

Some Aspects of the Geomorphology of South Western Nigeria

by

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SUMMARY

This thesis examines the influences of geology, past and contemporary weathering and erosion and other geographical factors on landform development in South Western Nigeria. It also describes the major landforms and some important landform elements* in the area.

South Western Nigeria is composed of crystalline and sedimentary rocks. The crystalline rocks are mainly metamorphics (gneisses, quartzites and schists) and igneous (granites and syenites) of Pre Cambrian age. The sedimentary rocks are predominantly sandstone intercalated with clay, limestone and shale, and the series vary from upper Cretaceous to Recent. The structural and lithological variations within these rocks, and the geological and tectonic history have largely determined the nature of the landforms.

The past and present pattern of rainfall, the constantly high temperature and the vegetation have affected the past and contemporary geomorphological processes. The drainage pattern and the river regimes to some extent follow the pattern of rainfall.

With the aid of the relative relief map, the generalised contour map, the Roughness Index, the Index of Dissection and the values of maximum valley slopes, South Western Nigeria can be divided into ten physiographic units to replace the three units recognised by Pugh (1955).

The most important geomorphological processes are chemical weathering and *fluvial* erosion, and these act differentially on the rocks to produce the landform types. The pattern of tectonic uplift has resulted in an absence of widespread pediplains hence the etchplain concept is applied to explain landform development.

On the basis of the surficial configuration of the different landforms, the varying amount of rock outcrops exhibited, the distribution of laterite

* See Glossary

and the degree of local dissection based on certain stream properties and the Percentage Hypsometric Integral, South Western Nigeria is divided into landform types. Three erosion surfaces are locally recognised on the sandstone series.

Analysis of the morphometric properties of inselbergs show that inselbergs developed in granite and syenite are larger and closer to one another than those developed in gneisses. This indicates that the evolution of inselbergs depends on the structure and lithology of the parent rocks. The basic process involved in the formation of inselbergs is that of deep weathering and erosional stripping under multi-cyclic phases. Pediments exhibit uniform slope angles on different landforms and on different rock types within the same vegetation zone, but pediment angles are significantly different under different vegetation. Basal depressions and basal knicks are intimately related, and the former are formed in relationship to surface and subsurface flow of water around inselbergs.

Valley slopes and valley cross profiles vary from one landform type to the other, but the values of maximum valley slopes are generally higher under the forest than under the savanna. Valley cross profiles suggest parallel slope retreat in lateritised landforms, but slope flattening where primary laterites are absent.

Laterites are of different types, and the physiographic locations of the different types reflect the pattern of past and contemporary landform development. In the contact zone between the crystalline and the sedimentary rocks, the Upper Cretaceous scarp is undergoing backward retreat. Where a thick laterite crust is present on the scarp, the values of maximum scarp slope are high and constant, but where the laterite is thin or absent, values of maximum scarp slope are low and irregular. This association of high slope

values and lateritic occurrence is seen on the sandstone residuals around Abeokuta. From these it is concluded that where lateritic caps or other cap rocks exist on weathered regolith, slope values would be high, and the slope would retreat parallel to itself, but where absent, slope values will be smaller and slope flattening will occur.

CHAPTER IINTRODUCTION

This is a study of the landform patterns and landform elements in a humid tropical environment in South Western Nigeria. Within this environment the processes of ^{chemical} weathering and ^{fluvial} erosion are ^{perhaps} more intense and have operated continuously for a longer period than those in the temperate zone. Accordingly, the landforms should illustrate the effect of these processes on a scale, and in a degree which is exceptional. Yet little is known about them partly for historical reasons and partly due to the vegetation cover. A more immediate and practical reason for study, however, lies in the fact that the greater proportion of the population in the tropics inhabits this zone. In Nigeria, especially, the rapid growth in population leads to increasing pressure on land which is the major resource available to tropical peoples. The utilisation of this resource to its maximum capacity depends on a comprehension of those features which are most difficult to change. Foremost amongst these are the physical factors such as slope, drainage and depth of weathered material. For this purpose, if no other, it is important to understand the patterns and factors of landform development.

The earliest descriptions of the landforms and landform development in the humid tropics are contained in the memoirs of explorers or administrators e.g. Falconer (1911), and Kitson (1913). In recent years a number of detailed studies have been carried out in Intertropical Africa. Many of the earlier workers, coming from the humid temperate parts of the world often expected similar geomorphic processes to operate in both humid zones. It is, therefore, not surprising that their interpretation of the humid tropical processes and landform patterns tend to be clouded by their a-priori opinions. Later workers, free from such inhibiting influences, are hampered mainly by limited

financial resources, lack of materials and the physical problems of penetrating the forest.

Before 1960, most of the geomorphological studies carried out in Nigeria were based on the 1:150,000 and 1:250,000 map series. These maps are generalised and inaccurate. Good airphotos were lacking, and the scales of those available were inadequate for detailed geomorphological research. The available geological maps were also overgeneralised, and again the scales made them limited in value for practical use. The thick forest of the area, coupled with the high rainfall, makes penetration and detailed study of landforms difficult. Even on airphotos, the thick forest effectively blankets the landform features. In consequence most researchers concentrated their efforts on the savanna areas where landform patterns are visible and easily related to rock types. Many of the theories of landform development in the tropics are based on studies in the semi arid and savanna areas, and are often applied, with little re-appraisal, to explain the landforms of the humid tropics.

The greatest obstacle to the comprehension of the geomorphology of the humid tropical environment is the lack of data on the processes involved, and on the landform properties. It is only recently that some data have become available on geomorphic processes such as depth and pattern of chemical weathering, stream runoff, or soil resistivity, but even these are sparse, and in most cases, not collected systematically. For instance, data on weathering have largely been collected from pre-determined sites suitable for dam construction. The quantifiable properties of the landforms have not been systematically surveyed. Slopes have been assessed in a generalised way for some areas by the F.A.O. (1962). In spite of these shortcomings, however, a lot of useful work has been done in analysing the processes and landform

patterns of the humid tropics especially in Nigeria, e.g. Thomas (1965, 1969), Pugh (1955), Wigwe (1966). Several theories of landform development have been advanced to explain the geomorphic processes and landform elements like inselbergs, pediments and valley slopes. Unfortunately, most of these are based on visual impressions of the landform elements with very little concrete evidence.

Aim of Thesis

The aim of the thesis is threefold. First, the main landform regions are identified on the basis of surficial material and configuration, and their inter-relationship demonstrated. Second, the important landform elements within each region are defined, measured, and the characteristic variations within them outlined. Third the development of these landforms and landform elements is examined within the framework of existing theories and the data obtained when the landform elements were measured.

The study outlines the broad landform patterns in South Western Nigeria which at present are not clearly understood. More important it illustrates the similarities and the contrasts in the landforms and landform elements developed on the crystalline basement rocks, and those developed on the sedimentary rocks under both savanna and forest. The data collected on the different landform elements has an intrinsic value as a contribution to the scanty data available for the humid tropical environment.

Methods of Study

Sample areas with different vegetation cover were studied on both the crystalline basement and the sedimentary rocks. For each sample area, the geomorphic processes were observed and the landform facets* measured.

Altitude readings were taken with altimeters which are the easiest instruments to use when covering a fairly large area. They are, however, only correct to

* See Glossary

+ 25 feet. Slope measurements were made with the Abney level, graduated ranging rods and tape measures.

Several problems were encountered in the practical field measurements. Bench^{marks} indicated on the maps cannot be identified on the field. The altimeters were always calibrated therefore at railway stations where there are reliable spot heights, and these served as the Ordinance Datum wherever they were present. The farmers, on whose field measurements were desired were usually suspicious and often refused permission. Areas of secondary forest regrowth were virtually impenetrable and large trees obscured vision in the thick forest. Geomorphic processes were not easily observed because their rate of operation is extremely slow, and in several cases could not be measured. (see Page 89) Field work took place between November 1968 and August 1969 in order to gain a fair impression of the geomorphic processes during the dry and rainy seasons.

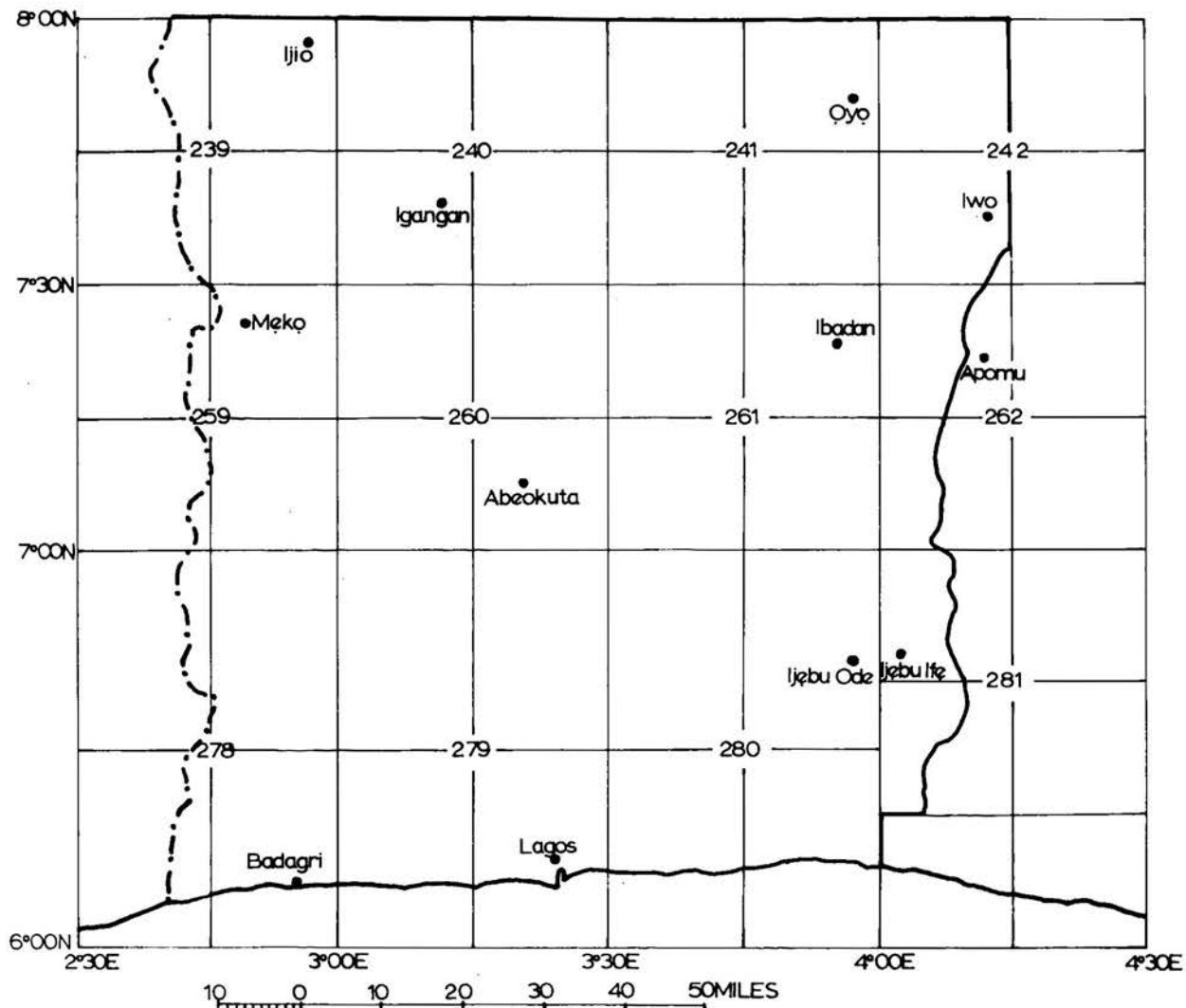
Since 1960, most of Western Nigeria has been mapped by the 1:50,000 series drawn from aerial coverage flown by the Canadian Aero Survey Company for the Federal Government of Nigeria. The airphotos are at a scale of 1:40,000. 42 of the 1:50,000 maps cover the field area (Fig. 1). Secondary data on landform elements were obtained from these and they also served as base maps in the field. The maps have a high degree of accuracy, and instrumental readings nearly always corresponded with points on the map, with the exception of ridge and inselberg summits where map data and instrumenta data could show differences up to 75 feet. The 1:40,000 airphotos covering the whole of South Western Nigeria were examined in order to plot the preliminary aspects of the field work, and to map landforms and analyse some drainage basins. The solid geology has been mapped at 1:250,000, (Hockey & Jones 1964) but unfortunately the rocks have no well defined boundaries. Notwithstanding

these shortcomings, geological maps nos. 59, 60, 68 and 69 of the Federal Geological Survey of Nigeria were used in the field.

Area of Study

The area selected for study covers approximately 9,000 square miles in South Western Nigeria (Fig. 2). It is located between latitude 6°N and $8\frac{1}{2}^{\circ}\text{N}$, and longitude $2^{\circ}40'$ and $4\frac{1}{2}^{\circ}\text{E}$ (Fig. 1) and lies in the humid tropics of West Africa. Included within it are Abeokuta, parts of Ibadan, Ijebu and Oyo provinces in the Western State of Nigeria. To the West, it is bounded by the international boundary between Nigeria and Dahomey, to the east by the Oshun river and to the south by the Gulf of Guinea. A line running north of ^{Ijio} ~~Ijo~~ to ^{Iganu} ~~Oyo~~ ~~to Iseyi~~ to ^{Isami} ~~Oke~~ ~~to north of Ijio~~ forms the northern demarcation (Fig. 2). Ideally, the area should be extended further north to the primary watershed between the rivers flowing to the Niger and those flowing to the Gulf of Guinea, but this watershed area has already been studied by Thomas (1965, 1969) and Wigwe (1966). Nevertheless a few trips were made to ^{the} Shaki area to compare or contrast the landforms with those to the South. The ^{coastline} ~~coastal area~~ was not studied since it justifies research by itself. Moreover detailed work has been done by Pugh (1953, 1954a, 1954b) and Webb (1958). Due to physical and financial limitations, field work could not be extended over all the 9,000 square miles of South Western Nigeria, sample areas covering 900 square miles had to be selected for study (Fig. 2).

