CHAPTER 5 — STRUCTURE & SURFACE

Contents

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5.1 PHYSIOGRAPHY

The physiography of Central Mocambique comprises a stepped topography rising inland to the Eastern Great Escarpment some 250 km from a low coastline which is fronted by a broad shallow continental shelf of 120 km width. Almost bisecting this plan on a N—S rectilinear curve is the southern end of the Great Rift Valley system of Africa, the Urema Trough, which extends south of the Niassa-Chire Trough for 280 km from the Zambeze-Chire junction to the sea at Beira and Sofala. At its southern end the Rift bifurcates just south of the main road and rail route which traverses the Rift floor to Beira. The western branch forms the Buzi Trough which in turn is linked to the Limpopo Trough and the Lebombo monocline in the south. The eastern branch joins the fracture system of the Mocambique Channel down the continental shelf front of the Southern Coast as evinced by the seismo-tectonic record (Fig 5.1 and 5.2).

The Urema Trough is bounded on the east by a remnant seaward inclined block of Cretaceous and Tertiary sediments, forming the Cheringoma Plateau. This block formed the coast plain to the Midlands, with which it forms and even convex profile, prior to the downthrow of a 40 km broad strip of land by rifting which formed the Urema Trough. The western side is formed by midlands of Precambrian migmatitic gneiss which rise inland to the base of the N—S trending Great Escarpment at 600 to 900 m altitude. The midland zone of Central Mocambique is also known as the Manhica Platform (Wellington 1955). The Great Escarpment rises abruptly from the midlands in rugged and precipitous scenery to over 2 000 m elevation. The crest is relatively narrow and descends more gently west of Inyanga to meet the Interior Continental Plateau of Rhodesia at 1 800 m descending gently westwards to 1 200 m towards the Kalahari Basin in the centre of the subcontinent. In contrast the southern sector of the Great Escarpment, from Vumba to Mt Selinda, descends steeply on the west to the deep N—S valley gouged out by the Sabi River.

The Great Escarpment on the Mocambique-Rhodesia frontier is composed chiefly of Precambian metamorphosed sediments, chiefly quartzites of the Frontier Formation, Umkondo schists and quartzites, small areas of Manhica talc schists, chlorite schists, quartzites, serpentines, banded ironstones and green stones. In the central part these metamorphic outcrops are interrupted by granite-gneiss of the Basement Complex. The Frontier Formation forming the escarpment crest was over-

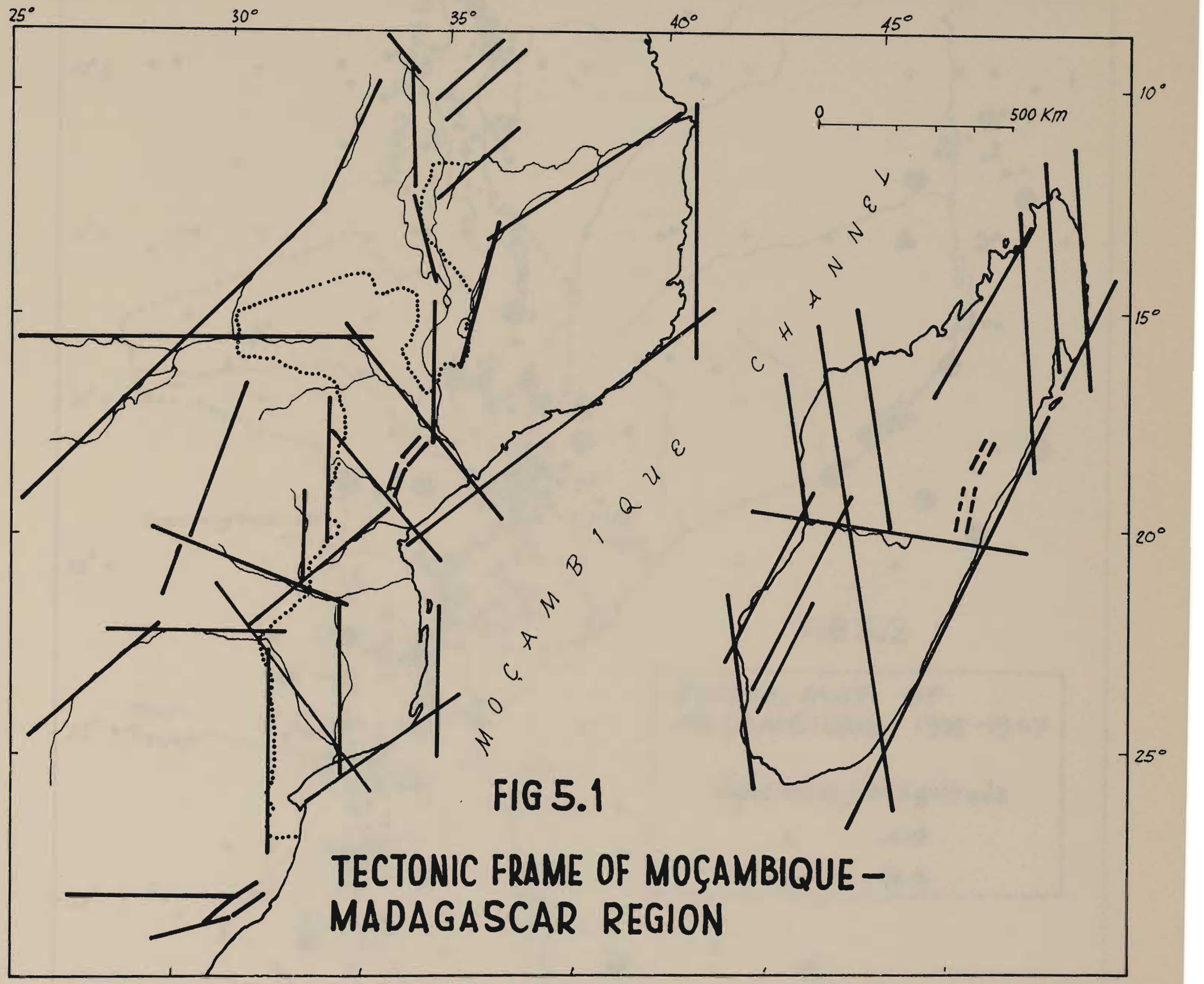


FIG 5.1

TECTONIC FRAME OF MOÇAMBIQUE-MADAGASCAR REGION

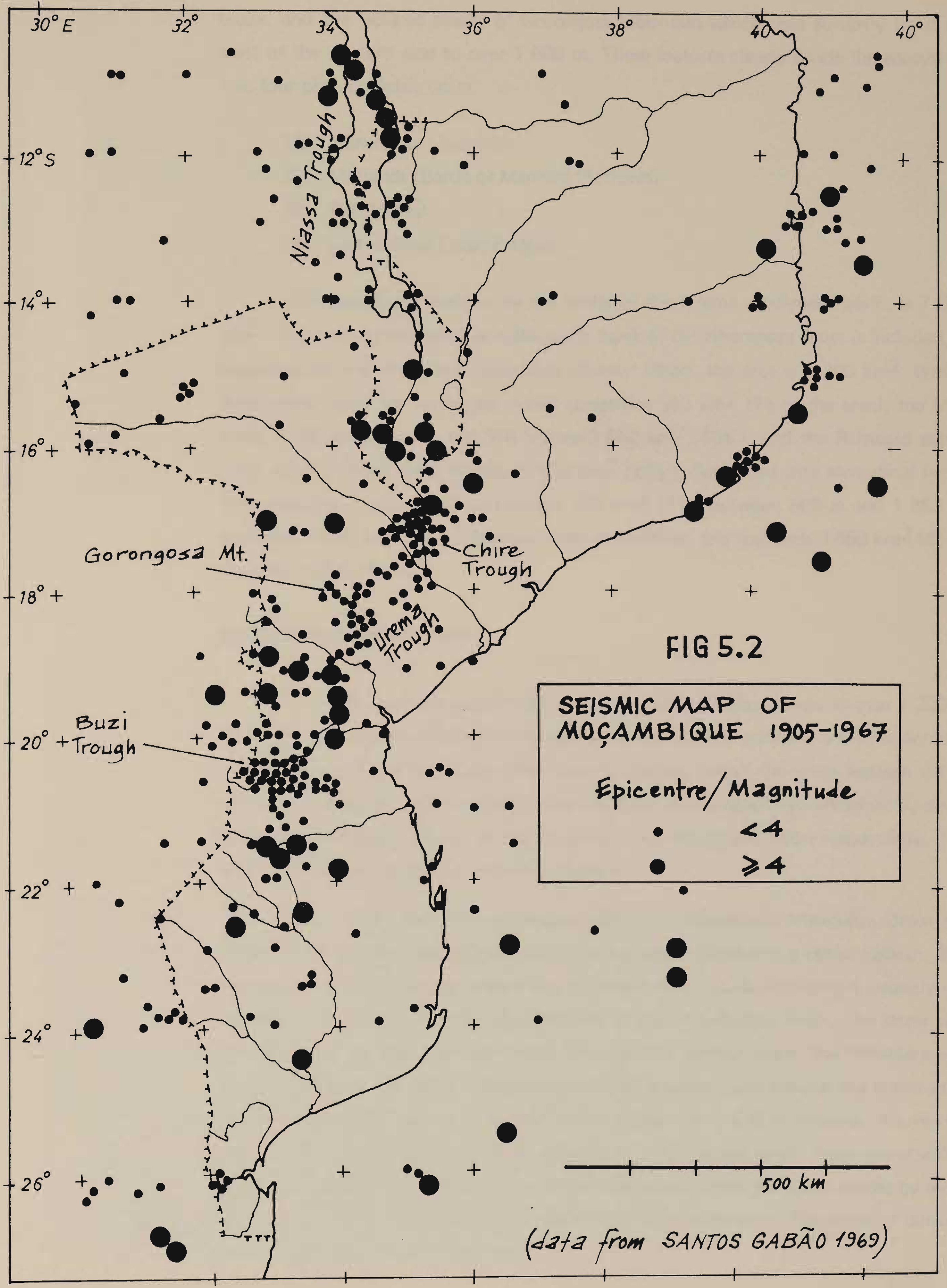


FIG 5.2

SEISMIC MAP OF MOÇAMBIQUE 1905-1967

(data from SANTOS GABÃO 1969)

thrust along a N–S fracture by Precambrian earth movements from the east. This fracture line extends for more than 300 km between latitudes 19° and 20°, interrupted at both ends by the transverse fractures of the Lower Zambeze in the north and the oblique fracture of the Buzi Trough in the south (Teale & Wilson 1915).

The broad coast plain of southern Mocambique is linked to the Zambeze and Niassa lowlands by the southern end of the Rift Valley and the low flat coastal margin of the Cheringoma Plateau. The plains of the seaward margin are formed in part by the Zambeze Delta alluvium which together form a NE trending shoreline, the delta front alone comprising nearly 250 km in length. South of Beira the coast changes to a S trend, the indent forming the Bight of Sofala. At this point the sea is only 155 km from the Chimanimani Massif of the Great Escarpment.

The geology of Central Mocambique is complex, providing a great heterogenity of rock structure and textures, many of which have undergone repeated tectonic fractures and earth movements since the Precambrian. Major dislocations and warping occurred with the breakup of Gondwanaland in the Jura-Cretaceous, followed by moderate movements in the later Cretaceous and Miocene, culminating in the early Pleistocene in a major episode of uplift and warping. The uplift formed the rim of the escarpment zone and elevated the interior plains of a continental plateau. The coast margins of the subcontinent were tilted downward to the sea with the formation of the Mocambique Channel and contemporaneous Rift Valley faulting on the crests of the downbent crust (Dixey 1955, 1956; King 1962).

The result of these tectonic movements was to impose a strongly developed fracture system on the landscape which controlled hydrographic development and thus the main lines of erosion and deposition by water. Close to the escarpment the fracture lines are chiefly N–S, and at right angles to this in the north is the E–W fracture line of the Kafue and Mid-Zambeze. The remainder of the country is dominated by strongly developed NE–SW and NW–SE tectonic lines superimposed on the older N–S lines (Teale & Wilson 1915); well illustrated by the trends of the coastline, Rift Valley, Midland drainage and especially the Lower Zambeze, Pungue and Buzi Rivers. These tectonic lines accord with the major fracture system of the continent (see Furon 1963, Fig 3). Sets of faults and fractures oblique to these, on NNE–SSW and NNW–SSE trends, are responsible for the Urema Trough and adjacent highground on eitherside, exemplified by the dyke swarms north and south of Gorongosa Mountain and the Inhaminga fault.

The physiography of the Gorongosa ecosystem is boldly defined by the 40 km broad Rift Valley trough, the sloping sides of which are formed by 300 m high plateaux, and the isolated massif of Gorongosa Mountain which rises abruptly from the crest of the western side to over 1 800 m. These features clearly divide the ecosystem into four physiographic units:

(1) Gorongosa Mountain
(2) Midlands (Báruè or Manhica Platform)
(3) Rift Valley
(4) Cheringoma Coast Plateau

The ecosystem, defined by the limits of the Urema catchment basin, is 7 850 km^2. If the entire mountain and the south bank of the Nhampaza River is included, as suggested for the new park boundaries (Tinley 1969), the area is 8 200 km^2. Within these latter limits the mountain massif comprises 550 km^2 (7% of the area), the Midlands 2 100 km^2 (26%), the Rift Valley 3 650 km^2 (45%), and the Riftward catchment of the Cheringoma Plateau 1 900 km^2 (23%). Separated into altitudinal limits these features comprise: mountainland 550 km^2 (7%) between 600 m and 1 863 m, midlands 4 000 km^2 (49%) between 100 and 600 m, and lowlands 3 650 km^2 (45%) less than 100 m (Fig 5.3).

GORONGOSA MOUNTAIN

The oval mountain massif rises in bold and picturesque scenery to over 1 200 m above the surrounding Midlands. The eastern precipitous escarpment is formed by bare granite bornhardts interspersed with forested ravines whilst the steep western flanks are deeply ribbed by radial drainage. The NE and S flanks have been breached by deeply incised headward erosion of the Vundudzi and Nhandare Rivers respectively. The western rim of the mountain remains unbreached.

Four main rivers, the Nhandare, Chitunga, Muera and Vundudzi, drain the massif in an annular pattern, contributed to by lesser streams in a radial pattern. The first two of these rivers join below the mountain and flow south along a strongly developed N–S fracture line in the Midlands to join the Pungue River. The latter two flow east and traverse the Rift Valley floor to the Urema Lake. The Nhandare and Vundudzi Rivers rise on the western rim of the mountain and traverse the entire summit area southward in deep V-shaped valleys below the 1 400 m contour. Above this contour the catchments are of open-concave to polyconcave relief. These upper valley areas have tightly meandered stream courses separated from the lower gorges by nickpoints with falls or rapids between the 800 and 1 000 m contours. The drainage density on the mountain is high to very high.

PLATE 1 GORONGOSA MOUNTAIN LANDSCAPE

(A) Gogogo summit area, the highest point (1863 m) against the skyline on the extreme left. Light areas are montane grassland and/or rock outcrops. Dark fine textured canopy in foreground is *Philippia benguellensis* fynbos thicket surrounded by rain forest canopy.

(B) The western rim looking toward the SE – source of the perennial Vundudzi (valley on left), Nhandare (valley on right) and Muera (foreground slopes). Vundudzi flows SE then turns east (left) into a second catchment basin below the line of cloud on its way to the Urema Lake. Note beheadment of Vundudzi and Nhandare headwaters by Muera.

(C) The seasonal tarn or pan on the plateau bench below Zombue summit in the centre of the massif. Montane grassland surrounded by rain forest and *Widdringtonia nodiflora* woodland (slopes on left of bench).

(D) Eastern escarpment of mountain with bare rockfaces of exfoliating granite and rain forest in the ravines.

The drainage of the summit area is aligned along the major N–S and E–W fractures in the mountain, and these form a zigzag pattern in the Vundudzi Valley on the eastern side where different sets intersect. Although the mountain drainage is controlled by the weak lines of the fracture system, both first and second order streams can either be meandered or coarsely reticulate. The streams rising on the NE and W of the mountain have etched deep amphitheatre catchments into the outer slopes.

The deeply incised drainage on the south and east of the mountain and the persistence of an unbreached divide forming a rim on its western side indicates that the upper mountain drainage was initiated on a planation surface inclined to the SE, and the south and east were possibly more easily erodable due to the well developed fractures. The cross-fracture system appears to have been a major factor facilitating river capture of one of the upper Nhandare valleys by the Vundudzi, which drains to the Urema Lake on the Rift Valley floor.

The valley capture point lies close to the main Nhandare Valley and is separated by a narrow saddle. The Vundudzi has thus effictively eaten back into the overall oval of the mountain to form an assymetric figure of eight shape, and comprises an upper catchment above 1 200 m and a lower basin between 500 and 1 200 m. Viewed from the SW or NE the massif has a higher western block with steep scarp faces. A similar shape and proportion is replicated by the higher pluton of Mlanje Mountain in Malawi (see Dixey 1927, Fig 7).

Although rapids are abundant there are only three major falls on the mountain. Two of the highest, some 100 m in height, occur on the Murombodzi stream at the 900 m contour and at the 700 m contour and are associated with a broad bench or step formed on the gabbro outcropping on the SW of the massif. A series of falls occur in close sequence on the Vundudzi River near the 1 000 m contour in the ravine just below the site of river capture.

Viewed from the Rift Valley (Fig 5.4) the mountain top comprises three main summit areas above 1 700 m on the western block, attaining 1 863 m at the highest point of Gogogo Peak in the SW. The largest summit area above 1 700 (4 km^2) is that in the SW which has the second highest peak Nhandohue(1 858)m at its southern end. The second highest summit area is Zombue (1 845 m) followed by the northernmost peak of Inhantete (1 762 m) overlooking the Nhandue River valley. The summit areas are grasslands on gently undulating to steeply rounded slopes with small areas of flat ground. Large, deeply fissured granite outcrops occur on the summits, supporting thicket, forest or patches of arborescent strelitzia. Springs, bogs and oozes are common on the summit areas, and one isolated seasonal tarn occurs on the plateau spur east of Zombue summit. The eastern block nearest the Rift Valley is surmounted by the forest-covered Nhansocossa Peak of 1 478 m height. The remnants of related planation surfaces on the mountain summits correspond to Gondwana and Post-Gondwana bevels, and the disposition of lower summit bevels and benches on the flanks of the mountain is shown in Fig 5.7. The most important benches or steps occur between 800 and 1 200 m (Figs 5.3 and 5.13).

Although the scarp faces are erosional and not due to recent faulting, earth tremors are frequent (Fig 5.2). Only one area of vertical cliffs occurs, on the NW corner of the massif which appear to be used for nesting by birds of prey, and possibly vultures, as evinced by the white streaked cliff faces. The greater part of the mountain is covered in rain forest and this clothes the magnificent deep gorges cut by the Nhandare and Vundudze Rivers on the south and east flanks. The Vundudzi River forms a second deep gorge where it leaves the mountain and enters the Midlands near Cavalo.

MIDLANDS

The Midlands which begin abruptly in the east at the fall line against the Rift Valley, and rises inland westwards to the Great Escarpment, is a maturely dissected former planation surface. Remnants of the former southeast inclined surface is shown by the accordance of the interfluves and relic dambo (mature) drainage not yet incised by the lesser tributaries of the main rivers. Deep, steeply sloping V-shaped valleys alternate with narrow steeply rounded interfluves.

The fall line is delimited by an abrupt, or gradual, drop to the Rift floor. In parts the crystalline hills rise to over 300 m within 2 km of the Rift floor which is at 80 m, eg. near Rerembe where the Mucodza River meets the Rift. In general the rise is much less abrupt attaining 300 to 400 m altitude over a 5 to 10 km distance as exemplified by the rise to the N–S interfluve separating the Nhandare Valley from Riftward drainage south of Gorongosa Mountain.

The Midlands have been gouged out along two sets of strongly developed fracture lines SE–NW and N–S, thus the deeply cut valley and spur topography trends along these lines. Although the lesser tributaries of first, second and third order generally show a dendritic pattern, all orders including the Pungue, Nhandare and Nhandue Rivers have incised meanders and river capture has probably been of common occurrence (eg. Nhandue drainage). In many parts these meanders may be superimposed from the original planation surface, but in others, meanders appear to have been formed by intersecting sets of opposing fracture lines. The Midlands has a high to very high drainage density.

PLATE 2 MIDLAND INSELBERG & HILL MIOMBO LANDSCAPE

(A) Mhanda Inselberg (1423 m) surrounded by a sea of Midland hill-miombo savanna. Mesic forest forming an apron around the outcrop base is a typical feature. Light areas in the miombo are relic dambos, incised and being invaded by savanna trees. Clumps are terminaria thickets. The dambo areas are remnants of the Midland late tertiary planation surface.

(B) Dry forest on the sands of an aggraded valley floor in dry *Julbernardia – Pterocarpus brenanii* miombo northwest of Gorongosa Mountain (Nhamacapinda River).

The deepest gorges in the system area are formed by the Nhandare and Pungue Rivers at their confluence. The Nhandare joins the Pungue along a major N–S fracture parallel to the Rift line nearby. The perennial Nhandare River which drains the southwest part of Gorongosa Mountain is joined from the west by a large 'sand river', the Vunduzi (not to be confused with the Vundudzi draining the eastern sector of Gorongosa Mountain to the Rift Valley), which rises on the Midlands and is thus a 'sand river', strongly seasonal in flow. The Nhandue and Nhamapaza are the other two large 'sand rivers', which rise on the Midlands and drain into the Rift. The Nhandue reaches the Urema Lake, and thus the Pungue, only during the rains. The seasonal Nhamapaza River has a wide braided riverbed which traverses the Rift Valley maintaining a SE course to meet the Zangue, a small tightly meandering subsequent course draining the Urema Trough north towards the Zambeze River. In the northwest of the system is a broad N–S valley formed by the Muche River which meets the Nhandue at the Rift junction. This valley appears to be a major fault related to the Rift dislocations. A range of rounded lava hills known as Panda mark the confluence area of the Muche and Nhandue. In the northwest of the system the large tributaries of both the Nhandue and Nhamapaza are also 'sand rivers'. All the rivers entering the Rift from inland across the crystalline Midlands are rejuvenated in their lower courses and descend to the Rift through deep rocky gorges over rock bars, rapids and small falls, and flood to over 10 m in their gorge tracts. However, those rivers such as the Nhamapaza which enter the Rift across the Continental Cretaceous meet the floor in broad valleys with braided courses.

Rising above the Midland interfluves are many inselbergs of various dimensions (Fig 5.5). Only Mhanda (1 423 m), which lies 50 km northwest of Gorongosa Mountain, and Cudzo (805 m), 20 km southwest of the massif, are of large size. These, and the smaller koppies west of the mountain, are exfoliated domes of granite cores also known as Bornhardts. Those in the eastern quadrant from the mountain are either composed of quartz breccia (Siciri, Xivulo), trachyte (Bunga trio and Panda) or basalt (Cuncue). Extending for nearly 30 km north of Gorongosa Mountain, like root outgrowths, is a series of four parallel ridges formed by composite dykes of granophyre and dolerite. The east and west faces of these ridges support different woody plant cover. Less conspicuous are dyks of granophyre forming outcrops and interfluve surfaces southwest of the mountain. Lying 40 km SW of the park are the Xiluvo Inselbergs formed by the breached rim of a carbonatite volcano now covered in forest.

RIFT VALLEY

The Urema Trough sector of the Great Rift Valley is shallow with relatively low sloped sides, unlike northern sectors of the Rift which have high and steep escarpment sides. The width of the Rift here averages 40 km, the same order of width recorded throughout the Rift system and is indicative of the thickness of the continental crust below the trough (Holmes 1965: 1 061). The Urema Lake and its outlet at the Pungue forms the lowest part of the Rift occurring within the study area, this is approximately 12 m above sea level. The margins of the lake are at the 15 m contour and from this basin the contours of the valley floor rise to 80 m at the margins. South of the Zambeze River the Rift Valley is faulted on both sides in a rectilinear curve beginning with a NNE–SSW trend and changing to N–S near the Pungue River, and thence NW–SE where it bifurcates and joins the Mocambique Channel.

The western faults probably predate Juarassic times and have been refractured along the same lines. In contrast the eastern faults are much younger, of Tertiary age, and these resulted in a stepped downthrow of strata on the inface of the Cheringoma block. The western side of the Rift is eroded to a gentler slope than that on the eastern Cheringoma side where there are geologically recent fault line scarps, particularly near Inhaminga.

The even seaward dip of the Continental Cretaceous north of the Nhamapaza River implies that the fractures shown on maps are without throw, the dip of strata continuing beneath the Rift Valley alluvium and faulted with displacement only on the inface of the Cheringoma noted above; ie. single sided (trap) block faulting on the Cheringoma side only. This Cretaceous (Ksm) and associated Stormberg Basalt is totally absent on the western side of the Rift between the Nhandue River and Vila Machado in the south. This and the occurrence of the small horst inlier of Precambrian metamorphic rock in the southwest of the system suggest that this sector underwent trough faulting (see Section 5.2).

A three to five degree seaward dip is typical of the whole region, including the Karroo and Precambrian below the Meso-tertiary cover (data from explanatory notes of Geological Sheets of Mocambique 1:250 000, 1968). The original incline between the Midlands, the remnant Cheringoma block and the lip of the continental shelf has been maintained, despite the large scale trough faulting of the Rift which separated the inland and coastal areas. As the Buzi block shows a similar profile relationship with its immediate hinterland, it is probable that they are islanded remnants left behind by a general widespread lowering of the continental margins, and not uplifted blocks as usually defined (eg. Wellington 1955, Flores 1964 ***et. al.***); an interpretation agreed

FIG 5.3 RELIEF & DRAINAGE

with by Professor L.C. King (*pers. com.* 1977). These releases of crustal tensions appear to have resulted from the gigantic downbowing of the faulted syncline forming the strait between Mocambique and Madagascar (Dixey 1956) (see Section 5.3). The seismic map of Mocambique shows the repeated occurrence of earth tremors recorded along the fracture line of the Rift (Fig 5.2).

Additional evidence that the eastern edge of the crystalline Midlands was faulted in pre-Jurassic time is shown by the extended consequent drainage, now dislocated, of the major rivers on a SE trend across the original single coast plain. This major plain was formed by the present Rift Valley floor together with the backslope of the Cheringoma cuesta. The extended consequent drainage on the SE fracture line has been maintained only by the Zambeze River. With separation of the Cheringoma sector of the coast plain by downthrow of the Rift trough, the other rivers were severed in the middle and formed subsequent drainage on the Rift floor. A singular feature of the Rift drainage pointed out by Mouta (1957) is the continued SE trend of all the major rivers crossing the Rift floor from inland, as well as the Urema Lake which lies on the same axis. Thus despite the large series of alluvial fans and shifting river courses, formed during accumulation of sediment, the shallowness of the underlying hardrock fracture system and its seaward dip continued to be an underlying control of drainage development. Due to these influences the Rift floor is assymetrical in profile with the lowest basins of the subsequent drainage closer to the foot of the Cheringoma inface. The incline from these basins up to the 100 m contour is over 20 km long on the western side and half, or less than half, this distance on the Cheringoma side.

With separation of the Cheringoma from the immediate hinterland, the beheaded consequent rivers became re-consequent, or resequent, on the seaward slope. If the inland SE drainage patterns are followed seaward the original extended consequent drainage can be paired. For example the Nhamapaza with the Mupa, Nhandue and Vundudzi with the Chinizuia, Corone with the Sambazo, and the Pungue with the Sangussi.

A diversity of sediments have been deposited in the Rift, but generally the sandier detritus have formed alluvial fans of all dimensions whilst the finest sediments gave rise to slacks and basins (Fig 6. 3). These basins are extremely flat with gently inclined margins and they occur as a necklace along the length of the Rift floor, pinched off at various intervals by the fan sand deposits which have grown out from both sides of the Rift. The close juxtaposition of two of these fans built by the Nhamapaza River from the west and the Mazamba River from the Cheringoma Plateau forms the divide at 59 m altitude between the Pungue and Zambeze drainage on the Rift floor.

This site is on the Tengane dambo in the NE of the ecosystem. Where the Urema Trough meets the Zambeze River the altitude is about 25 m, at a distance of 170 km from the Zambeze mouth. The Rift Valley floor has a low drainage density.

Both perennial and seasonal streams which traverse the Rift floor are tightly meandered. The Mucombezi, Vundudzi, and Mucodza Rivers which flow into the Urema Lake have incised their courses from 7 to 10 m below the floodplain surfaces from which they originated. The Vundudzi and Urema Rivers in particular have incised deeply through massive alluvial deposits. The Urema River is now underfit as it no longer forms part of the course of the Pungue River, and only during exceptional flood years is a bankfull condition reached when Pungue waters dam up the Urema's flow at their confluence.

Formed at the head of the Urema Lake is an extensive converging delta built by the confluence of deposits from the Nhandue-Mucombeze, Vundudzi, and Mucodza Rivers. This type of delta, as opposed to the diverging delta type typical of certain river mouths where they meet the sea, is replicated in larger scale across the continent by the Upper Niger, Chad, Kunene-Kuvelai in Ovamboland where it meets the Etosha Basin, and the Okovango where it abuts on the Makarikari Basin. In Mocambique the largest partial endoreic basin is represented by Banhine in Gazaland. Banhine is surrounded on its northern quadrant by an extensive converging delta of the fossil Save drainage, formed prior to its capture by headward erosion of direct drainage to the sea. This sequence is again replicated by river capture of the Kunene from Atlantic drainage which resulted in the major hydrology responsible for the formation of the Ovambo Delta, the Etosha Pan and its overflow to the Okovango River via the Omuramba Omaheke (pers. data). The junction of this Omaramba with the Okovango River is 60 km west of Rundu, just upriver from the village of Mawewe. The evolution of such alluvial processes as they pertain specifically to the Gorongosa ecosystem will be dealt with in Chapter 6.

Unique on the floor of the Urema Trough are two outcrops, or inliers, on the SW side between the Vundudzi and Pungue Rivers. One, Xivulo, is a small inselberg of 165 m height formed by quartz breccia. The other, a low rounded horst block rising to 78 m, is of Precambrian igmatitic gneiss with dykes of granophyre (Gorongosa granite) and dolerite. Immediately east of this isolated block with parallel N–S faults is a major fracture line (Fig 5.8) on the Rift floor made conspicuous by the N–S drainage and series of small pans which formed part of the Pungue's original river course (Fig 6 3). This N–S fracture reappears to form the Muche valley in the NW of the park. Apart from these two outcrops the remainder of the Rift Valley floor south of the Zambeze River is composed entirely of alluvial deposits.

