pediments are developed surrounding the larger inselbergs. The average slope of pediments is generally 3^o - 4^o (Fig. 6), but some exceptions are found; for instance, less than 2^o at the foot of the Manga and over 6° at the foot of the Kele. The surface of pediments is covered by reddish sandy materials of transported origin. The thickness of sediments is not known but it may exceed 2 - 3 m.

The lower edge of pediments is usually distinct. Peripheral depressions which clearly mark the outer ring of pediments are formed at the peripheral zone of the pediments surrounding the Voi, Mzinga, Mwakingali and Ndatani Hills. These slight depressions are mapped in Figs 4 and 5 as areas liable to flooding, and are indicated by grass vegetation and a darker tone on aerial photographs. Blackish soils are developed in these depressions (Sanders 1963.)

Pediplains

There are wide, gentle slopes of 8 - 16 km at the eastern foot of the Taita and Sagala Hills. The lower edge of these landforms are not clear, often changing gradually into plains. These landforms may be termed 'pediplain'. The relative height of escarpments facing the pediplains is 1000 - 1200 m in the Mraru Ridge of the Taita Hills and 500 - 600 m in the Sagala Hills. The re-entering angle between escarpments and pediplains is also sharp as that between inselbergs and pediments. But escarpments have been densely dissected by ravines, and foot lines are rather irregular compared to inselbergs. Coalescent alluvial fans and cones are well developed in the scarp-foot zone. Most of these depositional landforms are dissected by densely developed gullies and rills, and groove-shaped large gullies are found. Deeply excavated hollows in the scarp-foot zone, i. e. scarp-foot incisions are developed elsewhere (Fig. 4). A discussion on the formation and role of the scarp-foot incisions is made later.

The average slope of pediplains is less than 2^{o}, and is more gentle than that of the pediments surrounding inselbergs. The surficial deposits on the pediplains are composed mainly of sandy soils similar to those covering the pediments, but information as to the thickness is scarce. At the foot of the Sagala Hills there is a gully in which

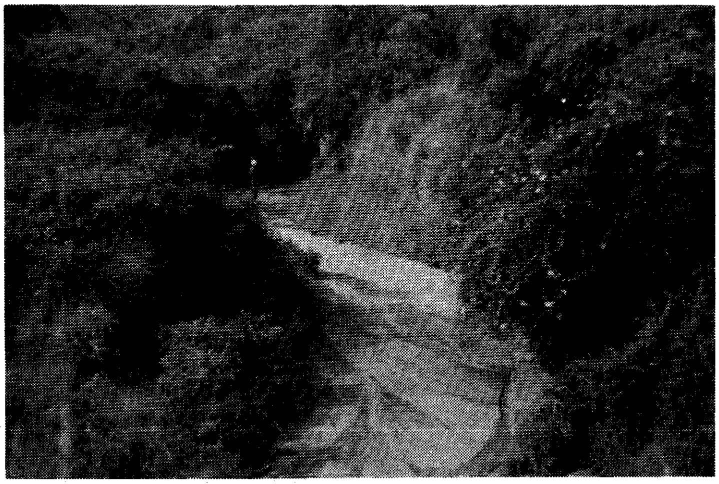

Plate 3 A gully dissecting the pediment at the northern foot of the Sagala Hills. (Photograph by H. Toya)

a profile of the pediplain can be observed (Plate 3). Steep-sided walls of this gully with a height of 3 - 3.5 m consist of reddish sandy soils, with fragments of decomposed gneiss in the lower part. But the thickness of sandy soils alters within a shorter distance and platforms of decomposed gneiss appear on the ground surface (Plate 4). This implies that the surface of bedrock is irregular rather than smooth. According to borehole data at Voi Airstrip, located near the lower end of pediplain at the eastern foot of the Taita Hills, unweathered gneiss is overlain by sand, murram and decomposed gneiss with a total thickness of 14.1 m (Fig. 7).