South Western Nigeria satisfies the definitions of humid tropical ^{propounded} environment [^] by Gourou, Garnier and Kuchler. Gourou (1947), sees the humid tropical areas as being delimited by the isotherm of 64.4°F (18°C) for the coldest month and by the 16 ins. isohyet for the rainy season, with enough rain for agriculture without irrigation. Garnier (1968, 1961)

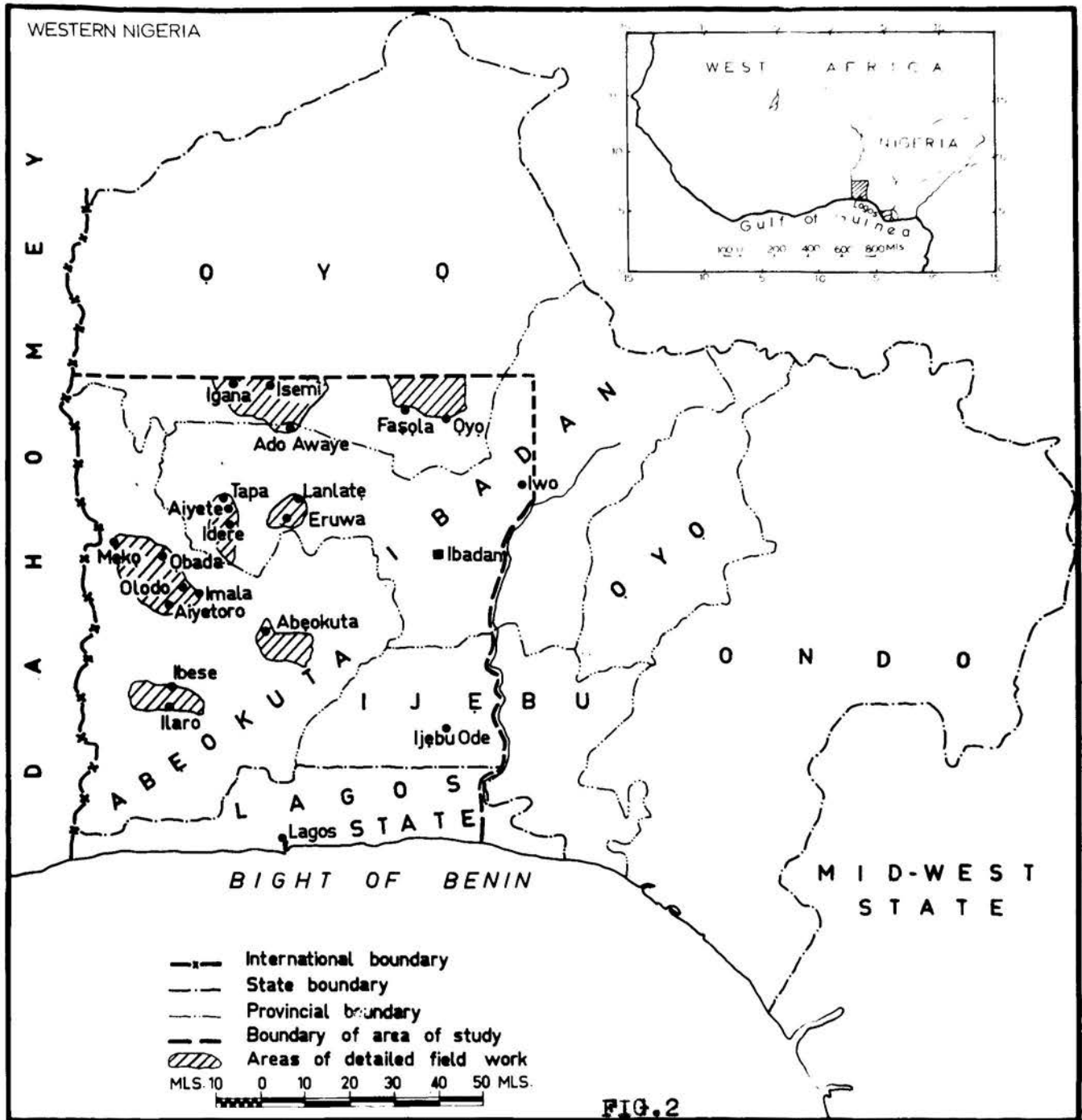


INDEX OF THE 1:50,000 MAPS COVERING SOUTH WESTERN NIGERIA

FIG. I

identifies the humid tropical area as one where the following conditions are satisfied (i) the mean monthly temperature for at least 8 months of the year equals or exceeds 68°F (20°C), (ii) the vapour pressure and relative humidity for at least 6 months of the year average at least 20 mb and 65% respectively and (iii) the mean annual rainfall totals at least 40 ins (1000 mm) and for at least 6 months, precipitation is 3 ins (75 mm) or more for each month. Kuchler (1961) uses vegetation as criteria and distinguishes two types of humid tropics; (i) areas where humidity is permanently so high that dry periods are either non-existent or are inadequate in duration and intensity to result in any significant degree of xeromorphy in the vegetation, (ii) areas where a distinct contrast exists between a drier and a wetter season but the changes brought about by the dry season are largely limited to deciduousness and a greater presence of grasses.

The thesis is in two parts. The first section is devoted to an examination of the physical background, the geomorphological processes and the broad landform pattern of South Western Nigeria. In the second, some important landform elements on the crystalline and sedimentary rocks are described in detail and their evolution outlined. Finally, the practical application of the ^{work}thesis is considered.



CHAPTER 2

GEOLOGY

The broad pattern of landform development in any given area is normally determined by the structural and lithological variation within the rocks. In South Western Nigeria, where chemical weathering appears to be the dominant geomorphological process, the effect of the geology on landform is still pronounced.

The greater part of South Western Nigeria is composed of pre-Cambrian rocks commonly referred to as the basement complex. These rocks extend over an area of approximately 5000 square miles. South of the basement complex are the sedimentary rocks, varying in age from Late Cretaceous to Recent times, which occupy an area of some 4000 square miles (Fig. 3). The rocks of the basement complex consist of the gneiss complex, granites, quartzites and schists. Outcrops are infrequent, however, due to the intense chemical weathering, sediment or lateritic cover and poor vertical down cutting by the rivers. When they occur, they mainly consist of small blocks in river channels, but they also form components of rock pavements, tors, corestones and inselbergs.

The sedimentary rocks lie unconformably on the crystalline rocks with a total thickness estimated at 3000 feet by Russ (1924) to more than 7000 feet near Badagri (Mobil Oil Coy drilling logs). These rocks have been studied only recently because of the economic interest generated by the discovery of potash near Ifo, together with the limestone and shale at Ewekoro which are now used for cement manufacturing. Exposures are few as the rocks are generally covered by a thick mantle of red earth, brown clayey sand and mottled clay resulting from deep weathering. They have been studied mainly by sections from unlined wells and holes drilled by

the Geological Survey Department of Nigeria.

In this chapter, the rocks of the basement complex will be examined, followed by the sedimentary rocks and the superficial drifts. The geological history will be discussed and a comparison attempted between the rocks of South Western Nigeria and those in other parts of West Africa.

The Basement Complex

There is no consensus of opinion among geologists as to the classification of these rocks. Wilson and Bain (1922), who studied them along the Western railway line from Iddo to Okuku, made a simple division, as follows, based on the absence or presence of foliation in the rocks, and age:

<u>Non foliated</u>	<u>Foliated</u>
Various alluvial materials	The Younger Intrusives - granites and gneisses
The sedimentary rocks	
The basic rocks	The Older Intrusives - gneisses and schists
	The sedimentary series - quartzites, gneisses and schists.

It is difficult to see how Wilson and Bain distinguished between the different gneisses, and further, categorisation based on age is well nigh impossible because these rocks have not been dated to any useful extent.

The following authors have classified the rocks as shown in the table below. Jones and Hockey (1964); and Oyawoye (1965) adopted a genetic classification while Haughton (1963) used the generic approach to classify the rocks as follows:-

Table 1 Classification of the basement complex rocks

<u>Jones and Hockey (1964)</u>	<u>Oyawoye (1965)</u>	<u>Haughton (1963)</u>
i. The Gneissic Complex	i. The Older	i. The Older Granites
ii. The Older Granites	metasediments	occurring as
iii. Charnokitic Intrusions	ii. The Gneisses,	batholiths
	Migmatites and	ii. Gneisses and
	the Older Granites	Migmatites
	iii. The Younger	iii. Schists, phylites,
	metasediments	quartzites,
		marbles and
		amphibolites

In this study, the rocks of the basement complex are discussed by mode of origin. This avoids the conflicting views about age, while a descriptive approach emphasises the distinctive characteristics which are relevant to geomorphology. Thus the rocks are conveniently divided into Igneous, Metamorphic and Sedimentary rocks, and discussed in terms of the pattern of occurrence, texture, composition and lithology. Superficial drifts are also examined.

THE IGNEOUS ROCKS

The Igneous rocks form a complex mainly composed of granites and granodiorites. Typical of these is the coarse porphyritic ^{younger} granite which covers an area of about 350 square miles (Fig. 3). Jones and Hockey (1964) believe that these were formed in three phases which they labelled Early, Main, and Late. The rocks are the products of magmatic intrusions as large batholithic bodies, as indicated their crystal sizes. They were also formed by the granitization of local rock bodies as witness the inclusions of schists. The two types which mainly occur in South Western Nigeria are

the granodiorites and the coarse porphyritic granites.

Granodiorites are found in a few localities, especially near Igbo ora. They occur either as small bodies or as inclusions within larger granitic masses, or as dykes cutting through gneisses. The rocks are medium grained and dark coloured, largely composed of plagioclase, microcline, quartz and biotite (Table 2). They may be massive or foliated dependant on the relative amount of biotite present.

Table 2 Modal Mineral Composition of Granodiorite

<u>Mineral</u>	<u>Percentage</u>
Plagioclase	49.4
Microcline	8.6
Quartz	17.4
Biotite	21.5
Myrmekite	0.5
Sphene	1.0
Apatite	0.4
Magmetite	0.3
Orthite	0.3
Pyroxene	0.9

Source-(Jones and Hockey 1964; p.33)

Coarse Porphyritic Granites cover very large areas as discrete bodies ranging from about 30 square miles at Eruwa-Lalate, to about 90 square miles at Idere-Tapa (Fig. 3). The percentage ~~which outcrops as parts of~~ ^{of bare rock outcrops as parts of} inselbergs, rock pavements, tors, and corestones is greater than for all the other rocks (Fig. 4). Three categories may be differentiated according to their mineral composition.

(a) Coarse, Porphyritic, Biotite, Biotite-Muscovite Granite is the

most widespread and occurs near Idere-Tapa, Eruwa-Lalate, and in Abeokuta township. The rock is light coloured and coarse grained. There are two types. Those which form the largest inselbergs contain very large felspar crystals (phenocrysts) 1.5" - 3" long (Plate 1); those with phenocrysts less than 1.25" in size, form smaller outcrops. The rocks usually have sharp boundaries with the country rocks, but they may grade into them e.g. at Idere, where they contain inclusions of darker rocks with fine crystals. Elsewhere the contact may not be discernible. The phenocrysts are predominantly microcline, and the other minerals which form the ground mass are tightly interlocked. Quartz occurs either as rounded inclusions within plagioclase and microcline or as irregularly shaped crystals. Muscovite together with biotite form the dominant basic minerals. Jones and Hockey (1964 p. 33) show the modal composition of the minerals thus:-

Table 3. Modal mineral composition of Coarse Prophyritic Granite

<u>Mineral</u>	<u>Percentage</u>
Plagioclase	32.2
Microcline	14.8
Quartz	32.6
Biotite	18.4
Myrmekite	0.1
Muscovite	1.2
Apatite	0.5
Magnetite	0.1
Orthite	0.2

At Eruwa-Lalate and Idere-Tapa, the trend of the rocks is mainly E - W and NNE - SSW as seen by the alignment of the porphyries. Vertical and

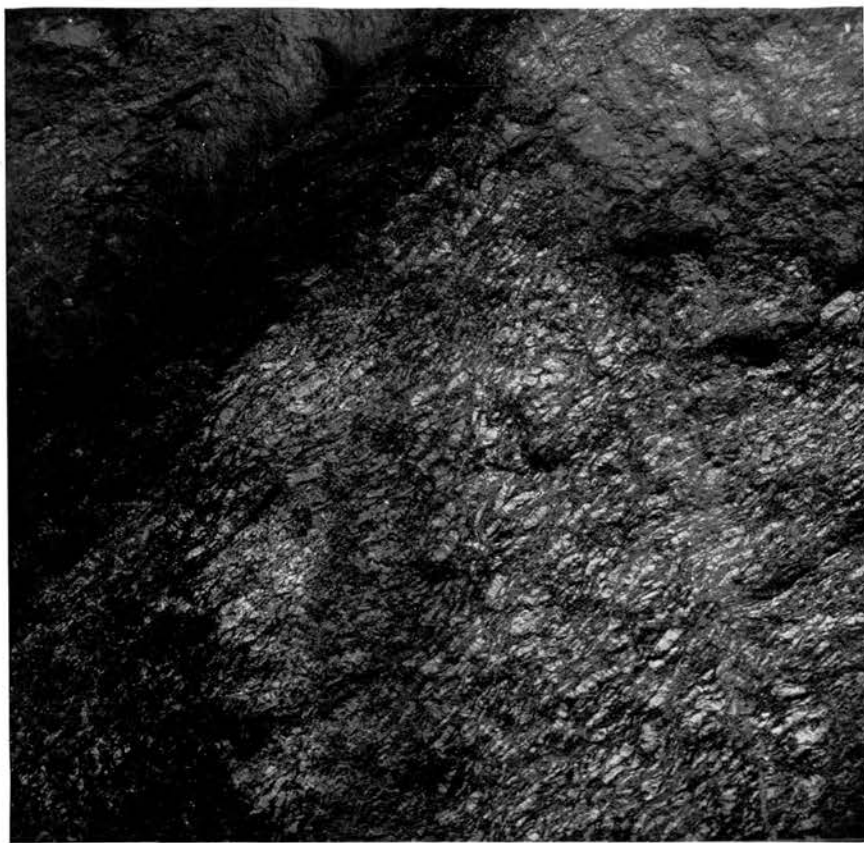


Plate 1. Outcrop of coarse, porphyritic, biotite, biotite-muscovite granite at Abeokuta. Note the size of the phenocrysts.