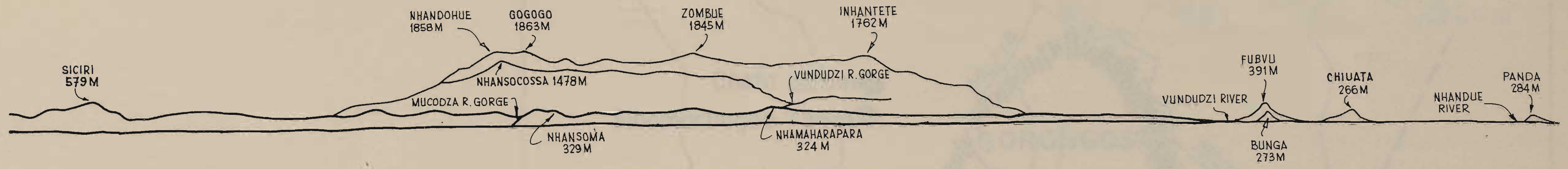


FIG 5.4 GORONGOSA MOUNTAIN & THE WESTERN SIDE OF THE RIFT VALLEY VIEWED FROM THE S.E. ON THE UREMA PLAINS

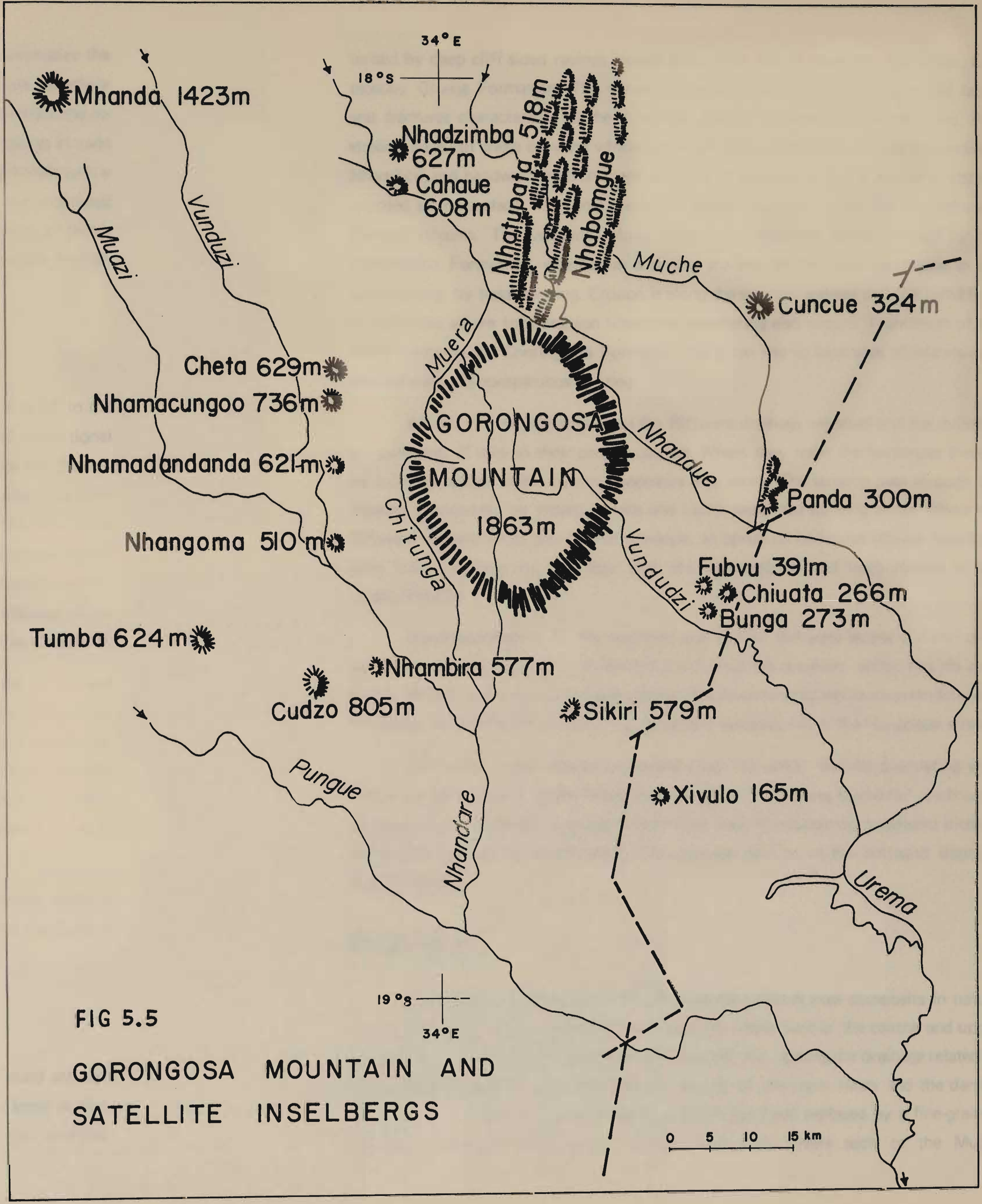


FIG 5.5

GORONGOSA MOUNTAIN AND SATELLITE INSELBERGS

Due to their flat open nature the floodplains of the Rift floor emphasize the physiographic importance of termite hills in the landscape. These hills are especially conspicuous on open floodplain areas where their bare conical shapes dominate the relief. In other areas the hills are covered in tall dense thicket which form islands in a sea of seasonally flooded grasslands. Most of the termite hills average 3 m in height with a diameter of 20 m, and these conical surfaces produced by biotic activity have enormous influence on the appearance and dynamics of plainsland. The highest density of termitaria occur on levees and splay deposits or on convex surfaces of the plains (see Section 6.3).

CHERINGOMA PLATEAU

As the plateau is in fact a cuesta in profile with a slight tilt of 3 to 5° to the SE, this has profound influences on the rate and degree of erosion and depositional processes resulting in quite different physiography on the Riftward inface and the seaward backslope. They are thus discussed separately. The Cheringoma's surface has been eroded mainly from two sides, by Riftward and seaward drainage, which now meet along a narrow N–S watershed formed by erosion of the inface scarp. As scarps retreat by erosion the crest moves in the direction in which the strata dip. This phenomenon is known as homoclinal shifting of watersheds (King 1963: 62). The significance of the reduction in catchment area by this and other processes is dealt with in Chapter 6.

Erosion, especially of the Riftward slopes, has been greatest in the central and southern part of the block. Thus the oldest intact surfaces remaining are most extensive in the north of the cuesta, the Inhamitanga area, and on the seaward interfluves. Three areas above the 300 m contour remain. The largest is in the Inhaminga area with the highest point of 379 m on a sand rise close to the cliffed scarp overlooking the Rift Valley. The other areas above 300 m are small and occur on the watershed south of Inhaminga near Cundue.

Piercing the Cretaceous and Tertiary deposits are two isolated volcanic necks of basalt, the larger of which form the Gadjiua Hills of 346 m altitude near the Cundue ravine. Both occur on the heavily faulted inface of the cuesta.

__Riftward slopes__

The inface rises in a series of steps related to the alternation of hard and soft strata and their differential erosion. The rise from the Rift is generally steep at first, then flattening out with much gentler rise between steps. The central part is characterised by deep cliff sided ravines incised more than 100 m deep into the softer, Cretaceous, Grudja Formation. The dense system of parallel, oblique, and normal faults and fractures characteristic of the inface has greatly favoured erosion processes. Five streams have cut these canyons which are either narrow (Muanza) or wide (Nhandindi-Nhamfici), and headward erosion stops abruptly at nickpoints in the harder sandstone exposed at the surface. The most spectular ravines have been cut by the Mazamba and Cundue streams. The yellowish-white calcareous sandstone cliffs, formed by the Cheringoma Formation, weather in a similar manner to the Cave Sandstone in the Drakensberg; by basal sapping. Erosion is along the strongly jointed and fractured lines of weakness where subterranean limestone weathering also occurs. Truncation of the strata overlying the Cheringoma Formation has given rise to extensive tablelands with skeletal soils and conspicuous jointing.

All the present day streams of the Riftward drainage are small and the majority are perennial, if only in their central courses. Where they meet the footslopes there is no running surface water as this disappears into sands. The streams pass through the stepped topography by means of falls and rapids separated by long pools. Where the Riftward streams meet the alluvial toeslope, an apron of coalesced alluvial fans have been built out onto the Rift floor with the sediments derived from erosion of the inface (Fig 6.3).

Headward erosion of the northern and central Riftward slopes is damped by exposure of hard calcareous sandstone strata, but the southern sector has no such barrier and active slump and donga erosion of deeply weathered argillaceous sandstone of the Mazamba Formation is occurring, especially conspicuous in the Musapasso stream.

The crest of the cuesta comprises deep red sandy latosols alternating with high watertable pallid to white sands. Dambo remnants form the headwater catchments of most of the Riftward drainage, others have been eliminated by headward incision which has reached the divide itself. The drainage density of the Riftward slopes is medium to high.

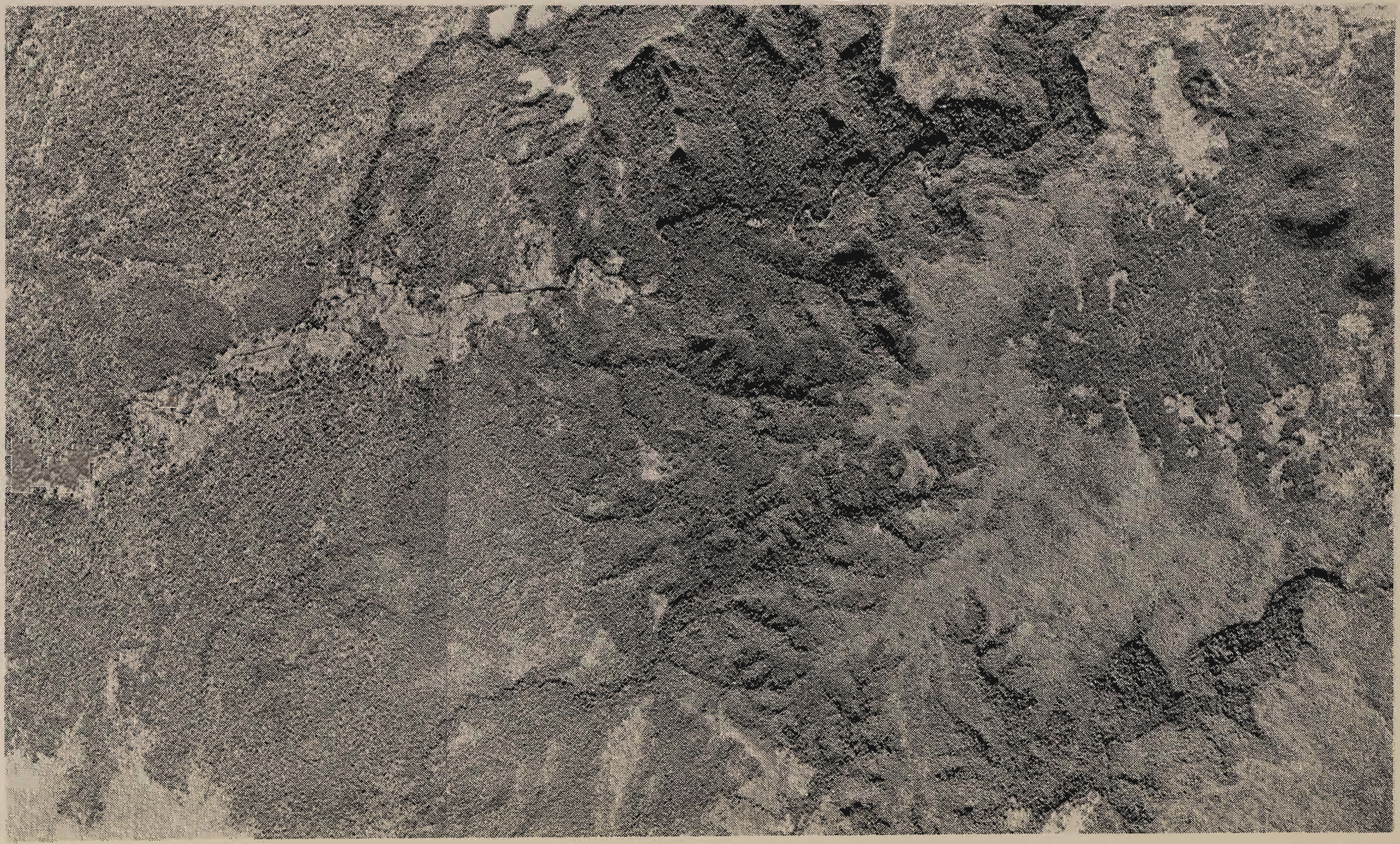
__Seaward slopes__

The resequent drainage of the Cheringoma Coast is now composite in nature due to truncation of the overlying sands over the major part of the central and upper catchment. Thus an original coarse-grained parallel and rectangular drainage related to the cross-fracture system of the cuesta is typical of the main rivers and the dambo drainage on the remaining areas of sands, and this has been replaced by a fine-grained dentritic drainage on exhumed sandy clays. The main rivers such as the Mupa,

PLATE 3 THE CHERINGOMA RAVINES OF THE RIFTWARD DRAINAGE

(A) Oblique air view of the forested Maciguadzi Ravine looking NE with the Gadjiua Hills formed by volcanic plugs of nepheline basalt on the crest of the Cheringoma Plateau. Limestone cliffs in right foreground.

(B) Massive limestone cliffs of the Cundue Ravine immediately north of the Gadjiua Hills. High forest in the ravines and dense scrub-thicket above the cliffs.



(C) The Cundue and Maciguadzi Ravines from the air with the Gadjiua Hills on the right (east) and Rift Valley floodplains on the left (west). Note, (1) forested ravines, (2) closed savanna-thicket mosaic on incised fan aprons in front of the ravines, (3) relic 'mesa grasslands' on impervious glauconitic clays (top centre of photo) being replaced by forest, (4) present aggraded floodplain now incised of Cundue stream (and cultivated), (5) white patches around the hills are cultivation clearings, (6) sparse savanna cover on stripped horizontal limestone strata between the two ravines.

Chinizuia and Sambazo have broadly meandered courses deeply incised into the middle to upper dipslope. These fifth order rivers also have wide braided channels enlarging by lateral erosion.

Where the underlying clays, formed by deeply weathered calcicargillaceous sandstones of the Mazamba Formation, have been exposed the headwater tributaries are deeply incised giving rise to a highly eroded polyconvex landscape, replicating the situation in the Musapasso River and other Riftward drainage to the south. Rapid erosion of these friable clays has resulted in numerous river captures and beheading of drainage as streams cut back laterally in the upper reaches. Thus a large part of the dambo drainage on the remaining duplex sands is in the process of extinction due to drying out and nickpoint migration from the coast.

An unique feature of the dambo drainage on the eluvial sands of the seaward slopes are the large numbers of oval pans originating from the broader and deeper permanent vlei areas in the dambos. The largest area of these pans is in the north of the cuesta between Inhamitanga and Marromeu. This area has also the largest areic sand area on the Cheringoma. Similar pan systems in Mocambique occur near the coast in the extreme north, inland of Mocimboa da Praia, and near Dombe below the Chimanimani mountains. In all three areas the oval pans occur on duplex sands. Elsewhere in the subcontinent similar pans occur; in the southern Kalahari (Kalahari Bult), eastern Transvaal, Western Orange Free State and northern Cape (Wellington 1955, Boocock & Van Straten 1962, Grove 1969, De Bruiyn (1971).

Complementary to the massive erosion of the coast plateau hinterland by the main rivers, is the apron of coalesced alluvial fans formed between the 100 m contour and the alluvial front of the Zambeze Delta flood plains. Some of these fans measure 25 to 30 km in length (apex to front), and the abandoned aggraded distributaries are indicated by forest cover. The intervening slacks form part of a younger dambo system of drainage with oval pans and vleis.

The wearing back of the major river valleys has eliminated the overlying duplex sands on some interfluves resulting in a rounded eroded topography, but in other situations the sands form valley-side scarps. In the latter situation interfluves remain flat to faintly undulating with dambo drainage.

The dipslope drainage patterns meet a longitudinal floodplain meander drainage abruptly near the coast. The complex of distributary meander belts, meander cutoffs, meander scrolls, and swamp slacks extend in a narrowing front from its origin at the Zambeze River to half the length of the Cheringoma Coast, ie. petering out near

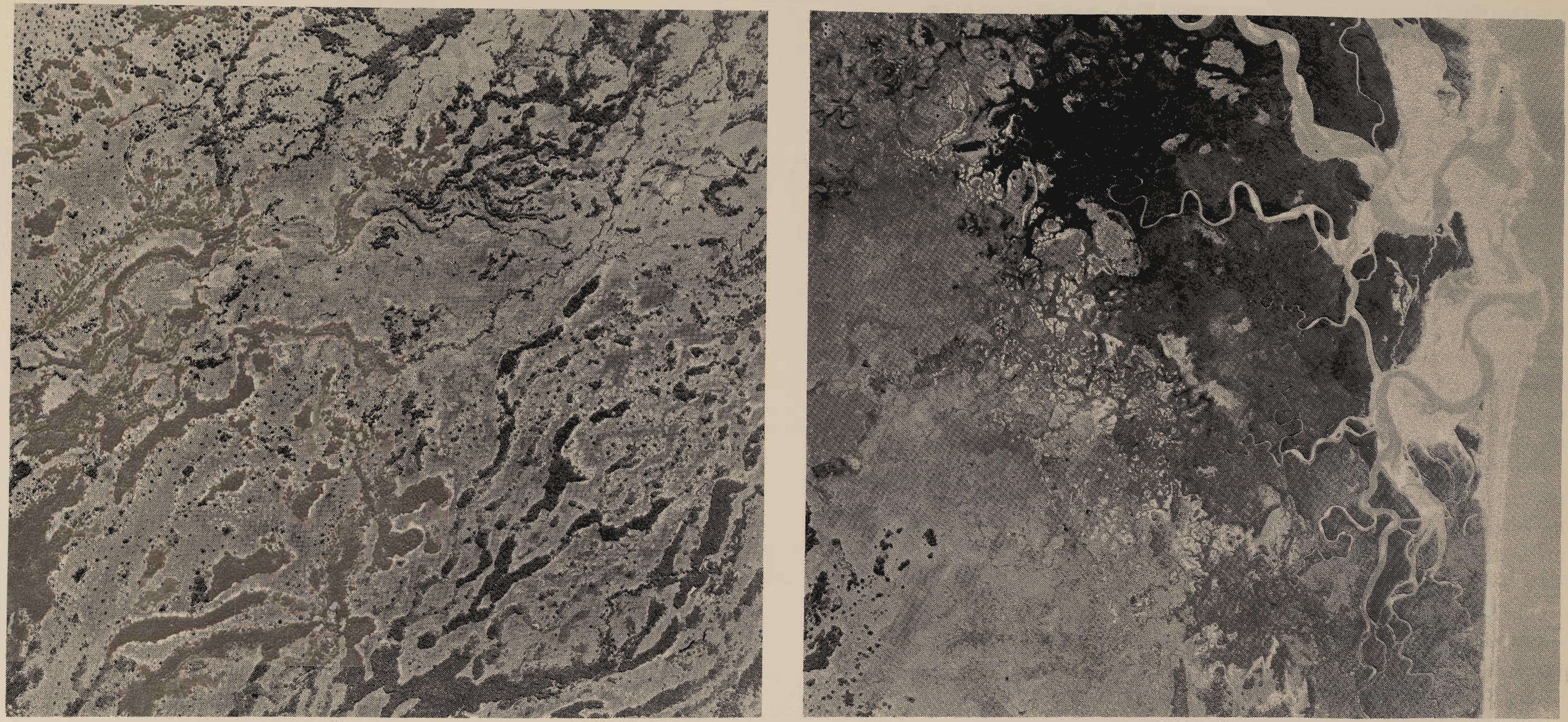
the Chinizuia River mouth. The larger resequent rivers have crossed this alluvial plain to form estuarine deltas covered in mangroves.

The Cheringoma Coast is classified as a barrier and swamp coast with estuarine deltas and linear beaches (Tinley 1971). Although the Cheringoma block was islanded in the Plio-Pleistocene, it is essentially a coastline of submergence (vide Holmes 1965: 828). The shallow and broad continental shelf extends to 120 km off the present coastline, and the continental slope descends abruptly at the 100 m isobath to over 2 000 m depth (see Tinley 1971b, Fig 6.). Recent research on this shelf has shown the existence of dune rock near the break in slope, thus the 120 km now under water was part of the Cheringoma land mass and the edge of the shelf was the old coastline. Continued coastal erosion is shown by truncated estuaries with new sand spits and active beach erosion (Tinley 1971b).

The estuary deltas are formed by fluvio-marine processes and these are protected by sand spits at their mouths. Only at the actual river or distributary mouths is there accretion of sediments. The linear beaches show two upper berms related to a equinox spring tide bevel and normal high tide bevel. In profile, the beaches show a steep upper slope and a long shallow lower slope. Separating the beach from the alluvial plains is a narrow barrier of low dunes of parabolic and hummock form. The highest attain only 14 m altitude as compared to the high parabolic dunes of the southern Mocambique Plain which attain 187 m at their highest (St Lucia Lighthouse). The parabolic dunes are formed by southerly gale winds. Near the Nhandaze and Mungari distributary mouths of the Zambeze Delta are large areas of alternating dune and slack relief which occur in parallel or curved lines empathetic with the shape of the coast. The largest parallel dune area extends 5 km inland from the beach, and older groups, now isolated, occur nearly 30 km inland from the delta coast. The inland groups are separated by slack vlei areas or mangrove swamps. The Zambeze Delta is of the arcuate type and three large distributaries are active all year — the Chinde, Cuama and Mucelo. The Cuama is actually a continuation of the main Zambeze course.

As in the Rift Valley, termite hills are a major feature of the Cheringoma coast plains. The hills formed here are much broader than those on the Rift floor and their influence on geomorphology, hydrology and ecology is considerable (see Sections 5.7 and 6.3).

PLATE 4 ALLUVIAL FANS & ESTUARINE MANGROVE FORESTS OF THE CHERINGOMA COAST



(A) Aggraded distributary courses (convex surfaces) colonized by miombo and evergreen forest alternating with acid dambo grass slacks on duplex podsolized sands. The existing perennial 'blackwater' streams have incised the slacks and these cuts are colonized by various kinds of hygrophilous forest. White dots are 'drowned' and eroded termitaria, dark dots are living termitaria covered in thicket.

(B) Southern tip of Zambeze Delta organic alluvial clays interposed between the estuarine mangroves (right) and the duplex sand fans of the dipslope rivers (left). White patches are salinas. Receding coastline clearly illustrated by truncated estuary mouth and mangrove creeks.

5.2 GENESIS OF THE PRESENT LANDSCAPE

Except where otherwise indicated this section is derived almost entirely from King (1962). Many of the regional and local events are fitted to his treatment by reference to the Mocambique 1:250.000 geological sheets revised in 1968 and the 1: 2 million map of the entire territory (Oberholzer 1968).

The implications of these landscape changes on the climate and its reciprocal role are personal interpretations except where otherwise noted.

Central Mocambique, in keeping with the remainder of the east coast of Africa (King 1972a, 1972b), took part in the diastrophic, sedimentary and volcanic history of the Gondwana super-continent. In the early Jurassic, basalt lavas, extruded from fissure swarms, formed vast lava plains blanketing the low relief formed by Karroo desertic formations.

The denudation and sedimentary processes, aided in part by the above horizontal structural control, cut across many geological formations and by the end of the Jurassic had reduced the landscape to a vast planation surface. Today the remnants of this Jurassic planation ('Gondwana') form the accordant summits of the highest parts of Africa's mountains and represent the oldest extant planations in the modern landscape (King 1962).

At the end of the Jurassic and in the early Cretaceous the incredible breakup of Gondwanaland took place, separating the southern continents and giving birth to new coastlines. The desertic continental climate of the super-continent was concurrently transformed to marine, coastal and interior climatic systems as the ocean areas grew in dimension between the separating continents. The first marine deposits of the Indian and Atlantic Oceans were laid down along the new outlines forming the African continent.

In Kenya, Tanzania and on the west of Madagascar, Permian marine deposits overlie the tillite and coal measures of the Karroo (Furon 1963), indicating that splitting of continental masses with marine transgressions took place from the north, in a gulf or a possible proto-Mocambique Channel. For this reason many authorities (Du Toit 1973, King 1962, Hallam 1973) suggest that Madagascar lay against East Africa and not Mocambique, as present outlines would suggest, having moved south to its present position. On the other hand Wellington, (1955: 460–473) supported more recently by Flores (1970), suggests that Madagascar fitted against Mocambique if the Jurassic volcanics on both sides are matched. In addition the presence of Tertiary volcanics on the Mocambique coast are matched on the west coast of Madagascar, and are absent from the East African coast. Wellington also points out that the Pre-Cambrian metamorphic rocks of Cap St Andre of NW Madagascar fits into the Lower Zambeze trough ("Lupata Gulf") where similar rocks would fit on either side. The sector where Cap St Andre would have fitted, is now occupied by Cretaceous alkaline lavas at the tip and a large area of Continental Cretaceous sediments 3 000 m thick. The SE part of this extraordinary thick deposit is now faulted by the Urema Trough and enters the Gorongosa region in the north. Flores (1970) fits Madagascar in a lower position with Cap St Andre against the Bight of Sofala (see Section 5.3).

The outpouring of early Jurassic volcanics was related to the increasing crustal tension which led to the final dismemberment of Gondwanaland; the lava emissions occurring along many fissures related to the main fracture system of the continent such as those of the Lebombo and Buzi, and between Lupata and Gorongosa which formed the edges of the Cretaceous sea. Prior to the Gondwana breakup there were also post-Karroo troughs formed in the Luangua, Mid and Lower Zambeze, and the Limpopo.

Wellington (1955: 460–473) suggests that prior to the break up of Gondwanaland the drainage derived from the land mass east of the present coast (Madagascar in his thesis) and flowed westward along the Middle Zambeze and Limpopo into an interior continental basin as far as the Congo and Orange river areas. It is also possible that these sediments filled the west branch of the southern end of the Rift Valley, lying beneath the Okovango delta front if it was faulted down in post-Karroo times. The break up of Gondwanaland truncated these drainage systems and downward bowing of the coastal margins reversed the drainage and initiated headward erosion toward the interior from the new ocean base level. This new cycle of erosion (Post Gondwana), which began dissection of the Gondwana planation surface, formed broad open valleys towards the crest of the convex warp and completely stripped off the remainder closer to the Cretaceous coast line by headward retreat of giant erosion scarps (eg. Figs 10 – 13 in King 1972a). King (1962: 158) reckons that the rate of retreat of such continental erosion scarps is about 30 cm in a 100 years, as evidenced by the Great Escarpment in Southern Africa and other parts of the world.

It was probably during the break up of Gondwanaland or just before, in the late Jurassic, that the younger syenite and granite intrusions (plutons) were emplaced which today form the island massifs of Mlange in Malawi (Dixey 1927) and Gorongosa, Morrumbala, Derre and Chiperoni in Central Mocambique (Oberholzer 1968). The last three inselbergs occur in the Zambezia District against the Chire Trough. Depending on the time of their emplacement, their summits were bevelled either by the last part of the Gondwana planation just before break up of the continents, or by the Post-Gondwana erosion of the early Cretaceous.

In the Late Cretaceous further uplift with outward tilting of east and west coasts was repeated which initiated a fresh cycle of erosion lasting until the mid-Tertiary (Oligocene). This cycle of planation, the 'African', reduced the whole continent to an extremely smooth plain the remnants of which today form the South African Highveld, the watershed of Rhodesia and the Serengeti Plains amongst other areas (see King 1962, Fig 119). In Central Mocambique remnants of the 'African' surface are found on the highest slopes of the interfluves joining the base of the great escarpment. The most extensive is that of the Chimoio interfluve between the Pungue and Revue valleys which leads up to the saddle in the escarpment at Umtali.

At the end of the Oligocene and in the late Miocene, moderate uplift created fresh base levels for a late Tertiary dicyclic erosion cycle which cut back widely spaced broad valleys into the extremely smooth 'African' landscape left as remnants on the interfluves. By the end of the Tertiary, therefore, the greater part of Africa was reduced to a rolling lowland with vast plains and widespread formation of duricrusts indicating a phase of extreme stability in the landscape. To accentuate the far reaching effects of the coming diastrophism of the Plio-Pleistocene, it is important to emphasize that the lowland form of the subcontinent at the end of the Tertiary meant the Interior was only 300–500 m above sea level (King 1962: 243).

The importance of these events, culminating in the late Tertiary duricrusted plains of continental dimensions, implies seasonal waterlogging on a vast scale which has important biogeographic implications as judged by present day spatial control of grass and woody vegetation by soil moisture balance. These aspects will be dealt with in Sections 5.7; 5.8 and Chapters 6 and 8.

If climatic patterns were similar to today over the 'low' southern Africa in the late Tertiary, the high rainfall (> 1000 mm) would have been confined to orographic lines and to an extremely narrow belt along the coast, with isohyets decreasing parallel to the coast inland to less than 400 mm in 300 mm judging by the present Mocambique Plain area of Gazaland. The interior of the subcontinent would have been desertic with vast playas of alluvium, and islands of marshes and savanna strips extending along drainage lines. Judging by today's desert grassland substrate, a greater part of the continent could have been desert grassland where a sandy veneer covered the plains. In such circumstances it would have been possible for Pliocene gazelles, ancestral to the springbok, to have occurred from the Karroo to the Sahara (Pliocene fossil ***Antidorcas*** occur in the Marghreb; Cooke 1964).

This monotonous, and probably arid landscape, was drastically changed in the Plio-Pleistocene by large scale land undulations and faulting. Intense upwarping elevated the interior to a plateau between 1 200 and 1 500 m and at the same time tilted the coastal margins strongly downward toward the ocean basins. These large crustal convexo-concave arches, called cymotogenes (King 1962 – the 'undulating ogeny'), tilted the coastal hinterland upward and depressed the continental shelf zone.

Reference to King's (1962) Fig 77, shows the outline of the cymatogenic arch through central Mocambique, from the Gondwana level at 2 400 m on the Frontier summits of Inyanga to the ***same surface*** found in boreholes at 2 000 m ***below*** sea level at Inharrime forming the ***floor*** on which Cretaceous sediments accumulated. Where previous coastlines lay close to the hingeline of the arch, little change occurred (as on the Natal Coast), but where the hingeline of the upwarp lay offshore broad coastal plains were added to the continent, as in southern Mocambique. Maximal uparching occurred inland as a rim over 2 000 m high, parallel to the coast and varying from 100 to 200 km distance from it. The uplifted and inclined planation surfaces of the late Tertiary then provided ideal conditions for massive headward and downward erosion by rivers, carving out great gorges, with rapids and waterfalls marking the inland invasion of erosion cycles. This marked diastrophic alteration took place slowly enough for the meandering drainage lines of the late Tertiary planation surface to incise their old age form downward as they carved out youthful valleys in the slowly arching landscape.

Where faulting took place, as in the Rift Valley, dislocations were rapid. Judging from the presence of Mio-Pliocene littoral and fluvial sediments on the crest of the Cheringoma Plateau, when the sea level of that time was 300 m higher than the present, the cuesta was left as a relic by the receding sea level and downfaulting of the Urema Trough associated with the sinking of the remainder of the Mocambique Plain in the early Pleistocene. Relatively fresh fault scarps and ravines face the Urema Trough, and the SE incline of the seaward plains enhanced headward erosion and incision of the fan distributaries formed originally by the inland rivers prior to rifting. The rifting on the western side of the Urema Trough was probably repeated along old fault lines of the Gondwana break up and earlier fractures. The western side of the Rift Valley is thus deeply eroded in comparison to the Cheringoma side.

As the rift valleys were trough faulted on the crests of tensional uparching, the old sedimentary formations would show least dip close to these dislocations. The upper Karroo sandstones, outcropping beneath Stormberg basalts in a narrow belt entering the NW corner of the Gorongosa region, are only slightly inclined to the east and the overlying basalt flows are inclined to the SW (Real 1966). However, cross faulting is abundant close to the Rift dislocations and the above disposal of strata may have no significant relation to the Plio-Pleistocene diastrophism. The younger granite plutons and the granite-gneiss cores which today form the inselbergs of the Manhica Platform would have been exposed first by the Post-Gondwana and early Tertiary erosion and planation.

At the end of the Tertiary the vast 'low' continental plain was deformed into an undulation by the Plio-Pleistocene land movements which bowed the coastlands downward as the hinterland was uparched to over 2 000 m, raising the continental interior to between 1 200 and 1 500 m. This change from a low continental plain with high rainfall probably confined to the coast (judging by the Mocambique Plain) with a desertic interior, to an interior plateau with a rim of over 2 000 m meant that a change in rainfall regimen to two highs (of about 2 000 mm ?) must have occurred. One associated with the coast as before, and the other with the orographic line formed by the rim. A high rainfall belt along the rim would then have carried the precipitation tail-off deeper into the interior than was possible from the coast, changing these lands from desert to savanna.

The massive erosion, consequent of this arching, gouged deep valleys with planation remnants of various dimensions left on the interfluve spurs, and reduced that vast rim catchment to relics. These landscape changes alone can account for the changes in climate, with rainfall highs confined to orographic remnants and low precipitation in the valleys and plains areas. In addition to river capture effects, these landscape processes alone can account for the underfit nature of most present day rivers relative to the size of the valleys they have carved in the past.

Headward erosion of the great escarpment from inland would have also been given greater impetus during and after uparching. The continental interior was depressed relative to the rim and became filled with further sediments. Over this vast network of marshlands, which could have stretched from Bushmanland to the Sudan river, capture and draining of marshes by headward erosion would have begun their separation and contraction in the earliest Pleistocene.

Although climatic changes related to glaciation or to long term oscillations of the westerlies and intertropical front are important, it seems to have been underestimated that the geomorphic processes associated with diastrophism alone be responsible for leaving a similar fossil record. Nickpoint breaching of wetlands can convert large areas of alluvium to aridisols as exemplified by northern Botswana where mopane savanna covers "fossil" flood plain surfaces. Such changes would have left a pluvial and interpluvial record from changes in drainage and runoff due to uplift and subsequent reduction of relief alone without requiring any change in climate.

In sum, the Plio-Pleistocene deformations of the Tertiary landscape and consequent erosion and sedimentation is chiefly responsible for the face of modern Africa (King 1962), including its climatic and biome patterns.

5.3 MOCAMBIQUE AND MADAGASCAR

The presence of Madagascar island, lying 400 km offshore at the closest point, and extending almost the full length of the Mocambique Coast, requires further explanation to elucidate landscape evolution and biogeographic relations in central Mocambique. Particularly as the position of Madagscar in the fit of Gondwana landmasses against the east coast of Africa has remained the most enigmatic part (Tarling 1971, Hallam 1973), giving rise to three contrasting theories.

The theory followed in this work is Dixey's (1956) interpretation of the geosynclinal nature of the Mocambique Channel and the permanence of Madagascar in its present or near-present position. Using new data, three recent publications augment this interpretation (Flower & Strong 1969, Darracott 1974, Kutina 1975). The other theories fit Madagascar either against the East African coast (Du Toit 1937, King 1962, Smith & Hallam 1970), or against Mocambique, in Gondwanaland times (Wellington 1955, Flores 1970, Wright & McCurry 1970). The biogeographic complications these theories raise is well exemplified by recent attempts to determine the possible position(s) of Madagascar relative to the mainland on the basis of its floral affinities (Wild 1975, Pócs 1975).