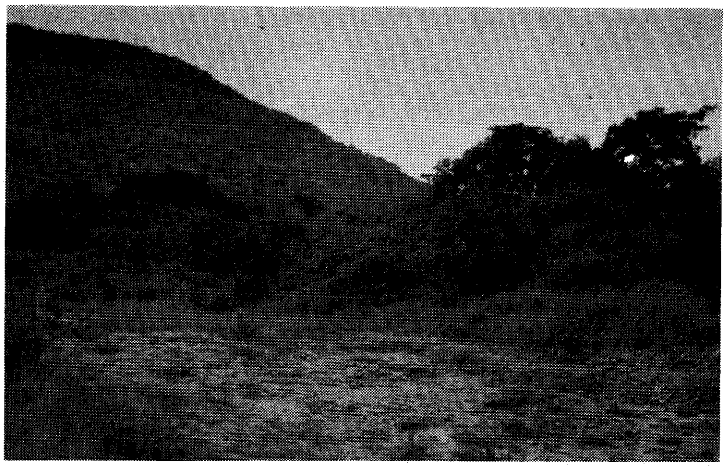

Plate 4 Rock platform which appears near the gully shown in Plate 3.
(Photograph by H. Toya)

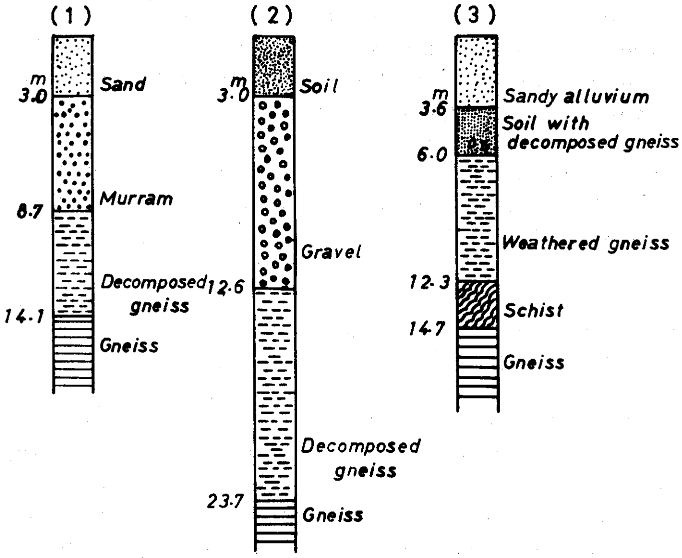

Fig. 7 Geological columnar sections in the vicinity of Voi town (From Sanders 1963).
Location of borehole site is shown in Fig. 4.

From the interpretation of the surface pattern on pediplains which is observed by aerial photographs, both surface modification and movement of surface materials resulting from rillwash and sheetwash are thought to be more frequent than on the pediments surrounding inselbergs. Gullies dissecting alluvial fans and cones transport surface materials downstream to form tongue-shapes new accumulation areas, and fine-grained materials are scattered by rillwash and sheet-wash over the lower parts of the pediplains as a result of occasional flooding.

PLAINS

Non-Dissected Plains

The main landform unit of the non-dissected plain is flat to gently sloping surface with a slope of less than 1°. The vast majority of the plain surface cover the area east of the Nairobi-Mombasa Road south to Manyani (the Voi Plain), and east of the Yatta Plateau (the Kalinzo Plain). The surficial deposits in most of the plain surfaces are reddish sandy soils, but the area liable to flooding during showers, i. e. slightly depressed area are covered by blackish soils. Within the area mapped in Fig. 4, the Voi and Mbololo Rivers are the only rivers which dissect the plain surface. These river channels incised the plain surface some 3 - 4 m and alluvial deposits are developed on the valley floor along the full course of the Voi and in the upstream area of the Mbololo. Alluvial deposits consist mainly of sandy materials with some clays and gravels.

Geological information on alluvial deposits of the Voi River, which is obtained from borehole data is shown in Fig. 7. As interpreted from columnar sections, the thickness of the alluvium seems to be 3 - 5 m. The depth of unweathered gneiss from the surface is 10 - 25 m, and the thickness of weathering profile of gneiss is 5 - 20 m. Based on the above information, the thickness of the weathering profile in the plain within this area is smaller than that reported for West Africa (e. g. Thomas 1966; Ollier 1969). Ojany (1969) states that the weathering profile in the Ukambani area is also not so deep.