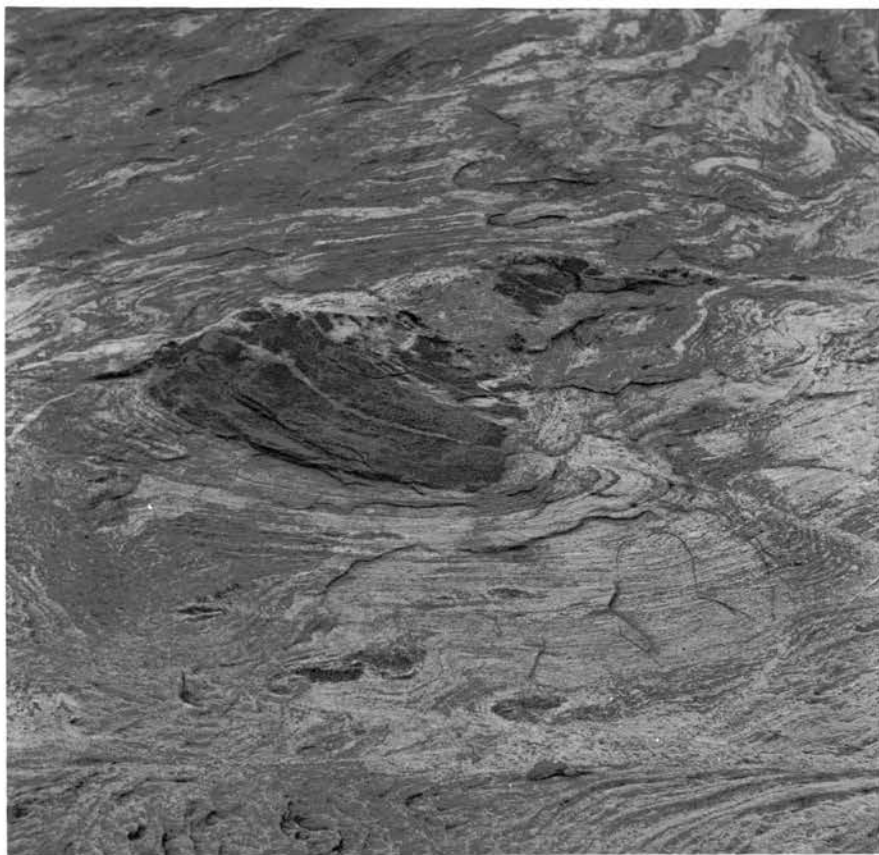


Plate 2. Outcrop of migmatized gneiss showing an intricate pattern of folding.

horizontal joints divide the rocks into large sub rectangular blocks. The dominant joint directions were studied in various places. Around Eruwa, they trend along 30° - 210° (NE - SW), 90° - 270° (E - W), 160° - 340° (SSE - NNW), 140° - 320° (SE - NW), 0° - 180° (N - S), 40° - 220° (NE - SW), 60° - 240° (NE - SW), 120° - 300° (SE - NW) and 80° - 260° (EEN - WWS). Most of the joints follow the trends of the rocks.

(b) Coarse Porphyritic, Hornblende, Granite-Syenite is found mainly around Oke-Iho and also near Oru (Fig. 3), and outcrops are frequent. Dark coloured, and medium to coarse grained, it is composed mainly of hornblende and microcline with variable amounts of quartz and biotite. The phenocrysts which are of microcline are generally less than 1" long. The modal mineral composition for a sample near Oru is shown in the table below.

Table 4 Modal Mineral Composition of Coarse porphyritic hornblende

<u>Granite-Syenite</u>	
<u>Mineral</u>	<u>Percentage</u>
Plagioclase	7.5
Microcline	49.7
Hornblende	16.6
Quartz	10.6
Biotite	8.2
Sphene	2.7
Myrmekite	2.1
Magnetite	0.3
Calcite	2.4

Source - (Jones and Hockey, 1964 p. 33).

The rock trends NNW - SSE in the Oke-Iho area. It is well jointed and the measured dominant joint directions are 170° - 350° (SSE - NNW), 120°

- 300° (SE - NW), 20° - 200° (NNE - SSW) and N - S.

(c) Undifferentiated Older Granite - These are large bodies of granite found mainly between Igana and Iwere. The rock is light coloured with medium to coarse grains. It is composed of fine grains of quartz, feldspar and biotite which form a dense groundmass in which feldspathic and quartz porphyries about 1" long occur. The rock is thought to be a porphyroblast (Jones and Hockey 1964) and has large inclusions of finely foliated dark schist. Joints are relatively sparse, and the measured dominant direction is 50° - 230° (NE - SW).

THE METAMORPHIC ROCKS

These rocks are said to be of sedimentary origin (Wilson and Bain, 1922, Russ, 1924, Jones and Hockey, 1964.) and have been metamorphosed in two phases. The earlier changed them into gneisses, schists and quartzites, and the later mostly affected the gneisses.

The Gneiss Complex: The gneisses are believed to have been migmatized during the emplacement of the granites (Oyawoye 1965). This changed their appearance, texture and structure, although the degree varies from one part of the gneiss to another. In some cases the proportion of the metasomatic material injected into the gneiss may be as much as 80% and the rocks are referred to as migmatites. Jones and Hockey (1964) expressed the difficulty of mapping these rocks separately and accordingly refer to all of them as migmatites on the Geological Sheet 59 of Nigeria. In this study, the term migmatite is used to refer to migmatized gneisses. Associated with migmatization is the plastic pattern of folding whereby the rocks have discontinuous, lenticular, wavy or curved folds (Plate 2). The rocks have nearly the same mineralogical composition and can best be differentiated on the

pattern of banding. Using this criterion, four types can be identified: Biotite hornblende gneiss, Banded gneiss, Semi-banded gneiss and Granitic gneiss.

Biotite-hornblende gneiss, which is highly migmatized occupies the largest area of all the rocks of the basement complex (Fig. 3). The rock outcrops, mainly where migmatization has been intensive, as complexes of domes and rock pavements, and also along river channels. It is distinct from the other groups because of the pattern of folds and the greater proportion of hornblende in the composition. The rock displays plastic folds and banding, with light bands alternating with dark bands. The bands are usually thicker at the axes of the micro-folds, and as observed in a quarry north of Abeokuta, the bands are from 0.3" - 9.0" thick. The light bands are composed of quartz and feldspar while the dark bands are composed of hornblende and biotite, both of them occurring as inclusions in each other. The proportion of quartz is high and locally may be up to 70%, occurring as inclusions in oligoclase crystals and in association with microcline. The rock is foliated and the mineral bands trend and are parallel to the direction of the foliation. It is well jointed with vertical joints being most common along the foliation trend. Wilson and Bain (1922) expressed ^{the view} that the main strike of foliation is ESE - WNW, but field ^{observations} ~~evidence~~ suggest that the major strike of foliation is N - S and occasionally NE - SW. Around Oyo the main strike of foliation is 20° - 200° (NNE - SSW), near Odo Ogun it is N - S, near Fasola it is 140° - 320° (SE - NW) and 90° - 270° (E - W). On Ado Rock it is N - S and at the quarry north of Abeokuta it is N - S. The dip of foliation is steep to vertical, but varies from place to place. It is 40° near Oyo, 60° at the quarry north of Abeokuta and

vertical at the quarry near Ibadan.

The banded gneiss is migmatized in parts, but lacks plastic folding. The bands are often persistent with alternating dark and light coloured, varying in widths throughout the rock. (Plate 3.) Large leucocratic bodies of quartz and of other rocks are often present and these split up the bands (Plate 4). The rock is mainly composed of the same minerals as migmatites except that microcline is absent and the amount of hornblende present is very small. It displays the same foliation and dip characteristics as migmatites.

The Semi-banded gneiss is poorly banded and indeed the bands may be absent. The rock then grades into homogeneous gneiss. The predominant minerals are quartz and feldspar with a little amount of biotite present.

The following rocks are gneisses, but they are not banded, and in some cases they have different structure and lithology from those discussed above. Biotitic gneiss occurs in a very small area north of Abeokuta, and outcrops mainly on the bed of the Ogun river. It is dark and medium grained and composed mainly of mosaics of oligoclase, quartz and biotite. Biotite occurs as schistose patches and account for more than 30% of the minerals. The rock is structurally weak and decomposes rapidly.

Granulitic gneiss outcrops on both sides of Iwere dome and also near Iserin. It is light coloured and fine grained. The composition is mainly of quartz, which accounts for more than 70% of the mineral constituents, microcline and biotite. The rock disintegrates into flaggy rubbles like quartzite.

Granulitic-muscovite-gneiss covers an area of about 15 square miles and outcrops as domes at Igana. The rock is fine to medium grained, and the minerals are saccharoidal. It is composed mainly of quartz, which

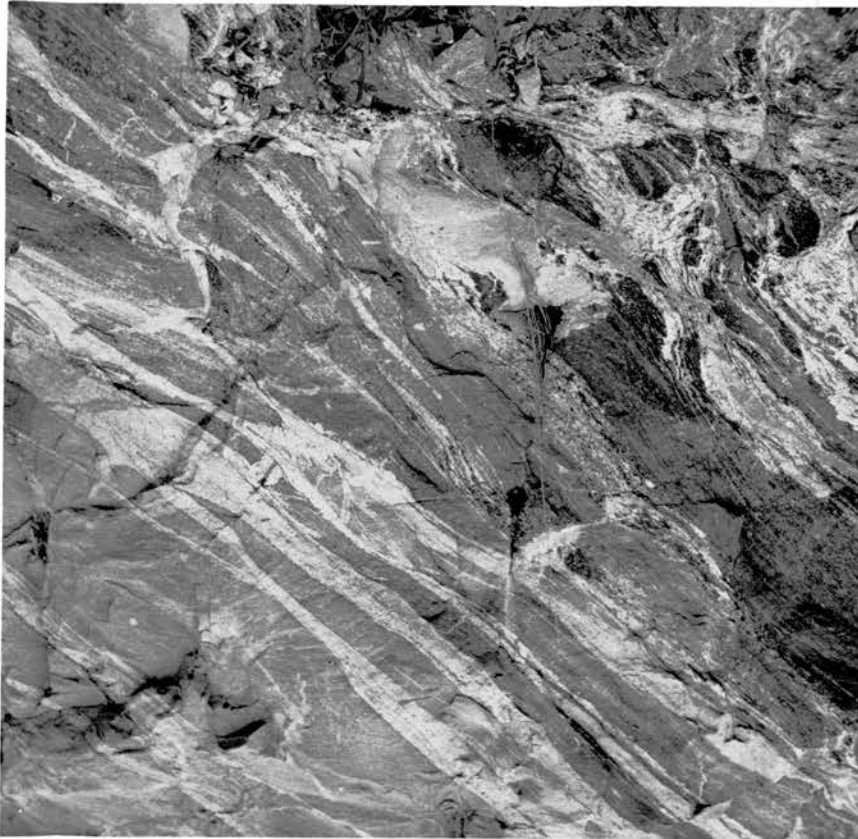


Plate 3. An outcrop of banded gneiss near Fasola



Plate 4. Banded gneiss displaying a dark inclusion

forms up to 70% of the mineral constituents, oligoclase and microcline with flakes of muscovite distributed within rock as thin bands.

Samples from the rock suffer rapid granular disintegration.

Quartzites and Quartz Schists

These rocks occur as elongated bodies and have a wide distribution, but their total area is small. They are found within and south of Ibadan township, south of Oyo, around Iseyin and at Olokemeji. Although they occur mainly as ridges and as lines of hills, outcrops are rare because the ridges are often smothered with the flaggy fragments. They are however, well exposed on the grounds of Iseyin Rest House and near the Premier Hotel at Ibadan (Plate 5). Quartzite is found mainly as massive bands, several feet thick, or as thin bands. It is largely composed of quartz which forms more than 95% of the mineral constituents. Muscovite is present, but where it forms more than 5% of the mineral composition, the rock becomes flaggy and foliation becomes more pronounced. The quartzite then changes into quartz - schist as can be seen on the grounds of the Iseyin Rest House. The rock is extremely well jointed (Plate 5) and most of the joints follow the N - S foliation direction of the quartzite. The angle of dip is extremely steep, and the quartzite at Iseyin Rest House has a vertical dip.

Schists cover a small area. As a rule the rocks weather rapidly hence outcrops are few. They can be differentiated according to the texture and mineralogy.

Amphibole schist occurs locally, mainly between Igana and Oke-Iho, but the total outcrops are limited. The rock is dark and fine to medium grained. Amphibole constitutes 80% of the mineral contents of the rock, with quartz and andesine occurring as infrequent bands. The rock is



Plate 5. Outcrop of quartzite on a road cut near the Premier Hotel at Ibadan.

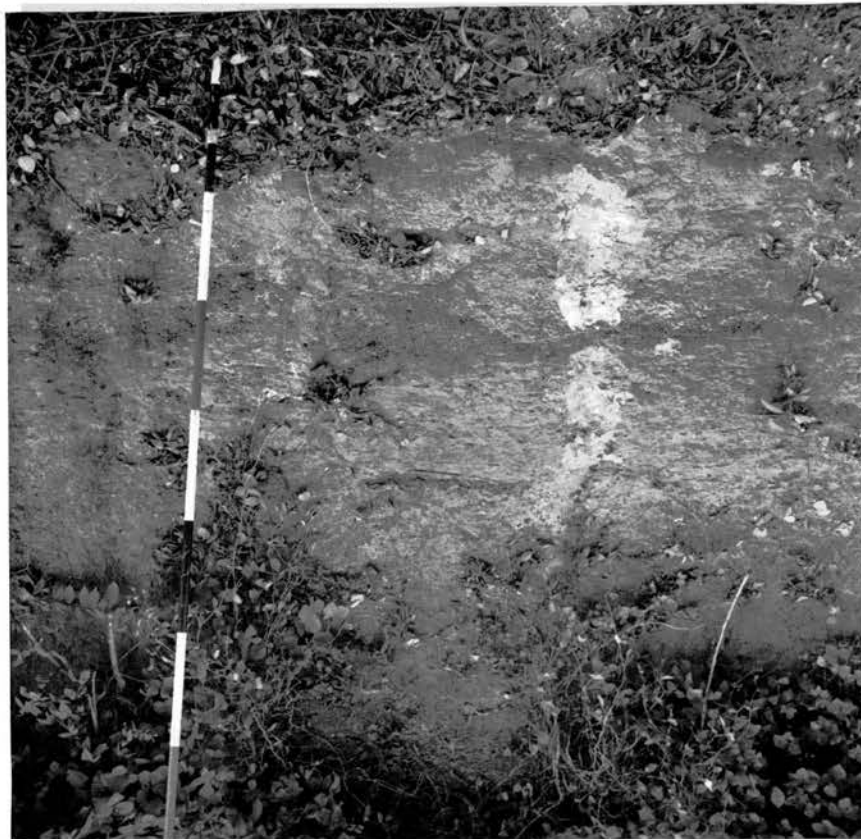


Plate 6. Quartz vein seen on a road cut near the University of Ife,

foliated and is often well banded.