Kutina's (1975) studies of Madagascar support the suggestion by Fisher ***et al*** (1967) and Fourmarier (1967) that the submarine Mascarene Plateau and Madagascar represent the uppermost remnants of a foundered or subsiding continental crust. This means a continuous area of Precambrian basement existed between the Mid-Oceanic Ridge and the present coast of Africa, of which the granitic Seychelles Islands represent the easternmost exposures. Darracott (1974) shows that the Mocambique geosyncline and Madagascar submarine ridge are probably all composed of thinned continental or transition crust. The existance of the Mocambique geosyncline, the complex horst of Madagascar, and the submerged Mascarene Plateau are obstacles to the derivation of India from eastern Madagascar as propounded by Smith & Hallam (1970) for example, and contradict the available evidence from the floor of the Mocambique geosyncline (Darracott 1974). These data point rather to India's origin on a separate plate in the central part of the Indian Ocean from between the Chagos fracture zone and Ninetyeast Ridge (McKenzie & Sclater 1971, Kutina 1975).

The fracture system of Madagascar and the mainland are identical, and this, with stratigraphic similarities, is the major aid to the theory of Madagascar's origin against Mocambique. However, the intersection of these fractures and their exaggeration by downwarping and faulting has given rise to the sympathetic zigzag strike of Africa's east coast and the west coast of Madagascar. In addition the continuation of

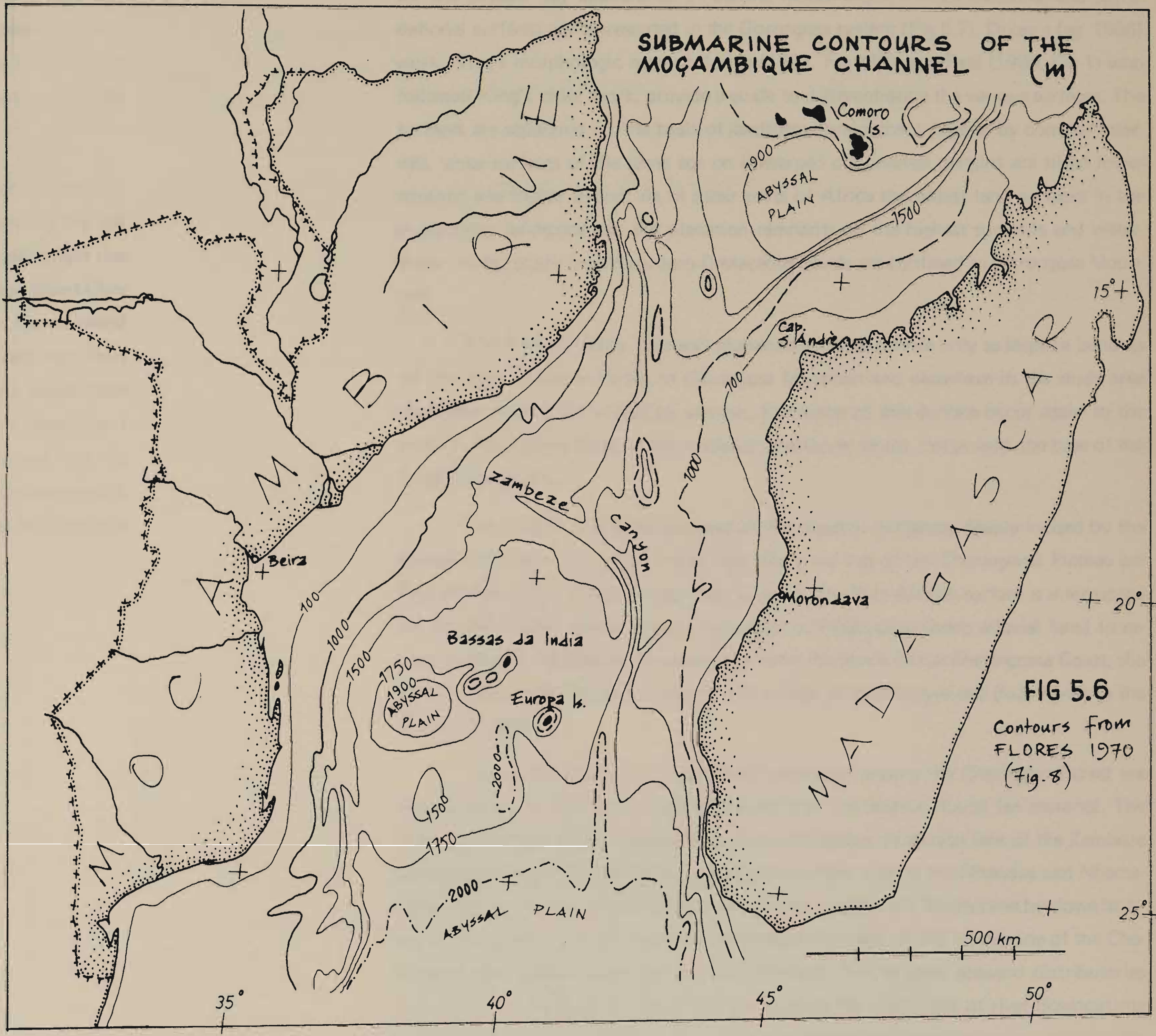

SUBMARINE CONTOURS OF THE MOÇAMBIQUE CHANNEL (m)

FIG 5.6

Contours from FLORES 1970 (Fig. 8)

major fractures is expressed by bathymetric contours in the Mocambique Channel (Fig 5.6). The most conspicuous of these is the continuation of the N–S strike of the northern Mocambique Coast southwards as the Zambeze Canyon (see Green 1972, Fig 12; Flores 1970, Fig 8). This canyon is separated by an oblique NNW–SSE rise above the 1 000 m isobath, which is the shallowest continuous link between the mainland and Madagascar at present. This rise marks the submarine divide between the Mocambique Basin in the south, into which the Zambeze Canyon empties, and the small Comoro Abyssal Plain immediately south of the islands.

Further evidence from this submarine ridge seems to be crucial for determining whether it lagged behind in the geosynclinal downwarping thus representing the last part of the geosyncline to be submerged. The Comoro Islands of volcanic origin rise from isolated 1 000 m deep platforms and are judged to be of Miocene age (Saint-Ours 1956, Besairie 1960). Completion of the separation of Madagascar from the mainland is judged to be at the Cretaceous-Tertiary time boundary 60 million years ago. Thus the relationship between the Mocambique mainland and Madagascar Island would seem to have been a gradual and continued sinking of the channel floor with intermittent faulting, possibly resulting in a gradually narrowing isthmus which remained into the Tertiary before final submergence, and 'stepping-stones' formed by the Comoro Archipelago in the middle to late Tertiary between the northermost coasts of Mocambique and Madagascar.

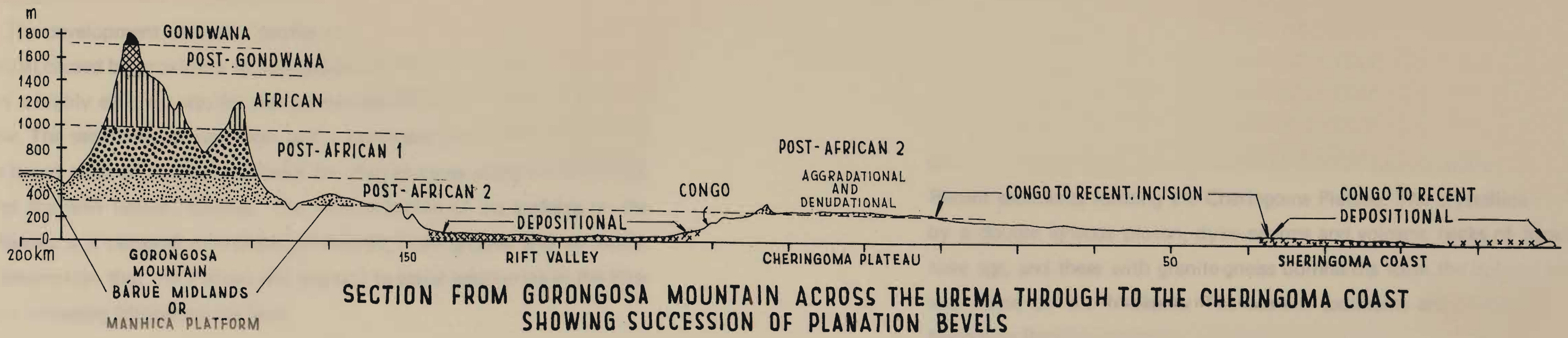
5.4 PLANATION SURFACES

Section 5.2 outlined the possible changes in landscape responsible for the present day appearance of Central Mocambique. All denudational and aggradational surfaces are represented in the Gorongosa system (Fig 5.7). Dixey's (eg. 1956) work, King's morphologic map of Africa (1962, Fig 119), and Real (1966, Fig 1) who followed King's older work, provide a guide to differentiating the various surfaces. The surfaces are separated on the basis of landform development assisted by contour intervals, since surfaces of the same age on upwarped continental margins are tilted lower seaward and higher inland. As in other parts of Africa the oldest land surfaces in the present-day landscape are the planation remnants on the highest summits and watersheds. In the study area these Juro-Cretaceous bevels are confined to Gorongosa Mountain.

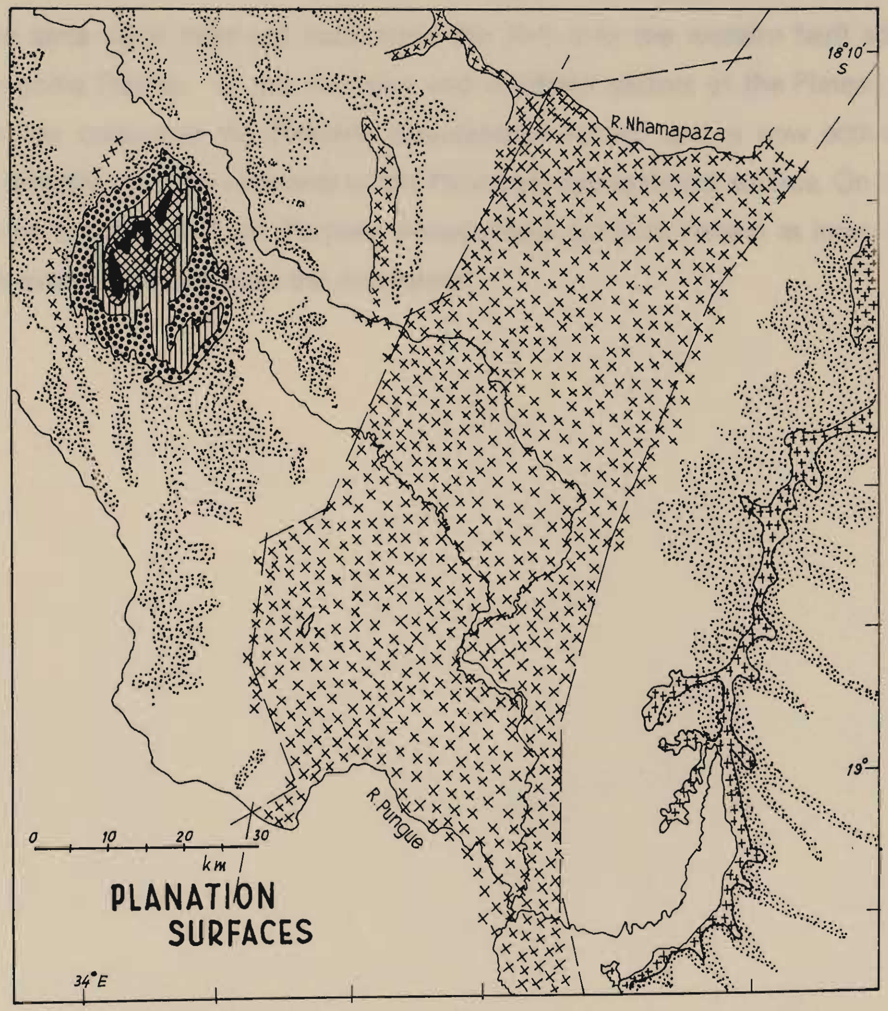
The African (Early Tertiary) planation surfaces survive only as steplike benches on the lower crests and sides of Gorongosa Mountain and elsewhere in the study area have been totally eliminated by erosion. Remnants of this surface occur again to the west on the highest parts of the midland interfluves which merge into the base of the Great Escarpment.

The accordant interfluve crests of the western midlands, deeply incised by the Congo Cycle, and the remnant flat crest along the top of the Cheringoma Plateau are Post-African (Late Tertiary) planation surfaces. The Post-African surface is interrupted by the Rift Valley whose floor is composed of Pleistocene (scarp alluvial fans) to recent sediments. Sediments of similar age form the plains of the Cheringoma Coast, the delta plains of the Zambeze, and the confluence of the Pungue and Buzi Rivers in the Bight of Sofala.

The sediments of the Mazamba Formation forming the Cheringoma crest are littoral facies at their base passing upward into continental fluvial fan material. The final sedimentary phase is probably due to coalescence of alluvial fans of the Zambeze and Pungue Rivers and the lesser rivers between them such as the Nhandue and Nhamapaza prior to rifting. This drainage was severed in the Early Pleistocene by downfaulting of the Urema Trough, resulting in reversed drainage on the inland side of the Cheringoma and beheading of the seaward drainage. The original seaward distributaries formed by the rivers from the hinterland became the main lines of river downcutting due to the 3–5° seaward incline, causing drainage rejuvenation superimposing the original distributary meanders. From their ***in situ*** exposure to eluvial pedogenic processes, a leached sand surface of almost pure quartz was formed with an impermeable



SECTION FROM GORONGOSA MOUNTAIN ACROSS THE UREMA THROUGH TO THE CHERINGOMA COAST SHOWING SUCCESSION OF PLANATION BEVELS



PLANATION SURFACES

REMNANT PLANATION SURFACES OF EROSION CYCLES ON GORONGOSA MOUNTAIN

(JUDGED BY THOSE ON MLANJE MOUNTAIN FROM DIXEY 1956, AND FOR ZAMBEZE BASIN IN MOÇAMBIQUE FROM REAL 1966.)

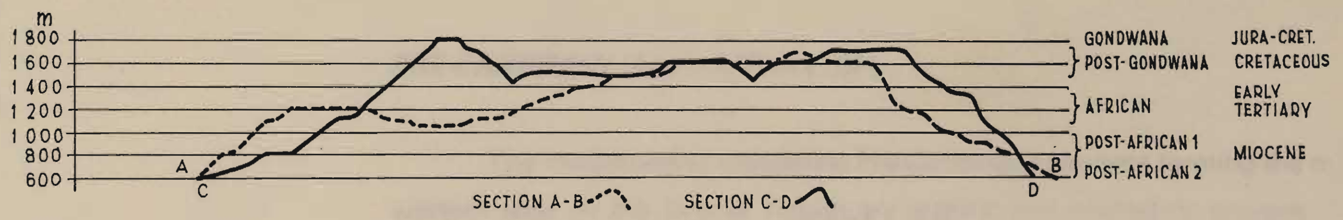


FIG 5.7 GEOMORPHIC SURFACES IN THE GORONGOSA-CHERINGOMA AREA

DENUDATIONAL

■ GONDWANA (JURASSIC)
▩ POST-GONDWANA (CRETACEOUS)
▥ AFRICAN (EARLY TERTIARY)
▦ POST-AFRICAN 1 (MIOCENE)
▒ POST-AFRICAN 2 (PLIOCENE)
☐ CONGO TO RECENT (QUATERNARY)

AGGRADATIONAL

⊞ END-PLIOSCENE SEDIMENTS
☒ PLEISTOCENE (FANS) TO RECENT

(SYMBOLS AS IN KING 1962, FIG 119)

iron-rich clay subsoil (C horizon) (data from Geological Sheet Sul–E–36/X of Mocambique, 1968). The development of such a profile ensures maximal capture of the relatively high rainfall, caused by proximity to the land-sea junction and a 300 m rise above sea level. Thus a highly efficient aquifer was formed which provides a perennial high watertable flow. The sediments derived from active headward and valley incision were deposited as a broad plain of coalescing alluvial fan distributaries along the entire seaward margin of the now isolated plateau. The differentiation of the surfaces on the Cheringoma Plateau is a personal interpretation derived from ground and air study, based on the assumption that the Plateau was exposed to aerial weathering in the Plio-Pleistocene by a retreating (dropping) sea level.

Cutting back from the Rift Valley, the Congo Cycle has gouged deep gorges and valleys far into the Midlands and into the foot of Gorongosa Mountian. Deep ravines of the same cycle have cut back from the Rift into the western fault scarps of the Cheringoma Plateau. In the northern and southern sectors of the Plateau the Congo Cycle has consumed the Pliocene denudational surface and is now actively eroding back directly into the remnants of the Pliocence aggradational surface. On the seaward slope of the Plateau Late Tertiary denudational surfaces remain as interfluve fingers which extend seaward from the watershed.

5.5 GEOLOGY

The geology of the Gorongosa region is complex, but clearly defined (Figs 5.8 and 5.9). The Rift Valley plains of recent alluvia separate a western midland of Pre-Cambrian metamorphic crystalline rocks from an eastern cuesta block of Cretaceous to Recent sediments forming the Cheringoma Plateau. The crystalline rocks are intruded by a double igneous pluton, dyke swarms and volcanic necks of Jurassic to late Tertiary age, and these with granite-gneiss bornhardts form the isolated peaks, mountains and ridges on the Midlands. The eastern sediments are pierced by only two small Nephaline Basalt necks of Pliocene age.

The following data is obtained from Real (1966) and the geological maps of Mocambique at a scale of 1: 250.000 (1968) and their accompanying explanatory notes (Geological Sheets Sul–E–36/R,Q,X,Z).

PRE-CAMBRAIN (Age > 570 m.y. BP)

The metamorphic crystalline Pre-Cambrian basement forming the midlands and western edge of the Urema Trough, are granitic and migmatitic gneisses. These metamorphic rocks belong to the Báruè Formation and are the oldest in the region. Abutting on the southwest of the study area, against the junction of the Pungue River with the Rift, is a large isolated outcrop of similarly aged metamorphics of the Manica System. This oval shaped area of gneisses mixed with hornblendes, pyroxenes, quartzites and schists is pierced through at the centre by a carbonatite volcano of Cretaceous age. An island of Precambrian with intruded Gorongosa granite, gabbro and trachyte occurs as a small horst, or foundered remnant, on the floor of the Rift Valley in the southwest of the park.

The Báruè Formation breaks down chiefly into sands of fine to coarse texture, but the associated mica contributes to the formation of layer-silicate clays such as montmorillonite. The crystalline midlands are cut by abundant dyke swarms of dolerite, granophyre, quartz, pegmatite and the double pluton of gabbro pierced by micropegmatite granite which forms Gorongosa Mountain. The dyke swarms are aligned chiefly in a N–S rectilinear curve parallel to the Rift Valley fractures. Cores of granite-gneiss form domed or bornhardt inselbergs of various dimensions south and west of Gorongosa Mountain. The highest of these, Mhanda, rises over 800 m from a flat interfluve to 1 423 m, midway between Gorongosa and the Great Escarpment. The dykes of basic rocks and areas of heavy mafic mineral content (eg. biotite) weather into

Age	Type	Symbol	Description	Formation / Series
RECENT	SEDIMENTARY	t	TALUS	
	SEDIMENTARY	QA_1	ALLUVIUM	
	SEDIMENTARY	Qc	COLLUVIAL FAN DATRITUS	
PLEISTOCENE	SEDIMENTARY	QP_1	SANDY ELUVIUM	
	SEDIMENTARY	QP_2	SANDY-CLAY ELUVIUM	
MIO-PLIOCENE	IGNEOUS	Bal	NEPHELINE BASALT	
	SEDIMENTARY	TT_{S2}	INHAMINGA SANDSTONE QUARTZITIC & CONGLOMERATIC	MAZAMBA FORMATION
	SEDIMENTARY	ch	CHERT	MAZAMBA FORMATION
	SEDIMENTARY	TT_{S1}	RED SANDSTONE QUARTZITIC LIMESTONE	MAZAMBA FORMATION
EOCENE	SEDIMENTARY	TT_i	NUMMULITIC LIMESTONE GLAUCONITIC SANDSTONE BASALLY	CHERINGOMA FORMATION
CRETACEOUS	SEDIMENTARY	Ksm	CALCAREOUS AND GLAUCONITIC SANDSTONE	GRUDJA FORMATION
	SEDIMENTARY	Ksc	ARCOSIC SANDSTONE (CALCIC-ARGILLACEOUS CEMENT)	SENA FORMATION
	IGNEOUS	Qzb	QUART-BRECCIA	LUPATA SERIES
	IGNEOUS	C	CARBONATITE	LUPATA SERIES
	IGNEOUS	Lτ	TRACHYTE	LUPATA SERIES
	SEDIMENTARY	Ls	LUPATA SANDSTONE	LUPATA SERIES
	IGNEOUS	γg	GRANOPHYRE	INTRUSIVE COMPLEX OF GORONGOSA MOUNTAIN
	IGNEOUS	γ	MICROPEGMATITE GRANITE	INTRUSIVE COMPLEX OF GORONGOSA MOUNTAIN
	IGNEOUS	θD	DOLERITE	INTRUSIVE COMPLEX OF GORONGOSA MOUNTAIN
	IGNEOUS	θ	GABBRO	INTRUSIVE COMPLEX OF GORONGOSA MOUNTAIN
	METAMORPHIC	Crnq	QUARTZITIC HORNFELS	
JURASSIC	IGNEOUS	Rβ	BASALT LAVAS	KARROO (STORMBERG)
	METAMORPHIC	Crnp	AMPHIBOLITE, PYROXENE HORNFELS	KARROO (STORMBERG)
PERMO-TRIASSIC	SEDIMENTARY	Rs	FELDSPATHIC SANDSTONE	KARROO (STORMBERG)
PRECAMBRIAN	IGNEOUS	θD	DOLERITE	
	IGNEOUS	P	PEGMATITE	
	IGNEOUS	Qz	QUARTZ	
	METAMORPHIC	Gm Gbi	GRANITIC AND MIGMATITIC GNEISS	BARUE FORMATION
	METAMORPHIC	Gl	MICA-SCHIST GREENSTONE SERPENTINE	MANHICA SYSTEM

FIG 5.8

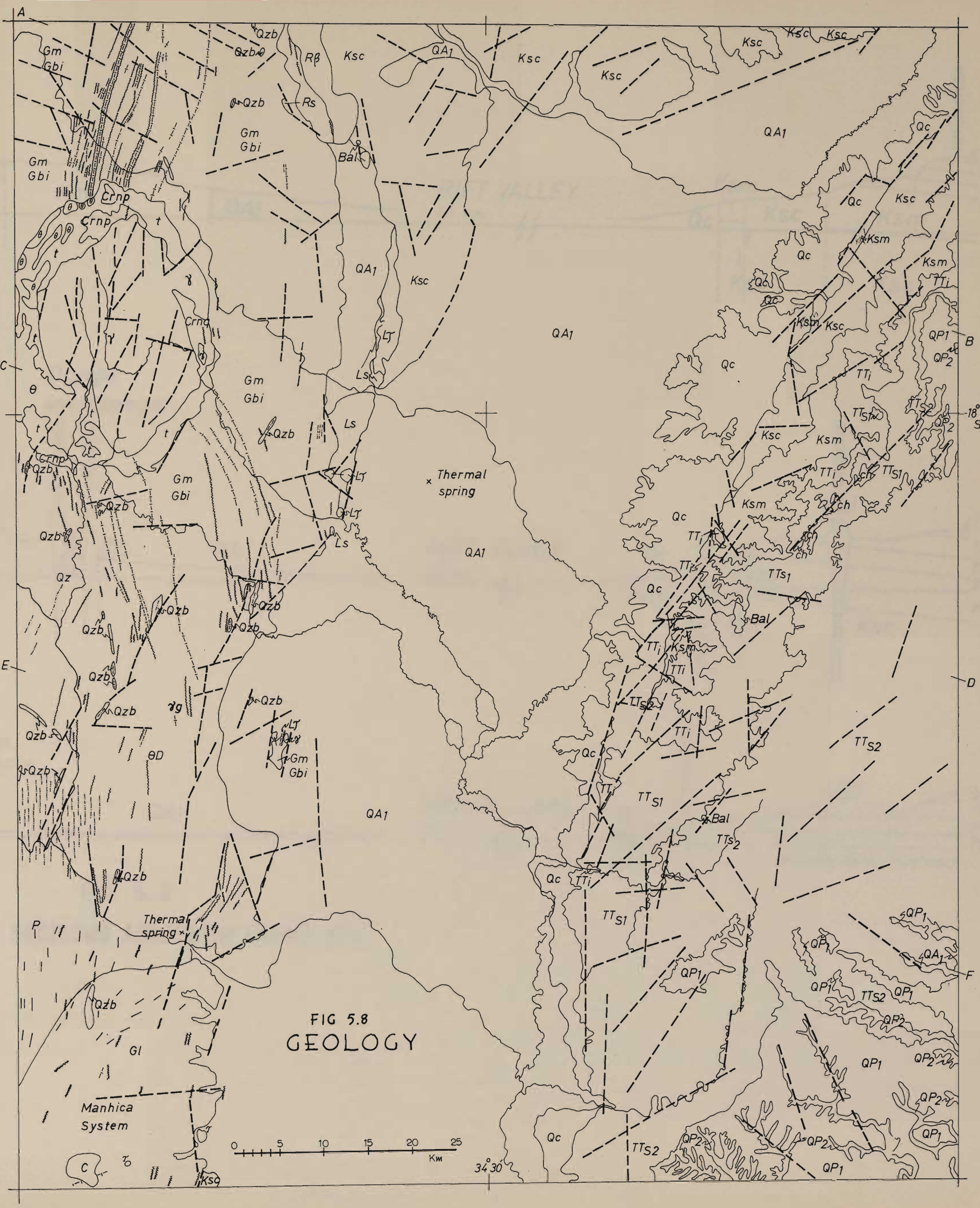


FIG 5.8
GEOLOGY

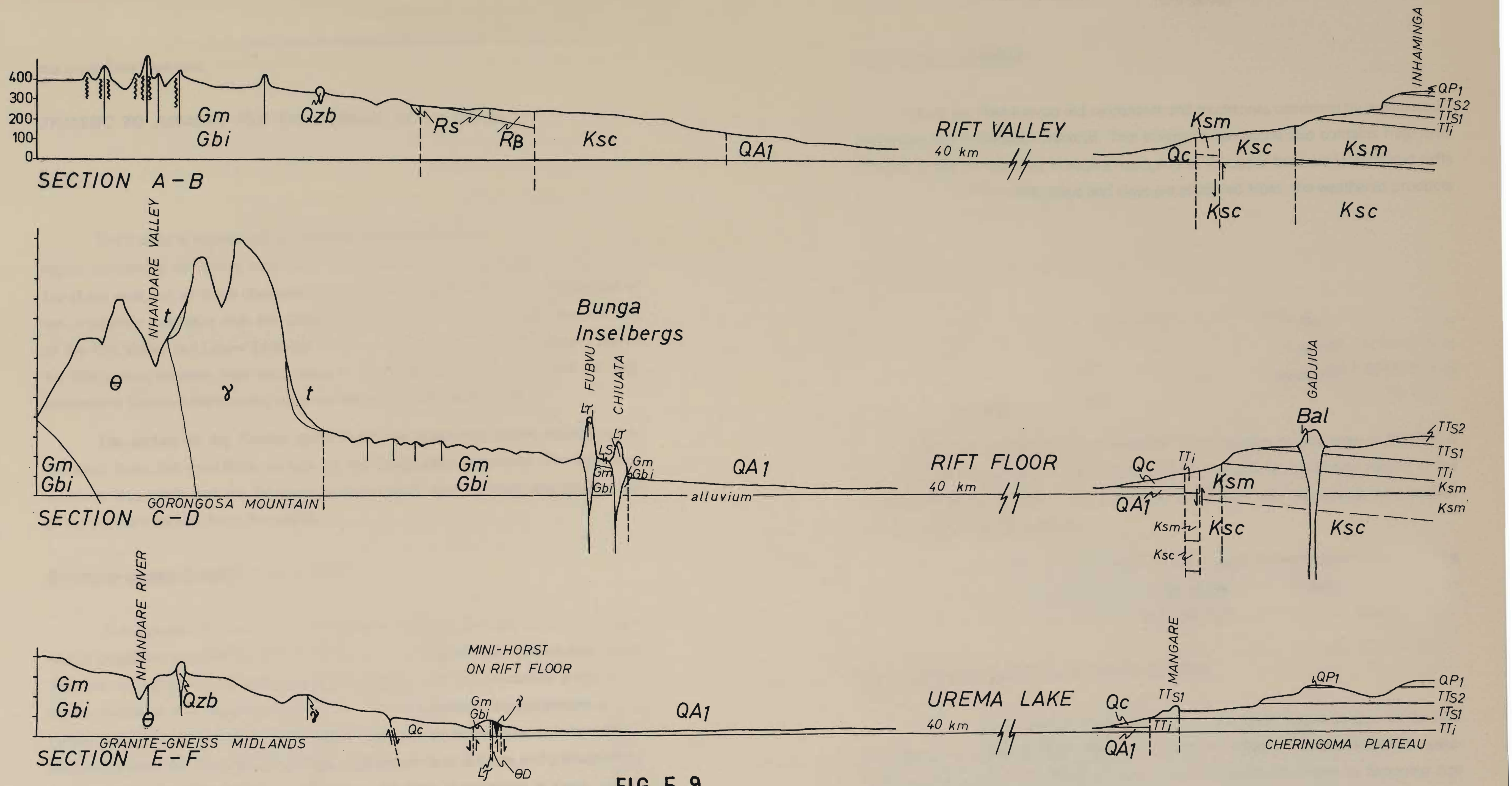


FIG 5.9

GEOLOGICAL SECTIONS ACROSS THE UREMA RIFT loamy textured latosols, providing the only fertile soils in the midlands. The geology of the other dykes add to the predominantly sandy soils and sediments derived from the crystalline basement.

TRIASSIC TO JURASSIC (Age: Karroo between 160 and 225 m.y.)

Karroo

The Karroo is represented by a narrow longitudinal area in the northwest of the region comprising sandstone, basalt and rhyolite. The acid lava peters out just north of the study area, and all three components of the Stormberg Series lie at the junction of the crystalline basement with the Cretaceous sediments along the major tectonic line of the Rift Valley and Lower Zambeze trough. A gap of 125 km on the western side of the Rift occurs, between their occurrence in the northwest of the region and the reappearance of Karroo basalts in the south on the Buzi River fracture line.

The surface of the Karroo series forms low undulating terrain sloping evenly eastward from the crystalline surface to the Cretaceous sediments. The sandstone weathers into sands, and the feldspars produce sandy clay or clays, and latosols and gritty clays are derived from the basalts.

Gorongosa Igneous Complex (Late Jurassic)

The sequence of basic and acid plutonic intrusion, forming Gorongosa Mountain, is judged to be of late Jurassic age to possibly early Cretaceous (Oberholzer 1968). The first intrusion was of gabbros and the contact with the crystalline gneisses produced pyroxene and amphibolite hornfels. The succeeding micropegmatite granite pluton, which forms the major body of the mountain, produced quartzitic hornfels on its contact with the Precambrian gneisses. Dyke swarms of dolerite and granophyre, associated with the main intrusions and having the same composition as them, pierced the surrounding gneisses on a north-south trend along the older lines of foliation or weakness in the crystalline rocks.

Latosols, gritty ferromagnesium-rich loamy clays are derived from the gabbros on the southwest slopes of the mountain. The central acid granite pluton produces mainly sandy and light ortho-ferrallitic soils, and humus-rich podsols with pipe drainage on the mountain summits.

UPPER JURASSIC TO CRETACEOUS (Lupata Series)

Upper Lupata Sandstone

These are Post-Karroo red sandstones and mudstones cemented by argillaceous-calcareous and tuffaceous material. This polygenic sandstone also contains fragments of most of the surrounding intrusive rocks, and in its upper beds are intercalated tuffs and ignimbrites. Red sandy clays and clays are produced from the weathered products with a calcium-rich subsoil.

Alkaline Lavas (Age: 131 m.y.)

Occurring as volcanic necks exemplified by the trio of Bunga Inselbergs or as fissure flows (Panda Ridge), these trachytes and phonolites are confined to the central western junction of the Rift Valley with the crystalline midlands immediately east of Gorongosa Mountain.

Twenty five kilometres southwest of the ecosystem on the edge of the Rift is Mt. Xiluvo, a Carbonatite volcanic neck with ring structure, containing calcite in the centre and volcanic breccias in the outer ring. The present day appearance is a breached volcanic crater covered in forest.

Cutting through all the above formations was a hydrothermal phase resulting in brecciated quartz dykes. One forms a small inselberg on the western margin of the Rift floor in the park known as Xivulo (not to be confused with Xiluvo above).

Continental Cretaceous (Lower to Mid-Cretaceous)

The oldest Cretaceous sediments are of continental origin, largely unfossiliferous and little stratified they attain a thickness of 3 000 m. These calcareous sandstones are known as the Sena Formation and are mainly of Albian to Senonian Age (Mid-Cretaceous). At the bottom, plant remains and scales of fish and arthropods with calcareous schists have been encountered (Real 1966: 69). The top of the formation passes without break into marine fossiliferous strata of the next formation. The Sena Formation comprises coarse to medium arcosic sandstone, cemented by calcic-argillaceous material, of beige, yellow grey or sometimes reddish colours. The main area of Sena (Ksc) calcareous sandstones is in north of the region, reappearing on the east side of the Rift on the inland side of the Cheringoma Plateau. Weathered products are sand and calcareous sandy clays.