The plain situated in the northern part of the area mapped in Fig. 3 (the Mtito Andei Plain) is being roughly dissected by deeply incised, steep-walled valleys. The plain, however, still maintains flatness.

Dissected Plains.

The dissection of the plain becomes distinct toward the main rivers of the Athi-Galana and Tsavo. These river channels themselves and their tributaries have incised the plain and have dissected the plain, forming an undulating plain with a width of 20 - 30 km (Fig. 3). Pediment slopes at the western and southern foot of the Yatta Plateau are also dissected by the tributaries of the Athi-Galana River (Fig. 5).

The plain surfaces situated in the interchannel areas are modified from flat to gently sloping convex top slopes. The headmost slopes of the valleys which are developed along the intermittent channels are gradually transposed to a flat plain, with a slightly concaved longitudinal profile. The cross section of valleys shows 'saucer-shaped valleys' (Louis 1964) which consist of three facets; a) concave-shaped valley side slopes, b) valley bottom floors, and c) incised channels. The uppermost part of valley side slopes usually joins the flat or concave top slopes, maintaining the continuity from the plain.

The present channels have incised valley floors 1 - 3 m deep. The development of alluvium on the valley floor is restricted within a narrow area. On the valley floor and lower parts of valley side slopes greyish soils are dominant. Spoon-shaped shallow erosion occurs due to recent sheetwash at the headmost areas of some valleys (Figs. 4 and 5).

The depth of the incised channels becomes large toward the main river. The top slopes decrease their elevation gradually, and in turn relative relief and slope angle of valley side slopes increase toward the main river. Stream density is also high in the area near the main river, and maximum density exceeds 60 per sq. km in the vicinity of Tsavo.

In accordance with the degree of dissection, stripping of reddish sandy soils as well as the weathering profile overlying the Basement System rocks become strong, and the structures of bedrock appear on the surface as the result of stripping (Plate 5). The regional structural trend, following mostly the NNW direction, is recognized on aerial photographs both by the elongated narrow rock ridges and micro-heights, and by the banded stripes indicating the gneissosity (Fig. 5). The narrow ridges which appear as rock ribs are composed of such harder rocks as granitoid gneiss, as mentioned early. On the other hand, the remaining areas of the dissected plain consist mainly of hornblend-garnet gneiss and migmatic rocks (Parkinson 1947; Sanders 1963). Migmatic rocks tend to form rock platforms which usually appear as micro-height on the plain-level (Sanders 1963). The continuity of the dissected plain can be traced along the Athi River to the east of Kanzalu Range, where rolling plain is developed (Fig. 9).

Most of the larger streams, except the Athi which flows in an NNW direction to the Tsavo River junction, flow across the regional strike of the Basement System rocks. But most of the smaller streams, mainly first order streams, are subsequent to the structural trend and follow an NNW direction (Fig. 5). There are many rapids and falls on the Athi-Galana River. At Lugard's Falls, one of the famous falls on the Athi-Galana River, where the river traverses gneissosity perpendicular, the present river bed has incised into unweathered bedrock to over 4 - 5 m (Plate 3).

The present river bed of the Athi-Galana is some 100 m lower than the adjacent end-Tertiary surface. No distinct erosion surface is recognized between the present river bed or valley floors and the end-Tertiary surface. The dissection of end-Tertiary surface by the incised stream is thought to have been promoted by tectonic upwarping of a cymatogenic type during the late-Cenozoic and Quaternary. It is, therefore, natural to consider that although the rate of denudation and stripping of etched surfaces was affected by climatic changes in the past, tectonic upwarping of the whole plain in southern Kenya can be regarded as the most important factor to cause the dissected plain in this area. As suggested by Doornkamp (1968) in central Uganda, the evolution of inselbergs on the Lowland Landscape which is equivalent approximately to the end-Tertiary surface in this area is largely controlled by tectonic upwarping. This consideration may also be applied to explain the evolution of inselbergs, bornhardt domes and ribs both on the non-dissected and dissected plains in this area.