Amphibolite occupies an area of about 30 square miles south east of Idiya, and is also found near Imala and east of Igboora where it outcrops as boulders or as bands in migmatites. The rock is very dark, fine to medium grained and composed mainly of hornblende and plagioclase with a small amount of quartz and biotite occasionally present.

Mica schists occur fairly widely, especially near Ibadan where the thin schist bands lie between parallel quartzite bands. As the rock is highly susceptible to chemical weathering, outcrops are few. Mica schists weather into red sandy clay which is used locally for brick-making (at Ibadan). It is composed of quartz and muscovite with small amounts of biotite and garnet. The rock is strongly schistose.

Pegmatites and Dykes

Pegmatites are common throughout the different rock types discussed above. There are two types - those composed mainly of ferro magnesian minerals found in migmatites; those composed of coarse grains of biotite, muscovite and quartz found in granites and other rocks. The crystals are large, being as much as 3" thick at Aro Quarry. The porphyritic types of pegmatites often occur as large bodies near granite-gneiss e.g. near Igana and at Asejire dam site .

Quartz veins are found as stringers in granites and gneisses. They are composed entirely of quartz with mica occasionally present. Frequently they persist long after their host rocks have been completely weathered. (Plate 6).

Basic rocks, such as diorite, gabbro, and pyroxenite, are also found in several localities, mainly as dykes intruded into the gneiss complex. Diorite forms low ridges and large corestones near Olokemeji and Igboora.

It is dark and medium grained and composed mainly of hornblende, andesine and some quartz. Gabbro also form small dykes and is composed of augite, hornblende and magnetite. Pyroxenite occurs as dykes and is composed of augite, olivine and plagioclase which undergo rapid chemical decomposition.

THE SEDIMENTARY ROCKS

The sedimentary rocks occur as far north as latitude $7^{\circ}15'$ at the Dahomey frontier and $6^{\circ}50'$ near the Osun river (Fig. 3). They continue unbroken from the contact zone with the crystalline basement to the coast. The northern boundary is characterised by an escarpment whose flat top is easily distinguished from the curves of the crystalline area. To the west of the Ogun river, this boundary is well defined, but to the east between the Ogun and the Ibu river, it is irregular and marked by numerous outliers of sandstone lying on the basement complex. East of the Ibu river to the north of Ijebu Ode, the boundary becomes distinct, but it merges imperceptibly into the basement complex near Ijebu-Igbo.

There is no agreement concerning the number of the sedimentary formations. Russ (1922) discussing the sedimentary series from Lagos to Abeokuta classified them into two groups; a group of red sandstone with sub-ordinated variegated clays; and a group of well stratified shales and sandstone often bedded. He estimated their total thickness at 3000 feet and dated the oldest to Eocene. Jones and Hockey (1964) recognised five formations in the sedimentary series:-

- i. the oldest Abeokuta formation of Upper Senonian (Late Cretaceous)
- ii. the Ewekoro formation of the Paleocene
- iii. the Ilaro Formation of the Eocene
- iv. the coastal Plain Sands of the Oligocene - Pleistocene and
- v. the Coastal and river alluvium of recent times.

Reyment (1965) recognised all the above five formations and two more; the Oshosun Formation and the Ijebu Formation. He agreed that the Oshosun Formation and the Ijebu Formation could be lateral variations of the Ilaro Formation.

The sedimentary series of the thesis area have been correlated with the sedimentary series of other parts of Nigeria (Table 5). The lower and middle Cretaceous Series, however are absent in South Western Nigeria. The reason for this is discussed later in this chapter.

Table 5. Correlation between the Sedimentary Series of South Western Nigeria and other parts of Nigeria

South Western Nigeria	North Western Nigeria	South Eastern Nigeria	Age
Alluvium	Alluvium	Alluvium	Recent
Coastal Plain Sands	Gwandu Clay Grit Group	Coastal Plain Sands	Oligocene- Pleistocene
Ilaro Formation	Calcareous Group Clay Shale Group	Bende-Ameki Group Imo Shale	Upper Eocene Lower Eocene
Ewekoro Formation	Upper Sandstone and Mudstone	Upper Coal measures	Paleocene
Abeokuta Formation	Masaurus Shales Lower Sandstone and Mudstone	False bedded Sandstone Lower Coal Measures Asata Nkporo Shale group	Upper Senonian
	Gundumi Grit Ilo Group	Awgu Ndeaboh Shale group	Senonian to lower Cretaceous
Crystalline Basement	Crystalline Basement	Crystalline Basement	Lower Paleozoic- Pre Cambrian

The Abeokuta formation, consisting mainly of sandstones, is the largest of all the sedimentary series and occupies about 1,300 square miles. It is not well exposed as it has been weathered into mottled sandy clay more than 100 feet deep everywhere (Fig. 4). Exposures are seen only rarely at the trenches of the consequent stream heads. The formation is higher west of the Ogun river than east of the river. The rock grades laterally into other formations and is mapped on topographic, soil sample and pit sample evidence.

The formation varies in thickness from 800 feet at the Dahomey border to 600 feet near Wasimi and 400 feet near Ijebu Ode. The different strata within the formation change rapidly and it is often difficult to distinguish the individual bands. A typical stratigraphical succession in a generalised form from base to top will show conglomerate 2 feet - 3 feet thick, arkosic sandstone, grits, sand, clay, shale and sand. Oolitic sandstone occurs near the base occasionally, and the conglomerate may be absent in any locality. Bitumen has been seen near the Yemoji river. Cross bedding is common within the strata. The formation lies unconformably on top of the basement complex and the depth of unconformity varies from place to place. The high amount of sand within the different strata makes the whole formation pervious, and this has led to deep chemical weathering. Reyment (1965) used palaeontological evidence to date the formation as Upper Senonian, while Tattam (1943), apparently with no evidence, believed it to be Eocene.

The Ewekoro formation consisting mainly of Shale and limestone occur south of the Abeokuta formation. The surface of the formation is marked by an ill-defined depression, the Lama Hollis Depression (Pugh 1954), which continues into Dahomey. The formation is rarely exposed except at

Ewekoro village where it is being quarried for cement works. It varies in width from about 8 miles on the Dahomey border to 1 mile south east of Shagamu, and seems to disappear some distance east of the town. The total thickness of the formation is about 500 feet. A typical section across the formation from base to top will show marl, limestone, and shale. Reyment (1959) mentioned that the shale was deposited in a shallow body of water. The limestone bands total 100 feet, and individual bands are hard. The shale is laminated and friable where exposed. Reyment (1959) dated the formation as Paleocene. The shale and limestone are impervious hence marshes and swamps have developed on the formation.

The Ilaro formation occurs south of the Ewekoro formation and its northern boundary is marked by an escarpment. It covers a fairly large area, but it is poorly exposed. Within the yellowish, unconsolidated rock, the sands are coarse and angular, and poorly sorted, while there is a considerable amount of clay. The formation is extremely porous and has been deeply weathered. It includes strata containing phosphate and glauconite especially near Ifo railway junction; these have proved of limited economic importance. Reyment (1965) used mollusc remains found in the rock to date it from Middle to Upper Eocene.

The Ilaro formation is succeeded southwards by the coastal Plain Sands and the boundary between the two is difficult to establish. The latter formation is composed mainly of red earths, loose and ill sorted sands which Parkinson (1907) termed the Benin Sands. The abundance of clay in it has led to the rejection of this title. The coastal Plain Sands have a maximum thickness of about 360 feet. A typical stratigraphical succession from the base to the top shows soft, poorly sorted clayey grits, pebbly sands, sandy clays with occasional lignite and sand. The

formation is pervious. Plant remains have been used by Jones and Hockey (1964) to date it from Oligocene to Plio-Pleistocene.

The recent formations consist mainly of littoral and lagoonal sediments which grade into one another on the landward sides of lagoons and near the mouths of the larger rivers. The formations vary in width from 15 miles east of Lagos to about 5 miles near Dahomey. The maximum thickness exceeds 7000 feet near Badagri at the surface, ^{where} the rocks are composed of old beach ridges. Stratigraphically they are composed mainly of clays, mud and sand with varying proportion of vegetable matters.

Structure of the Sedimentary Rocks.

The constituents of the sedimentary rocks vary from coarse materials at the base to fine materials at the top, and also vary in this manner laterally where the southern boundary of one grades with the northern boundary of the other.

The rocks are unfolded, but minor flexures are present. This contrasts strongly with the folded Lower Cretaceous shale groups of Eastern Nigeria. The rocks dip gently southwards and south-south-westwards at 1° . They are probably faulted. Certainly along the Ogun river south of Abeokuta, this would account for the fact that the Abeokuta formation west of the Ogun river is higher than that east of the Ogun river. The low escarpment of the Eocene sandstone overlooking the Ewekoro formation is also probably due to faulting.

Superficial Drifts

These are composed mainly of alluvial and colluvial materials, laterites and some wind borne deposits (Fig. 4).

Alluvial materials are found mainly on the flood plains of the larger rivers like the Ogun, Yewa, Ibu and Oshun, and are also found inland along

their smaller tributaries. Their characteristics depend on their physiographic location. Those connected with upper level terraces especially along the Ogun are composed of unsorted coarse sand, sub-rounded pebbles and clay lenses. Those at the flood plain are composed of fine to medium grained sand and silt and often show evidence of stratification.

Colluvial materials are found mainly at the foot slopes of the Upper Cretaceous and Eocene escarpments. They are usually composed of brownish gritty clay and unsorted sand and clay fractions

Laterites are mainly of two types. The primary type formed in situ are found on the Cretaceous sandstone, occasionally on the footslope of the escarpment, and at various locations on the basement complex. The detrital type are found on the footslope of the escarpment and at various locations on the basement complex.

Wind borne sediments, though widely distributed in Northern Nigeria, have not been found to any appreciable extent in the South West. They are occasionally present as fine sediments in hollows and grooves on high inselbergs. They are grey in appearance and except where trapped in joints, they are quickly washed away in the wet season. It appears that the sediments are washed down by rain from the fine dust present in the atmosphere during the harmattan. The table below summarises the characteristics of the various superficial sediments found in South Western Nigeria.

Table 6 Sediment Characteristics and Location

Sediment	Nature	Location
Brownish Grey fine alluvium	Fine sand mixed with clay; very friable, with occasional stratification	Found along the river channels in the sandstone area around Aiyetoro and Ilaro
Grey medium-coarse alluvium	Medium sand mixed with coarse sand and clay containing large amounts of rotting vegetable matter	Found along the flood plains of Ogun, Yewa, Ibu and Oshun
Grey-white alluvium	Medium to coarse unsorted sand. Clay completely absent. Used for building and other constructions	Found along the smaller tributaries in various places on the basement complex
Terrace alluvium	Composed of ill-sorted, sub rounded pebbles and stones, sand and occasional clay lenses	Found along the Ogun and seen clearly at Olokemeji
Brownish gritty clay	Mixture of clay and decomposed laterite	Found on sandstone escarpment footslopes between Imala and Obada
Primary Laterite	Massive, pisolitic, extremely hard	Found on the Upper slopes of the Cretaceous Sandstone escarpment and on the sandstone upland
Detrital laterite	Broken up primary laterite rubbles in some cases undergoing recementation	Common on lower slopes of sandstone escarpment and in various places in the basement complex
Ferruginised Sandstone	Amorphous large masses of hard sandstone indurated by ferric oxide, but often broken into smaller pieces	Common in the Eocene sandstone north of Ilaro

Geological History.

The sedimentary rocks have been dated to a large extent, but this cannot be said of the crystalline rocks whose age and geological history are still not well established. The following account, pieced together from several sources, can only tentatively indicate the broad outline of the geological history of the rocks.

It is believed that the various gneisses, quartzites and schists are of sedimentary origin (Wilson and Bain 1922, Jones and Hockey 1963, Russ 1924). Russ, in particular, mentioned that there were two periods of sedimentation, the first led to the formation of the gneiss complex by regional metamorphism and the second led to the formation of fine grained sediments which were compressed, isoclinically folded and converted into schists. Evidence cited for the sedimentary origin of these rocks are the frequent alternation of quartzite and mica schist bands, the gradation of quartzite into quartz-schists, the dip of the gneisses and the quartzites, the banding and foliation, and the flaggy partings of the various gneisses and schists. The disposition of these old sedimentary series is equally difficult to establish because of the absence of marker rocks. Quartzites, which could be used, are not always distinctive enough as they grade into schists. Nevertheless, Jones and Hockey (1964 p. 54-55) postulated that the old sedimentary series were probably folded into either an anticlinorium or synclinorium trending in a SW - NE direction. Wilson and Bain (1922) were of the opinion that these rocks were thrown into a series of gentle folds in a north to south direction. What is clear is that the rocks were folded, as witness the dips of the quartzite bands and migmatite in the field. These pre Cambrian rocks have been dated to 3,200 - 3,400 million years

B.P. by Furon (1963), and their equivalence, the Dahomeyan basement of sedimentary origin, is said to be of similar age. The Birrimian and the Atacorán rocks which are of sedimentary origin dated to 2000 - 3000 million years B.P. by the same author are found in Ghana, but are absent in Western Nigeria.

After the old sedimentary series were ~~followed~~ ^{folded} they are ~~believed~~ ^{believed} to have been metamorphosed in two distinct phases as mentioned earlier. There is no agreement about how this metamorphism took place. Oyawoye (1965) believes that the migmatization of the gneisses was by 'lit-per-lit' replacement while Jones and Hockey (1963) believe that it occurred in two phases, a 'lit-per-lit' replacement, and an intrusive replacement.

The granites are believed to have been emplaced within the country rocks, and, during this process, various pegmatites and dykes were formed. Emplacement has been postulated in three phases (Jones and Hockey 1964) i.e. an earlier one leading to the formation of granodiorite, a main one leading to the formation of the coarse porphyritic granites and the various porphyroblastic gneisses, and a later one when the pegmatites and the basic dykes were formed. These rocks have been dated by the above geologists to 495 ± 20 million years B.P. With granitic emplacement the existing gneisses suffered shearing and faulting, while crustal tension also led to the formation of a series of joints and faults in them. These faults are now difficult to trace as they were partially filled up by intrusive materials.