Marine Cretaceous (Senonian to lowest Eocene)

Known as the Grudja Formation (Ksm), its initial strata on the previous formation is indicated by the presence of **Lopha (Alectryonia) ungulata** shell fossils in a matrix of yellowish-green glauconite sandstone. Interbedded are highly fossiliferous arenaceous marls and limestone, the whole formation attaining about 200 m thickness. Other fossils include **Ostrea, Cardium, Cardita** and fragments of **Inoceramus** (Real 1966: 70). Higher in the formation, fossils of **Gryphea, Viniella, Baculites** and bryozoans, teeth of fish and ostracods appear. At its uppermost it passes without discordance into Eocene sediments characterised by the abundance of **Nummulites forminifera.**

TERTIARY SEDIMENTS AND VOLCANICS

Cheringoma Formation (TTi) (Age: 54 m.y.)

Eocene fossiliferous sediments of the Cheringoma Formation comprise a neritic, warm water facies of white to pinkish calcareous limestone of about 70 m thickness. This formation is characterised by the abundance of foraminiferan fossils (Nummulites). The sandstone weathers into overhangs and caves, and forms sheer cliffs in the deep ravines of the Riftward drainage from the Cheringoma Plateau.

Mazamba Formation (TTS) (Age: between 7 and 26 m.y.)

Mazamba Miocene (TTSI) to probably pliocene (TTS2) sediments are represented by the medium to coarse reddish sandstones of about 130 m thickness appearing ***discordantly*** over the Cheringoma Formation. The sediments are at first littoral and fossiliferous, grading upward to yellowish-grey unfossiliferous sandstone of continental deltaic origin.

The lower member (TTSI) of the Mazamba Formation comprises red and purplish medium grained sandstones with argillaceous cement and coarse bedding containing small gasteropods and lamellibranchs. The upper component (TTS2) is a coarse to medium arcosic sandstone with conglomerate horizons, cemented by calcic-argillaceous material, and locally by silica. This sandstone is red with grey or yellow bands, and the weathered conglomerates form a gibber surface in some areas, for example in the southeast of the study region near Semacueza. The conglomerate is composed of coarse and large river worn pebbles derived from formations now west of the Rift Valley including granite, gneiss, quartz and basalt. Cherts of white, grey or red colour outcrop on the plateau, related to the rise of siliceous water through fractures during faulting silicifying the lime and sandstones of the Tertiary sediments.

Tertiary Volcanics

Piercing the above sedimentary strata in the central western part of the plateau is a volcanic neck of nepheline basalt. This Pliocene intrusion is today a low rounded inselberg rising to 345 m, its summit at about the same level as the highest plateau, remnant near Inhaminga which attains 379 m above sea level.

QUATERNARY TO RECENT (Age: c. 3 m.y. to Recent)

Weathering and eluviation of the Mazamba Formation during the Pleistocene resulted in the formation of two pedogenic units on the Cheringoma Plateau. Upper siliceous sands (QP1) forming beige pinkish-yellow, orange or deep red (oxisol) permeable sands. The pallid sands have an impermeable mottled clay horizon at about 100–150 cm depth and support forest whilst the deeper chroma without such a horizon support miombo savanna. The impermeable horizon belongs to the second unit (QP2) underlying the first at various depths or typically near the surface in the dambos and drainage lines. The lower unit is much richer in iron oxides and clay forming high watertable areas covered in grasslands.

The Rift Valley surface is a mosaic of recent argillaceous and arenaceous alluvium, with fine black hydromorphic silty clays in the lower parts. Alluvial fans occur at the foot of both sides of the Rift Valley, and on the eastern side have coalesced laterally to form an apron at the break in slope. The fans on the western side appear to be older than those on the Cheringoma side, related to possible differences in age of faulting and dislocation on either side. The alluvial fans are all clearly demarcated in the field or on air photographs by their cover of tall thicket or dry forest. Dry forest is typical on the sandier deposits which are however underlain by a compact impervious gravelly-clay.

On the Cheringoma Coast several kinds of dunes occur along a linear coastline interrupted at intervals by extensive estuaries of mangrove swamps. Low dunes of parabolic, blowout and parallel (swash bank) form occur. The parallel dunes with alternating vlei troughs are confined to the Zambeze delta areas where aggredation has been rapid. Between the dunes and estuarine swamps of the littoral and the sediment of the Cheringoma Plateau is a vast mosaic of freshwater and brack marshes and alluvia of the southern sector of the Zambeze Delta.

On the gentle seaward slope of the Cheringoma Plateau, between the Zambeze and Chiniziua rivers, is an extensive series of oval pans surrounded by forest. These pans have a similar genesis to those in central South Africa and will be treated with other fluvial processes under the following chapter.

5.6 HYDROGRAPHY

Marine and terrestrial waters meet and alternate intimately, with the seasons, and the tides, over a broad ecotone formed by the overlap of shallow seas with low coast plains in Central Mocambique. The littoral here is classified as a swamp and barrier coast dominated by the arcuate delta of the Zambeze in the north, and numerous estarine deltas separated at intervals by long, linear, sandy beaches (Tinley 1971).

During the summer rains, vast areas of the coast plains are flooded behind low barrier dunes, leaching out much of the saline deposits of the previous dry season. In the winter dry season, these flats are invaded in large part by seawater at the surface, and in the subsoil, when high spring tides of 6,4 m amplitude have maximal reach. The high tidal regime is also responsible for damming up terrestrial waters, which together with the seawater, have strong scouring effects on outgoing tides.

To emphasize the breadth of this land-sea junction still further, the Urema Lake on the floor of the Rift Valley is more than 100 km in a straight line from the sea, and its bed is only about 12 m above mean sea level. On such flat ground a multitude of small and large habitat changes can be expected over extensive areas, wrought merely by changes in degree of waterlogging, and fresh or salt water influences.

DRAINAGE

Contributing to this intimate junction of terrestrial and marine ecosystems are six drainage systems derived from: (1) the continental interior (the Zambeze and to a lesser extent the Save), (2) the Great Escarpment (the Pungue and Buzi perennial rivers), (3) the Midlands (Manhica Platform) (seasonal 'sand rivers' as exemplified by the Nhandue and Nhamapaza which enter the Gorongosa region), (4) isolated massifs, – (a) the radial perennial stream flow from Gorongosa Mountain, and (b) the perennial streams off the dipslope and scarpslope of the Cheringoma cuesta, (5) a lake system – the Urema Lake which is the sole example from Central Mocambique, and (6) swamps, marshes and dambos of alluvial plains and drainage lines in plainsland (Fig 5.10). Cutting across this seaward drainage at right angles is the Rift Valley which in the past (early to mid Pleistocene ?) linked Zambeze and Lake Niassa waters (Chire) with the Pungue, and Buzi Rivers, and possibly the Save. This link was severed by the confluence of two alluvial fans which built out from opposing sides of the Rift – formed by the Nhamapaza from the Midlands in the west, and the Mazamba from the Cheringoma Plateau. The divide occurs at the neck of the Tengane ***tando*** (fig 6.3), at an altitude of 59 m, and where the Rift Valley crosses the Zambeze River it is 25 m above sea level.

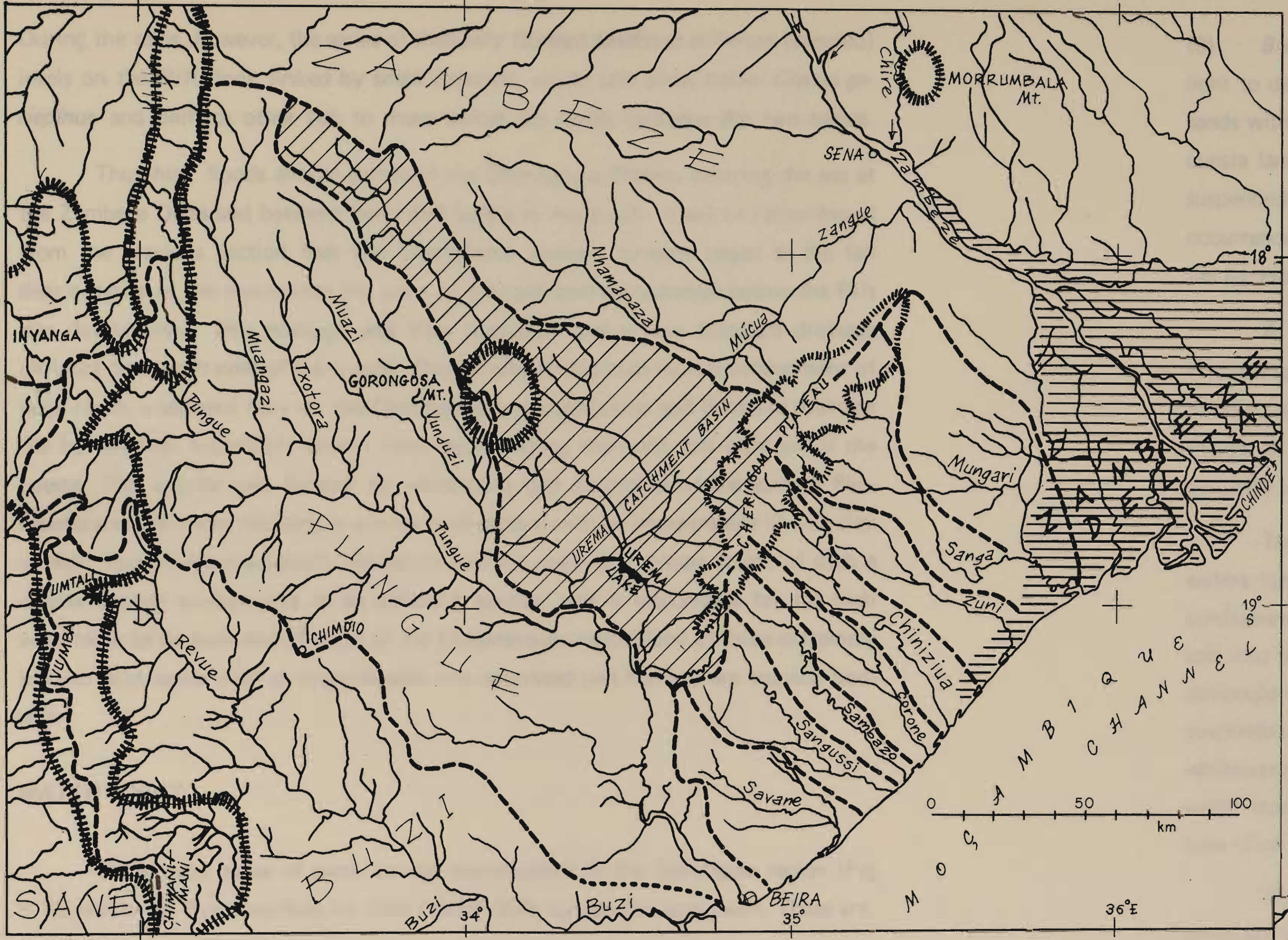
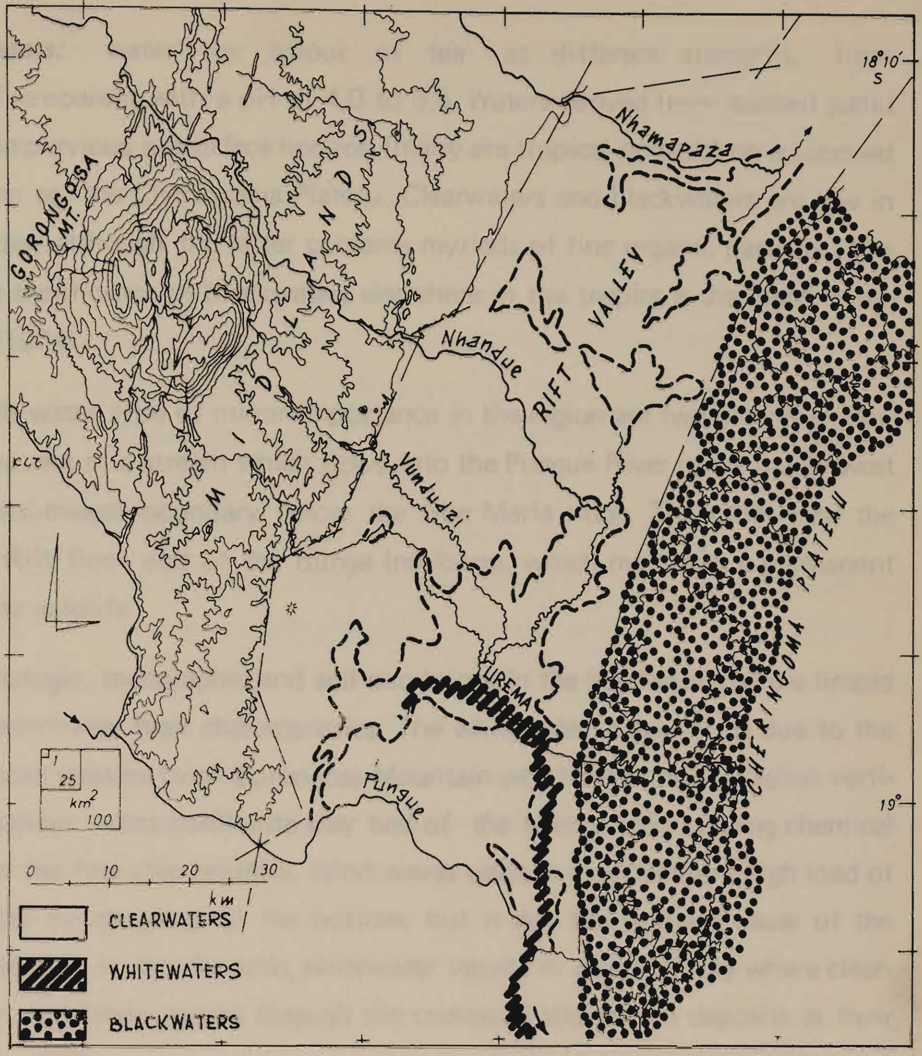
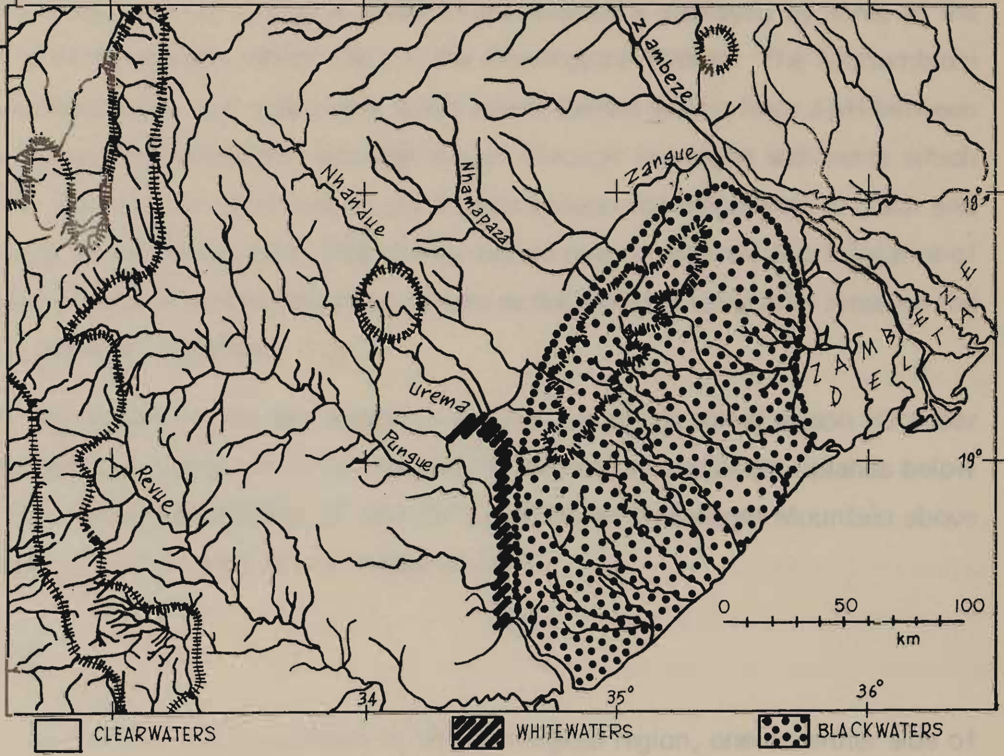


FIG 5.10 HYDROGRAPHIC BASINS & WATER TYPES OF CENTRAL MOÇAMBIQUE



WATER TYPES OF THE GORONGOSA ECOSYSTEM



During the rains, however, the series of shallowly flooded ***tandos*** at different (stepped) levels on the Rift floor, linked by small channels, would still allow barbel ***Clarias gariepinus*** and perhaps other fish to move across the divide between the two basins.

Thus high floods almost surround the Cheringoma Plateau entering the sea at the Zambeze Delta and between Beira and Sofala in the south. It will be remembered from the previous section that the Cheringoma seaward streams began as the fan distributaries of the rivers from the west on a broad land-sea junction before the Rift was downfaulted. This drainage was then truncated and a new Riftward drainage initiated from both sides of the trough. Though greatly depleted by this beheadment of large rivers, a seaward flow on the Cheringoma was maintained and Riftward drainage fed by the high watertable duplex sand aquifer along the crest and dipslope of the cuesta. This aquifer was formed by weathering and eluviation of the surface Plio-Pleistocene sediments resulting in a loose sand surface with an impermeable illuvial clay subsoil. Runoff is consequently almost nil and the catch and release action of such a duplex sponge surface acts as an efficient aquifer, and is responsible for the high watertable sands here and of most of the Mocambique coast. Many of these extremely leached acid sands with an impermeable iron saturated pan horizon are tropical podsols.

WATER TYPES

Three main types of water can be distinquished in the Gorongosa region (Fig 5.10), similar to that described by Sioli (1975: 200) for the Amazon Basin. These are:

(1) ***Whitewaters:*** loamy turbid water of yellowish-ochre colour with extremely low transparency, and a pH of 6 at the height of the dry season (9 October 1971). The Urema Lake on the Rift floor, its outflow, the Urema River, and the Pungue River below its confluence with the Urema are the only examples in the region. Where the Urema white waters meet the clear water of the Pungue they remain distinct for a considerable distance. Derived from fine defloculated clays and silts of the shallow lake bed.

(2) ***Clearwaters:*** limpid pale green colour, highly transparent in the dry season, with a pH of between 5,5 and 6. The rivers which rise on the continental interior (eg. Zambeze), the Great Escarpment (eg. Pungue), Midlands (eg. Nyamapaza) and Gorongosa Mountain (eg. Vundudzi) belong to this water type. The regional waters of this type derive mostly from mountain and deeply dissected landscapes of crystalline rocks. On Gorongosa Mountain the Vundudzi stream has a pH of 5 and after traversing part of the Rift floor becomes a pH of 6. The Mucodza stream from the mountain has a pH of 7 where it crosses the Rift floor.

(3) ***Blackwaters:*** water the colour of tea at different strengths, from light to dark. Transparent, with a pH of 4,0 to 5,5. Waters derived from leached pallid sands with an impervious subsurface horizon (many are tropical podsols) on a subdued cuesta landscape eg. the Cheringoma Plateau. Clearwaters and blackwaters are low in suspended matter, although the latter contains myriads of fine organic particles. The occurrence and significance of blackwaters elsewhere in the tropics is discussed in detail by Janzen (1974).

A fourth water type of minor importance in the region are two perennial thermal springs. The one in a stream which flows into the Pungue River immediately west of the park's southwest boundary below the Bue Maria ridge. The other near the middle of the Rift floor east of the Bunga Inselbergs, which maintains a permanent pan, little used by wildlife.

The lithologic, topographic, and soil conditions in the headwaters of the limpid waters types determines their characteristics. The whitewater, however, is due to the confluence of acid streams from Gorongosa Mountain which flow through saline vertisols into the shallow montmorillonite clay bed of the Urema Lake causing chemical defloculation of the fine clay micelles. Wind waves assist in maintaining a high load of suspended matter by churning up the bottom, but is not the primary cause of the whitewater condition. In the Amazon, whitewater results in a similar way where clearwater from the high Andes passes through the coalesced alluvial fan deposits at their base (Sioli 1975 203).

The most striking change in water characteristics is displayed by some of the Riftward draining streams which rise on the Cheringoma Plateau. The Mutsambidzi stream originates from high watertable sands where dambo waters have a pH between 4 and 5. In its midcourse the drainage passes through limestone sediments which changes the waters to an alkalinity of pH 8, high enough for halophytes to occur and light deposits of calcareous tufa. This change occurs over a relatively short distance of several kilometers and is confined to the stream as the adjacent soils, even those on the limestones, are acid in reaction.

At the height of the dry season in the pre-rain spring torrid season (October 1971) the water temperatures of all samples in the Rift and adjacent uplands below the 200 m contour was between 27 and 29° C, whilst on Gorongosa Mountain above the 1 000 m contour a forest stream measured 18° C.

AQUIFERS

There are two major aquifers in the Gorongosa region, one on either side of the Rift Valley, which are responsible for through-the-year flow of water (Fig 5.11). The most important of these quite different aquifer types is Gorongosa Mountain whose isolated high relief triggers its own orographic rain regime releasing perennial flows, one of which traverses the heart of the park across the Rift Valley. The mountain catchment is approximately 600 km^2. The other important aquifer is the crest area of the Cheringoma Plateau where a sand mantle overlies impervious clays absorbing almost all rainfall and releasing it in streams seawards and Riftwards. These streams, however, do not reach the Rift floor in the dry season, but disappear into their sandy beds and alluvial fans where the scarp slopes meet the Rift floor. They, therefore, do not contribute to the surface water resource of the Rift Valley, remaining available at the surface only on the slopes of the Plateau itself. The effective catchment zone on the crest of the plateau, left by headward erosion from both sides, is a linear area of 120 x 25 km (ie. c 3000 km^2).

High watertable sands and 'blackwaters' occur south of the study area on the Mocambique Coast Plain to where it ends at Mtunzini on the Natal Coast. They reappear again in patches southwards along the coast where pallid duplex sands occur, and extensively again on the southern and southwestern Cape coasts and mountainlands. Yet in-depth studies of high watertable sands in southern Africa appears to be confined to that by Van Wyk (1963) in northern Natal and Zululand, and by Henzen (1973)in his monumental study of the Cape Flats sandveld aquifer.

The largest perennial river in the system is the Pungue,but because of its position on the southern boundary limit of the park this river only sustains life contiguous to it in that part – wildlife on the left (north) bank and tribespeople on the right (south) bank. The drainage of the Gorongosa region forms part of the Pungue hydrographic basin which is about 29 500 km^2 in extent.

In the north of the park is a small but important perennial surface water in the lower course of the Muche River. This occurs despite the Muche having a catchment in the crystalline gneiss of the Midlands which are extremely poor aquifers. The reason for this surface water seems to be due to the extensive sandy infill of the broad lower Muche Valley (see Fig 5.8) which acts as a sump in a similar manner to the duplex sands of the Cheringoma Plateau, trapping runoff from the sides as well as the direct rainfall.

The phreatic watertable in the Rift Valley floor lies at about 8 m below the surface (at Chitengo Camp), implying that an impervious stratum occurs below that level. Replenishment of this water must be from the edges of the trough where the alluvia thin off against the old land rocks as most of the surface soils, including the sands, of the Rift floor are impervious to percolation beyond 1 m depth. As the deep cracking vertisols of the floodplains and slack-basins are underlain in many areas by sand however, an important recharge of this sump probably occurs at the time of flooding before the clays swell and seal off further downward movement of water.

DRAINAGE REGIMENS

The perennial surface water of the Gorongosa region is laid out in a N-shaped pattern linked together at the base by the Pungue River (Fig 5.11). Lying at the centre of this pattern is the Urema Lake, which is the intermediate recipient of almost the whole region's drainage, which then passes on down the Urema River to the Pungue. The Pungue in the south and the seasonal Nyamapaza River in the north, both flow away from the Urema catchment due to their intervening bar deposits which now act as interfluves on the Rift floor isolating the Urema catchment. The central position of the Urema Lake in the floor of the Rift Valley thus makes it an effective local base level of primary importance to which all erosional and depositional processes are eventually related. This fundamental position of the Urema will only be replaced by the Pungue when either the convexity forming the critical height at its outlet is incised sufficiently to drain the lake, or when the lake is filled with sediment.

Urema Catchment

The Rift Valley is a flood plain ecosystem reliant on both the amount and distribution of rain in the Urema catchment as well as that in the Rift Valley itself. The changes in this input are clearly displayed by the extension and contraction of the lake waters across the surrounding plains. During maximal flooding the Urema Lake expands from a dry season minimum of 10 km^2 to about 200 km^2 area. In the ten summers between 1966 and 1976 four maximal floods have been experienced (66/67, 69/70, 73/74, 75/76) and six low to medium floods. The area of slack floodplains at the confluence of the Pungue and Urema Rivers, known as Dingedinge, expands from nil, at the height of the dry season, to 120 km^2 under flood waters (Fig 5.11). Whereas Gorongosa Mountain is the most important perennial resource, in flood periods the Nhandue River which rises in the western crystalline Midlands and the Pungue River also play important roles. During high flooding the Pungue waters effectively dam up the outflow from the Urema catchment thus favouring increased deposition of sediments and the preservation of the critical height at the outlet of the Urema. The Nhandue, like the Nhamapaza, is a broad 'sand river' whose flow rises and falls in empathy with every rainfall change. By contrast the Pungue, Gorongosa Mountain, and Cheringoma catchments provide a more sustained high water regime during the rains. At the same

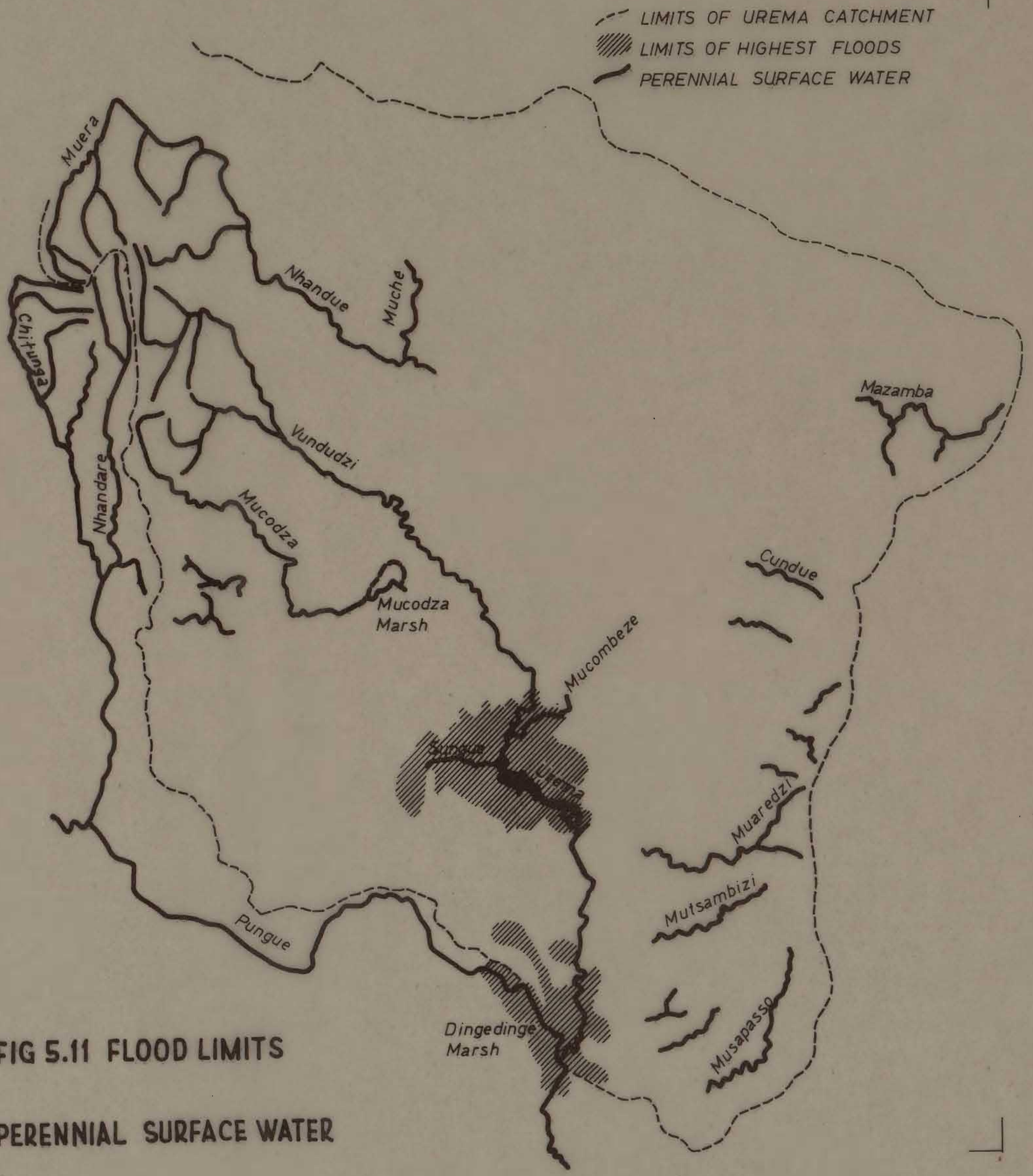
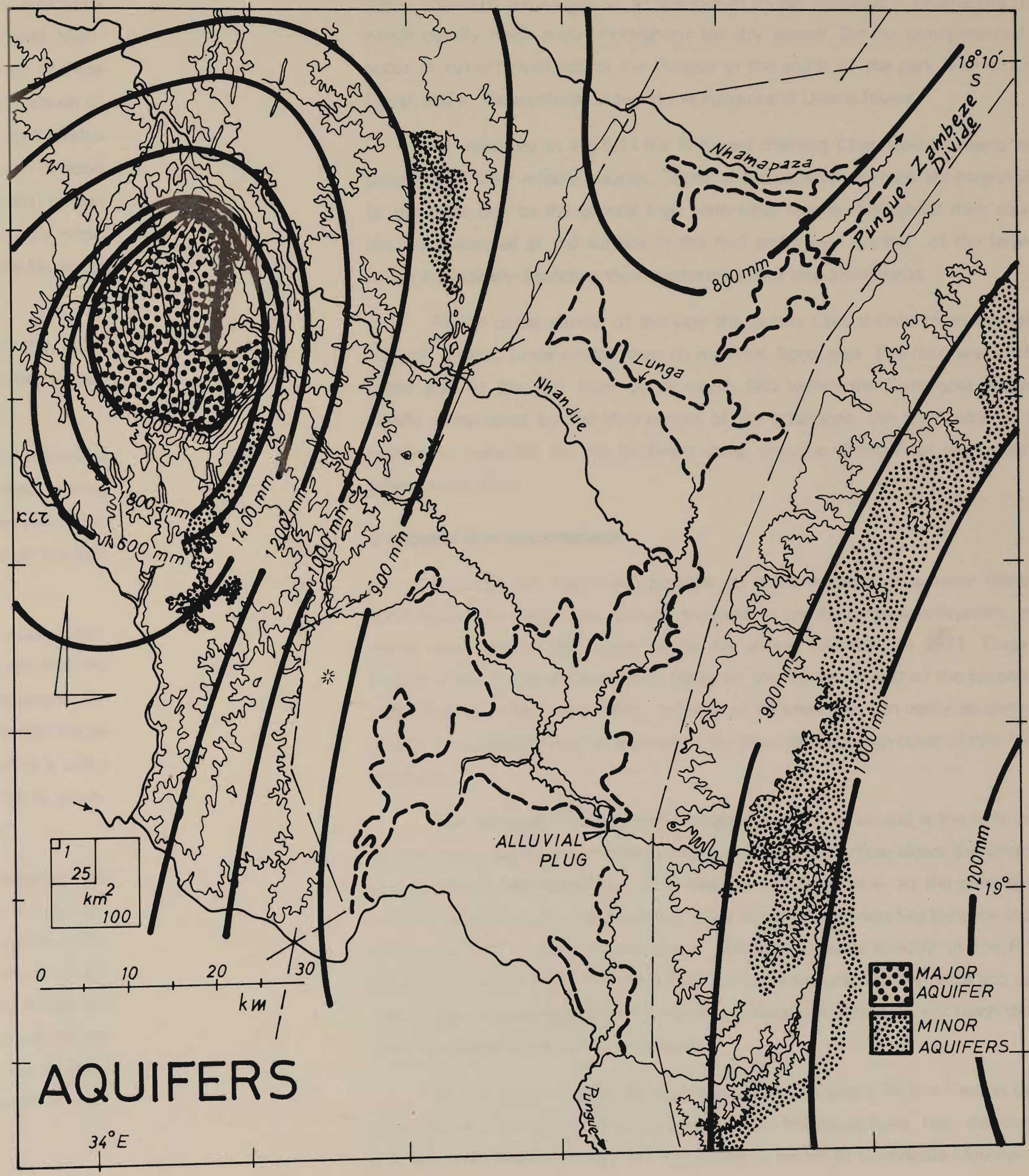


FIG 5.11 FLOOD LIMITS

PERENNIAL SURFACE WATER


18°10' S
Pungue - Zambeze Divide
Nhamapaza
800 mm
Lunga
Nhandue
2000 mm
800 mm
1600 mm
1400 mm
1200 mm
1000 mm
900 mm
ALLUVIAL PLUG
900 mm
1000 mm
1200mm
19°
Pungue
1
25
km²
100
0
10
20
30
km
MAJOR AQUIFER
MINOR AQUIFERS
34°E

AQUIFERS

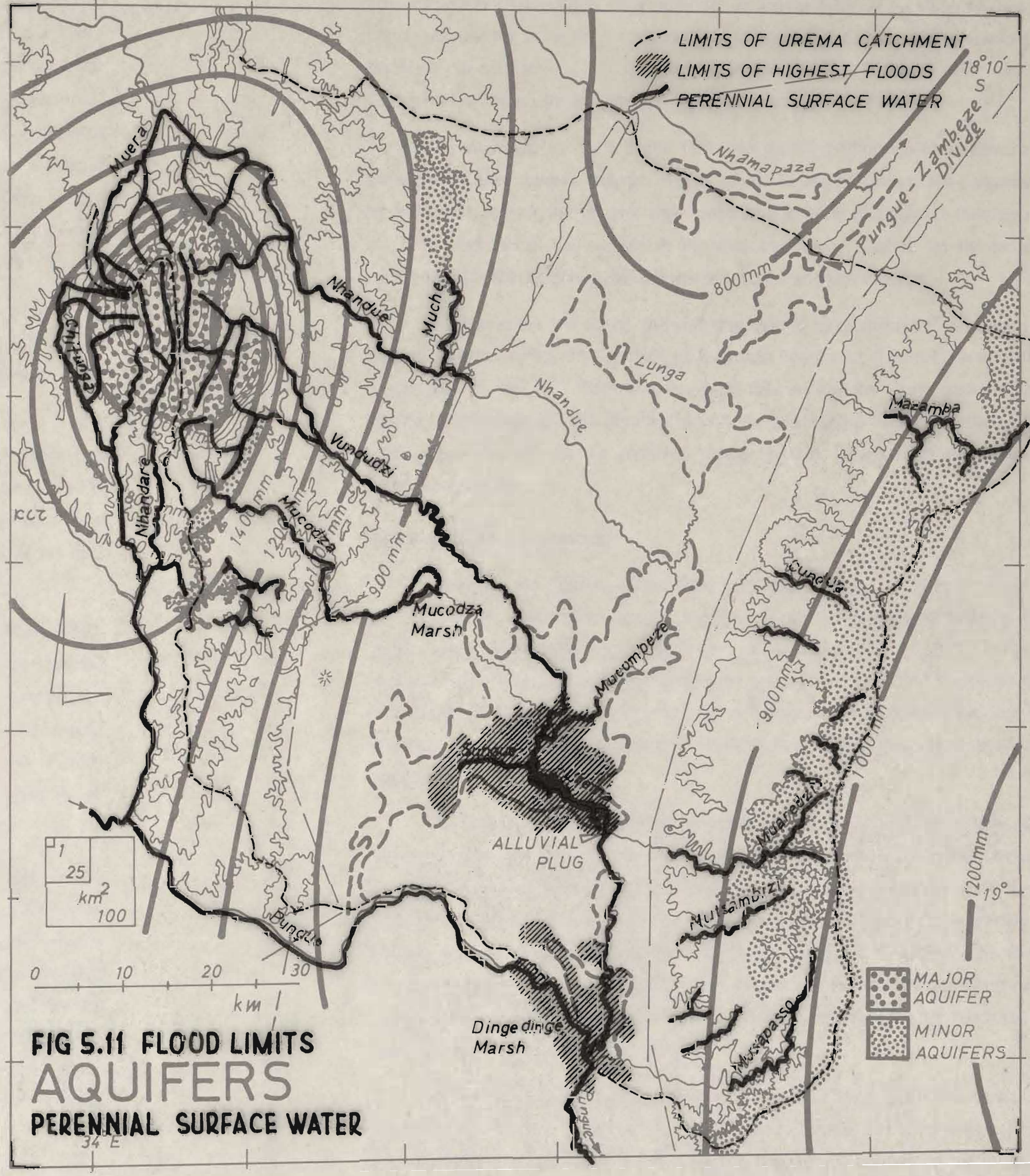


FIG 5.11 FLOOD LIMITS
AQUIFERS
PERENNIAL SURFACE WATER

time the differential amounts and distribution of rain in the various parts of the catchments can result in large discrepencies in timing of floods from different directions which has enormous consequences on changes and direction of fluvial processes. Maximal floods are typically recorded in January and February at the culmination of these differential inputs. For example, if the Cheringoma Plateau experiences a succession of heavy afternoon cumulonimbus thunderstorm rains which develop into light stratus rain over the remainder of the region at night, the plateau streams come down in flood while other drainage stays at low flow. Under such conditions the Muaredzi stream which joins the Urema River at the lake's outlet floods into the lake and only when the lake waters have reached sufficient height to cross the sill formed by the Muaredzi alluvial plug do the waters reverse and flow back down the Urema River.