RECENT PROCESSES ON PEDIMENT SLOPES

Gullying and sheetwash erosion are the main present-day geomorphic processes in this semi-arid savanna region, apart from chemical and mechanical weathering of bedrock. The active gullying and sheetwash erosion are reported in many parts of the semi-arid region in southern Kenya, for instance, in the area south of the Taita Hills (Walsh 1960) and in the Ikutha area (Walsh 1963). On the mantled pediments, above all, these processes are the only active processes which cause the movement of surface materials as well as the modification of surface forms. The shape and distribution of recent surface modifications are show

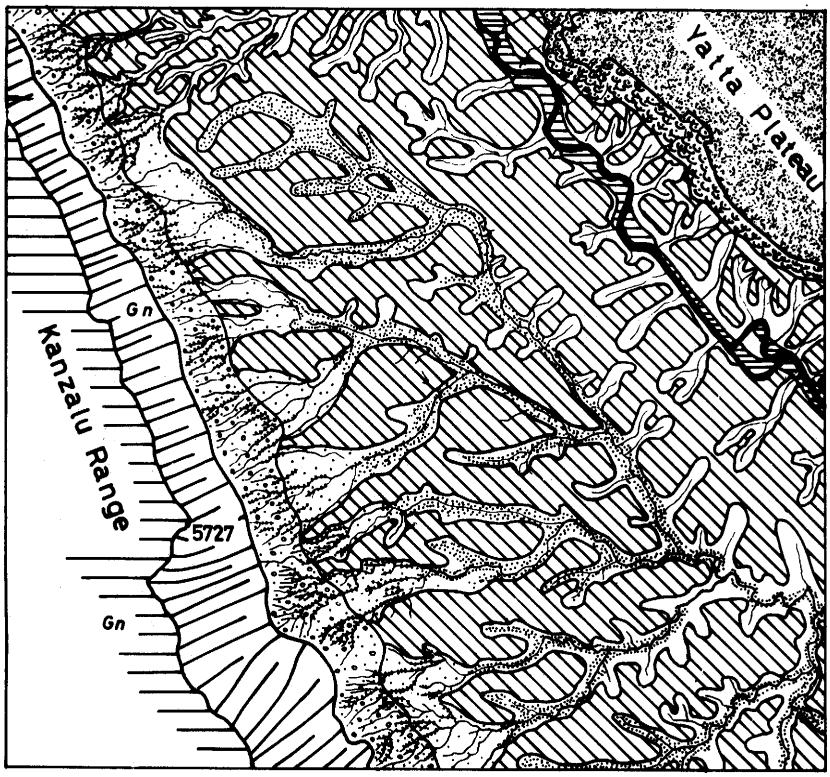

Fig. 8 Pediments being dissected by deeply incised gullies, eastern foot of Mbatini Hill, north to Sultan Hamud (bottom)

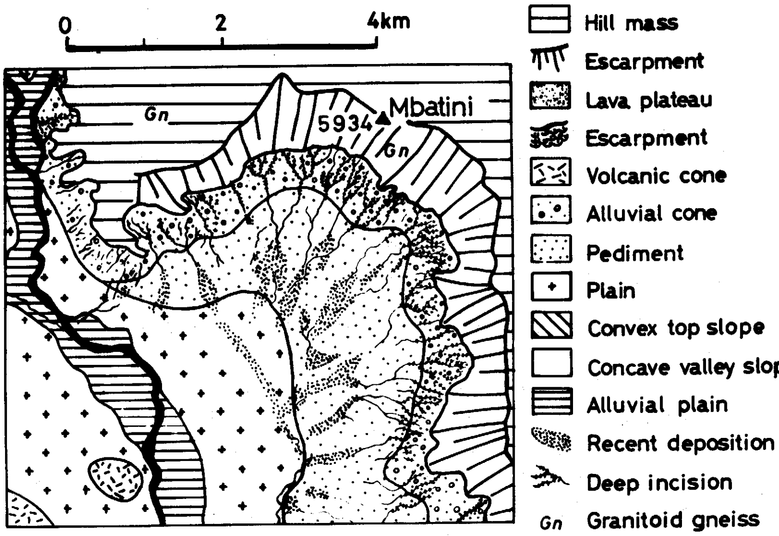

Fig. 9 Dissected pediments and rolling plain at the eastern foot of the Kanzalu Range (top)