Following the granitic emplacement, a long period elapsed before newer rocks were formed. According to Russ (1922) at the beginning of the Cretaceous period, a sea transgression occurred all over Southern Nigeria and moved along the Niger Valley to part of Northern Nigeria.

and in Northern Nigeria, but not in Western Nigeria. It was in the upper Senonian period that new rocks were formed. The sedimentary rocks derived their basal materials from coarse sediments eroded from the crystalline rocks and deposited along the then coast line. In turn, this was followed by the deposition of marine materials. As the sea retreated, this pattern of deposition continued. Thus the sedimentary series vary from fine materials from the top to coarse materials at the bottom, and this variation is both lateral and vertical. The basin of deposition existed right from Togo to the Niger Delta where it was cut off by a ridge of basement rock. This may perhaps explain the absence of lower Cretaceous rocks in Western Nigeria. After the Paleocene, deltaic and estuarine deposits became important.

When these sediments were being deposited, the basement complex in Western Nigeria probably suffered a flexuring into a low asymmetrical arch whose axis trends NNW - SSE (Falconer 1911 p. 233-4). This axis forms the present water divide between streams flowing to the Niger and streams flowing to the Gulf of Guinea. Kitson (1913) however believed that the basement complex was uplifted (a) in the Pliocene (b) in the Oligocene - Miocene and (c) in the Quarternary periods with the last uplift being in a NW - SE axial movement along the primary watershed of Western Nigeria. These flexuring and uplifts of the basement rocks are probably equivalent to the cymatogenic arching which King (1962) described for the crystalline rocks of West Africa at the end of the Cainozoic age. The flexuring of the basement rocks is perhaps responsible for the basin, over 7000 feet deep, found along the present coastline by the Mobil Oil Drilling Group (1960) which could have been formed as a result of being a syncline or as a result of downwarping due to isostatic pressure exerted by

sediments overlying it.

Comparison between South Western Nigeria and other parts of West Africa

Except for the absence of the lower and middle Cretaceous sediments in South Western Nigeria, it appears there is no significant difference in the broad geology of South Western Nigeria and the other parts of West Africa. Only along the coastal area of Senegal and parts of Ghana are Ordovician and Jurassic sedimentary rocks found (Haughton 1963). The absence of Mesozoic sedimentary rocks has been attributed by King (1962 p. 60) to the fact that West Africa was still joined to South America up till the early Albian (Upper Cretaceous) period. This may partly explain the absence of these rocks. Continental depositions of pre Cretaceous period are found in several places in the interior of West Africa, but are absent from the coastal area. In ^{the} case of the crystalline rocks, the gneiss complex of Nigeria also found in Dahomey appear to be present in Ghana and elsewhere. The rocks in Ghana are younger with the Birrimian and Atacoran series dated to 2000 - 3000 million years B.P., the Tarkwaian dated to 1,850 million years B.P. by the Falemian dated 600 - 3000 million years B.P. by Furon (1963). The older granites of Nigeria have been widely recognised in West Africa.

The rocks discussed above are differently affected by chemical weathering and erosion, and these geomorphological processes are caused by rainfall variation and intensity, high incidence of temperature and other geographical factors discussed in the following chapter.

CHAPTER 3

CLIMATE AND VEGETATION

The most important geomorphological processes in the humid tropics are chemical weathering and ^{fluvial} erosion, and both are related to climatic elements like rainfall and temperature. Rainfall determines the availability of water for chemical reaction while temperature determines the speed of chemical weathering. As the availability of water for chemical weathering varies directly with the amount of rainfall, the greater the rainfall, the greater will be the volume of water available for chemical weathering. Direct variation between chemical weathering and availability of water is modified by several factors most especially vegetation. Vegetation produces organic matters which further intensify chemical weathering, but at the same time it often decreases the water available for chemical reactions through evapotranspiration. More important, where vegetation is thick, as in the forest, part of the rainfall may not reach the ground, and the volume of water is reduced by retention in the canopy. Also in the forest especially where chemical weathering is pronounced, water is not an important erosional agent. In the savanna where the vegetation is sparse, the volume of water available for weathering and erosion is not much decreased by the vegetation.

Chemical weathering appears to have continued ^{through} since geological times in the humid topics. Evidences of past climatic change in the humid tropics are not convincing and are discussed in Chapter 5, but it seems that the annual precipitation in the past was sufficient to promote deep chemical weathering.

The availability of water for contemporary weathering will be discussed in relationship to rainfall pattern and intensity in South

Western Nigeria.

Rainfall

The rainfall of South Western Nigeria and other parts of Nigeria is mainly determined by the interplay of two air masses, the tropical continental (Tc) air masses which are cold and dry with temperature less than 65°F , and the tropical maritime (Tm) air masses which are warm and moist, with temperature higher than 65°F , but not lower than 60°F (Garnier 1958). As both air masses have different characteristics, they are separated by the Inter Tropical Front (I.T.F.) or the Inter Tropical Convergence Zone (I.T.C.Z.). Thompson (1951) objected to the use of these terms in the tropics especially between Latitude 10°N - 10°S and propounded that the term "Equatorial Air Stream Boundaries" be substituted. Beckinsale (1957) however, is of the opinion that since the zone between the air masses advance and oscillate to give much rain, there is nothing wrong with the use of the terms "I.T.F." or "I.T.C.Z." These terms will be retained for the purpose of this discussion.

The I.T.F. remains north of the equator all the year round lying between latitudes 6°N . and 8°N . in January, moving to latitude 20°N . in July. This northward and southward movements of this front is responsible for most of the rainfall in Western Nigeria. Other factors responsible for rainfall include the local heating of the ground which gives rise to convectional thunderstorms and high hills and ridges causing orographic effects. The rainfall has a double maxima with the highest rainfall in June and July, a minor dry period in August and higher rainfall in September and October (Appendix 1). Mean annual rainfall figures vary from 45ins. at Egbeda to 72ins. in Lagos (Fig. 5), while the length of the wet and dry seasons vary from place to place (Appendix 2).

In places with short dry seasons of up to 2 months, especially in the

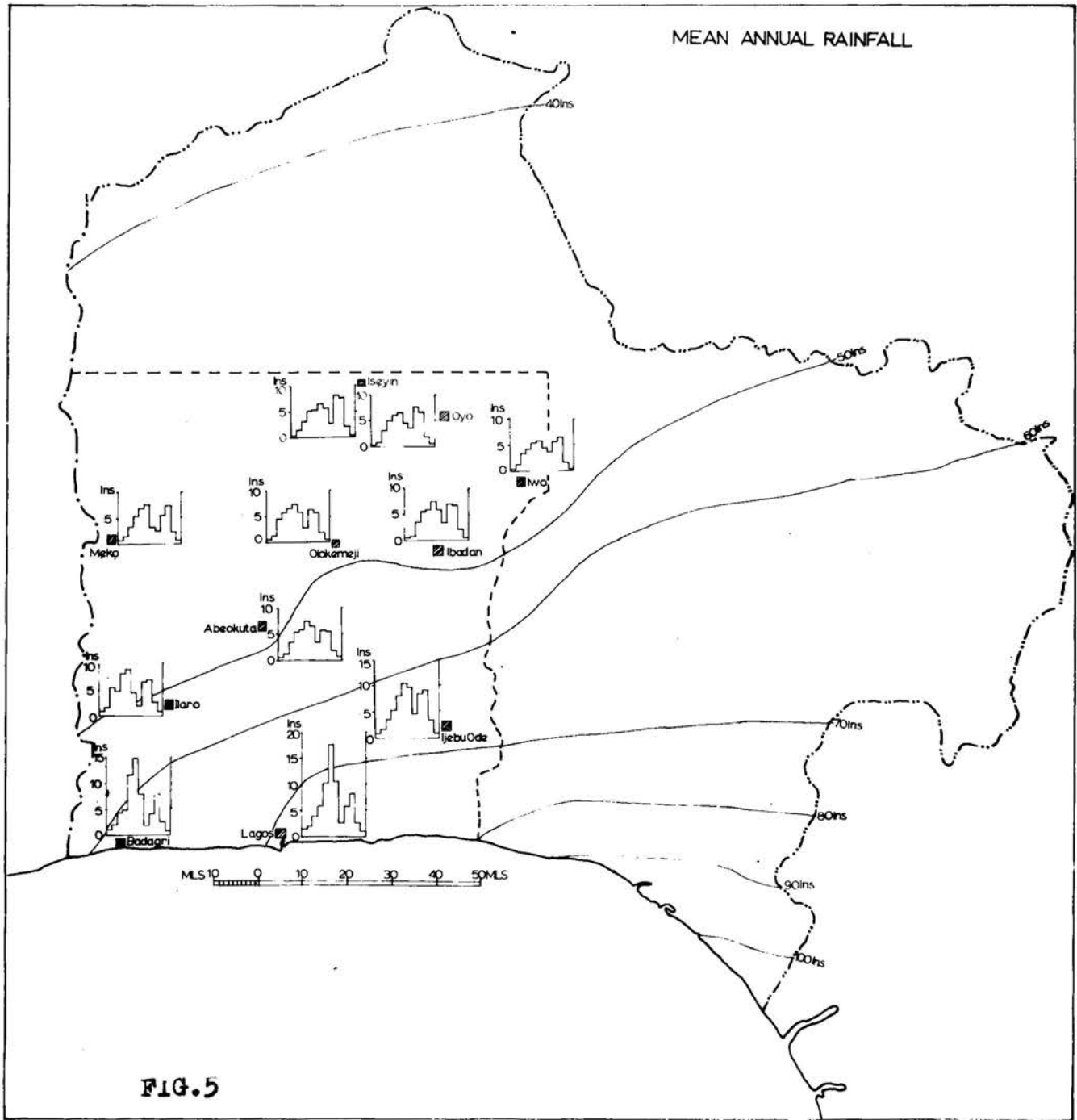


FIG.5

forest, there is water surplus throughout the year, and geomorphic processes like chemical weathering and leaching are continuous. In the savanna area where the dry seasons vary between 5 - 7 months, geomorphic processes like chemical weathering, leaching and erosion are pronounced in the wet seasons, but inhibited in the dry seasons. Here, during the dry season, the upper soil horizons dry out except around inselbergs and along river valleys where gallery forest are often present, and where chemical weathering is continuous.

More important than the total rainfall to the geomorphological processes, are the rainfall pattern and rainfall intensity. There is a problem in defining these due to the absence of reliable data for many stations. Harrison Church (1957) observed that climatic statistics should be used with caution in West Africa because of the ways in which they have been collected. Many instruments are located in atypical sites, such as the grounds of agricultural or medical departments, and most of the observers are untrained. Since 1938 the data collected can be used with greater confidence because it was gathered under the supervision of the Meteorological Department of Nigeria. Data collected since 1952 by the Department of Geography, University of Ibadan can be regarded as accurate (Hopkins 1965) and ^{are} ~~is~~ used below to discuss rainfall intensity.

Rainfall Pattern - There are three types of rainfall; viz. precipitation from the thunderstorms experienced around late March to early May, and from October to November; the less violent frontal rain from about mid May to early October; and the highly localised orographic rainfall. The convectional thunderstorms are intense, and the volume is high; as they occur at the beginning of the rainy season when stream levels are low, the rains cause the

streams to rise sharply and to effect some linear erosion, but the stream levels come down shortly, and the stream beds are often filled with debris. Further, the intensity of insolation from February to early April is high, and this is the time of bush burning in the savanna. The squalls of late March and early April leads to sudden chilling of exposed rocks and in this way may effect some physical disintegration. Lichens covering the bare rocks are removed and fresh surfaces exposed. Exposed land surfaces at the end of the dry season especially in the savanna, are often powdery and the sudden thunderstorms may cause widespread sheet erosion with streams consequently choked with debris derived from such surfaces. In heavy clay soils, large cracks open up during the dry season. The first heavy rains penetrate down into the body of the soil making them unstable.

The frontal rains fall over a long period, and the total volume is probably greater than the thunderstorms. As the rains continue from mid May to early October, the rain water saturates the ground and effects leaching and weathering both in the forested and in the savanna areas. Orographic rains are localised on hill slopes especially near the stream sources and such rains often cause the stream levels to rise rapidly. In the dry season, the top of high hills like the Ilele hill (1,657 ft. a.s.l.) is misty and often covered by clouds.

Garnier (1953) analysed the pattern and intensity of rainfall for Ibadan. This is reviewed here to illustrate the intensity of the thunderstorms. He used the data collected in 1952 and noted that 1/3 of all the rains fell in storms giving over 1ins., a further 1/3 fell in storms with precipitation between 0.5 - 1.0 ins. In the first category, over 80% of the fall occurred in the first 20% of the duration, and in case of falls less than 1ins, 50% of the total fell in the first 20% of the time (Table 7).

Table 7Rates of Rainfall per hour (in ins.) at quarterly intervals

	0- $\frac{1}{4}$	$\frac{1}{4}$ - $\frac{1}{2}$	$\frac{1}{2}$ - $\frac{3}{4}$	$\frac{3}{4}$ -1
fall over 1.0 ins.	2.07	1.61	0.78	0.36
fall 0.5 - 1.0 ins.	1.04	0.67	0.40	0.13

In 1952, a rate of 2.0 ins. per hour was exceeded five times. A further observation was that thunderstorm rains arrived in showers with an initial rate of fall of 3 ins. per hour or more. This intensity lasts for about 30 minutes after which it tails off into drizzle.

The data for the University of Ibadan between 1957-1966 has been analysed (Table 8) to show the mean monthly rainfall and the mean highest precipitation for one day. The latter is also expressed as a percentage of the total for each month in order to show the intensity of individual storms, especially in the dry season between December to March. Appendix 3 shows the mean rainfall in one day for most of the towns in South Western Nigeria.