The flood waters from the mountain are relatively 'clean' but where they meet the runoff from the heavily cultivated, dissected Midlands they acquire a heavy load of red loam and sand from erosion.

The Nhandue which has the largest catchment (c. 3 700 km^2) of all the streams entering the Urema basin carries the largest quantities of sandy sediments during floods. Depending on the level of the Urema Lake, these flood waters are responsible for the cut and redeposition of Rift Valley alluvia in the central sector of the Rift floor.

The Muera River which rises on the western rim of Gorongosa Mountain, directly opposite the source of the Vundudzi and Nhandare Rivers, flows north into the Nhandue River. Together with streams from the northern slopes of the Mountain, the Nhandue River is kept wet at the surface all the way to where it meets the Rift Valley near the Muche River confluence. Above and below this sector, the Nhandue is a dry 'sand river' with water available to elephant and man below the sand, its depth dependent on the distribution of the rains and the severity of the dry season.

If Gorongosa Mountain waters flood before those of the surrounding areas, this causes the rise and partial flooding of the Urema Lake. Thus when large scale floods enter from the Nhandue or push back from the Pungue their erosional impact is buffered by the already flooded plains and deposition of sediments occurs as distributary fans back from the lake. The effectivity of fluvial processes during floods are thus dependent not only on the break in slope, but also on the prior degree of flooding or saturation. The consequences of the differential timing of flood events in the landscape development of the Rift Valley are dealt with below where the processes at work in each topographic unit are detqailed (Ch. 6).

Between the Nhamapaza and Nhandue Rivers on the Rift floor is a narrow deep creek, known as the Lunga, of an abandoned former Nhandue – Nhamapaza river bed, which usually holds water throughout the dry season. Similar semi-perennial waters occur in cut-off riverbeds of the Pungue in the south of the park west of Chitengo Camp, and in the southeast between the Pungue and Urema Rivers.

As indicated in Fig 5.11 the Riftward draining Cheringoma streams are only perennial in their middle courses. Those of the seaward drainage are perennial closer to the coast, due to the general high watertable regime throughout their course, and are more seasonal at the surface in the mid and upper reaches of the larger rivers which are actively dissecting their catchments back and downwards.

At the driest period of the year the Urema Lake shrinks to an area of about 10 km^2, twenty times smaller than its maximal flood area. The total seasonally inundated area of the Rift floor sector which falls within the Gorongosa ecosystem is clearly demarcated by the distribution of the grasslands, the flood edge of present regimes is indicated by the relatively sharp tree-line junction of the savannas and other woody cover.

Dry season flow measurements

Although no figures are available on flood volumes or summer flows of the more important rivers and streams involved in the Gorongosa ecosystem, measurements were made at the height of the dry season (October) in 1971. These figures highlight how the entire ecosystem hangs on the slender thread of the perennial flow from Gorongosa Mountain which, because of its smallness, can easily be destroyed or altered to a seasonal flow by damage to the mountain's sponge cover of rain forest and grassland.

The Vundudzi Stream, which traverses the Rift floor and is the only perennial surface flow contributing to the Urema Lake and its overflow down the Urema River, was supplying only 0,6m^3/sec (21 ft^3/sec) at the driest time. At the same time a volume of 0,2 m^3/sec of water left the lake's outlet, three times less than the input. The other mountain stream, the Mucodza, which contributes directly to the Rift floor provides a surface flow of 0,02 m^3/sec to its mid-course marshy delta and only half this amount is released below the marsh. Its waters therefore do not reach the Urema Lake during the height of the dry season.

At the same time, the Pungue River flow was about 16,5 m^3/sec as measured above rapids 2 km above its confluence with the Nhandare River. Near this confluence the Nhandare River, born on the southwestern sector of Gorongosa Mountain, had a volume of 1 m^3/sec. No measurement was made of the Muera Stream off the northwestern part of Gorongosa Mountain which keeps the Nhandue River bed moist down to the edge of the Rift floor.

Rift and Cheringoma drainage towards the Zambeze

The section of the Rift Valley north of the Urema catchment is drained by the Macua, alias Zangue, which meets the Zambeze River opposite its confluence with the Chire River. The Chire drains Lake Niassa. Almost all the Zambeze-ward drainage entering this sector of the Rift Valley are seasonal, large 'sand rivers' rising mostly on the extensive area of friable Continental Cretaceous calcareous sandstones west of the Rift.

Of these the largest is the Nhamapaza River whose fossil bar deposits form the northern boundary of the ecosystem on the Rift floor. It is a 'sand river' for its entire length to where it joins the Zangue, but its subsurface water is much deeper and thus less easily available to elephant and man.

During exceptionally high floods, as in the summer of 1958, the Zambeze waters pushed back up the Rift Valley both ways, north up the Chire into Malawi and south flooding Dimba Marsh. Such floods also inundated more than 18 000 km^2 of delta grasslands, and swept large numbers of buffalo and waterbuck out to sea (Tinley 1969). Thus in the recent past vast areas of alluvial grasslands of the Urema and Chire Troughs were all affected periodically by the additional flooding of Zambeze waters. The summer of 1958 was the last time the Zambeze was able to flood large areas of the central lowlands of Mocambique, as soon after this the Kariba Dam was completed. In addition to the effects of the dam, the flooding in the delta had been confined mostly to the main rivercourse by a series of dykes erected by the Sena Sugar Company to protect settlements and plantations. This reduced flooding has dried out the rich alluvial soils and they have become alkaline or saline. As alluvial grasslands are maintained solely by seasonal flooding, the removal of this periodic phenomenon has released the invasion of savanna and forest which will in time eliminate the pure grass habitat.

The key to the survival of the Zambeze delta grasslands now lies almost entirely with the high watertable runoff from the sandy dipslope of the Cheringoma cuesta abutting them. But these nutrient-deficient (Janzen 1974) peaty blackwaters carry no silt and the flooding is 'clean'. The southern sector of the delta includes the Marromeu Buffalo Reserve and the tapering end of the alluvial grasslands which enter the present study's montane to mangrove transect. The advent of a second gigantic water storage scheme on the Middle Zambeze at Caborabassa means that the southern delta alluvial

grasslands are increasingly dependent on flooding from the Cheringoma Plateau. As saline waters spread far into these grasslands during high tides and encroach from the subsoil, the possibility of freshwater marshes being replaced by saline grasslands is very real. In addition, the entire Mocambique Coast is at present being eroded and sea invasion of mangrove swamps is common on the central coast. Only at the actual distributory mouths of the delta is there accretion of sediments. On such a low fragile coast, the balance between erosion and deposition is delicate and the effects of the large dams on reducing the supply of sand during floods for the maintenance of this delicately poised coastline is an unknown factor (Tinley 1971b).

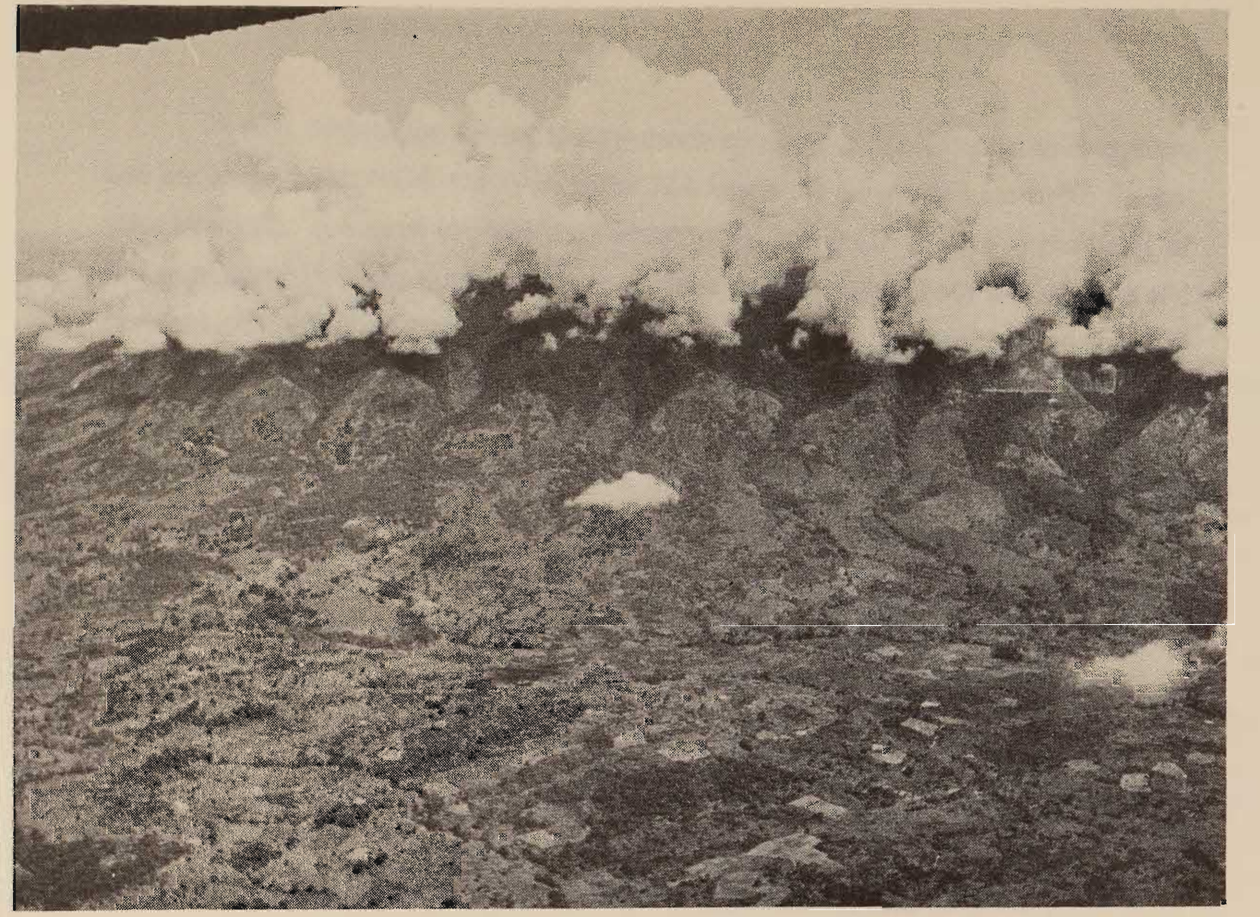
SEASONAL PANS

A feature of the Rift Valley is the myriads of small seasonal rainfilled pans. These are in addition to the numbers of much larger cut-off courses, slacks, and other past drainage depressions which also hold water for varying periods. Some of the pans are deep enough to hold water until July, but the reliability of these surface water islands is totally dependent on the distribution and amount of rainfall. Late rains result in longer lasting supplies, and midsummer droughts, or generally poor summer and autumn rains, result in their quicker loss to the system. From July onward they are mostly dust dry, and the remaining moist areas are the floodplain marshlands and actual riverine zones. The floodplains themselves become drier than the adjacent savannas at this season due to the salinity of their soils. Pans are less common on the Cheringoma Plateau and rare in the hill miombo on the west.

There are on the average two pans per hectare (200/km^2) on the Rift Valley floor, giving a tremendously even spatial distribution of water in the rains and autumn. Each pan is about 20 m in diameter, or larger. As noted in the section on termitaria, many of the pans form an integral part of the geomorphic dynamics of termite hills, thus in many areas there are as many pans as termite hills, which average three to the ha (300/km^2).

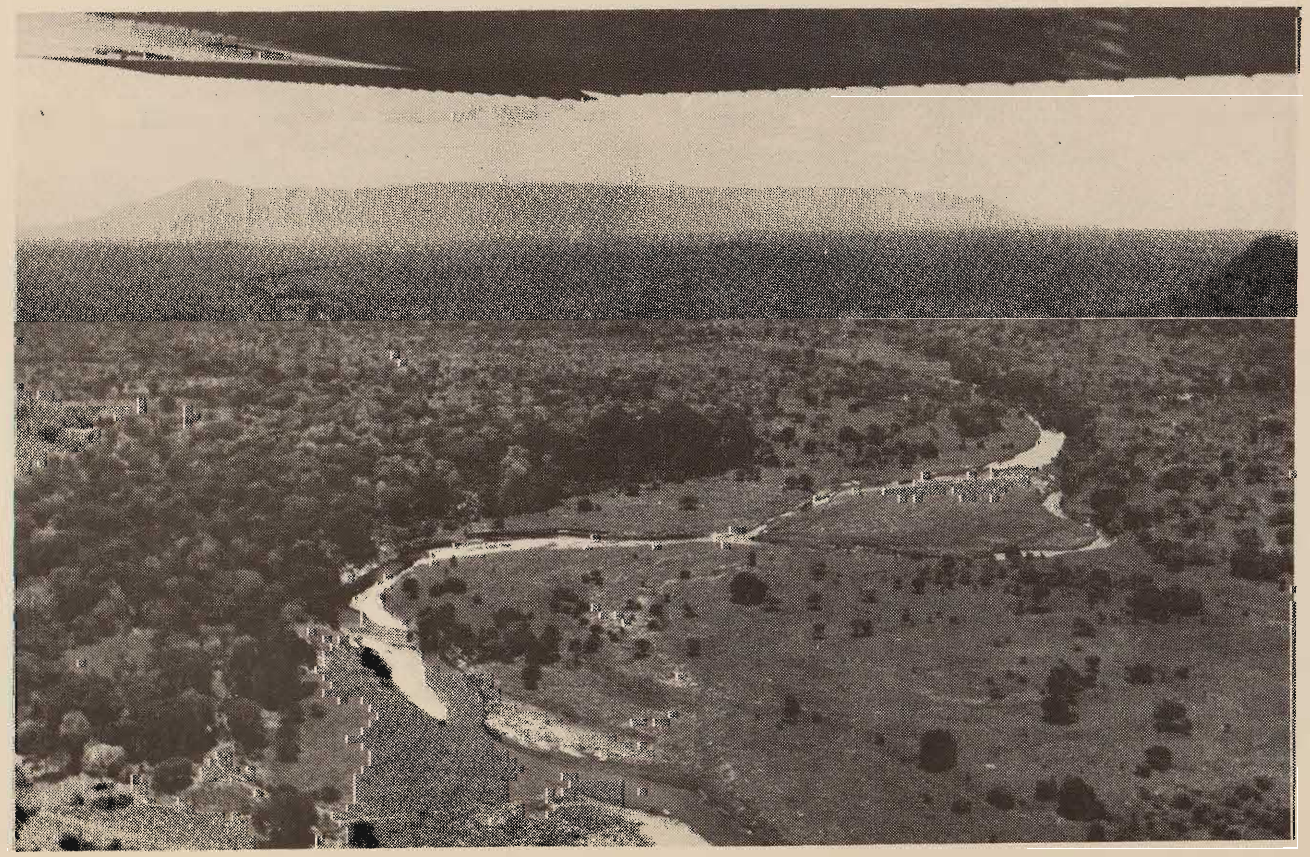
Although these depressions can be linked temporarily during, and just after, heavy falls of rain they are in effect endoreic, islanded from one another. Together with the islands of termitaria thickets they are responsible for multiplying the diversity and abundance of resources in the savanna ecosystem. The archipelagos of seasonal pans allows the spread of wildlife and their utilization of the savannas before they are forced back to the permanent riverine zones.

PLATE 5 THE KEY WATER CYCLE OF THE GORONGOSA ECOSYSTEM



(A) Initial development of orographic cumulo-nimbus due to forced ascent of moist sea-air against the slopes of Gorongosa Mountain.

(B) The catchment source area, on the summit of Gorongosa Mountain, of the perennial Vundudzi River which is the main feeder of the Urema Rift Valley lake.



(C) Bunga Inselberg (extreme right) where the Vundudzi River meets the Rift Valley after traversing the intervening Midlands (dry forest at left on fossil splay deposit.

(D) The Urema Lake on the Rift floor — main receptacle for drainage from both sides of the Rift Valley trough, including three streams from the mountain. View to the east with converging delta on left and Sungue arm on right.

SUMMARY OF THE WATER FACTOR

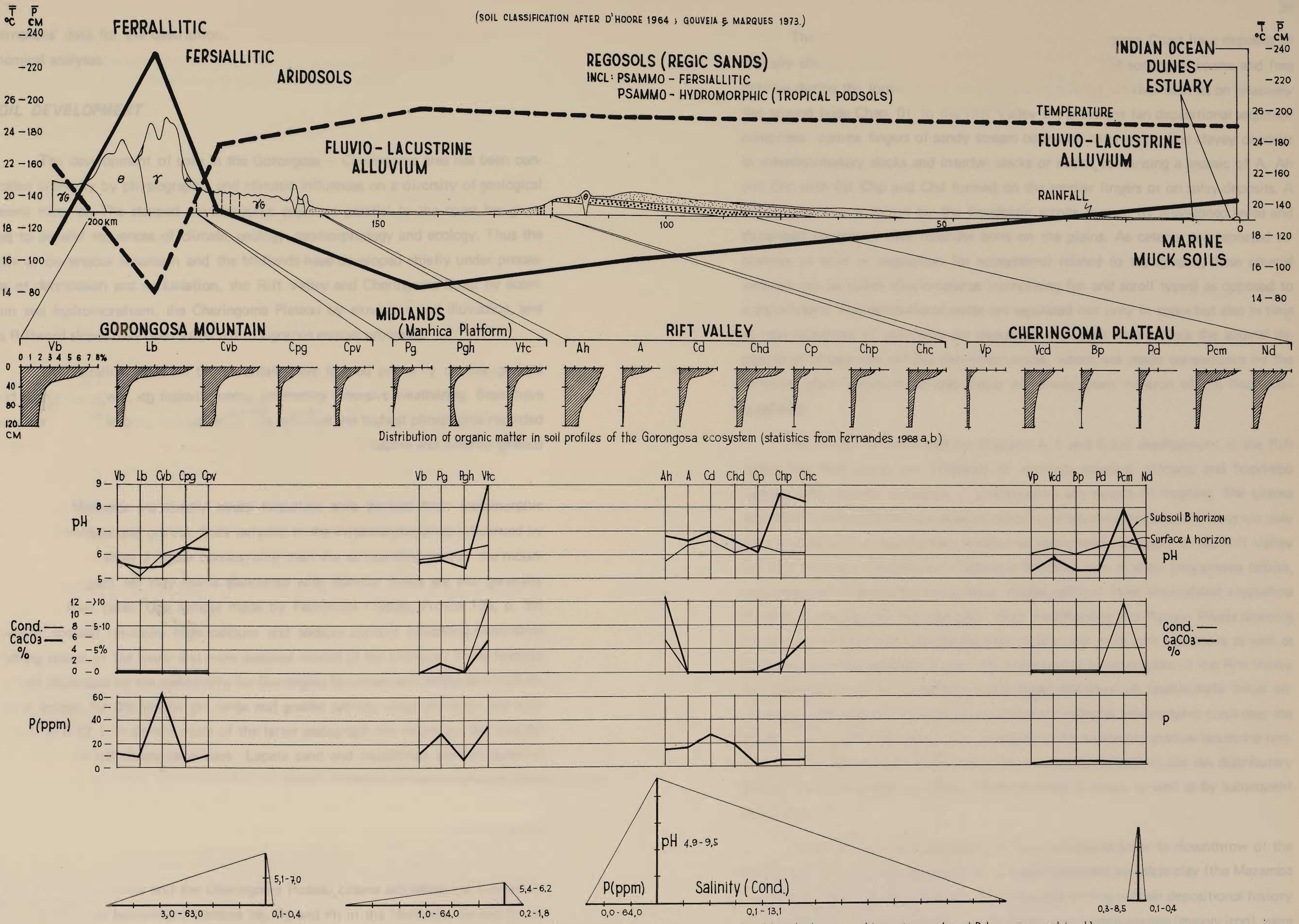
In sum, despite the apparent abundance of water in the Gorongosa ecosystem one particular water holds the key to life. This key is the perennial water from Gorongosa Mountain, the most important of which is the Vundudzi Stream – the heart of the ecosystem. Like the other mountain streams its flow is small but it is a strong and constant one. Whether these mountain streams are reduced to a trickle that does not reach the Rift floor during a period of consecutive dry years is not known. The threat of a dam on the Pungue River in the gorge tract west of the Rift, and the canalization of water from below the dam, highlights further the importance of the mountain's supply. The mountain water is thus the primary salient factor in the survival of the Gorongosa ecosystem and of more than 15 000 tribespeople living around the massif. Protection of this mountain catchment island is therefore of prime importance to ensure its copious, but at the same time tenuous,harvest of water.

The second key factor is a corollary of the first, and that is to damp down natural headward erosion of plainsland by protecting the critical heights of local base levels, which are fundamental for the maintenance of a flood and ebb regime. Together these two factors are the crux of the Gorongosa ecosystem.

5.7 SOILS

The 1:5 million soil map of Africa (D'Hoore 1964) and the 1:4 million soil map of Mocambique (Gouveia & Marques 1973) show that the Gorongosa-Cheringoma area contains seven main soil groups which are related to both the main physiographic features and the geology. These are (1) Ferrallitic soils on Gorongosa Mountain, (2) Fersiallitic soils on the crystalline Midlands, (3) Brown and reddish-brown Aridosols on the Continental Createaceous which forms part of the upland – Rift Valley junction in the north of the ecosystem, (4) Fluvio-lacustrine alluvium of the Rift Valley and southern sector of the Zambeze Delta which fronts the Cheringoma Coast, (5) Regosols (Regic Sands) of the Cheringoma Plateau, comprising psammo-fersiallitic and psammo-hydromorphic (Tropical Podsol) soils, and (6) Estuarine alluvium (marine muck soils) on the coast (Fig 5.12). An excellent detailed soil study done by Laperre (1971) at the Luabo Sugar Estates provides a valuable guide to the complex mosaic and alluvial catena of soils present in the Zambeze Delta.

Soil surveys of the Gorongosa Mountain area (Fernandes 1968a) and Gorongosa National Park (Fernandes 1968b) were mapped from air photos with field control, and the samples analysed in detail. Unfortunately, due to insufficient correlation between plant communities and soils, Fernandes grouped a number of quite different soils into single units, for example: dry forest on sand, knobthorn savanna on sandy clays and fever tree woods on hydromorphic soils are all classed as one type. In addition, the boundaries to some of his pedo-units traced from air photos are unreliable as they were sometimes drawn along the outline left by veld fires, or along the tonal change on air photos depicting the contour separating wet and dry surfaces of the same bottomland soils. His two alluvial soils A and Ah are thus shown as a single unit on the maps (Fig 5.13), the two types forming a mosaic. Finally, no soil survey exists of the seaward slope of the Cheringoma Plateau. For these reasons I made a large number of soil pits and auger samples throughout all clearly defined communities and across their ecotones. Of these, 136 samples from 39 profiles were kept for basic analysis of pH, salinity and base status. These data will be correlated mostly with the profile bisect drawings of habitats in Chapter 8. Fernandes' 1968 data are used here to separate out the factors of ecological importance depicted on small scale maps adjacent to the main soil map (Fig 5.13). Other relevant data are graphically represented for comparative purposes in Figs 5.12 derived from statistics listed in the tables of Fernandes' work. Fernandes (1963a, 1963b) divided the soils of Gorongosa Mountain and the national park into seven groups of 21 pedo-units based primarily on their geological, and to a lesser extent their chemical or textural, relationships (Fig 5.12 and 5.13/Table 5.1/Appendix 1). Reference should be made to



Distribution of organic matter in soil profiles of the Gorongosa ecosystem (statistics from Fernandes 1968 a,b)

Comparative pedographs of soil diversity (range of pH, salinity and phosphorus variation in soils of the 4 physiographic regions - A and B horizons combined)

FIG 5.12 TRANSECT OF PHYSIOGRAPHIC SOIL GROUPS IN THE GORONGOSA ECOSYSTEM

Fernandes' data for the descriptions of soil profiles and their detailed physical and chemical analyses.

SOIL DEVELOPMENT

The development of soils in the Gorongosa – Cheringoma area has been controlled primarily by physiographic and climatic influences on a diversity of geological parent material. The stepped physiographic sequence parallel to the coast has given rise to parallel sequences of climate, geology, geomorphology and ecology. Thus the soils of Gorongosa Mountain and the Midlands have developed chiefly under processes of denudation and colluviation, the Rift Valley and Cheringoma Coast by accretion and hydromorphism, the Cheringoma Plateau by eluviation and illuviation, and its Riftward slopes have been subjected to vigorous erosive processes.

The ferrallitic soils on the mountain have formed primarily on fine grained acid granite in a wet, cool environment promoting intensive weathering. Bases have been leached out in both residual and talus soils but the highest phosphorus recorded in the ecosystem are contained in talus soils derived from gabbro and dolerite igneous rocks.

The Midlands are mostly sandy fersiallitic soils derived from metamorphic migmatitic gneisses and granite. Soils sampled in the metamorphic areas influenced by pegmatite dykes show a higher conductivity than the surrounding soils or the mountain. The compact red clay loams associated with dolerite dykes are also generally leached of their bases. One sample made by Fernandes (1968b, Profile 135, p. 39) however, showed relatively high calcium and sodium content indicating diminished leaching power of the lower and more seasonal rainfall of the Midlands. These features are well illustrated by the pedographs for Gorongosa Mountain and Midlands which are similar except for the smaller pH range and greater salinity range shown by the Midlands (Fig 5.12). In construction of the latter pedograph, the values for the soils derived from the red clayey-calcareous Lapata sand and mudstones were excluded as they form an extremely small, though unique occurrence, in the ecosystem. These soils occur on the junction of the Midlands with the Rift Valley and have one of the highest contents of phosphorus and total bases in the ecosystem including calcium, potassium and sodium.

In the Midlands and the Cheringoma Plateau, catena sequences are formed by hill soils and their bottomland dambos (eg. Pg and Ph in the Midlands, Bp and Pd on the Cheringoma). Thus a toposequence is superimposed on lithosequences as exhibited by Gorongosa Mountain and the Cheringoma Plateau.

The Rift Valley and alluvial front to the Cheringoma Coast have deposits of laterally changing sequences of soils related to differential sorting of coarse and fine detritus during the formation of alluvial fans or shifting of river courses on relatively flat ground (vide Chap. 6). In the Rift Valley the prevalent fan depositional sequence comprises convex fingers of sandy stream beds with intervening fine clayey deposits in interdistributary slacks and interfan slacks or basins, comprising a mosaic of A, Ah and Chc with Cp, Chp and Chd formed on the sandier fingers or on splay deposits. A similar sequence is shown by the floodplain scrolls formed by abandoned levee and streambed courses in river meander belts on the plains. As catenas are repeated sequences of soils or vegetation (or ecosystems) related to topography, these alluvial versions can be called alluvio-catenas (comprising fan and scroll types) as opposed to a topo-catena. The depositional series are separated not only in space but also in time as new sequences of sediments are deposited with each flood. Thus the alluvial depositional phases also exhibit chronosequences, which are made conspicuous by the different plant communities and stages of woody plant invasion of the floodplain grasslands.

As clearly demonstrated by Chapters 4, 5 and 6, soil development in the Rift Valley has been under the influence of strongly seasonal climatic and flood-ebb regimes with extreme variations in precipitation and extent of flooding. The Urema and other interfan basins, have received sodium and calcium saturated sediments not only from the Cretaceous and Tertiary limestones immediately adjacent to the Rift Valley but also from the Precambrian crystalline Midlands rich in sodic plagioclases (albite, oligoclase and andesite) and to a lesser degree, calcium from intercalated crystalline limestones (see Section 5.5 Geology). Thus the Nhandue and Pungue Rivers draining the crystalline Midlands contributed both quarts and mica rich sediments as well as alkali felspars. The infusion of base rich constituents from all sides of the Rift Valley and their deposition in a seasonally water-logged siliceous-rich (particularly mica) environment, has favoured the formation of montmorillonite halomorphic clays over the greater part of the Rift Valley floor, probably under seasonally shallow lacustrine conditions. The sandier soils of the floor are all directly related to old fan distributary courses and splays; they are thus already leached in origin as well as by subsequent eluviation.