in detailed geomorphological maps (Figs. 4 and 5). As observed on these maps, spoon-shaped shallow erosion hollows resulting from sheetwash have occurred on some pediments, and gullying is dominated on alluvial fans and cones at the scarp-foot zone of the Taita and Sagala Hills.

Spoon-shaped erosion hollows are typically developed on the pediments surrounding the inselbergs having a height of 200 - 350 m. The typical examples are on the pediments around the Voi, Irima, Manga and Mbulia Hills (Fig. 4). On the other hand, such erosion hollows are not formed on the pediments surrounding the lower relief inselbergs and bornhardt domes, and the smooth slopes are preserved as recognized on the pediments of the Mzinga, Mwakingali and Ndatani. In the former case, the head of the eroded area does not start at just the scarp-foot of inselbergs, but from the mid-slope of pediments. The depth of the eroded area is 1 - 2 m in general, and bottoms are slightly dissected by gullies (Plate 7). The lower end of the eroded area is usually followed by fan-shaped or tongue-shaped accumulations. These minor landforms indicate recent transportation of surface materials in form of both rillwash and sheetwash caused by occasional heavy showers.

Spoon-shaped erosion results in only a minor and local change to the surface form of pediments, and adjoining areas still preserve smooth surface slopes. This indicates that this type of erosion has occurred in recent years. Although the exact time when erosion began is not known, such heavy shower as of December 26, 1927, exceeding 200 mm/ day, is thought to be a significant cause. The relationship between rainfall intensity and the rate and mode of erosion is one of the problems to be investigated in the future. From the interpretation of spoon-shaped erosion hollows, it is considered that loose surface sandy soils are underlain by hard lateritic soils with pans, which are less permiable than surface soils.

Scarp-foot incisions by rills and gullies are recognized elsewhere along the foot zone of steep-sided high escarpments—for example, at the eastern foot of the Taita and Sagala Hills. This process, as suggested by Twidale (1967), can contribute to maintain the sharpness of slope break between hills and pediment slopes. From the distribution of scarp-foot incisions, it is natural to consider that the occurrence of this type of erosion depends on the height and steepness of hillslopes, and the size of the catchment area behind rills. These factors can affect the concentration of overland flow from hillslopes and contribute to the development of scarp-foot incision.

Ojany (1969) reported that deep weathering of bedrock is being proceeded in the scarp-foot zone of inselbergs in the Ukambani area, southeast of Nairobi. He also stated that chemical weathering is dominant in humid seasons. This suggestion may be applied to this area, and deep weathering has prepared the erodible conditions in the scarp-foot zone. Therefore, deep weathering is considered as a causative factor, but not an immediate factor controlling the development of scarp-foot incision. In this sense, the concentration of overland flow increasing hydraulic energy, which is controlled by the above-mentioned morphometric elements can be said to be the direct process that attack deeply weathered foot zone to form deeply excavated gullies and rills. Higher relief of hills in this area brings greater precipitation. Thus, the dissection of pediment slopes by gullies and rills have proceeded rapidly in the scarp-foot zone of the higher hill masses. This consideration can be applied not only to this area but also to other regions under different climatic conditions.

As mentioned earlier, surface modification and the movement of surface materials are more pronounced on the pediplains at the foot of higher hill masses than on the pediments surrounding inselbergs. These recently occured changes of landforms are also controlled by the above-mentioned hydro-geomorphic conditions of hinterland areas.