Table 8

Rainfall Intensity based on % of 'most precipitation in one day' to the total amount of rainfall for the month

1957 - 1966	J	F	M	A	M	J	J	A	S	O	N	D
a) Mean monthly rainfall	ins. 0.19	1.20	3.55	5.45	6.38	7.70	7.50	5.56	6.30	5.82	1.81	0.44
	mm. 4.8	29.8	91.2	136.2	159.6	192.5	187.3	139.1	165.2	145.5	45.2	11.0
b) Mean of 'most precipitation in one day'	ins. 0.15	1.01	1.52	1.82	1.84	2.03	1.87	1.84	1.73	1.10	0.58	0.30
	mm. 3.6	25.2	38.0	45.6	45.9	50.8	46.8	46.1	43.2	27.6	14.4	7.6
c) Mean No. of days when rain fell	1	2	7	11	12	16	18	15	15	15	6	1
(b) expressed as % of (a)	76.0	84.7	41.6	33.5	28.8	26.4	25.0	33.1	28.0	19.0	32.0	69.1

From tables 7 and 8, it can be concluded that there is usually a heavy concentration of rainfall over a short period. The net effect of rainfall intensity depends on several factors e.g. the infiltration rate and the infiltration capacity of the soil, and the nature of the surface. Other things being equal, heavy concentrations of rainfall in a short time lead to rapid exhaustion of soil infiltration capacity and this in turn leads to rapid runoffs and soil erosion. Horton (1945) emphasised this when he observed that there is a limit to the infiltration capacity of any type of soil, and the greater the intensity of the rain, the quicker this capacity is reached after which runoff starts and sheet erosion is effected. This is certainly true for the savanna areas and for unprotected soil surfaces where the rate of runoff after storms is high. It is not necessarily applicable in the forest area as vegetation helps the infiltration capacity of the soil and further breaks down the impact of the rain drops. Here the kinetic impact of the rain drops is broken by the vegetation and the volume of water is reduced by retention in the canopy. The leaf litter layer under the forest is capable of absorbing most of the rain water which falls, and the underlying humus top soil is usually moist. Thus runoff under the forest is mainly subsurface.

Akinola (1966) studies the intensity of rainfall at Ibadan and established a direct relationship between the high intensity of the storms, flood incidences and sheet erosion in the town. Beckinsale (1957) emphasised the effects of tropical rains and wrote that "the physical effect of such down pours need no embroidering. Flat areas are quite submerged and on steep slopes where the soil cover always seems so thin, rain sodden lubricated masses may slip downhill, trees and all". The erosional effects of the high rainfall intensity are felt mostly on unprotected soil surfaces.

The impact of raindrops leads to soil compaction and the pores in the layer below the soil surface become clogged with finer soil fractions washed down from the surface layer. Rapid drainage through the soil layer just below the surface is retarded or stopped and this leads to rapid surface runoff and erosion. It may also be a factor in the formation of iron-pans in sandy soils. The breakdown of the crumb structure of the soil by the impact of heavy rains also make the soil less resistant to erosion and decrease its water holding capacity. This is responsible for large scale soil erosion in Eastern Nigeria.

Temperature

Temperatures are constantly high in South Western Nigeria with a maximum exceeding 90°F. in February and March and a minimum of about 69°F in August due to the heavy cloud cover. The annual temperature range is small, varying from 5°F in Lagos to 10°F in Oyo, but the diurnal range is higher 15°F in Lagos and 25°F in Oyo. The mean maximum temperature increases inland from the coast while the mean minimum decreases inland from the coast (Appendix 4). The constantly high temperature promotes chemical decomposition.

Recordings of soil temperature are available for a few stations, but there are several gaps in the data, and they cannot be considered reliable. The data collected by the Geography Department of the University of Ibadan is consistent for 1957-66 and Table 0 summarises the temperature at depths of 2 ins., 4 ins., 8 ins., and 12 ins. at 9 a.m. G.M.T.

This table shows that there is a temperature inversion in the top 8 ins of the soil, but more significantly after 4 ins., soil temperature increases with depth to a consistent value at 3 feet. Rain water is warm, but it is further heated in draining through the surface layers of the soil and its

potentiality to effect chemical weathering is increased.

Table 9

Temperature for soil (in °F) 1957 - 1966

Depth	J	F	M	A	M	J	J	A	S	O	N	D
Monthly average:												
for 2 ins	82.2	83.2	85.1	84.3	83.7	81.4	78.9	77.6	79.0	80.0	82.4	81.7
for 4 ins	79.8	82.3	84.2	82.2	81.8	80.3	78.1	76.8	78.6	79.5	80.0	82.0
for 8 ins	82.6	85.2	86.4	84.5	83.5	82.2	80.4	79.3	79.9	81.1	82.8	83.6
for 12 ins	85.2	86.8	87.9	85.6	84.8	83.2	81.4	80.0	80.7	82.0	83.7	84.6

Relative Humidity

Relative humidity is high all over Western Nigeria (Appendix 4). Even in the dry season, it reaches up to 80% in January and 75% in December. In the rainy season it may be as high as 100%. This high relative humidity, coupled with the high temperature, leads to the uncomfortable dampness and stickiness experienced in the humid tropics. In the rainy season, the relative humidity is high, but the temperature is relatively low, and this leads to low evaporation, and a water surplus. It is this water surplus that decides the amount and intensity of chemical weathering. Further, high temperature and high relative humidity encourage oxidation of the soil organic contents.

Evapotranspiration

Evapotranspiration in South Western Nigeria is difficult to assess. Where data exist, ^{they are} it is punctuated by gaps. At Ibadan University, six different types of tanks are used giving six different results for the same area with a maximum difference of 54 mm. in a month. Garnier (1957) calculated the mean annual water surplus to the mean annual water deficit in Nigeria and assessed

the mean evapotranspiration for South Western Nigeria at between 48 ins and 60 ins, with the actual water surplus at between 8 ins and 10 ins. The net effect of the water balance, as it affects the water table is still difficult to determine. Local water tables in weathered zones within large rocks rise quickly in the rainy season, but in case of the regional water table there is a time lag before the surplus water infiltrates through the overlying material; and the more this water is retained by the soil, the more intense the weathering becomes.

Vegetation

Vegetation affects the volume of water available for weathering and erosion, and the micro climate, and the geomorphic processes within each vegetation zone vary. Primarily the vegetation of South Western Nigeria is determined by the mean annual rainfall, the severity of the dry season measured by mean relative humidity and the length of the rainless period. There are several factors affecting the distribution of each vegetation zone. For instance the rain forest has been disturbed mainly by farming and grass fire, the combined effect of which is the evolution of derived savanna. This phenomenon is so widespread that the true vegetation climaxes can only be seen in forest Reserves (Fig. 6). The boundaries between the different vegetation zones are not defined because of intermingling of the communities of the adjacent zones.

The vegetation can be subdivided (based on Keay 1953) into 6 units (Fig. 6), each will be discussed, and the geomorphic processes in the different types will be examined briefly. The vegetation types are:-

Mangrove Forest and Coastal Vegetation

Fresh Water Swamp Forest

Lowland Rain Forest

Semi Deciduous Rain Forest

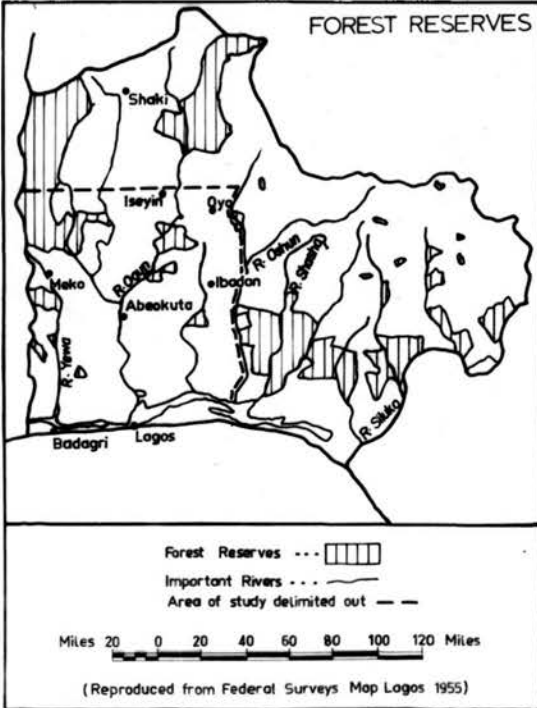
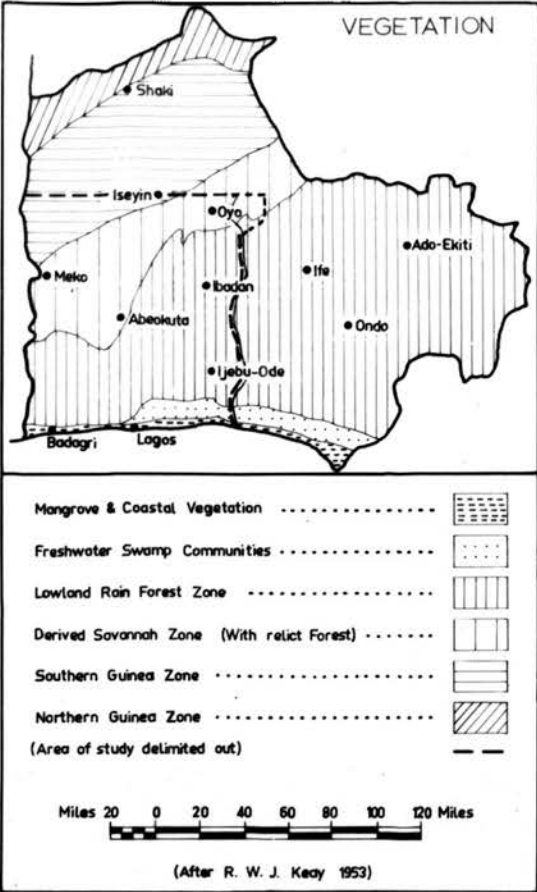


FIG.6

Derived Savanna

Guinea Savanna

Mangrove forest and coastal vegetation are found along the coastline and on the muddy banks of the river mouths where the water is brackish. The vegetation is zoned; red mangroves extend to the limit of the diurnal tide and is flooded daily; white mangroves and sedges succeeds it inland; while the third zone is composed of rhizophora whose still roots are prominent. The fresh water swamp forest is found near fresh water lagoons, and is composed mainly of raphia palm, and a few tree species like symphonia gabonensis which may reach up to 100 ft. Grass grows up to 5 ft. at the outer edges of the forest. In the mangrove areas, the tree roots trap silt and help alluviation. Further, the trees produce litter with acidic chemical composition which under water resists decomposition, thus the alluvial deposition in the coastal area has a large organic content, and the rate of chemical decomposition is slowed down by the presence of too much water.

The lowland forest follows the swamp forest and covers a large part of South Western Nigeria. The forest is composed of four tiers; the emergent stratum in which the trees are up to 200 ft. high, with their canopies rarely touching; the second stratum is about 50-120 ft. high, and the canopies form a lateral continuum. Below is the third layer up to 50 ft. high, with spreading canopies and short boles joined together by various types of climbers. Beneath the third layer are the understorey and shrub layers. There are many tree species often more than 70 species exist within an acre making the exploitation of the commercial trees difficult. The forest floor is covered by leaf litter, and as the rate of chemical decomposition is fast, the humus layer is thin. As the length of the dry season is short in the forest area, less than 2 months; chemical weathering and leaching are continuous and the upper soil horizons are

acidic. Generally runoff under the forest is small due to the leaf litter absorbing the water, but water trickling down the tree trunks often erode the the bases of the trees to expose the lateral roots.

The semi deciduous rainforest occupies the transitional zone between the forest and the savanna, and contains several tree species shedding their leaves in the dry seasons. Here the dry seasons vary from 4-5 months leading to seasonality of processes. Leaching and chemical weathering are important in the rainy season, and in any year with abnormally high rainfall, erosion becomes pronounced. The humus layer is thicker than in the forest zone and the upper soil horizons are less acidic as leaching is not continuous throughout the year. Where the forest is cleared, compaction of soil by raindrop impact leads to eluviation, and Cunningham (1963) has shown that the soil surface can be lowered up to 1 in. in a period of three years.

The derived savanna is found mainly in Abeokuta and Oyo Provinces. In the Southern areas, the trees are higher and more frequent, with ~~grass~~ ^{grasses} fewer, but to the north, trees are fewer, stunted and gnarled, with tall grass dominant. Relict patches of forest are seen around inselbergs and along stream valleys where water is available all the year round (Plate 7). The Guinea savanna is found mainly to the west of Oyo province and it consists of open woodland and tall grass. The trees are short and have fire resistant barks; they are gnarled and stunted. The grass is tussocky (Plate 8) and the commonest is the cylindrica imperata. As mentioned earlier the length of the dry seasons in the savanna varies from 5-7 months, and this means that chemical weathering and leaching operate mainly for half of the year. Due to the sparse vegetation cover, however, there are less obstacles to rain drop impact, runoff is large, and erosion by surface wash is more pronounced than in the forest area.

Generally in South Western Nigeria, there is surplus water to effect the



Plate 7. Derived savanna near Oyo. Note the forest patch in the valley at the middle of the plate.



Plate 8. Guinea ^asvanna near Iseyin.

geomorphic processes of weathering and erosion, the temperature is also high enough for chemical weathering, but the intensity and duration of these processes vary from one vegetation zone to the other. But it is hardly possible to associate a particular landform with a particular type of vegetation. Cotton (1947) associated inselbergs with the savanna area and termed the complex 'the savanna landform'. In South Western Nigeria, inselbergs occur both in the forest and in the savanna, hence the designation of the savanna landform is unjustified. Major landform differences appear more related to the local geology than to the vegetational environments, but it must be emphasised that processes like *fluvial* erosion are more pronounced in the savanna than in the forest.

APPENDIX 1

Mean Monthly Rainfall up to 1960 (in inches)

Stations	No. of years	J	F	M	A	M	J	J	A	S	O	N	D	Yearly Total
Epe	18	0.8	1.1	3.5	4.4	8.3	12.3	10.7	2.8	7.4	6.9	2.7	0.6	61.5
Lagos	68	1.2	1.8	3.9	5.8	11.1	17.9	10.4	2.6	5.6	8.2	2.7	1.0	72.2
Badagri	15	1.0	2.0	4.2	4.8	11.5	14.8	7.6	1.8	4.0	7.9	2.3	0.8	62.7
Ikeja	17	1.0	1.7	3.7	4.2	8.1	11.9	6.8	2.3	6.9	7.2	2.6	1.3	57.7
Ilaro	10	0.9	1.6	5.3	4.7	8.0	8.9	4.1	1.9	6.3	6.7	2.3	0.8	51.5
Abeokuta	23	0.5	1.1	3.5	5.4	5.9	7.5	6.5	3.3	5.6	5.5	1.8	0.5	47.1
Ijebu Ode	32	0.7	1.4	3.3	5.1	8.0	10.2	9.5	4.2	8.1	9.0	3.1	0.6	63.2
Meko	10	0.7	1.4	3.2	5.3	6.9	7.5	3.1	2.5	5.5	7.2	2.1	0.7	46.1
Ibadan	50	0.4	0.8	3.6	5.3	5.9	7.2	5.9	3.2	7.0	6.7	2.0	0.3	48.3
Iloro	11	0.4	0.9	3.6	5.5	5.8	6.4	3.5	3.2	7.9	6.8	1.9	0.5	46.3
Oyo	55	0.2	0.9	3.1	5.0	6.0	6.4	4.5	3.4	7.5	6.5	1.9	0.4	45.8
Egbeda	23	0.2	0.9	3.1	4.7	6.4	5.8	5.2	3.8	6.4	6.7	1.8	0.2	45.2
Iseyin	11	0.1	1.4	3.0	5.0	5.1	6.4	5.5	2.7	8.0	7.6	2.0	0.2	47.0
Oshogbo	32	0.3	1.0	3.3	4.4	5.7	5.9	5.3	3.9	7.7	7.5	1.7	0.2	47.2
Iwo	22	0.3	1.1	3.4	4.1	5.4	5.8	4.4	3.6	5.6	6.3	1.6	0.3	41.9
Olokemeji	38	0.5	1.1	4.5	5.8	6.5	7.2	5.9	2.8	6.1	5.8	1.9	0.4	48.5

Source:- Nigerian Meteorological Department.