The final sediments deposited on the Cheringoma prior to downthrow of the Rift trough were alluvial fan materials of sands cemented by calcic-clay (the Mazamba Formation). Due probably as much to differential sorting in their depositional history as to subsequent eluvial processes, quartz sands, rich in sesquioxides (mainly iron), were formed at the surface. The calcareous material was leached downward and laterally to

TABLE 5.1

The soils of Gorongosa Mountain and the National Park
(according to Fernandes 1968a, 1968b)

	GEOLOGY & SOIL	LOCATION	VEGETATION (as listed by Fernandes)
I	*Acid Rocks*		
(1)	**Pg** – brown granite-gneiss	Midlands	*Brachystegia* savanna
(2)	**Pgh** – hydromorphic (dambo)	Midlands	Dambo grassland
II	*Basic Rocks*		
(3)	Vb – red basaltic	Gabbro of Mt., Midland dykes	forest, thicket, savanna, grassland
(4)	Lb – basaltic lithosols	Mountain	forest, grassland
III	*Colluvium* (Talus)		
(5)	Cvb – red colluvium	Mt., Midland dykes	Moist *Brachystegia* (miombo)
(6)	Cpv – reddish brown colluvium (mixed acid and basic)	Mt and adjacent midlands	*Acacia, Combretum, Pericopsis, Harungana*
(7)	Cpg – brown colluvium (granite-gneiss)	Midlands S. of Mt.	Miombo savanna
IV	*Calcareous*		
(8)	Vcd – red indurated limestone	Cheringoma Plateau	*Acacia nigrescens, Combretum, Diplorhynchus*
(9)	Vtc – red argillaceous limestone	Midland-Rift junction	*Brachystegia glaucescens* savanna woodland
(10)	Pcm – brown calcareous marls	Cheringoma	Thicket-savanna mosaic
(11)	Chc – grey hydromorphic	Rift margins and floor	*Acacia*, mopane, *Dalbergia*, baobab savannas
V	*Detrital fan material*		
(12)	Pd – brown leached clays	Cheringoma	*Trachypogon* grassland, *Uapaca-Parinari* savanna
(13)	Cd – grey soils	Rift floor and margins	*Piliostigma, Acacia, Combretum* savanna
(14)	Chd – grey hydromorphic	Rift floor and margins	Fever tree, *Hyphaene, Combretum imberbe* savannas
(15)	Nd – black soils	Cheringoma – Rift junction	thicket-savanna mosaic (*Spirostachys* et. al.)
VI	*Sands (regosols)*		
(16)	Vp – red sands	Cheringoma	Miombo savanna
(17)	Cp – grey sands	Rift sides and floor	thicket-savanna mosaic
(18)	Chp – grey hydromorphic	Rift sides and floor	savanna-Dry Forest mosaic
(19)	Bp – white or pallid sands	Cheringoma	Miombo-thicket mosaic
VII	*Alluvium*		
(20)	Ah – hydromorphic clays	Rift floor	floodplain grasslands
(21)	A – non-hydromorphic alluvia	Rift floor	*Acacia, Lonchocarpus, Piliostigma* savannas

SUMMARY OF SOIL FEATURES

	Mountain and Midlands					Midlands			Rift Valley							Cheringoma Plateau					
	Vb	Lb	Cvb	Cpg	Cpv	Pg	Pgh	Vtc	Ah	A*	Cd*	Chd	Cp	Chp	Chc	Vp	Vcd	Bp	Pd	Pcm	Nd
Free draining	+		+	+	+	+		+		+	+		+			+	+			+	
Impervious		+					+		+	+	+	+		+	+			+	+		+
Hydromorphic (G)							+		+			+		+	+			+	+		
Calcareous								+	+						+					+	
Saline								+	+						+						
Sandy				+		+							+	+		+		+			
Latosols	+	+														+					

* certain soils are a mosaic of free-draining and impervious subsoils eg. A, Cd

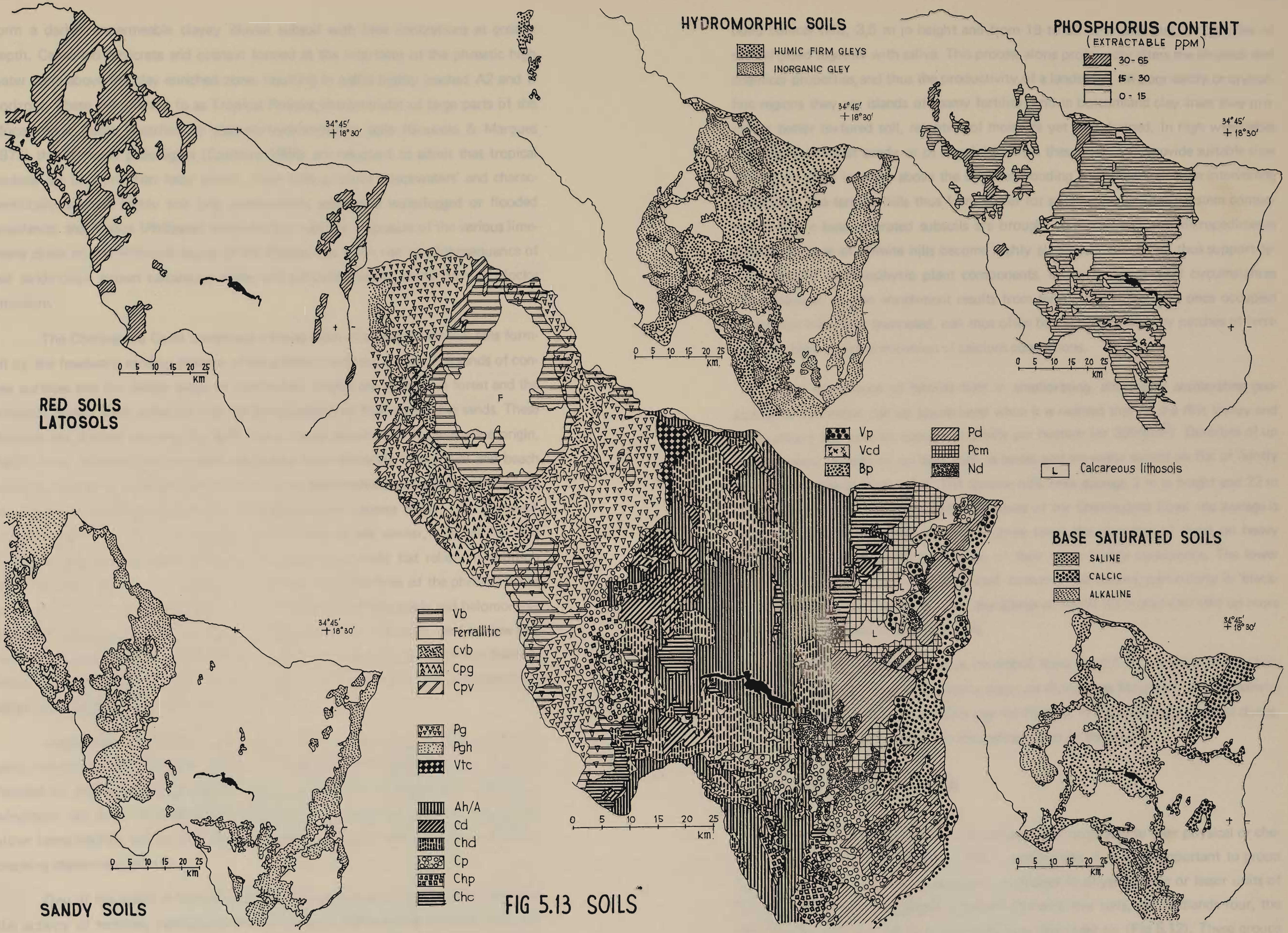


FIG 5.13 SOILS

form a darker impermeable clayey illuvial subsoil with lime concretions at greater depth. Cemented ferricrete and ortstein formed at the interfaces of the phreatic high water table above the clay enriched zone, resulting in pallid highly leached A2 and B horizons. These are referred to as Tropical Podsols, characteristic of large parts of the Mocambique Coast, classified as psammo-hydromorphic soils (Gouveia & Marques 1973) though some pedologists (Casimiro 1968) are reluctant to admit that tropical podsols are of more than local extent. Such soils produce 'blackwaters' and characteristically support highly acid bog communities, seasonally waterlogged or flooded grasslands, and fynbos (***Philippia***) scrub-thicket habitats. Exposure of the various limestone strata on the Riftward slopes of the Plateau has given rise to a lithosequence of red sandy-clays, brown calcareous marls, and colluvial melanic sandy-clays of blocky structure.

The Cheringoma Coast comprises a broad plain of coalesced alluvial fans formed by the headward eroding streams of the plateau's seaward slopes. The sands of convex surfaces and the deeper sands of distributary fingers are covered in forest and the interdistributary slack areas are acid dambo grasslands on high watertable sands. These deposits are fronted abruptly by dark heavy clayey alluvium of fluvio-marine origin, partly from Zambeze Delta deposits and partly from estuarine (mangrove) and beach deposits. As can be expected from their complex geomorphic history, these deltaic soils are diverse occurring as mosaics and alluviocatenas (see Laperre 1971). The coastal environment is hot year-long, with high humidity and no real winter, high rainfall, and poor drainage due to impervious horizons and/or extremely flat relief. In addition, high tidal range results in a seasonal alternation of salt content of the phreatic water extending many kilometres inland. These soils support hydromorphic and halomorphic grasslands and large areas of papyrus and reed swamps. On the coast itself are low barrier and parabolic dunes covered in thicket with interdune slacks of freshwater habitats, where fine black peaty clays or silts are formed. The freshwater in these sites occurs as lenses overlying the deeper seawater in the sands.

Large areas of mangrove swamps occur at intervals along the coast. These organic-rich soils are inundated by seawater at high tides, exposed during low tides and flooded by freshwater during the summer rains. Within one kilometre of the coast, wind-born salt spray is continuously added by day, from the onshore trade winds, either being leached out by rains through lateral drainage or accumulating in the deep cracking impervious vertisols.

One of the major influences in soil formation across almost the entire region is the activity of termites, particularly the hill building ***Macrotermes*** termites. This biological influence involves mining of the subsoil which is transferred to the surface to build conical hills, 3,5 m in height and from 18 to 50 m in diameter, of particles of subsoil glued together with saliva. This process alone profoundly alters the physical and chemical properties, and thus the productivity, of a landscape. In poor sandy or crystalline regions they are islands of loamy fertility, and in bottomland clay areas they provide a better textured soil, retentive of moisture yet well drained. In high watertable landscapes, whether sandy or of floodplain type, these small hills provide suitable sites for woody plant invasion above the seasonal flooding which maintains the intervening grasslands. The termite hills thus form nuclei for savanna or forest ecosystem components. Where base saturated subsoils are brought to the surface, the micropediments around the base of termite hills become highly alkaline or saline and thus support typical desertic or halophytic plant components. Under different local circumstances either calcium or iron enrichment results from termite activities. Sites once occupied by termite hills, now truncated, can thus often be identified either by patches of ferricrete (ouklip) or a concentration of calcium concretions.

The importance of termite hills in ameliorating, altering, or accelerating geoecological succession can be appreciated when it is realised that on the Rift Valley and Delta alluvia there are an average of 3 hills per hectare (or 300/km^2). Densities of up to 6/ha occur on convex surfaces such as levees and are wider spaced on flat or faintly concave surfaces in these areas. The termite hills here average 3 m in height and 22 m in diameter. In the high watertable, acid sands of the Cheringoma Coast the average is 1,5/ha (150/km^2) but these are nearly three times the diameter of those on heavy alluvia due to radial spread by erosion of their more friable consistence. The lower number per unit area may also be related to nutritional factors, particularly in 'blackwater areas (vide Janzen 1974). The low domes of nearly 50 m diameter take up more space per hectare than unmodified soils.

In the ***Brachystegia*** savannas (miombo) there are 0,5 to 1 termite hill per hectare on the average. No hill termitaria occur on Gorongosa Mountain, on the skeletal soils overlying limestone on the Cheringoma Plateau, in the mangroves or coast dunes, but termites are nevertheless active throughout most of these areas.

PHYSIOGRAPHIC SOIL GROUPS

Rather than group soils at the primary level according to their physical or chemical characteristics, or geological origin, ecologically it is more important to group them as they are associated in the field, ie. related to physiographic or lesser units of the landscape. Thus Gorongosa Mountain contains five soils, the Midlands four, the Rift Valley seven and the Cheringoma Plateau and coast six (Fig 5.12). These groups are then separated on the basis of their physical and/or chemical properties.

Although only two main soils were distinguished by the writer in the southern end of the Delta alluvia on the Cheringoma Coast (indicated by ***Diheteropogon*** and ***Brachiaria*** grasslands), Laperre (1971) recognised 22 soil mapping units in the Delta close to the Zambeze River near Luabo, which indicates the kind of complexity which results from the multiplicity of influences at play in the deposition of sediments. However, the number of soil mapping units ultimately depends on whether coarse or fine levels of pedological criteria are used for their separation.

It is significant that of the 22 soil units referred to above,almost all (except the tidal creeks) support floodplain grassland, that is, one kind of ecosystem dependant for its maintenance on adequate seasonal flooding. Thus soil moisture balance over-rides pedological criteria at the ecosystem level, but these criteria together with the degree of flooding or waterlogging, also related to microrelief, determine the species composition of the grassland.

The properties and features of the physiographic soil groups will be discussed briefly as they relate to edaphic, and thus their ecological, influences. Specific details can be found in Fig 5.12 and 5.13/Table 5.1/Appendix 1.

Mountain Soils

Of the five soils recorded from Gorongosa Mountain by Fernandes (1968a), three are colluvial talus soils and two are sedentary, derived from gabbro. Fernandes sampled the summit areas of the mountain with the aid of a helicopter, and designated the summit grasslands as skeletal rock outcrop soils, and basaltic lithosols. The higher parts of the entire mountain are micropegmatite granite, thus the soils will be ferrallitic. No profile description exists of soils covered in rain forest.

Summit grasslands

No profiles of summit soils were made and only the following data can be provided. The summit grassland soils are black turfy or peaty clayey sand underlain by reddish kaolinitic sandy clay and weathered rock (humic ferrallitic soils). The soils are hollow as they resound when stamped upon, due to pipe or underground drainage. Vlei areas and drainage line bogs become incised at intervals by formation of sinkholes (marked by clumps of tree ferns (*Cyathea*)), which eventually link-up to form narrow deep stream courses. Pipe drainage is characteristic of many mountain ferrallitic soils and the removal of the fine pallid kaolinitic material at depth, or its saturation, is also responsible for slumping on rounded slopes. Landslip scars are abundant on parts of the Gorongosa summits but are not large enough to initiate forest clumps as occurs on the Nyika Plateau in Malawi (Shroder 1976). The vlei or bog soils of the summit are acid organic hydromorphic peats of over 1 m depth in parts, underlain by brown to yellow compact sandy clay and weathered parent material.

Physical and chemical properties

The residual soils Vb and Lb have sandy clay loam, organic-rich, surfaces with blocky or prismatic clayey subsoils, reddish brown in colour, with good to poor (Lb) permeability. These leached acid soils developed on basic rock have the highest organic matter content in the Gorongosa – Cheringoma transect.

By contrast the three colluvial talus soils have a more neutral pH, between 6 and 7, loamier surface and good permeability. The more clayey nature of the gabbro derived colluvium compared to the sandier loam texture of the other colluvia is well expressed by their organic content which is highest on the heavier compact Cvb and poor on the sandier Cpg and Cpv.

Fernandes (1968a) has mapped the greater part of the Gorongosa massif as Lb soils derived from basalt, despite his knowledge that the parent rock is micropegmatite granite. Some error in titling may be the reason for this. One soil profile seen by the writer where hunters had dug an animal trap in the upper montane forest showed a profile similar to the description given by D'Hoore (1964: p. 167, Profile 28) for a ferrallitic forest soil from the Ivory Coast.

On the northern slopes of Gorongosa Mountain are areas of Amphibolite and Pyroxene Hornfels. These ferromagnesian minerals weather at a rate sufficient to provide significant amounts of available cations and trace elements for plant nutrition (Bear 1965). No samples are available from this area nor are there many peasant cultivators established there who could verify the cultivable period or productivity of these soils. The northern xerocline slopes are covered in savanna and thicket.

The talus soils Cvb derived from gabbro basic rocks show the highest extractable phosphorus content in the transect (> 60 ppm).

Drainage and erodability

Excessive runoff occurs on the mountain slopes, but where deep latosol solums are moistened to great depth, landslips occur. A large area of slumped topography occurs on the bench of the southern slopes, formed by gabbro derived soils. The sandier talus soils are all highly vulnerable to donga erosion where protective rain forest has been removed for cultivation. By contrast the compact red clayey latosols are highly resistant to erosion even when bared for cultivation. The reason for this resistance to erosion is apparently due to their relatively high free iron oxide content which maintains a high aggregate stability (Van der Eyk *et.al.* 1969: 95).

Environmental features

The greater part of Gorongosa Mountain is covered in rain forest, but the savanna and grassland slopes and summit grassland are subject to annual grass fires. Termite hills are absent from the main part of the mountain, thus termite influence will be mainly subterranean, in aeration of the soil and mineral input from the breakdown of organic material and from their excreta. The lower edges of the rain forest is being invaded by peasant shifting cultivators which has resulted in considerable erosion of the slopes and riverine sites. The lower slopes and basal pediment of the mountain has a dense human settlement of shifting cultivators, those on the better textured clayey loam soils using the same cultivation sites for up to twenty years without requiring a fallow period (see Chapter 7).

Midland Soils

Physical and chemical properties

The greater parts of the Midlands comprise poor sandy skeletal soils derived from Precambrian migmatitic gneiss. This general soil poverty is ameliorated by basic and pegmatitic dykes which produce deeply weathered latosols with higher cation and trace element content. Their texture allows for good water absorbing and retaining capacities compared to the excessively permeable sandy Pg soils. The rapid filtration of rainwater through Pg soils, and apparent loss in joints and fissures is probably responsible for the strongly seasonal nature of rivers which rise in the Midland crystalline region. The subsoils of the red latosols and the sandy fersiallitic soils, as well as their bottomland counterparts (Pgh), are all slightly more acid than their surfaces.

Vtc is a unique soil developed on Lupata sand and mudstones, a small occurrence of which is found between the Bunga Inselbergs and the Nhandue River in the west of the Rift. This soil is high in exchangeable cations,(particularly Ca and)Mg, as well as high extractable phosphorus, and has the second highest organic content after the latosols. Both Pg and the dambo Pgh have low organic content, typical of sandy soils, but the dambo soil shows a subsequent increase at 120 cm, unique in the transect.

Most of the Midland soils are shallow (> 40 cm), supporting *Brachystegia* savanna, but on interfluve crests and other sites are pockets of deep sandy soils to 120 cm depth which support islands of evergreen thicket within the miombo savanna. Thicket development on termite hills in the crystalline soils is poor compared to those on alluvia or duplex sands, possibly due to poorer moisture retention as they are sandier in composition.

Drainage and erodability

Surface drainage of the Midland soils is excessive due to the steep topography. The sandy soils are droughty and are vulnerable to sheet and donga erosion where slopes are cleared for cultivation. The loam textured latosols are resistant to erosion and have better internal water relations than the more sandy or clay varieties. Most of the dambos in the Midlands are relics and are becoming extinct by active incision and headward erosion of stream sources. Erosion of dambos, as with other alluvia, takes place primarily by undercutting and slumping of the upper solum typical of duplex soils. The dambo gley soils are inundated or waterlogged for nearly half the year, and for the second half of the dry season are dry and extremely hard due to their high clay content. This seasonal swing from hydromorphic to xeric condition is similar to that of the alluvial vertisols where high salt content is an additional factor for their aridity in the dry season.

Environmental features

The skeletal hill soils all support closed canopy *Brachystegia* (miombo) savanna with a medium to tall grasslayer, and are thus subject to annual and sometimes twice yearly fires. The dambo or drainage vlei soils support grasslands maintained by excessive hydromorphism, consequently they are burnt between midyear and the end of the dry season. The surface soils in the savannas are grey to black in the surface 10 to 20 cm due not only to finely divided litter, but largely to fine charcoal from aeons of fire.

Large areas of the Midlands south and east of Gorongosa Mountain have been modified by shifting hoe-cultivation. The longest permanent cultivation is on the latosols, and the shortest used are the sandy fersiallitic soils which require 15 to 20 years fallow to build up sufficient fertility for further cultivation. On the latosols, the primary *Brachystegia* savanna cleared for cultivation purposes is replaced during fallow by scrub-thicket. This secondary cover rehabilitates the nutritional status of the soil faster than under the primary cover allowing for much shorter periods of fallow (see Chapter 7). Apart form the moisture factor, soil productivity in sandy soils is tied almost exclusively to the nutrient level in the surface 10 cm.

Hill building termites occur throughout the Midlands and in addition mound building ***Cubitermes*** termites, which use faecal matter to cement soil particles, occur in the dambos. The litter in the miombo is largely consumed by termites and in this way bases and organic matter are transferred to, and concentrated in, the termitaria in otherwise extremely base deficient and nitrogen poor fersiallitic soils (Trapnell ***et. al.*** 1976).

Rift Valley Soils

The soil groups of the Rift floor are clearly separated,yet related by the differential sorting of sediments during their deposition under fluvio-lacustrine processes. The fine sediments associated with the basins and slacks show a textural gradation from finest Ah, to Chc, and A the coarsest of the depression and levee soils. All the other soils Cd, Chc, Cp, and Chp are related to the coarser sandier materials of alluvial fans, splays and colluvium of the Rift sides.

Physical and chemical properties

The striking feature of the Urema Trough sector of the Rift Valley is the extensive area of open short-grass plains. This system of floodplain grasslands is based almost entirely on saline, black, hydromorphic clays of the humic firm gley type. Interspersed are patches of A (non-hydromorphic) and Chc soils forming a mosaic. The hydromorphic gley appears to be dominated by montmorillonite clay as evinced by the large areas of gilgai microrelief of alternating basins and rises, and by their deep cracking when drying, and swelling properties when wetted (Table 5.2). The underlying factor resulting in gilgai microrelief in some areas,and their absence in others on otherwise similar vertisols,appears to be the occurrence of sands below the clays. It is suspected that where sand occurs they form a loose fluid subsoil (between 2 and 3 m depth) on which incipient sinkholes (the microbasins) can be formed by the expansion and contraction of the overlying clays.

These soils are saturated with calcium, magnesium,and sodium and contain a relatively high extractable phosphorus content. Free lime, as concretions, is found in patches within the profile, often in the friable grey sandy clay beneath the gley horizon as shown by profiles exposed in donga erosion. In many areas the floodplain vertisols are underlain by sand at 3 and 4 m depth.

The Chc, or mopane and ***Sporobolus*** soils, are closely related to the hydromorphic gleys and appear to be their dry land counterpart,occurring at a slightly higher level or step in the microtopographic sequence of slack deposits. Due to far less waterlogging and lack of actual inundation, the exchangeable cations, particularly calcium and sodium, in these soils show the highest values in the Rift.

The large termite hills built by ***Macrotermes*** termites on the convex surfaces of the hydromorphic gleys are ringed with a basal pediments of white salt due to leaching of the salt-rich subsoil brought to the surface to form the growing apices of the hills. The evaporite deposits are usually bare of plants, or support one grass species, ***Sporobolus virginicus***, and in the past were collected for domestic use by the tribespeople.

Of the more leached sandy soils of fans and colluvial deposits one, Chp, has an impervious subsoil with high alkalinity. All the others, and the surface of Chp, are base deficient soils, Chd showing development of laterisation and redder chromas. Of this group Cd and Chd with loamier topsoils have relatively high extractable phosphorus content.

As clearly demonstrated by the profiles in Fig 5.12 organic matter content is highest in the finer textured soils, particularly the hydromorphic humic gleys which crack deeply in the dry season, allowing for a high build up of organic material throughout the profile as it is washed into the cracks by the first rains. The poorest in organic material are the sandy Cp soils. In sum the pedograph for the Rift Valley shows the largest range of pH and salinity, a much lower phosphorus range but generally with higher overall content (Fig 5.12).

The most saline soils in the transect occur in the Rift Valley, and these support ten different plant communities as a mosaic (Fig 5.14). It is not clear whether certain soil factor combinations and/or drainage differences (Fig 5.15) which influence soil moisture balance and the severity of sodic effects are at play, or whether plant succession is responsible. The evidence displayed by Fig 5.14 shows one group of communities on topsoils that are leached and acid due to either their sandy nature or to excessive waterlogging, and a small group of halophytic communities on soils which are alkaline throughout the profile. It is significant that where the shallow sandy acid surface is truncated by sheet erosion the remaning profile is alkaline throughout. The removal of the sandy surface immediately alters the soil moisture balance to extremely xeric and sodic conditions. The succession of fine soils in the Rift Valley related to different periods of sedimentation, and microrelief control of length of flooding and waterlogging, shows that the hydromorphic base saturated vertisols evolve to aridosols, as typified by the mopane soils, solely as a function of reduction in moisture content.

TABLE 5.2

Gilgai Soil Profiles

MICRO–BASIN	MICRO–RIDGE
Site: Urema floodplains of Rift Valley floor (near Sungue drainage)	*Landform:* 2° slope, alluvial plain *Substrate:* Vertisols of alluvial basin
Plant Cover: *Echinochloa stagnina* and *Vossia cuspidata* grasses	Plant Cover: *Cynodon dactylon* and *Digitaria swazilandensis* grasses
0–5 cm Black (10YR 2/1) clay, firm moderately developed blocky structure; no lime concretions; pH (H_2O) 5,7; Resistance 660 Ohms; abundant grass roots; relatively sharp lower boundary.	0–8 cm Black (5Y 2/1) clay; very hard, strongly developed, blocky structure; wide and deep vertical cracks; no free lime; pH 6,5; Resistance 380 Ohms; abundant grass roots; relatively sharp lower boundary.
5–20 cm Black (10YR 2/1) clay, friable granular structure; no lime concretions; pH 5,5; Resistance 620; frequent fine and medium roots; merging lower boundary.	0–15 cm Black (5Y 2/1) clay; gley; very hard; strongly developed course blocky structure; slickensides; no free lime; pH 6,4; Resistance 210; frequent grass roots; merging lower boundary.
20–50 cm Black (10YR 2/1) clay, gley, slickensided wedge shaped aggregates; friable; break down to granular structure; no lime concretions; other profiles contain some free lime deeper down; pH 5,4; Resistance 260.	15–45 cm Black (5Y 2/1) clay; gley; extremely firm; coarse angular blocky structure; slickensides; no free lime; pH 6,1; Resistance 140; merging lower boundary.
	45–60 cm Olive black (5Y 3/1) clay; gley; strongly mottled red and orange soft Fe/Mn concretions; firm; moderately developed blocky to prismatic structure; slickensides; no free lime but other profiles contain lime concretions; pH 6,3; Resistance 90.

Summary:

– Friable granular structure in easily broken aggregates with slickensides	– Very hard to firm, strongly developed, coarse blocky structure with slickensides
– Gley horizon deep.	– Gley horizon shallow.
– Brownish black colour.	– Olive black colour.
– More acid, less saline, moister soil.	– More neutral, more saline, drier soil.

– Seasonal Succession: In the midwinter dry season *Cynodon* and *Digitaria* invade the microbasins from the microridges where they have long turned brown, and form green patches amongst the remains of the hygrophilous *Echinochloa* and *Vossia.* The herbivores graze in the same pattern following the change in soil moisture.

Due to their much higher fine content, alluviosols and aridosols have a much higher available moisture content than most soils, but due to their salinity this moisture is lost to plants as it is bound up with the salts and the finest gleyed particles (Serrano 1973). For this reason the grasslands on the faintly inclined higher slopes of the floodplains dry out several weeks after cessation of the rains. The first grassland to go brown is the sodic ***Sporobolus kentrophyllus*** community. By contrast, the ferrallitic and fersiallitic clayey soils have a poor moisture retention capacity unless they are of a loamy texture (Serrano 1973). On the Serengeti Plains, where all soils have high levels of base saturation Anderson & Talbot (1965) also suggest that physical factors such as effective depth above impermeable horizons, or absence of a gley horizon and texture are more important than nutrient factors in determining the grassland pattern.

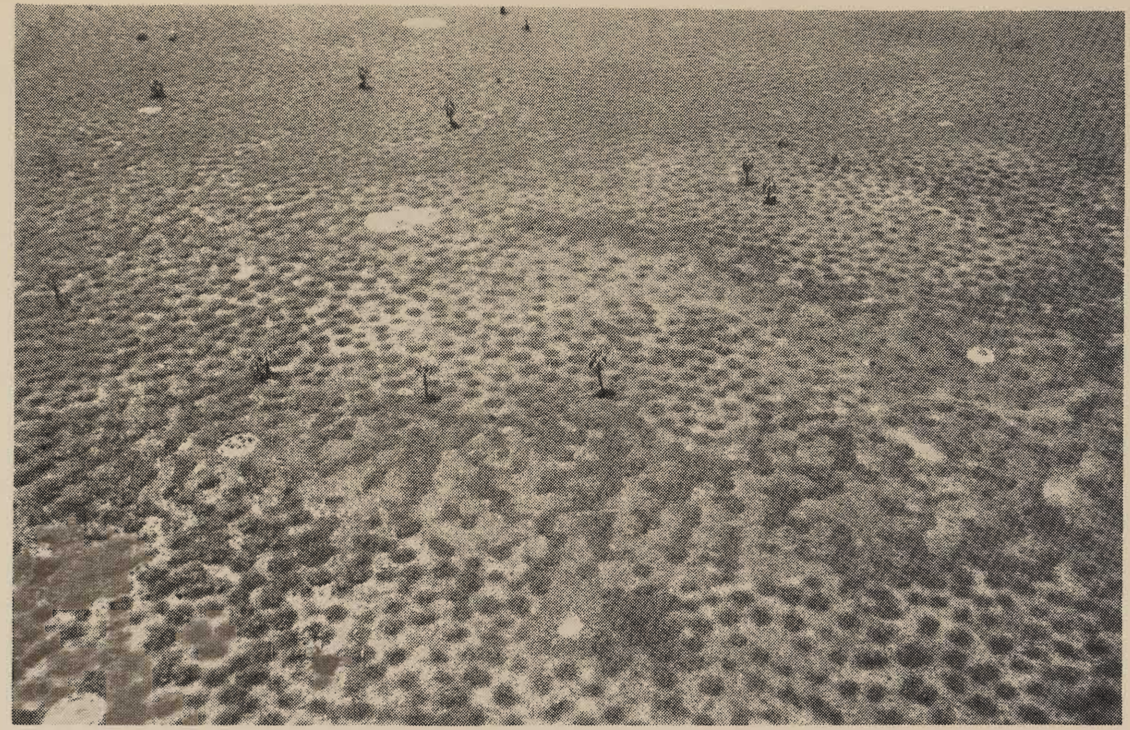
The relatively poor to restricted drainage in the sandy clay topsoils of the Cd and Chd soils provide temporarily waterlogged or puddled conditions for the shallower rooted grass stratum of the savannas, and floodplain grass species such as ***Digitaria swazilandensis*** abound as a lower layer amongst medium to tall ***Panicum, Digitaria, Urochloa*** and ***Hyparrhenia. Hyparrhenia rufa*** is typical of the heavier loamy clays and is used by tribal cultivators as an indicator of soil areas with high potential for cultivation on semi-permanent or recurrent basis (see Chapter 7 Man).

Drainage and Erodability

Although all the Rift Valley soils are subject to seasonal waterlogging, anaerobic conditions are only long lasting in the gleyed soils, and temporary in the porous, sandier non-hydromorphic alluvium, fan and splay deposits. However, even the sand fan deposits which support dry forest are waterlogged in summer to within 50 cm of the surface. At this depth free water is encountered as it is held up by the coarse gley at 120 to 150 cm below (Fig 5.15).

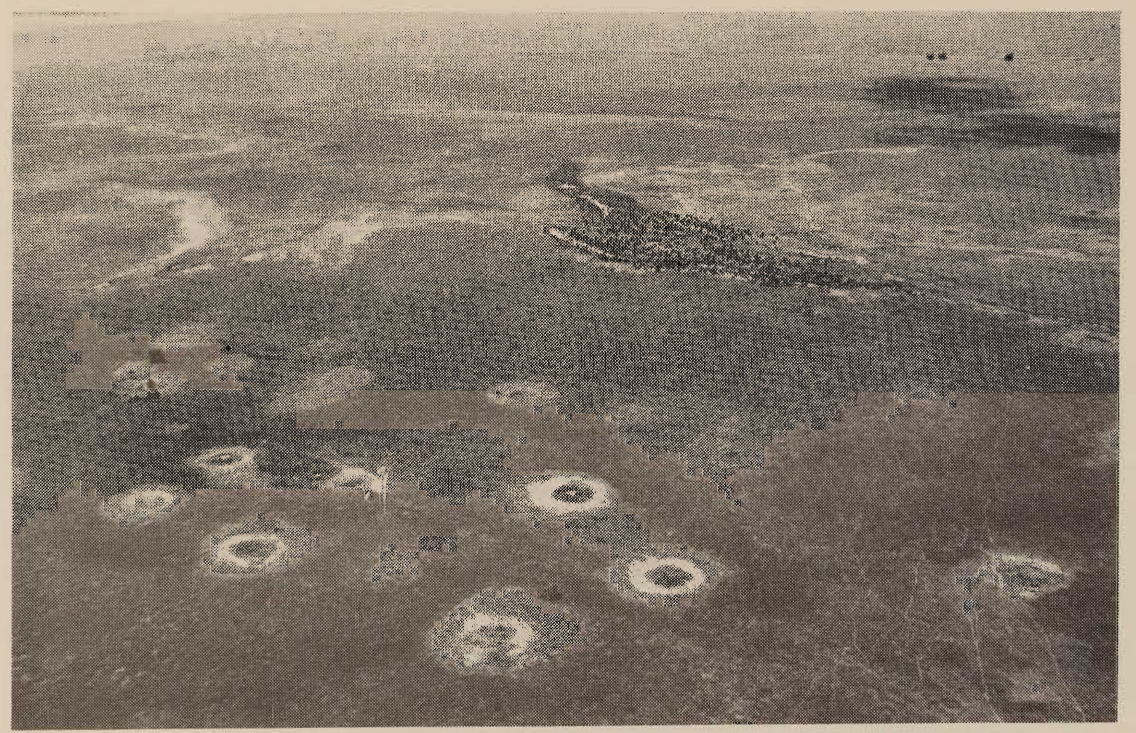
The Cd and Chd soils tend to have a surface which is easily puddled, but is relatively free draining below 20 cm. Sheet erosion is evident on all these clayey surfaced soils, as can be seen by the pedestalled grass tufts. As shown in Chapter 6, the Rift Valley alluvial plain is now in an intermediate phase of erosion where most of the vlei basins are in the process of extinction through headward erosion of nickpoints and donga formation. Despite their deep cracking nature, the humic gley vertisols are strongly cohesive and erosion is primarily by donga formation from undercutting and slumping. For this reason most of the basin and slack areas on the Rift floor are perched above the incised drainage and will remain vlei areas until lateral incision breaches the low gradient responsible for the time lag between incision and loss of vleis.