In the southern peripheral zone of the Machakos hilly country, there are slightly dissected pediments at the foot of the Mbatani Hills, just north of Sultan Hamud (Fig. 8). As observed on aerial photographs, densely developed gullies excavated the scarp foot-zone deeply, and transported a large amount of materials downstream. Within the peripheral zone of the Machakos hilly country, the most dissected pediment slopes are found at the eastern foot of the Kanzalu Range. Aerial photographs show that the incised streams of the tributaries of the Athi dissected the pediment slopes to form rolling plain sloping gently to the east (Fig. 9). The annual rainfall in the peripheral zone of the Machakos hilly country is greater than that in the Tsavo-Voi area, and is over 750 mm (Fig. 2). Although the main cause of stream dissection is thought to be tectonic upwarping of the region, higher precipitain in that zone provides conditions favoring the development of deep gullies and rills which dissect the pediment slopes.

From the above considerations, it seems probable that most of the pediments and pediplains in southern Kenya had already been exhausted and appear to be in the process of being gradually destroyed under the present climatic condition, rather than being formed, though the degree of modification differs from area to area.

ANTHROPOGENICALLY ACCELERATED EROSION

In such a developed country as Japan anthropogenic process in changing the surface of the terrain is a prominent geomorphic process at the present time. The modification of the surface forms by engineering activities and occupance of the surface by man-made structures are the principal processes that interfere with the hydrologic cycle as well as the geomorphic cycle. These interferences sometimes contribute to the occurrence of catastrophic geomorphic accidents resulting in such natural disasters as landslides, flood damages, etc.

In the semi-arid region of Kenya, two different types of anthropogenic erosion can be observed. One is due to over-grazing of cattle and sheep. The other is due to engineering acitvities such as the construction of roads. As suggested by Twidale (1967), such anthropogenic processes tend to accelerate gullying and sheetwash erosion in the semi-arid and arid regions. Toya (1966) reported the accelerated gully erosion due to over-grazing in the northwestern foot slopes of Mt. Kenya. This type of erosion can be observed elsewhere in the savanna region of Kenya where cattle and sheep are grazed on hillslopes and pediments. On the hillslopes many animal-made steps which easely initiate soil erosion are often found. These steps are typically developed on the hillslopes in the Masai Grazing Land.

In the grazing land of the Kapti Plain, pediment slopes of Komo Rock, Chumbi, Wani and other inselbergs are characterized by a distribution of numerous stripes extending radially from the inselbergs (Fig. 10). Those patterns on aerial photographs indicate a recent movement of surface materials caused by sheetwash. Such patterns are not observed on the pediment slopes in the Tsavo-Voi area. It is considered that over-grazing in the Kapti Plain denuded vegetation, especially bush