Appendix 2

Mean No. of Rain Days (when rainfall $\geq 0.01''$) up to 1960

Stations	No. of years	J	F	M	A	M	J	J	A	S	O	N	D	Total
Lagos	68	4	4	8	10	18	23	15	10	17	15	8	3	135
Badagri	15	3	3	6	7	11	15	8	3	9	11	5	2	83
Ikeja	17	2	4	8	8	15	19	14	10	18	16	8	3	125
Iloro	10	1	3	7	8	12	14	9	6	12	13	5	1	91
Abeokuta	23	1	3	8	8	12	14	11	9	14	15	4	1	100
Ijebu Ode	32	1	3	8	7	12	15	14	10	16	14	5	2	107
Meko	10	1	3	7	10	12	13	8	6	12	13	4	1	90
Iloro	11	1	3	7	9	12	14	11	11	16	16	5	1	106
Ibadan	50	1	3	9	9	13	16	15	12	17	17	5	1	118
Oyo	55	0	2	5	6	10	10	8	9	11	13	4	1	79
Egbeda	23	0	2	5	7	8	9	7	6	10	11	3	1	69
Iseyin	11	0	2	6	7	9	9	8	7	13	12	4	1	78
Oshogbo	32	0	2	7	8	10	11	11	10	13	13	5	2	92
Iwo	22	1	3	7	8	11	12	11	8	14	15	5	1	96
Olokemeji	38	1	2	8	10	11	12	11	8	11	13	4	1	92

Source:- Nigerian Meteorological Department.

Appendix 3.

Mean Rainfall in one day up to 1960 (ins.)

Station	No. of years	J	F	M	A	M	J	J	A	S	O	N	D	Greatest for the year
Lagos	68	0.01	1.32	1.13	1.77	2.11	2.89	1.68	0.16	1.15	2.14	0.77	1.78	2.89
Badagri	15	0.27	1.02	2.44	0.34	1.64	2.72	0.97	0.11	0.56	1.11	0.68	1.08	2.72
Ikeja	17	0.00	1.23	2.32	1.20	1.45	1.13	0.64	0.68	1.33	2.10	0.88	1.25	2.32
Ilaro	10	0.10	0.50	2.54	0.64	1.75	2.77	1.50	0.05	1.88	1.12	0.60	1.33	2.77
Abeokuta	23	0.35	2.09	1.23	0.67	0.41	1.72	1.14	0.13	1.79	3.02	0.36	0.87	3.02
Ijebu Ode	32	0.00	1.84	1.32	2.85	1.76	3.55	2.15	0.30	1.20	2.60	0.55	1.10	3.55
Meko	10	0.75	0.85	1.31	0.62	1.80	1.43	0.45	0.15	1.14	2.35	1.82	0.59	2.35
Ibadan	50	0.00	0.45	1.51	2.24	0.68	1.44	0.90	0.32	2.20	0.58	0.72	0.65	2.24
Oyo	55	0.00	1.30	0.61	2.11	1.24	1.25	2.16	0.33	0.71	2.63	1.31	1.96	2.11
Iseyin	11	0.00	0.40	1.38	1.47	1.70	1.05	2.15	0.29	1.18	2.71	2.70	0.64	2.71
Iwo	32	0.00	1.42	2.34	1.84	0.88	0.72	1.17	0.48	0.73	0.72	0.95	0.00	2.34
Olokemeji	38	0.00	0.75	1.69	1.11	0.94	1.10	0.66	0.24	0.88	1.45	0.72	0.85	1.69

Source:- Nigerian Meteorological Department

Appendix 4

1953-66 - Mean Monthly Maximum & Minimum Temperature (in °F) and Relative Humidity (at 9 GM Tin %)

	J	F	M	A	M	J	J	A	S	O	N	D	Year
<u>Lagos</u>													
Mean Max.	86.8	87.8	87.8	87.4	86.4	83.4	81.0	81.2	81.4	83.6	86.4	86.2	84.95
Mean Min.	75.2	74.9	77.8	77.6	76.2	74.6	73.6	73.6	73.6	74.4	75.8	75.8	72.22
Mean R.H.(%)	82.5	80.2	78.4	79.8	81.0	85.8	86.4	83.8	83.6	82.2	83.2	84.8	82.64
<u>Ikeja</u>													
Mean Max.	88.6	91.8	91.4	90.0	87.8	83.8	81.4	82.4	82.8	85.2	88.0	88.8	86.83
Mean Min.	70.6	73.8	73.6	73.8	73.0	71.0	71.6	71.8	70.8	71.0	72.3	72.2	72.12
Mean R.H.(%)	87.5	88.4	83.7	81.8	84.8	89.4	90.8	88.4	86.0	86.6	87.3	89.0	87.00
<u>Ibadan</u>													
Mean Max.	90.2	94.0	93.2	90.0	88.2	85.0	82.0	81.4	83.0	85.8	88.5	89.2	87.54
Mean Min.	67.8	72.6	73.2	72.2	71.6	70.8	70.8	70.0	70.0	70.3	72.0	70.0	70.94
Mean R.H.(%)	70.5	77.8	77.4	79.6	81.8	84.2	82.4	87.2	85.4	84.0	81.2	78.6	80.84
<u>Oyo</u>													
Mean Max.	93.0	95.3	94.3	92.6	90.5	87.0	85.0	83.0	85.0	90.0	92.0	93.0	90.60
Mean Min.	69.0	71.5	73.5	71.5	71.5	71.0	73.0	69.5	70.5	70.0	70.5	67.5	70.75
Mean R.H.(%)	69.0	67.7	76.0	74.3	77.0	81.0	85.0	86.0	83.0	82.0	65.0	67.0	76.83
<u>Oshagbo</u>													
Mean Max.	89.6	93.8	93.8	90.2	88.2	85.6	83.8	81.4	83.2	85.8	89.0	89.0	87.78
Mean Min.	65.4	70.0	72.0	71.8	71.0	70.2	70.6	69.4	69.8	69.6	71.6	68.2	69.97
Mean R.H.(%)	71.7	75.8	79.4	82.6	82.6	85.4	86.0	88.6	86.4	85.8	81.2	78.8	82.25

Source:- Nigerian Meteorological Department.

CHAPTER 4

* PHYSIOGRAPHY AND DRAINAGE

The most striking aspect of the physical geography of South Western Nigeria is the topographic contrast between the sedimentary area and the crystalline basement area. The sedimentary series form a cuesta relief pattern which suggests a uniclinal structure, while the crystalline area is hummocky.

The coastal area comprises a complex of lagoons, creeks and alluvial flats. Inland, the land rises gently for about 40 miles, reaching an altitude of about 450 feet A.S.L. at the Eocene escarpment north of Ilaro, although east of this point it is lower at 250-300 feet A.S.L. To the north, the escarpment is succeeded by a depression a few miles wide. Beyond this, the dip slope of the Cretaceous escarpment rises inland for about 30-50 miles, reaching an altitude of about 850 feet A.S.L. at the scarp top north east of Meko. The height of the scarp is lower near Imala, 600 feet A.S.L., and near Abeokuta, 500 feet A.S.L.

The slope of the Cretaceous scarp is well marked west of the Ogun river, but indistinct to the east of the river. The formation of the cuesta landscape is the result of three factors. First, the sandstones are widely covered by a resistant cap of laterite, hence erosion is slow. Where the crust has been breached, erosion has been accelerated. Second, the sandstones are generally covered by thick forest; where deforestation has occurred, soil erosion and gullying may be spectacular as at Shasha Training Camp near Ijebu Ode. Third, the sandstones are coarse and permeable, and these textural properties make them resistant to soil erosion. The dip slopes of the Eocene and Cretaceous escarpments have been dissected by consequent streams.

* See Glossary

The crystalline area just north of the Cretaceous escarpment is at a lower level. The landscape is generally well dissected with moderate relief, but it may be extremely rugged where the granites and migmatites form complexes of high domes. Quartzitic ridges are common, and can be traced for several miles. The land rises generally in a S-N direction, but more specifically in a SSW-NNE direction.

Physiographic Regions

Three main physiographic regions were recognised by Pugh (1955).

The Coastal Creeks and Lagoons

The dissected margin - which consists of the transition zone between the crystalline rocks and the sedimentary rocks to the sea.

The Western Plains and Ranges - which includes a variety of landscapestypes grouped together by virtue of their development on crystalline rocks.

This attempt at classification is commendable, bearing in mind the extremely crude, small scale maps which were available, but unfortunately the criteria on which the classification is based are not stated.

Physiographic classification aims at grouping the landscapes according to their surface configuration. By itself, a classification system is inherently subjective, and lends itself to generalisation. While some approximation may be permitted, a measure of quantification has to be introduced. Several authors have approached this problem using some elements of objectivity. Hammond (1954) employed three parameters; the local relief, the general slopes and the profiles. Thrower (1960) used a combination of the relative relief map (choropleth map) and slope analysis

to produce the physiographic classification of Cyprus.

The physiographic classification of South Western Nigeria in this study is based on a combination of the following:

- i) an inspection of the generalised contour map;
- ii) the relative relief map;
- iii) the degree of dissection in the different sections;
- iv) the roughness Index;
- v) the value of the maximum valley slopes;
- vi) Projected Profiles.

The generalised contour map of the area is synthetised from the 1:50,000 sheets into a 1:250,000 map. This gives a clear indication of the level areas, and allows delimitation of the undulating and flat areas. It is however, of limited value otherwise, as the contour crenulations showing marked dissection have been smoothed off (Fig. 7).

The relative relief map is based on one-mile-grid lines and the choropleth method has been used rather than the isopleth method (Fig. 8). This has the advantage that no interpolation is necessary, while the pattern of occurrence of the different height can be visually inspected and grouped together on an areal bases, and if necessary analysed.

Of the several methods proposed for calculating the degree of dissection perhaps the most fascinating is by Dury (1952). Dury sees the degree of dissection essentially as "the mean available relief" i.e. the volume of land available for erosion in an area. He proposes that this volume can be calculated from the areas of the actual surface and the "stream-line surface" obtained by planimeter. The latter surface is that which passes through the bottoms of main valleys and is obtainable by drawing generalised contours. The difference between these surfaces will be the available relief or the

GENERALISED CONTOUR



FIG. 7

the dissection index. This method may be approximate for a small area, but it is inappropriate in a large area.

A simpler method, which can be easily adopted by other users is proposed as follows. A transparent overlay is placed on the map of the area whose degree of dissection is to be assessed. The contour lines delimiting the upper break of valley slopes are traced on the overlay, care being taken not to include valley floors and slopes, but to include the flatter upper parts of the spurs. (Figs. 9 and 10). Slopes more than 2° on spur ends are regarded as valley slopes. The areas of valley floors and slopes are calculated, the interfluvial areas are also calculated, and expressed as percentages of the whole area. The greater the value for valley floors and slopes, the more dissected the area; e.g. where values stand at 25% for valley floors and slopes, and 75% for interfluvial areas, the dissection can be regarded as youthful.* Where values stand at 50% for both valley floors and slopes, and interfluvial areas, the dissection can be regarded as at early maturity,* and where values stand at about 75% for valley floors and slopes, and 25% for interfluvial areas, the dissection can be regarded as at advanced maturity.* This method is subjective, but the more care taken in delimiting the interfluvial areas and the valley slopes, the more accurate the result. Further, it will not give the depth of dissection, but it is useful when used in conjunction with the relative relief map.