PLATE 6 GILGAI, SALT RINGS & PANS

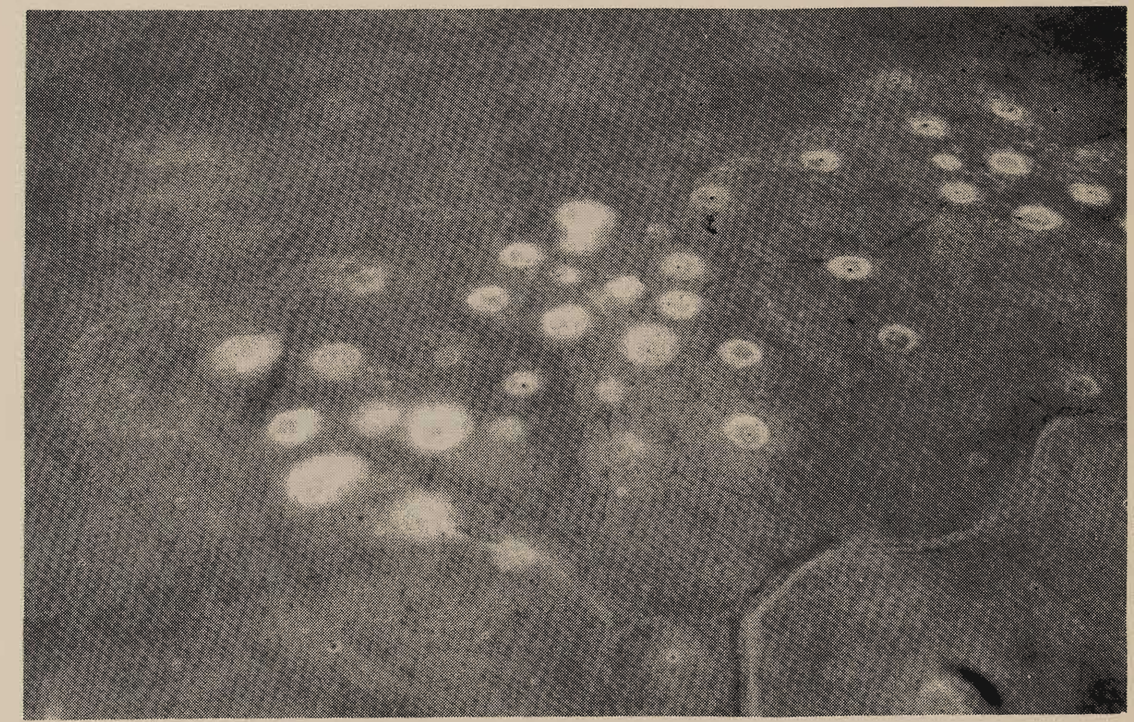


(A) Gilgai microrelief on saline vertisol clays of the Urema floodplains. The microbasins are the dark oval patches of hygrophilous grasses separated by the light areas of lawn grasses on microrises and broader convexities. Isolated trees of *Hyphaene benguellensis*, and eroded (white) termite hills.

(B) Mopane savanna woodland leafless in October, depicting mature community which originally invaded gilgai floodplain soils on the microconvexities resulting in a clumped physiognomic pattern. Seasonal rain-filled pans probably developed on eroded termite hill sites (see A, C, D here).



(C) Salt rings developed on micropediments of termite hills by downwash leaching of salts from saline subsoils brought to the surface by the termites. The evaporite deposits are either bare or sparsely covered by *Sporobolus virginicus*. Other hills have been eroded down to form pans (white centred). Large herd of buffalo concentrated on slack marsh pastures in background.



(D) Pans formed in the centre of salt rings by erosion of the termite hills, on convex area of the floodplains. Note initial stage of canalized game path link between main drainage line and the pans formed on termite hill sites (foreground).

Effective flooding and/or waterlogging is thus cumulatively less effective resulting in aridification of the hydromorphic base saturated vertisols and their conversion to aridosols. Hydromorphic grasslands are thus being replaced on every front by savanna and thicket, and forest elements are invading the donga drainage lines due to increased aeration and alteration of the water balance to a riverine free-water situation. Concentration of sheetwash and lateral subsoil drainage towards the incised drainage lines thus magnifies the seasonal alternation of flood and xeric extremes on the alluvial plains, and maintains all year mesic to wet conditions on the incised drainages. In addition to the larger donga incisions are many small nickpoints initiated on the gentle slopes of the alluvial basins.

If floodwaters from Gorongosa Mountain spread out on the Urema Plains before heavy falls of rain have occurred locally, a considerable amount of this water flows down the deep cracks in the vertisols to the underlying phreatic watertable, before the profile is sufficiently wetted to expand and become impervious.

In addition to the wash of material from erosion toward depressions, the Urema Lake waters derive a direct daily input from 3 000 resident hippo, which graze the surrounding grasslands at night. Due to their habit of establishing footpaths outward from lakes or rivers and between basins, hippo are a major influence in initiating and accelerating incision of floodplain and vlei basins, and thus their dessication and reduction in size.

Environmental features

Except for the short floodplain grasslands of ***Cynodon dactylon*** and ***Digitaria swazilandensis*** which usually escape fire, all the Rift valley savannas are burnt annually. The most destructive fires are on the sandy clay Cd and Chd soils where tall ***Hyparrhenia*** grasses occur, and also a giant form of ***Panicum maximum***, which attain 4 m in height reaching into the lower branches of the savanna trees. On the treeless floodplains large conflagrations occur on the vertisols supporting tall ***Vetiveria nigritana*** and ***Setaria eylesii*** grass areas. Fires begin chiefly in May (earlier in dry years) and occur through until the first rains in November or when the grass fuel is exhausted. Most forest and thicket patches escape being burnt due to the change to shorter grass cover on their edges or suppression of grass by trampling by wild ungulates.

The concentration of over 35 000 wild ungulates on the Rift Valley floor probably makes an important contribution to the organic matter and nutrient status of the soils. Such an influence could be greatest seasonally at the time of increased

TABLE 5.3

Examples of the differential penetration of unseasonal and first summer rains on the Rift Valley Floor

(recorded 24 hrs after cessation of rain)

Rain infiltration *cm* depth	
	Example 1. Unseasonal Rain of 4 mm on 27 Aug 1971 (drizzle from stratus)
10	Base of bare termitarium (sandy clay)
6–7	Sandy clay loam ***Piliostigma, Acacia, Sclerocarya*** Savanna – Cd
6	Beneath mulch of flattened grass (***Urochloa, Panicum, Digitaria***) – Chd
5–6	Microperennial ***Cynodon-Digitaria*** floodplain grassland on vertisol – Ah
5	Beneath base of grass tufts (***Panicum, Digitaria***) – Cd/Chd
4–5	Saline soils with a 5 cm sand veneer (***Sporobolus*** grass cover) – Chc
4	Deciduous Thicket on sand (bare of leaves)
1	Sheet eroded (sand veneer removed) sodic clays – Chc
0	Dense mulch of flattened grass.
	Example 2. First summer rain of 11 mm on 14 Oct 1971 (torrential rain from coalesced CuNi thunderstorms from the SE)
12	***Echinochloa-Vossia*** vertisols (Dingedinge area) – Ah
10	***Borassus*** clay loam – A soils
8	Thicket on sand
8	***Urochloa-Digitaria-Panicum*** sandy clay – Chd
7	Saline soils with a 5 cm sand cover – Chc
5	Sandy clay loam ***Piliostigma, Acacia, Sclerocarya*** – Cd
2	Sheet eroded sodic clays – Chc
	Example 3. First summer rain of 32 mm on 24 & 25 Oct 1972 (steady rain from SW frontal stratus)
30	Dry Forest on sand
25	Beneath pile of elephant dung on Cd soils
22	Beneath base of large tufted grasses on Chd soils
21	Beneath mulch of flattened grass and leaf litter on Cd soils
20	***Acacia nigrescens*** savanna – Chd soils
14	Summit of termite hill covered in thicket
14	Saline soils with a 5 cm sand veneer (***Sporobolus*** grass cover) – Chc
14	Microbasins of gilgai on floodplains – Ah soils
10	Bare ground with algal patena – Chd soils
10	50° rainward slope of termite hill
6	Microconvexity of gilgai on floodplains – Ah soils
2	Sheet eroded sodic clays – Chc.

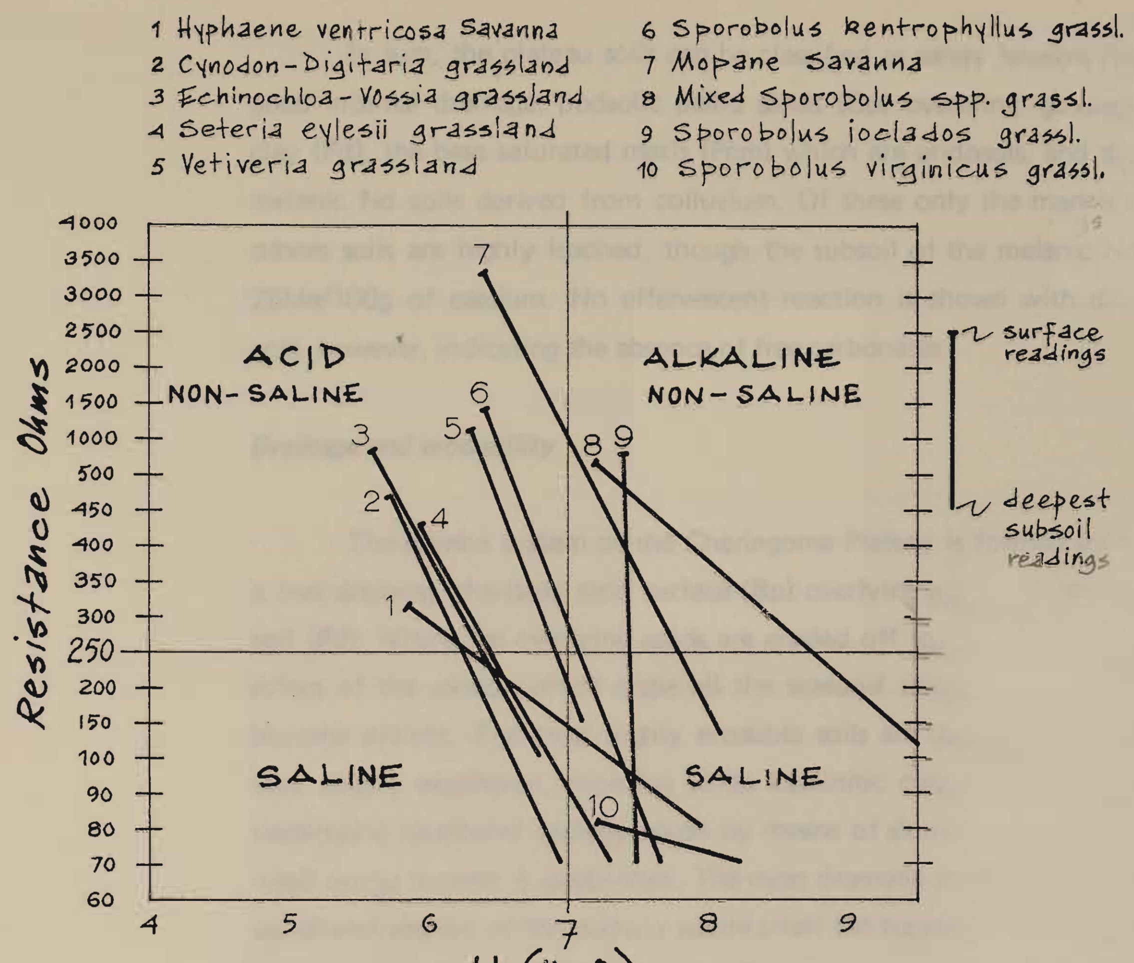


FIG 5.14 SALINE HABITATS

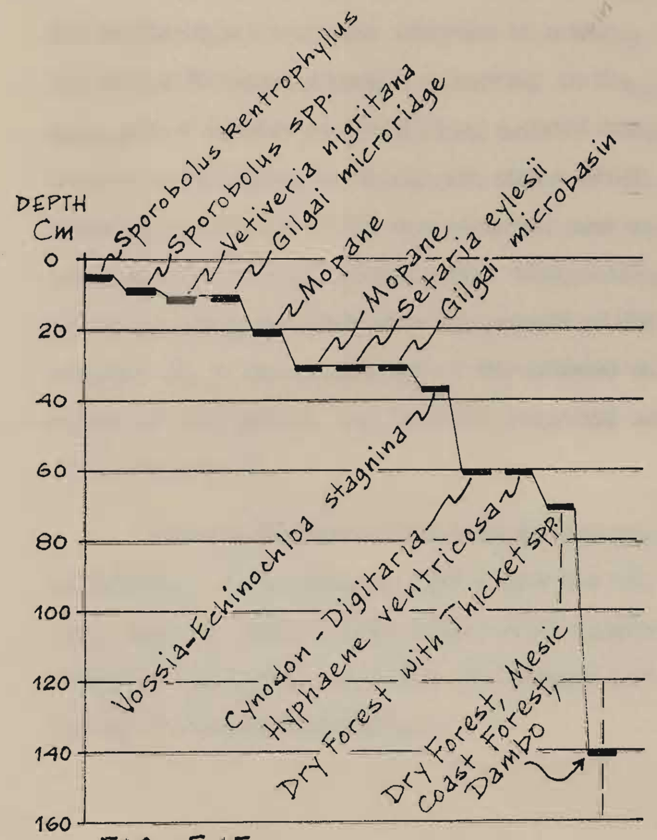


FIG 5.15
DEPTH OF PAN HORIZON
FROM SURFACE

termite and scarabid beetle activity during the rains and autumn, and where high concentrations of wildlife occur on deep cracking vertisols in the dry season.

An important influence in soil water relations is the mulch of grass flattened by large herds of buffalo and elephant, or from lodging of tall grass at the end of the dry season. In these sites greater penetration of rain occurs (Table 5.3) and thus better primary production of preferred food grasses such as ***Urochloa mosambicensis, Digitaria milanjiana*** and ***Panicum*** species.

In the past, shifting cultivation and cotton cultivation took place in the south of the park between the floodplains and the Pungue River. Over 20 years have elapsed in which no further disturbance of the surface soils has occurred, though extreme compaction or surface capping is still evident in some areas of secondary scrub.

The soils of the Rift Valley are muddy and soft in the wet season where the surface is composed of clay and/or loam, and these and the sandy clays and vertisols, in particular, set in the dry season and become extremely dry and hard requiring a pick to construct pits.

Cheringoma Plateau Soils

Physical and chemical properties

Due to the final phases of geologic deposition, the summit of the plateau is of inherently infertile silica sands. According to the explanatory notes on the geological sheets, these subsequently underwent a genesis of eluviation and illuviation which resulted in the development of a mosaic of sandy red latosols with peaty, highly acid bogs in the dambos and depressions. Active, deep ravine erosion of the Riftward faulted slopes of the cuesta exposed the limestones and marls underlying the sand mantle of the summit. Of these only the marls (Pcm) have resulted in soils with high base saturation and alkaline subsoils. The remainder of the Cheringoma soils are thoroughly leached, as demonstrated by their subsoils having a higher acidity than the surface. This contrasts with the Rift Valley soils where all but the sandy Cp soil are neutral or have more neutral or alkaline subsoils. The cuesta soils are also all markedly deficient in extractable phosphorus. The soil diversity pedograph for the Cheringoma Plateau shows the lowest ranges for P and salinity, but a much larger pH range than the mountain or the midlands due to the influence of the limestone geology (Fig 5.12).

Organic matter is again lowest in the sands Vp and Pd and highest in the heavier textured Vcd, Pcm, and Nd soils, and of these the highest content throughout the profile occurs in the red Vcd latosols derived from crystalline limestones.

In sum, the plateau soils can be classified as sandy latosols (Vp and Vcd) with good internal drainage, podsolic pallid sands (Bp) overlying groundwater laterite or clay (Pd), the base saturated marls (Pcm) which are aridosols, and the heavy textured melanic Nd soils derived from colluvium. Of these only the marl is base-rich, all the others soils are highly leached, though the subsoil of the melanic Nd contains up to 28Me/100g of calcium. No effervescent reaction is shown with dilute hydrochloric acid however, indicating the absence of free carbonates.

Drainage and erodability

The dambo system of the Cheringoma Plateau is formed by a duplex soil with a free draining, eluviated sand surface (Bp) overlying a leached, impermeable clay subsoil (Pd). Where the overlying sands are eroded off to expose the Pd clays the sponge effect of the sands, (which traps all the seasonal rainfall) is destroyed, and dambos become extinct. The most highly erodable soils are the Pd clays which appear to be very deeply weathered, exposing white kaolinitic clay at 20 m. These soils and the underlying weathered geology erode by means of slumping on a large scale once headward donga erosion is established. The most dramatic area eroded in this manner is the southwest section of the plateau where small flat-topped remnants of the older duplex surface remain as interfluves or peninsulas.

The red sandy latosols, like their gabbro and dolerite derived counterparts from the Midlands, are relatively resistant to erosion and these form scarps where backwearing of the Riftward slopes is occurring. In the central and northern section of the plateau, active erosion of the plateau summit materials is held up or damped by the exposure of limestone or sandstone strata which are resistant to headward incision. In other parts soil truncation has occurred over extensive areas leaving a veneer of skeletal soil over strongly cross-jointed, horizontally bedded, limestones. Solution cavity slumping seems a prerequisite for growth of the ravines which have cut back into the plateau. As in the southwest of the plateau active headward erosion of the seaward slopes of the central area has also occurred with narrow deep valleys formed in the clayey sediments.

Toward the end of the rains, springlines are evident on the slopes of the rounded landform of the plateau crest where the impervious clay horizon comes to the surface. Some of these impermeable horizons, cemented as ferricrete (ouklip), are now exposed at high levels and form the present surface capping of tributary interfluves in valleys of the seaward drainage.

In sum, there is active reduction of the old surfaces which are efficient high watertable aquifers as they trap the total rainfall, and extension of waterlogged and/or xeric clay surfaces each supporting different ecosystems. Into the latter, fingers of forest are invading the banks of the incising donga drainage. In areas where active sheet erosion of the pallid Bp sands is taking place, the large hill termitaria are the last surfaces to be eroded, relics of the first pioneers of the dambos of the past. The termite hills have thus acted as the first sites for woody plant invasion in a high watertable system and now act as the last sites of thicket and forest clumps when the intervening terrain is being converted from closed savanna and forest to open scrub savanna or grassland.

Environmental features

The Cheringoma Plateau crest has a seasonal mean summer rainfall of between 1 000 and 1 200 mm, with a winter dry-season interrupted frequently by light showers from tailing-off coastal rains. The autumn and midwinter is characterised by high humidity at night due to nocturnal orographic fog, and the heavy guttation of plants on high watertable substrates. Unlike the Rift Valley and hinterland, no mild period occurs on the plateau and the coast (Fig4.13). As in the remainder of the system, annual veld fires occur sporadically over the dry season period from the autumn until spring. from the autumn until spring.

At the heads of the Riftward drainage are dambo relics which are waterlogged until the mid dry season, and newly formed scarp-edge dambos which are waterlogged by lateral ooze from the sand-clay contact exposed by scarp retreat.

Cultivation on the Plateau is associated mainly with settlements found along the old road to Inhaminga some 10 km from the present road and rail route along the divide, on the Riftward slopes. Both the red latosols and some stream margins in various soil types have been cultivated in patches. More recently, ravine forest has been cleared for cultivating on talus soils on the alluvial floors at the outlets to the ravines. These are depicted in Fig 6 and in Chapter 7.

Termite hills built by ***Macrotermes*** are abundant on the plateau crest and attain their largest dimensions (6–7 m high) on the pallid duplex sands and dambos, and their highest density of 3/ha. In the skeletal soil areas on limestone, termite hills are rare or absent.

Cheringoma Coast Soils

The Coast soils have resulted primarily from redispersal and deposition of the plateau summit sands and sandy clays over the duplex Bp – Pd on the one hand, and from riverine and estuarine (marine alluvium on the coast front) on the other, deposited in a seasonally flooded or waterlogged environment of extremely low gradient.

Physical and chemical properties

All the fan and slack soils are extremely leached, acid, high watertable sands which are cemented in parts as ferricrete or ortstein under the fynbos communities. The coast alluvium of heavy textured dark soils is a mosaic of many types related to their depositional history and microrelief. Some are leached with porous subsoils (eg. that supporting ***Diheteropogon*** grassland), and others are highly saline with firm gley subsoils (eg. ***Brachiaria*** grasslands).

The estuarine or mangrove soils were not sampled. Estuarine soils develop under reduced conditions and have a high sulfide content derived from seawater during tidal inundation and from the high input of raw organic material from the mangroves and their associated animal life (D'Hoore 1964: 72; Odum & Heald 1975). Within estuaries there are mosaics of soils with different properties, one kind supporting ***Rhizophora*** and another ***Avicennia*** (D'Hoore 1964). Analysis of ***Avicennia marina*** soil from the central west coast of Madagascar facing Mocambique, showed an alkaline (pH 7,2) yellowish brown clayey surface horizon overlying an acid (pH 5,4) greyish blue, rusty-orange mottled, sandy clay subsoil. Extractable cations were highest in the surface (especially Na and Mg) and extremely low in the subsoil (D'Hoore 1964: 135, Profile No. 5). Evidence for the importance of the mangrove ecosystem as a highly productive substrate in littoral marine waters is advanced by Odum & Heald (1975: 129–136). The estuarine mangrove swamps of the Cheringoma Coast are protected within bays formed by low barrier dunes covered in thicket, and long sand spits form the estuary mouths.

Drainage and erodability

The marked poverty of the geology and soils of the seaward slopes of the Cheringoma cuesta, with extreme leached conditions dominated by silica sands has resulted in extensive development of groundwater laterites and ortstein, with highly acid bogs, vleis and swamp forests in the dambos. All the seaward drainage is thus characteristically of the 'blackwater' type which develop on podzolised profiles.

Surface permeability of all the cuesta sands is high, if excessive, but high watertable conditions pertain at varying depths between 80 and 200 cm below the surface. Due to this high porosity and low relief the sands trap almost the whole annual rainfall except that intercepted by the plant cover and last by evaporation. The major water movement through the soils is lateral giving rise to oozes, springlines and bogs.

Extensive areas of the sandy high watertable coast plains thus become shallowly flooded to about 20 cm during the summer months. The flooding clearly shows how the grasslands and wooded cover are separated by microrelief, the latter confined to the convexities of the plains, which escape flooding. The heavier textured alluvial soils which lie between the seashore and the inland sands of the cuesta are also flooded during the summer months by runoff from the cuesta. In the winter dry season high tides and invasion of saline phreatic water has major reach inland, with lesser influence during the rains. As an extreme example; during construction of the Caborabassa Dam subsoil invasion by saltwater penetrated the Zambeze Delta to 70 km inland in the dry season killing fields of sugar cane.

As the coast is a plainsland of low altitude above sea level, striking erosion is evident only on the beaches and mouths of estuaries. To a lesser extent lateral undercutting of banks by the major streams of the seaward drainage results in slumping of banks and their cover. Scattered over the plains are many scoop-outs, some of which form small lagoons or pools, which appear to have been formed by floodwaters breaching the sides of streams and removing an oblong depression of sand.

Except at the actual estuary mouths, where accretion is occurring, the whole Cheringoma Coast, in keeping with the remainder of the Mocambique Coast, is in a phase of erosion (Tinley 1971b). Beach erosion by waves have already exhumed extensive areas of semi-consolidated mangrove and reedswamp muck soils. Extensive sections of dead and dying mangroves now stand exposed to direct wave action at high tide. Wave action is undercutting the low barrier dunes causing extensive slumping and death of the dune thicket cover carried with the sand. Slumped areas then become initial sites for parabolic dune formation by wind erosion. Evidence of old scars shows that dune formation has occurred in a saltatory manner related to phases of sea erosion or to accretion.

Environmental features

Soils of relatively high organic content on the coast are the floodplains, swamp forest, peat bogs and mangroves. The savannas and dambos are poor in organic matter particularly as they are burnt annually and the forested sands are rich in organic matter only within 5 or 10 cm of the surface. As soils are derived chiefly from a silica dominated geology they are both inherently poor and extremely leached with electrical resistance (R) readings as high as 17 300 ohms in the podzolic (Bp) sands; compared to the most leached dry forest soils in the Rift Valley floor which attain 7 200 ohms. The red sands covered in ***Brachystegia*** savanna are much less leached, with readings of 7 100 ohms, comparable with the sandy ferriallitic miombo soils of the Midlands with readings of 9 700 ohms. By bringing to the surface the deeper clay horizons, termite hills in the highly leached podzolic sands, provide islands of heavier textured and more fertile soils with a dramatic change in resistance to 700 ohms.

The alluvial grasslands are burnt twice annually by hunters to attract game, in the normal dry season period and during dry spells in the midsummer rain season. This produces a quiltwork of grasslands at different stages of growth attractive to the large wildlife population of the adjacent Marromeu Buffalo Reserve. Here over 23 000 wild ungulates are concentrated in an area of 1 600 km. Buffalo make up 16 000 of this total and some of the herds number over 2 000 animals. These herds seldom move far from their preferred pastures, and high nutrient return must be responsible in part for the virility of these floodplain delta grasslands (Tinley 1969, 1975). The ungulate population on the strip of the delta alluvium south of Marromeu is very much lighter, and in small highly dispersed groups in the coast hinterland on the Cheringoma.

Shifting cultivation occurs in patches, related mostly to the distribution of lumber activities. Forests are cleared for cultivation and utilised for up to 5 years before new clearing is required. As an indication of the high watertable properties of these soils, rice crops are grown in succession related to the degree of waterlogging. The dambos are not generally used for cultivation unless they have been incised by stream action.

In sum, the coast soils are predominantly highly leached, high watertable quartz sands with groundwater laterite and ortstein developed in the subsoils. They are the poorest soils in the whole transect and support some of the richest forests. Other sands are podzolic with a pallid subsoil overlying an impervious C horizon. The only base saturated soils in the entire area of the coastward slopes of the Cheringoma cuesta are the heavy clay alluvia of the southern end of the Zambeze Delta near the sea. Forest and grassland are on physically and chemically similar high watertable sands, microrelief, and thus degree of waterlogging and flooding being the sole control of their spatial distribution – forest on convex surfaces and grassland on flat or shallowly concave surfaces. ***Brachystegia*** savanna on the duplex pallid sands is seral to forest and that on the deep sandy red latosols has a well developed grass stratum, and thus appears to be in a state of homeostasis as a savanna system.

KINETIC EVOLUTION OF SOILS

In the Gorongosa—Cheringoma transect, two examples of quite different textured soils will be used as examples of soil evolution influenced by external geomorphic changes and internal pedogenic changes. This succession can be under an unchanging climate or due to changes in climate. One is the firm humic gley of bottomlands (alluvial vertisol), and the other the sandy groundwater laterite, both of which are developed under hydromorphism and weather to form similar tableland morphology on almost any scale. The changes occurring within these soils due to external and internal influences is made strikingly conspicuous by the changes in their vegetative cover, related principally to changes in their soil moisture balance.

Alluvial Vertisol

The fine textured clays, probably dominated by montmorillonite, with deep cracking and swelling properties and a strongly gleyed subsoil are typical of the slacks and basins of the Rift floor. These base-saturated clays were probably laid down in shallowly flooded depressions, followed by drying out and evaporation in the dry season. A succession of fine vertisols were deposited on the faint slopes formed by the slacks or basins so that the upper members were less influenced by flooding and the lower lying members influenced more by hydromorphism. As changes in degree of waterlogging and length of flooding occur, related to changes in run-off, the vertisol soils, which support floodplain grasslands, are invaded from the margins by clay-savanna tree species including mopane ***Colophospermum mopane, Acacia borleae*** and ***Acacia polyacantha.***

If the same climatic regime is maintained, the major factor responsible for reducing soil moisture content is the incision by headward migration of nickpoints which breach the local base levels responsible for the original hydromorphic conditions.

By providing better drainage conditions, which decreases the internal waterlogging of the vertisol, increased alkalization of the B horizon takes place modifying the acid surface soil increasingly toward neutral or alkaline conditions. In this manner, in simplistic terms, a hydromorphic soil evolves into an aridosol.

The subsoil claypan becomes increasingly compacted or cemented to a hardpan or calcrete (in arid regions). Incision and headward erosion of nickpoints exposes the pan horizon and a stepped topography results from the microscarps formed and the redeposited material from the nickpoints. On each surface released from excessive waterlogging a new invasive phase of savanna trees occurs giving different even-aged stands on successive surfaces.

In this way hydromorphic grasslands are invaded and replaced by mopane, for example, as the soil becomes an aridosol: well exemplified elsewhere in southern Africa such as in northern Botswana on the 'fossil' slack soils of a mega-Okovango Delta. Further soil evolution then depends on the durability of the hardpan to erosion and thus contraction of the aridosol area and its replacement by broken down, transported and redeposited soil and/or pan rubble material which either provides further heavy clay areas or a mosaic of sand and clay as shown in the Limpopo Valley in Moçambique.

Sandy Groundwater Laterite

The example used here is from the high watertable sands of the Cheringoma Plateau, which were laid down in a littoral freshwater fan environment. Extreme leaching, due to maximal rain penetration on a quartz sand surface, resulted in illuviation and deposition of nutrient-poor clay to form a pan layer. At this stage only grasslands of the dambo type could have been supported over the greater part of the cuesta due to low relief and maldrainage conditions (see Fig 6.3).

Changes in primary base level resulted in incision of fan interdistributary slacks and the dambos, increasing aeration through more efficient runoff. The iron-rich claypan which developed under waterlogging became more cemented over large areas forming ferricrete (ouklip) and ortstein. In its indurated state ferricrete is well drained due to jointing and irregular cracks and allows invasion of woody plants. However invasion of woody plants is not dependent on the final cemented state of ferricrete but commences in the claypan state where better drained convex surfaces or incised sites occur.

Under the same geomorphological processes described above for the vertisol, tablelands are formed where the ferricrete is exposed and the grey, more clayey, kaolinitic material below the pan horizon is extended at the expense of the surface sands and hardpan. Under such conditions clay systems (eg. acacia, mopane) replace the sand system (eg. forest, miombo or ***Terminalia***). The eroded, transported and redeposited sands either form coalescing fans of duplex sands at the break in slope, as shown along the Rift-Cheringoma junction, or the material results in aggradation and braiding of existing rivers.

The above examples of continuous or kinetic change in soils rather than development towards a stable end point (climax) is paralleled by the vegetative cover, the ecosystems and their faunal components. These aspects as related to geomorphic and edaphic changes will be dealt with in Chapter 6.

Most soils, even in residual sites, are therefore polygenetic as they bear the imprint of more than one soil-forming episode due to changes in soil endoclimate (moisture balance) and/or to climatic change. It is important to emphasise that different soil forming conditions do not require a change in climate ***per se***, but can evolve solely through the influences of geomorphic and edaphic change.

5.8 SOIL MOISTURE BALANCE

INTRODUCTION

The soils of the Gorongosa – Cheringoma area are summarised in graphic form by Fig 5.12. Although the plant species composition in various communities may be influenced by soil properties such as nutrient status, pH, salinity and texture, the overwhelmingly important factor determining the spatial distribution of forest, savanna and grasslands is soil moisture balance. This balance is a function of a single feature, or several in combination, ie. texture and consistence, presence or absence of a pan horizon, distance of this horizon from the surface, macro and microrelief, and salinity.

Although most of the data in this section refer to the Gorongosa – Cheringoma transect, the writer obtained evidence on edaphic features from a diversity of systems across southern Africa. Soil pits, dug to a maximum of 7 m depth, and auger samples were made at different seasons, and before and after rains. Whilst no quantitative soil moisture determinations were made, the moisture status of profiles were empirically assessed by sight and feel. The most accurate method for determining the subtleties of microrelief control of drainage and soil moisture balance on plainsland is by traversing and observing surface flow during and just after rain, and at flood and ebb periods. This procedure is not only precise but is conclusive and rapid, and a prerequisite for meaningful interpretation of measured and plotted levels.