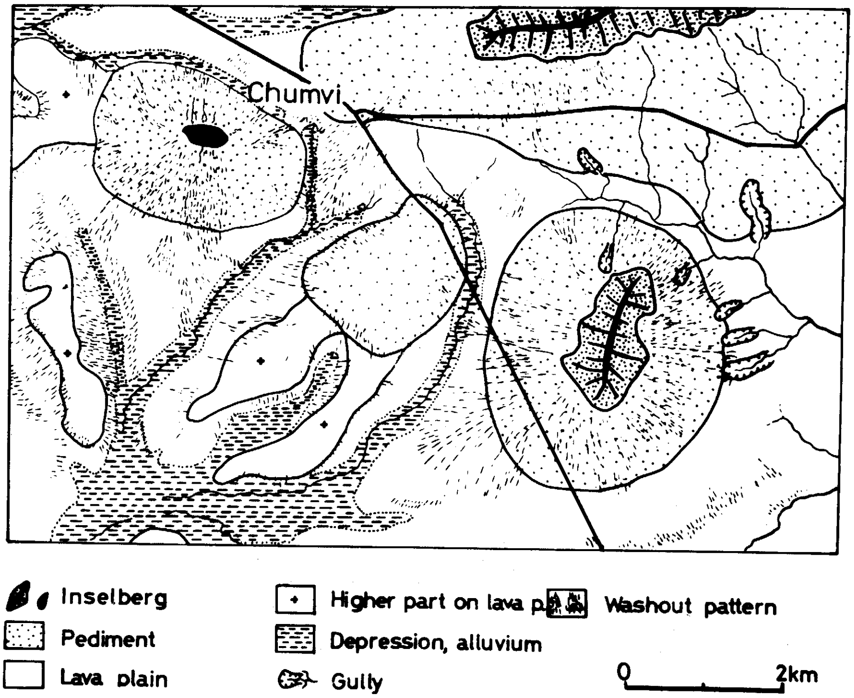

Fig.10 Washout pattern on pediments, Kapti Plain

vegetation, and accelerated soil erosion in a form of sheetwash. The amount of rainfall in the Kapti plain (c. 500 - 750 mm/ year) is slightly larger than in the Tsavo-Voi area and may be another factor affecting such a process in that area. Accelerated erosion in the form of gullying and sheetwash due to the construction of roads can be found not only on hillslopes but also on plains throughout southern Kenya.

These recently accelerated processes must be regarded as a severe problem because the progress of the development of the semi-arid savanna region might accelerate more modification of the surface features. The morpho-conservation is a most necessary task in the tropical semi-arid regions where the bedrock is deeply weathered. The soils derived from the weathering of gneisses are usually sandy, and are sensitive to gullying and sheetwash erosion. The progress of the above-mentioned processes may also destroy natural vegetation which support wildlife in the savanna ecosystem. In this respect, morpho-conservation as well as soil conservation are the principal tasks for the future environmental conservation of the semi-arid savanna regions in tropical Africa.

CONCLUDING REMARKS

As mentioned above, the occurrence of inselbergs and pediment slopes, as well as the surface features of dissected plain in the Tsavo-Voi area are controlled basically both by the structure of the Basement System rocks and by the relative resistance of rocks to weathering and erosion. It can, therefore, be said that inselbergs and pediments which are the most typically developed landforms in the tropical semiarid region of Basement System rocks, are essentially rock-controlled landforms, rather than climate-controlled landforms. As reviewed, for instance by Stoddart (1969), it is very difficult to distinguish climatic geomorphology from other geomorphology, especially in the case of landforms resulting from fluvial erosion.

However, it should be doubtless that the present climate, vegetation, and deeply weathered bedrocks are interrelated to produce a characteristic environment for the present geomorphic development in this tropical semi-arid region. If this is correct, it is necessary to clarify the distinctive processes contributing to the landform evolution under the present climatic condition, which differ from other processes that are active under a different climatic regime. For this, scale of landforms should be selected, and precise and quantitative analysis of active processes must be noted. On the other hand, climate control on landforms appears as an integrated result of not only the present climatic condition but also the past climatic changes during the Quaternary and earlier.

At least, in southern Kenya, the dissection of pediment slopes is clearly related to the amount of present rainfall which is controlled by the present relief. It seems probable that most of the pediment slopes in southern Kenya had already been exhausted and appear to be in the process of being gradually destroyed by gullying and sheetwash erosion as well as by the stream incision, rather than being formed. It is doubtless that the dissection of pediment slopes and the end-Tertiary surface by incised streams have been promoted by the tectonic upwarping of the whole inland plain in southern Kenya during the Quaternary.

It is natural to consider that the pedimentation, forming smoothly curved pediment slopes had been proceeding under more arid climatic conditions in the past than the present as a process of denudation of older etched surfaces. It might have begun from the latest stage in the end-Tertiary peneplanation. To find more valid answers to these problems it is necessary to restore the history of the climatic changes and tectonic movements during the long past times, which affected the geomorphic development in this region. The comparative studies on similar landforms developed under the different climatic regimes from the viewpoint of continental and global scales should also be a requisite.

Most of the above-mentioned are the much-discussed questions and the problems awaiting solution in climatic geomorphology. In conclusion, mention should be made of fluvial geomorphological study on present-day processes in semi-arid regions in East Africa. Such anthropogenically accelerated processes as gullying and sheetwash erosion under the present climatic condition, and their effects on the hydrologic cycle should be studied from the viewpoint of environmental conservation in the tropical semi-arid regions. This interim report is the preliminary of geomorphological studies in the Basement System rocks in the tropical semi-arid regions of East Africa.

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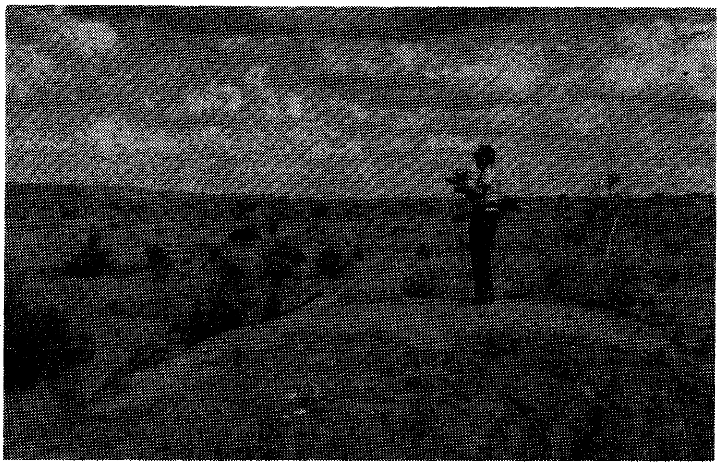

Plate 5 Rock platform in the dissected plain, 5 km south of Lugard's Falls

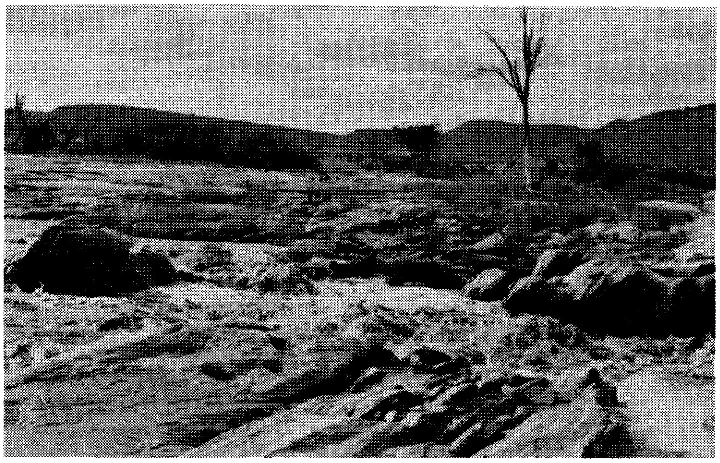

Plate 6 Lugard's Falls and Yatta Plateau. The Athi traverses gneissosity perpendicular

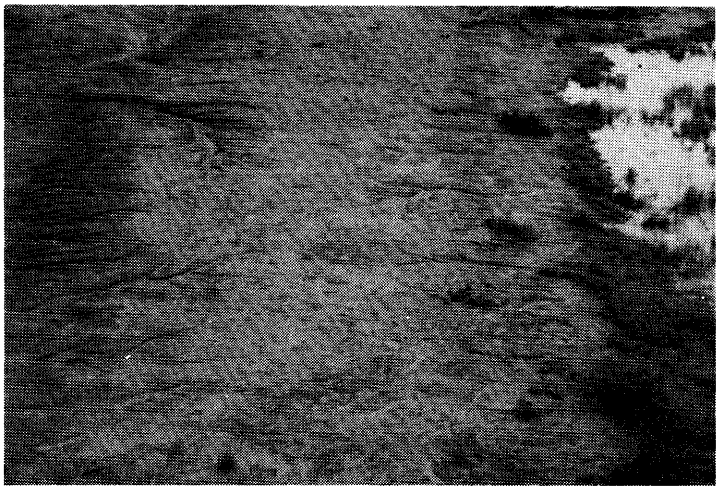

Plate 7 Minor erosional features on the bare ground, east foot of Mudanda Rock. Taken immediately after a thunderstorm of 52.2 mm (23 January, 1970, Photograph by H. Toya)