Ideally, the kind of in-depth study required of this subject is that exemplified by Branson ***et. al.*** (1970, 1976). They use two measurements, osmotic stress, and physical soil moisture retention force or tension (stress). Together these are called ***total soil-moisture stress*** and the use of this measurement is more meaningful than the standard soil moisture-content analysis. For example, clayey and sandy soils with the same moisture content have different stress values or moisture availabilities (Branson ***et. al. op. cit.***).

GENERAL FEATURES AND EXAMPLES

In montane situations, with high orographic rainfall, grasslands occur on soils with an impervious or poor subsoil drainage (indicated by mottling in the subsoil horizons). Forest occurs on free draining or relatively porous soils of a reddish orange chroma (indicating better aeration), and swamp forest occurs in boggy drainage lines or vleis. The soil under grassland is waterlogged when rains occur and dries out excessively during dry periods. The forest soils are moister, and at the same time better aerated even in swamp conditions where there is either running surface water and/or the trees are clumped on mounds above the general anaerobic bog conditions. It is significant that as soon as grass soils in montane areas are incised by donga erosion and slump scars, resulting in better moisture conditions and aeration, forest initials are the primary invaders on the new surfaces (eg. see phographs in Schroder 1976). Many of the mature forest patches in these sites are primary and not fire relics as interpreted by the majority of workers (eg. Chapman & White 1970), including geomorphologists influenced by the fire-only approach (Schroder 1976).

In sandy lithosols, as exemplified by the crystalline Midlands, miombo savanna occurs on excessively drained soils of less than 50 cm depth immediately overlying quartz-rich parent material. Where deeper soils of about 100 cm or more depth occur, the miombo is invaded in the fieldlayer by thickets of forest components. In the shallow soils the pervious parent rock is close to the surface and excessive through-drainage occurs. In the deeper soils a larger amount of rainwater is trapped. The soils from the two sites have the same physical and chemical properties, the only difference being their depth and thus their moisture balance. In sands or sandy lithosols, savannas or pure grasslands can occur either on those with a pan horizon or on very deep sands with no impervious pan within reach of the annual rain penetration. In the latter case adequate water occurs only during the rains. In arid areas such as the Kalahari some savanna trees die back to groundlevel during years of less than mean rainfall and recoppice with the advent of the next rains. Where pan horizons occur throughout, forest, thicket and closed savanna are separated from grassland by microrelief. The grassland on slightly lower ground where excessive waterlogging produces a dambo or vlei grassland. Such an edaphic complex is well illustrated by the "Dambo Miombo" on the Cheringoma Plateau.

Dune forest/thicket occurs on some of the youngest and most infertile geomorphic surfaces. Its luxuriance would appear to be a function of soil moisture balance as certain talus soils (Cvb) on Gorongosa Mountain have very high phosphorus and nitrogen content and these may support forest, grassland, or savanna under different soil moisture regimes.

The influence of fire on plant communities is conspicuous where a delicate balance exists in the soil moisture content of virtually the same soils under different conditions of relief, and forest is thus confined to high moisture sites such as gullies. Only a change in the rainfall regime to pluvial conditions would allow forest to spread and coalesce under such conditions. On the Cheringoma Plateau however, savanna and grasslands are, with the exception of the deep red sands, all under active invasion by forest (forest extension) as dambos are incised on the one hand, and savannas on high watertable sands are encroached from forest initial clumps on termite hills and those around tree bases.

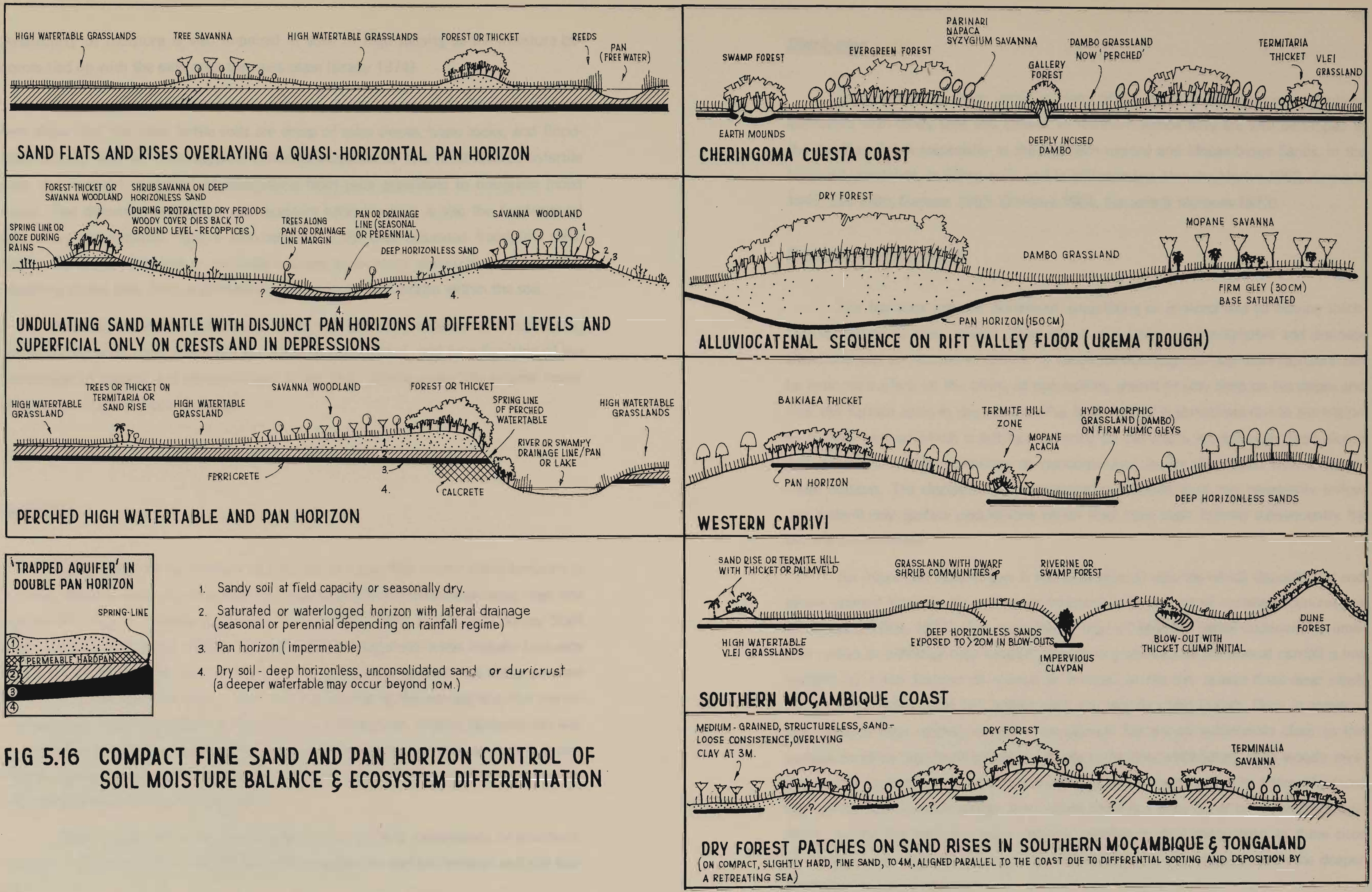
On the Rift Valley floor, in the driest climatic regime of the transect, forest occurs in two sites only; on duplex sands of fan deposits, and in riverine (levees) sites on free draining loamy soils. The savannas are either on clays with seasonally extreme soil moisture conditions (eg. mopane) or on deep sandy soils (eg. ***Burkea***).

Thickets on the Rift floor are associated with similar sites as is forest, and these include especially termite hills which provide a similar moisture balance to the duplex sands or riverine levees. Better water penetration, availability and aeration is shown by termite hills which rise above the vertisols and support large thicket clumps (including forest components), or are reduced to saline patches if accumulations of salts from the saturated subsoils are brought to the surface by the termites.

In Gazaland, between the Save and Limpopo Rivers in southern Mocambique, vast areas of sands and clay soils provide a mosaic of substrates which determine the occurrence of miombo, mopane, forest, thicket and grassland. In the higher rainfall coast sector, deep red sands support miombo savanna and scattered through this are islands of white, or pallid, duplex sands which support dry forest. The sandy clay soils with an impervious gley are either dambos or support mopane, red sands with subsurface calcrete support mixed baobab, acacia and broadleaf savannas as well as thickets. The distance of the calcrete from the surface, and thus the effective entrapment of rainfall, appears to determine the kind of cover. In the lower rainfall interior miombo replaces dry forest on white duplex sands and mopane is predominant on the clays.

In sum, edaphic control of ecosystems is through soil moisture balance with forest occurring on high water-retaining, but relatively well drained sites, and grassland and savanna on both gley soils or deep horizonless sands which exercise the same seasonal extremes of moisture availability. For this reason forest is typically found on the youngest geomorphic surfaces such as talus, foredunes, duplex sands of alluvial fans, riverine strips, donga and slump scars, rock outcrops, and termite hills. But within a topo or alluviocatena the sites may be the oldest as they were the first to be exposed above excessive flooding or waterlogging. Savannas are typical of planation surfaces of low relief, or of excessive drained hill country such as Northern Mocambique or the Midlands west of the Urema Trough, and grasslands occur both on planation surfaces and mal-drained hill country.

It is important to point out that the plant cover as individual species, and not as habitats, does not necessarily maintain or follow the same sites throughout a isohyetal gradation, but follows the moisture balance most suitable for life requirements in a particular zone. For example, in a transect from the Rift floor eastwards to the coast, the forest occurs on those sites with the best year-round moisture availability.



1. Sandy soil at field capacity or seasonally dry.
2. Saturated or waterlogged horizon with lateral drainage (seasonal or perennial depending on rainfall regime)
3. Pan horizon (impermeable)
4. Dry soil - deep horizonless, unconsolidated sand or duricrust (a deeper watertable may occur beyond 10M.)

FIG 5.16 COMPACT FINE SAND AND PAN HORIZON CONTROL OF SOIL MOISTURE BALANCE & ECOSYSTEM DIFFERENTIATION

Availability of moisture is also impaired in soils of high salinity as the moisture becomes tied up with the salts once the rains cease (Brady 1974).

The evidence of soil chemical properties in the Gorongosa – Cheringoma transect show that the most fertile soils are those of talus slopes, basic rocks, and floodplain alluvia and all these support different ecosystems. The most leached infertile soils also support a variety of ecosystems from pure grasslands to evergreen moist forest. The determining factor is soil moisture balance which is also the fundamental control of productivity. This is especially so in the base saturated floodplain soils, where insufficient flooding or too little rain (eg. midsummer droughts) results in rapid browning of the grass from aridification and increased salinization within the soil.

Thus the nutritient differences noted, for example, between soils supporting forest and savanna, may only hold for those examples sited, and be a function of the differences of organic and element input in the two habitats under the original causal differences of soil moisture balance.

PAN HORIZONS, DUPLEX SOILS AND COMPACTED FINE SANDS

Definitions

Pan is used here as a collective term for all subsurface impermeable horizons in the soil whether they are compacted or indurated. Pan horizons have more than one genesis and vary in morphology (Mohr & Van Baren 1959, U.S.A. Soil Survey Staff 1960, Termier & Termier 1963). The indurated or cemented types include ferricrete (ouklip), calcrete, silcrete, *et. al.*; the compact or claypan horizons are either perched or firm gley illuviated horizons. They are formed below the surface but like the cemented types may be exposed at the surface by truncation. Argillic horizons can also be a developmental stage toward the true pan or cemented horizon, so that it is possible to have all stages in the same area. Some of these horizons are fossil and bear no relation to present surface configurations.

Duplex soils are those with abrupt textural, and consistence or structural, transition (Van der Eyk *et. al.* 1969: 253) between the surface horizon and the subsoil.

Compact fine sands are very fine grained and sufficiently coherent for steps to be cut and used in the profile pit, contrasting with loose sands of coarser grade which collapse.

Distribution

Impermeable horizons occur in many of the world's soils and are particularly associated with sandy soils and alluvia. In southern Africa they are well developed in the Kalahari Sands (especially in the northern region) and Mocambique Sands, in the Highveld grasslands, in valley soils, and in aridosols (eg. Van der Merwe 1962, Azevedo 1945, Sys 1960, Ganssen 1963, D'Hoore 1964, Gouveia & Marques 1973).

Occurrence and disposition

Pan horizons may be horizontal, undulating or inclined and of varying thickness according to their genesis. They occur in a variety of topographic and drainage situations and are absent in others. In sandy, undulating country these horizons can be near the surface on the crests of convexities, absent or very deep on the slopes and near the surface again in depressions (Fig 5.16). This is sometimes due to truncation of a fossil horizon which is left as a remnant on the crests, eroded away from slopes and deposited in the depressions or reincorporated in the depression with a deeper fossil horizon. The disposition of impermeable horizons does not necessarily follow the present day surface undulations which may have been formed subsequently by cut and fill processes.

An important type of pan is the groundwater calcrete which deposits out and grows upward towards the surface as massive hardpan sheet of coalesced concretions (Netterberg 1969, 1971). For example, an area of deep red sands underlain by lime-rich waters or lithology may support only pure grasslands as the annual rainfall is not trapped by a pan horizon or change in texture. In the dry season these deep sands become completely dried out, killing back any woody plant initials. Only in consecutive years of high rainfall, or when the calcrete has grown sufficiently close to the surface to allow tap roots of woody plants to become established, does woody invasion occur. In sandy areas which have been bared by overstocking or other influences rain penetration is much deeper than where there is a grass cover as no evapotranspiration pumps the sand dry again, woody invasion is thus encouraged in these sites by better water relations allowing the establishment of tap roots to reach the deeper permanent moisture sources.

Pan horizon control of hydrology and their function as aquifers

The pan layer acts as a moisture barrier until a relatively high moisture level is built up. This gives a much higher field capacity than that encountered in freely drained soils (Brady 1974, and pers. data). Sandy soils have a high infiltration capacity, high total conductivity and high permeability, with extremely low moisture holding capacity (Brady 1974). Yet endoreic freshwater lakes, occurring along the Mocambique coast and the upper Zambeze and Lulua-Sankuru branches of the Congo River, rise on Kalahari Sand plains due solely to the presence of pan horizons.

When the pan horizon becomes waterlogged (saturated), drainage is lateral in this horizon and in the porous soil immediately overlying the impermeable layer. If the pan is overlain by loamy or sandy clay material, water is more easily lost by evaporation from the soil surface than if it is covered by loose sand. Loose sand is full of airspaces and this inhibits waterloss by evaporation, hence a pan horizon covered by loose sand is highly efficient as an aquifer. In addition surface runoff is minimal and almost the whole annual rainfall is trapped by such duplex sands. The distance of the pan horizon from the surface as determined by depth, and microrelief of the covering soil, play a fundamental role in moisture balance. The distance affects the amount of saturation possible and, with texture, the degree or rapidity of waterloss by runoff and evaporation, together determine the extent of moisture retention. Where perched gleys occur in sandy or friable soils as in the South African Highveld, only grasslands are supported as the soils are too wet during the rains (growing season) for woody seedlings and are extremely dry and hard subsequently in the winter dry season, when fire and frost are additional deleterious factors to soil aridity.

Firm humic gley soils are only hydromorphic due to poor drainage, and, once they are drained, become aridosols. Their fine content and high salinity reduces moisture availability drastically and their surface becomes puddled or capped so that a great part of the annual rainfall is lost by sheetwash, thus increasing soil aridity further. Thus the efficiency of pan horizons as aquifers depends on their being covered by a sand mantle.

Because of the high water holding capacity of many pan horizons, lateral flow can be maintained even during droughts as there is sufficient soil moisture for rapid saturation to occur in times of less than mean annual rainfall. The preceding degree of saturation is a fundamental factor governing rain and flood effectivity in plainsland hydrology. As the hydrology of plainsland lacks the dynamic of slope gravity as a force in the transmission of water, the lateral movement of water in the impermeable layers is sensitive to the presence of extraneous factors which alter the water tension away from the direction of flow. Boreholes, drainage canals or headward erosion of nickpoints, and tree roots are examples of factors which alter lateral water tension. Deep sands with uniform texture are areic, the total seasons's rainfall penetrates to a certain depth and then is dried out by evapotranspiration of the grass cover with the advent of the dry season.

In some areas several watertables are separated by dry soil or dry cemented layers, the upper water-bearing zone is then called a "perched" watertable or aquifer (Lobeck 1939: 116–117). Because plains catchments are shallow, variable in distance from the surface and sensitive to extraneous factors, they need to be of large area to be efficient as aquifers. The best example of the efficiency of duplex sands as aquifers in the study area is afforded by the perennial streams which rise on the Cheringoma Plateau. Where the sand mantle is removed by erosion exposing the subsurface claypan, streams dry up and dambo drainage lines are invaded by savanna.

Pan horizon control of the spatial separation of ecosystems or communities, and of succession and phenology.

The presence or absence of a pan horizon, its distance from the surface, and soil permeability to rain, which is a function of texture and relief, are the most important combination of factors governing soil moisture content and thus the spatial distribution of woody cover and grasslands (Fig 5.16). The surface texture of soils thus determines the level of moisture rechange and the amount of water remaining in the soil after rain and subsequent evaporation and, as Walter (1971) points out, this is far more important than the amount of rain.

It has been pointed out above that excess of soil moisture on a perennial or seasonal basis is a major factor determining the presence of open grasslands. The only other worker who has stressed this fact, from his study of the significance of the spatial separation of wooded cover and grasslands in Central and Southern Africa, is Michelmore (1939). It is surprising how rarely this work is referred to and how it has been overlooked, with the result that the conventially held dogmas on grassland genesis persist; for example, that the Highveld grasslands are due to frost and fire, or only to the former. A glance at road cuttings throughout the Highveld shows the real factor responsible for the predominance of grasslands – impeded drainage due to perched gleys and ouklip. They are in fact classified as gley-like podzolic soils (Van der Merwe 1962).

The important feature not mentioned by Michelmore (1939) is that it is not only excessive waterlogging during the growing period in the rains, but also the excessive drying out of the soils in the dry season, that kills back any woody plant root development. In the Highveld woody plant invasion occurs where the best water balance and aeration pertains, such as on rock outcrops and in gullies. Protection from fire is the reason generally put forward for the presence of woody plants in these sites. The Highveld pan horizons are prone to excessive drying out as they are within 40 cm of the surface. Where these grasslands are sheet eroded, or incised by headward erosion of nickpoints, they are invaded by arid savanna from the west, by moist savanna and forest elements from the north and east, and by subdesert in the Southwest. These invasions are due to changes in soil moisture balance.

Pan horizons at greater depth (down to 200 cm) covered in sandy surface soils are able to absorb the total annual rainfall and these are the sites, depending on micro-relief and rainfall regime, where either the densest type of woody vegetation occurs, or where dambos occur. Such relationships occur in South Central Africa through a rainfall regime of about 200 mm to 1 500 mm. The importance of a sandy surface which minimises runoff and ensures maximum entrapment of rainfall is also the fundamental factor determining the spatial separation of grassland and dwarf shrubland in desert regions.

In Bushmanland which is Karroid subdesert, grassland occurs on rounded and plains (tableland) relief where soils are covered with a sand veneer. Where this sand is truncated by sheet erosion, dwarf shrubs invade the base saturated subsoil, now at the surface, to the exclusion of the grasses. In a similar manner Karroid dwarf shrubs are invading Highveld grasslands where the duplex base-rich subsoil is exposed at the surface by erosion of the friable mantle which permitted seasonal waterlogging and thus the predominance of grasses. Thus the explosive invasion by desertic systems (Karroo) are not necessarily due to a change in climate at all, but rather to soil moisture and pedological changes influenced by normal geomorphological processes which are in turn accelerated or initiated by misuse of land.

A similar relationship exists across South Central Africa north of the tropic where sands overlie base saturated clayey subsoils. Where erosion is removing the sand, moist savanna systems (eg. miombo, ***Burkea, Terminalia***) are being replaced by arid savanna systems such as mopane and acacia. This invasion is not confined to the tension zone where active replacement is occurring but also around the islands of clay formed by termite hills where nuclei of arid systems are spreading and coalescing as the sands are truncated or thinned by erosion.

Where pan layers or fine compact sands occur in sand country their presence is made conspicuous by denser and/or taller woody cover than the surrounding deep horizonless sands. Striking examples include ***Acacia erioloba (ex. giraffae)*** woodland patches in the Central Kalahari on the crests of convexities surrounded by scrub savanna on deep sand, ***Terminalia prunioides*** thicket in the eastern part of the Etosha Basin, ***Baikiaea*** thicket in the Caprivi surrounded by savanna woodlands of ***Dialium, Pterocarpus, Burkea, Ricinodendron*** and ***Erytheophleum*** on deep horizonless sands dry forest on the Mocambique Plain occurs on duplex pallid sands or on bands

of fine compact sands, which are surrounded by miombo savanna on adjacent, deep medium grained loose red sands. On the Mocambique coast, deep horizonless sands (20–30 m) behind the foredunes are covered in pure grasslands which merge with vlei grasslands on high watertable sands. Here as with the Central Kalahari scrub adequate soil moisture is only available at the time of the rains, and with the onset of the dry season the sands dry out as the grass cover uses up all the available moisture and woody plants die back to groundlevel and coppice again the following year. To add to this determinant of scrub-physiognomy are factors such as fire and frost (in the Kalahari and S.W.A.). Thus both deep (⩾ 30 m) horizonless sands and sand with a pan horizon in the same area are responsible for a pure grassland cover due to extreme soil moisture regimes. Mobile dune areas which are bare allow for the same maximal penetration and retention of rain as sands bared by other causes such as overstocking, and here dense woody plant invasion of thicket or forest occurs. As verified by personally collected field evidence across southern Africa "fire acts mainly in widening the boundaries of open grasslands formed by other causes. . . ." (Michelmore 1939). Where there is surface flow of water in dambos or the presence of mounds above stagnant conditions swamp forest occurs, and this ends abruptly where it meets the stagnant bog conditions responsible for the vlei grassland (see also Michelmore 1939).

The prevailing opinion regarding the forest patches in upland and montane is that they are relics, which they evidently are in many cases as evinced by the presence of isolated straight-boled canopy trees surrounded by grassland – relics of a former more extensive forest cover. ~~As~~ of important is that the majority of forest patches are related to soil sites with optimal moisture retention and aeration under the present climate and geomorphic dynamics, whilst the grasslands are on seasonally extreme sites. The forests on the Nyika Plateau in Malawi are generally looked upon as relics from fire whereas the geomorphological work of Schroder (1976) shows that all the forest patches in his study area on the Nyika were related to slump scars which ameliorate the water balance markedly. The forests in his study area are therefore not relics at all but initials in various stages of development. A similar relationship pertains in the Natal Drakensberg where grasslands occur on impervious montmorillonitic clays of flat and steeply rounded terrain, and the forest patches are confined to deeper or moister soils of talus slopes, rock outcrops, slump and donga scars, ravines and stream banks.

From desert to about a 1 000 mm rainfall which is strongly seasonal, clay soils are the most xeric substrates, sands have a greater availability of moisture depending on the presence or absence of a pan horizon and deeply fissured stony or rock outcrop areas which allow for maximal absorption of rain have the best water relations hence the dense thickets associated with outcrops (see also Walter 1971). Thus duplex sands and rock outcrops, like riverine strips which are exotic to arid regions, enable high rainfall systems, or their elements, to extend far into arid areas compensating for lower rainfall. This is illustrated by the rain forest initial ***Trema orientalis*** which occurs at Ameib in South West Africa amongst granite inselbergs in a rainfall area of 230 mm. At the same time saturated clays and deep sands carry arid biome components into and through moist regions, exemplified by ***Salvadorea persica*** which extends from the Sahara to the Namib on sodic clays (Tinley 1975).

One fundamental principle emerges from the apparent diversity of situations under which forest, savanna and grassland are to be found. And that is that they are separated out by the soil moisture regimes of the various substrates in any particular area or region and these determine their basic spatial occurrence. This differential selection is determined by the moisture demands and tolerance of the various systems, or their components, under the particular circumstances of climate, relief, soil properties and competition. It is important to emphasise that competition exists not only between habitats but within habitats as well, exemplified by the savannas which are duplex systems comprising a grass and woody strata. The subject of scrub encroachment being a function of soil moisture change when the grasses are removed from competition by overgrazing or erosion is well described by Walter & Volk (1954) and Walter (1964, 1971) for sandy clay soils in South West Africa.

Walter (1971) gives another example of soil moisture subtleties. ***Tamarix*** trees can be grown in desert if the soil is kept moist through the profile until the taproot has reached the groundwater, after which they require no further aid. As this cannot happen under natural conditions the area remains bare desert. This example questions whether the even-aged stands of old ***Acacia erioloba*** in the Kalahari are not related to exceptional years of consecutive high rains which wet the profile deep enough to allow the taproots to reach deep groundwater.

By occurring on sites with different soil moisture balance in different climatic zones these systems or their components are in fact occurring in the moisture balance sites sufficient for their requirements as described, for example, by Smith (1949). One or other system expanding or contracting depending on whether geomorphological processes or significant climatic change allows for such opportunism, accelerated or retarded by the action of fire, frost, man or animal.

Generally the effect of consecutive years of high rainfall in the arid zone (< 600 mm) is opposite to the moist zone (> 600 mm). In the arid zone there is an increase of woody plants as their roots can grow deeply enough to secure sufficient ground moisture to become established and drought years promote the extension of grassland. In moist regions high rainfall promotes grasslands and forest, and drought years promote extension of savanna.

Contrary to the repeated statements that the savannas of Africa are mostly (if not all) secondary anthropogenic systems (eg. Walter 1964) these are totally refuted not only by the biotic richness and uniqueness of this major biome type but also from the evidence of the controlling influence of soil moisture balance across the continent.

As can be appreciated from the above data the presence and dispositon, or absence, of a pan horizon not only influences the type of plant cover possible and thus the phytomass physiognomy and structure composition, but will also profoundly influence phenology. Onset of deciduousness in savanna trees for example is triggered by loss of available soil moisture and/or low temperatures. Midsummer droughts over a two month period (typically January and February) in areas of poor moisture balance allows for evapotranspiration to deplete the soil moisture sufficiently to cause unseasonal leaf fall followed by a repeated leaf and flower flush in many trees with the onset of rains again in March (see Chapter 8). In consecutive years of less than mean rainfall the pre-rain woody flush in the arid savannas is repressed until the advent of the first rains 3 to 4 months later, when they flush simultaneously with the grass strata. Here again there is a differential effect caused by the recharge capacity and moisture balance of the particular soil.

The effect of plant cover type on the water balance of pan horizons

Large quantities of water are necessary for the metabolic requirements of growing plants. A given quantity of water in the soil is moved from the hydrosphere to the atmosphere far faster through the metabolic energy of plants than would be the case from direct evaporation. The tremendous amounts of water transpired by plants is proven by numerous quantitative studies, some of which are reported in university textbooks. A typical example from Temperate Lands reads "A single corn plant (in Kansas) between May 5 and September 8 transpired 54 gallons of water. An acre of such plants (6 000 plants) would transpire during the season 324 000 gallons of water, which is equivalent to a sheet of water 11 inches deep over the entire acre. It has been estimated that an acre of red maple trees growing in soil with ample moisture, may lose in a growing season an amount of water sufficient to cover the acre with 28 inches of water . . . Of the total quantity of water absorbed by the roots of plants as much as 98% of it escapes from the plant by transpiration" (Robbins ***et al*** 1959: 185–198).

In clays the prominence of fine capillary pores is conducive to unsaturated flow whilst in sands the large pores encourage saturated flow (Brady 1974). Hence duplex sands have available a large water storage capacity but are sensitive to use by dense woody plant cover which creates a multiplicity of local tensions and leaves little for lateral movement of water.

For example; an area of dry forest on duplex sands at St. Lucia was cleared for pineapple plantations. In two summers the pan horizon became fully saturated in the absence of the dense woody cover, lateral flow began, reactivating springs and oozes on slopes which had not flowed for more than 20 years. This moisture was sufficient to kill the margins of forest patches which abutted on the "fossil" drainage of the slopes. A similar response occurs where miombo on duplex sands is cleared for cultivation and the pan horizon becomes saturated and fills towards the surface drowning the crops.

The woody cover on duplex sands is thus self-preserving in the natural state where the pan horizon is kept from being waterlogged for too long by evapotranspiration. A report in the Farmers Weekly (June 2, 1971, Vol. 120, p. 13) records the die-back of eucalyptus in the plantation areas of Natal and the Eastern Transvaal due to insufficient moisture. The measures recommended to resolve the problem of die-back is to thin out the plantations to relieve water stress. Natural die-backs to restore the balance between available soil moisture and cover density also occurs in the arid savanna where scrub-thickets of ***Acacia mellifera*** are killed (thinned out) by drought years. The restoration of springs which had not flowed for several decades in the Tsavo National Park occurred when overpopulation of elephant transformed thicket into open grassy savanna.

Overstocking, cultivation and autumn fires can together or singly extend the area covered in thicket, resulting in the extinction or dimunition of freshwater springs and streams. This non-climatic phenomenon is documented over many parts of the continent. The vegetation which uses only the surface of soils is grassland, and it is only under grassland that a very high field capacity can be attained and maintained (Tinley 1971a).

Influence on primary productivity

The base saturated hydromorphic floodplain soils support a high year-round production of grass only because they are well watered. Once drainage becomes more effective their productivity is confined to the rain and flood-ebb periods only. In the savannas, grasslands and deserts primary production is controlled almost entirely by

the incidence of rain. Walter & Volk (1954), and Walter (1964, 1971) has shown that primary production increases proportionally to rainfall in a linear relationship for South West Africa.

The presence of pan horizons in certain situations such as dambos or vleis allows for a much longer primary production deep into the dry season. In deep sand areas and soils with a pan horizon close to the surface (eg. perched gleys of Highveld), or on saline aridosols, primary production of shallow rooted grasslands is totally reliant on amount, distribution and the interval between rains.

Structural control of landscape development

Where pan horizons, especially the cemented forms are exhumed by erosion of overlying soil these more durable substrates slow down the rate of landscape change and impose a tableland morphology, with all that that implies, in geomorphic succession and moisture balance of its various facets. The most important factor of structural control is its influence on the soil moisture balance of each land unit. These land units comprise plateau, waxing slope, scarp, talus, and waning slope. Once cemented, hardpans are not impervious as are their clayey developmental stages, but allow deep rainwater penetration along fissures (refer to Final section in Soils above).

Compact Fine Sands

The surface of the broad Mocambique Coast Plain is composed predominantly of duplex sands of various kinds (pers. data). These sediments and the profiles they form are polygenetic. On the one hand, they are derived from erosion of the hinterland and deposited in giant (eg. fossil Limpopo – Save Delta) laterally coalescing alluvial fans on the continental margin from the Zambeze South to Mtunzini on the Zululand Coast (Umlalazi River mouth). In the area affected by the Limpopo, extensive areas of fine red "Kalahari" Sands occur, these are possibly derived from stripped off Kalahari sands in the hinterland and redeposited over the boulder beds overlying older ferricretes and calcretes that now outcrop as scarps.

On the other hand, these fluvial fan deposits were resorted and redistributed by a transgressive marine phase when the Pliocene Sea covered the greater part of the Plain (calcretes?), and again during its regressive phase in the Pleistocene (King 1972) when new sediments from inland would have been spread in fan sequences. The combined influences of fluvial and marine littoral processes (including wind) resulted in parallel systems of dunes and slacks. The most conspicuous of these today are probably related to periods of stillstand in retreat of the Quaternary Sea to its Recent position.

On the Mocambique Plain, south of the Save River to about Lake St. Lucia, a characteristic feature, seen from the air, are these depressions (fossil estuaries) and low rounded (eroded) dune lines parallel to the present coast. This feature is made conspicuous by similar lines of disjunct, dark forest patches surrounded by large areas of tree savanna, or treeless grassland.

Investigation on the ground shows that in the more arid (600 mm) inland sectors of the Plain, the dry forests occur on duplex sands with an impervious claypan horizon at about 70 to 120 cm depth. Seaward, where the rainfall increases to a 1 000 mm, the dry forest patches are confined to fine, strongly compacted sands (without clay) which alternate with extremely loose, median grained sands supporting savanna (*Terminalia* or miombo) with an impervious claypan at 3 m depth. The fine compacted dry forest sands in the late autumn are dust dry to 3 m depth, whilst free water collects at 3 m depth under ***Terminalia sericea*** savanna. It is possible that a greater sump is formed at depth (beyond 3 m) by the linear fine sand deposits which may then be recharged by direct rainfall as well as by lateral movement of water from the adjacent savanna duplex sand. Deeper pits are required in the dry forest fine sand patches to unravel their soil moisture story in full.

Comparison of the 1940's air photo coverage of the Mocambique Plain with recent photos, shows clearly that in the interval of 30 years with annual veld fires the dry forests have neither decreased or increased in size. They are aligned and associated with duplex sands and/or compacted fine sands deposited in parallel irregular patches, probably by the retreating Pleistocene Sea and the closely following fluvial fan sequences.

In other areas, such as on the seaward slope of the Cheringoma Plateau, evergreen moist forests occur on duplex sands with an impervious horizon at 150 to 250 m depth, and here their faintly higher microrelief separates them from the abrupt change to dambo grassland of the adjacent flat drainage lines which also have an underlying impervious pan horizon. Microrelief and thus degree of waterlogging alone appears to separate these contrasting ecosystems here.

Summary Point

These field observations indicate that soil moisture balance is the most significant edaphic feature as it over-rides all other properties, or influences their effects.

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