The Roughness Index can be defined in terms of the density of contour lines, being high in areas of dissection and low in plateaux and plains. It has been calculated using the method proposed by Hook (1959) who gave the formula:

$$R I = \frac{(N \times M)/4}{A} \times 10$$

N = Total number of contour intersections with grid lines in all 4 directions

* See glossary

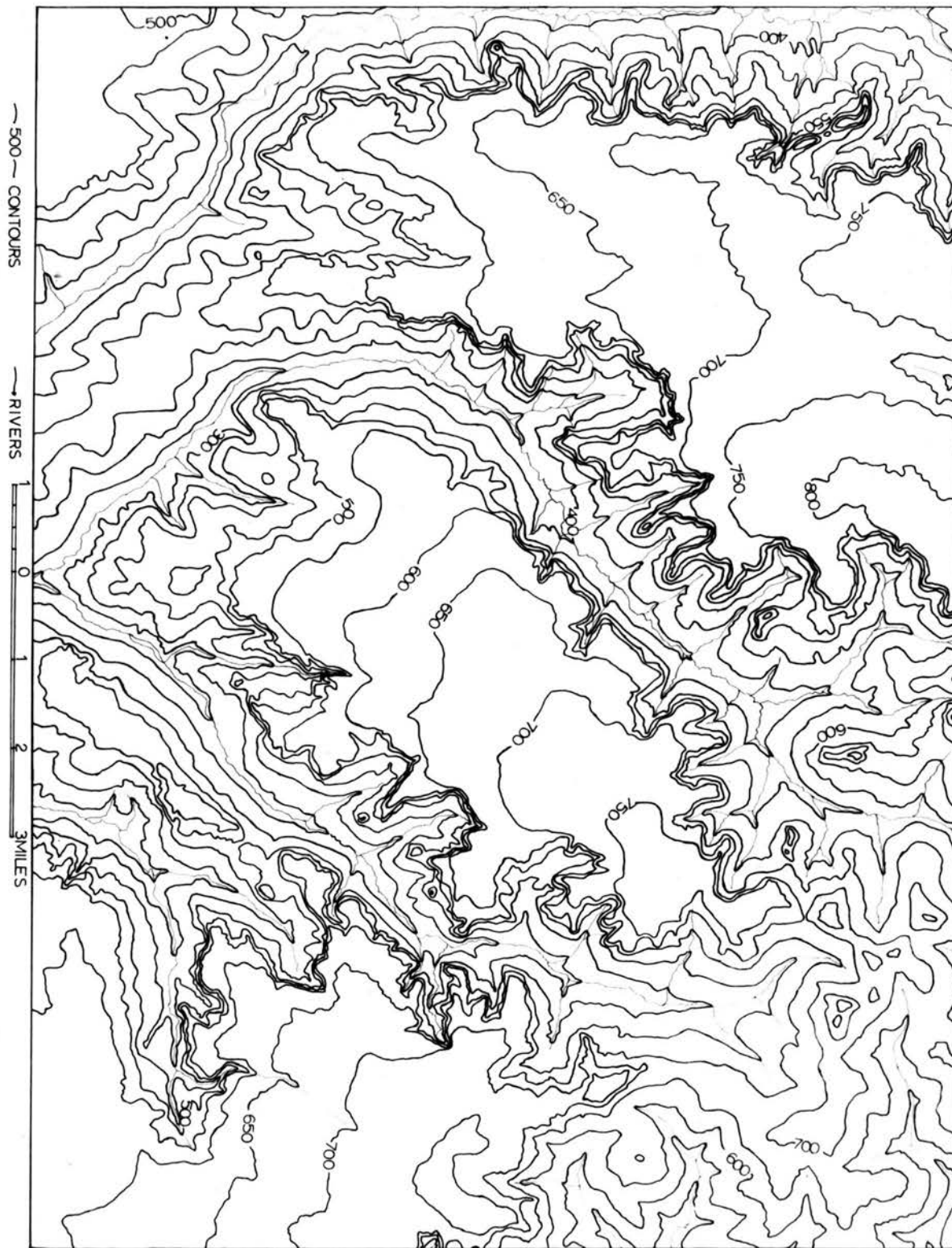


FIG. 9

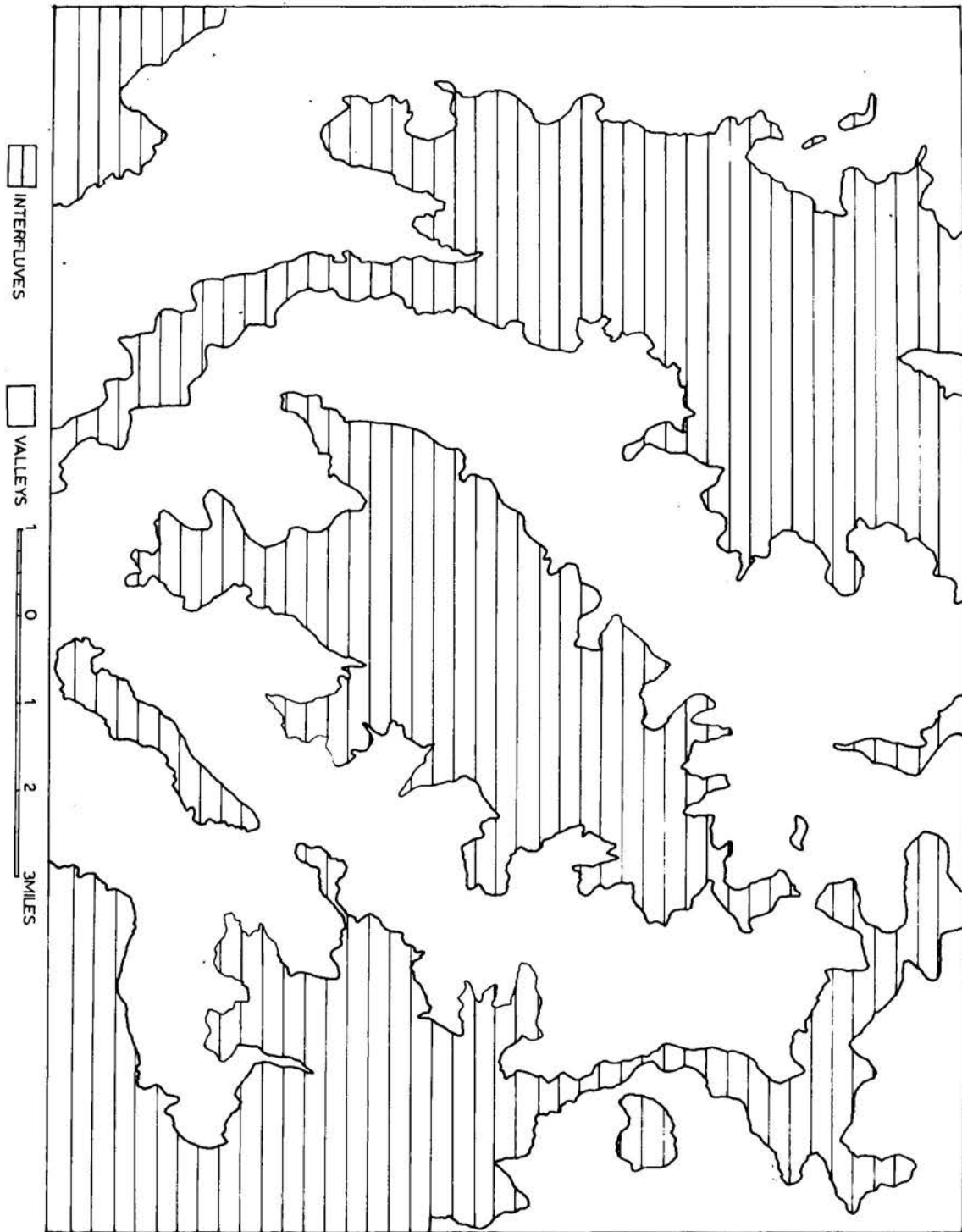


FIG. 10

M = Distance in miles between the grid lines

A = Land area of map in square miles

10 = a constant.

The distance between the grid lines used is one mile.

The maximum slopes of the different topographic regions have been calculated using Strahler's (1956) method. Calculation was done mainly for the sedimentary areas where contour spacing is more uniform, and, for each region, more than twenty samples were used. The data collected by F.A.O. (1962) have been used for the crystalline area, but as the number of samples is unknown, the means and standard deviations have not been calculated. The average slopes for the sedimentary area were calculated using Wentworth's (1930) method.

$$\text{Av. slope} = \frac{\text{Average no of contour crossing per mile} \times \text{Contour Interval}}{3361 \text{ (a constant)}}$$

The combination of all these various parameters give the following physiographic regions in South Western Nigeria. It should be noted that in some cases the boundaries are extremely difficult to establish, and, of necessity some overlapping and approximation has occurred (Fig. 11). The regions are

- i. Coastal Creeks and Lagoons
- ii. Coastal Plains
- iii. Alluvial Flats
- iv. Dissected Southern Upland
- v. Ewekoro Depression
- vi. Southern Meko Plain
- vii. Northern Upland
 - (a) Area of Deep Incision
 - (b) Area of mature dissection
 - (c) Dissected Margin.

viii. Dissected Terrain

(a) with low ridges and hills

(b) with high ridges and hills

ix. Gently undulating terrain with occasional hills

x. Hilly Terrain

An analysis of the local relief (Fig. 12), stage of dissection and Roughness

Index of each unit are given in Tables 10 to 12.

Table 10

Analysis of Relative Relief

Physiographic Units Number	0-50'	51- 100'	101- 150'	151- 200'	201- 250'	251- 300'	301- 350'	351- 400'	401- 450'	451- 500'	501- 550'	551- 600'	> 600'
	%	%	%	%	%	%	%	%	%	%	%	%	%
i.	100	-	-	-	-	-	-	-	-	-	-	-	-
ii.	69.3	25.0	5.7	-	-	-	-	-	-	-	-	-	-
iii.	100	-	-	-	-	-	-	-	-	-	-	-	-
iv.	14.8	40.1	30.6	11.8	2.5	0.2	-	-	-	-	-	-	-
v.	92.8	6.0	1.2	-	-	-	-	-	-	-	-	-	-
vi.	82.0	18.0	-	-	-	-	-	-	-	-	-	-	-
vii.a.	25.0	25.3	24.1	16.8	7.5	1.0	0.3	-	-	-	-	-	-
b.	15.3	36.2	31.0	15.0	2.0	0.5	-	-	-	-	-	-	-
c.	0.7	10.0	21.0	33.8	21.5	13.0	-	-	-	-	-	-	-
viii.a.	14.0	51.6	22.4	6.2	2.8	1.1	0.7	0.4	0.3	0.2	0.1	-	0.1
b.	11.5	25.0	13.5	13.7	9.9	8.3	5.7	2.1	3.1	0.5	2.1	-	3.0
ix.	33.3	47.8	13.3	3.0	1.1	0.4	0.6	0.3	0.3	-	-	-	-
x.	-	7.7	9.2	10.8	7.7	14.0	8.5	6.4	8.5	6.4	6.4	4.6	10.2

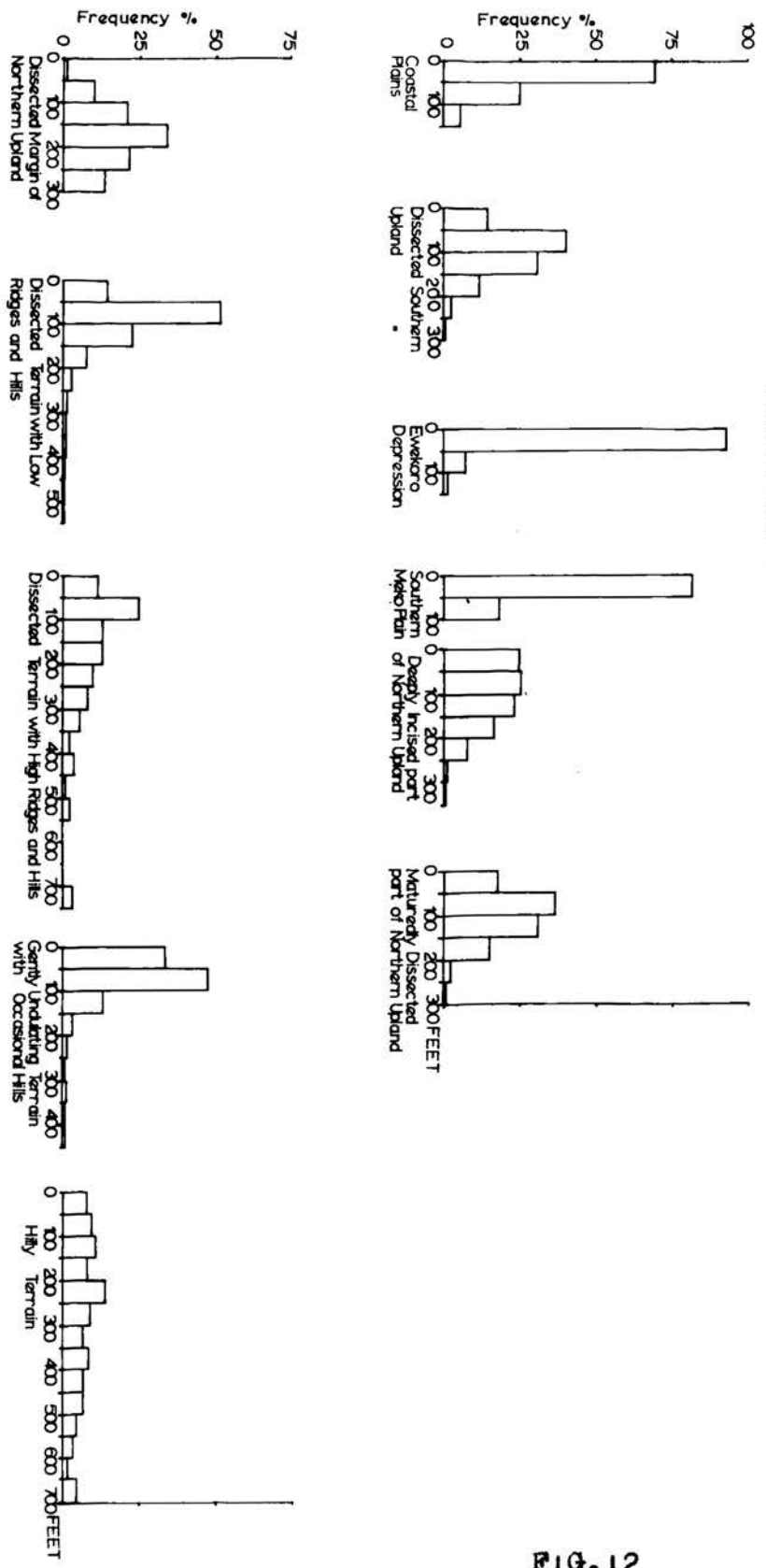


FIG. 12

Table 11

Stage of Dissection

Physiographic Units No.	Percentage of area in valley floors & slopes	Percentage of area on Interfluves	Stage of Dissection
i.	-	-	Undissected
ii.	11.1	88.9	Early Youth
iii.	-	-	Undissected
iv.	49.9	50.1	Early maturity
v.	-	-	Undissected
vi.	9.0	91.0	Early Youth
vii _a	40.5	59.5	Late Youth
b	62.2	37.8	Middle maturity
c	85.0	15.0	Advanced "
viii _a	71.5	28.5	Advanced "
b	71.0	29.0	Advanced "
ix.	70.8	29.2	Advanced "
x.	88.6	11.4	Advanced "

Table 12

Roughness Index and Maximum Valley Slope

Physiographic Unit No.	R.I.	Maximum valley Slope range	Mean	Standard Deviation
i.	-	-	-	-
ii.	13	2.5° - 5.0°	3.5°	0.4°
iii.	-	-	-	-
iv.	33	3.5° - 9.5°	6.5	0.7°
v.	-	-	-	-
vi.	11	1.0 - 3.0	1.3°	0.5°
vii _a	27	12.5° - 30.0°	18.5°	2.1°
b	35	5.0° - 7.5°	6.1°	0.35°
c	61	7.5° - 18.0°	12.5°	1.85°
viii _a	46	4.0° - 8.0°	-	-
b	41	8.0° - 10.0°	-	-
ix.	26	1.0° - 3.0°	-	-
x.	71	10.0° - 30.0°	-	-



Coastal Sands, Creeks and Lagoons

This unit covers a large area varying in width from about 15 miles in the east to about 6 miles along the border of Dahomey. It includes the lagoons, the outer sand ridges and beaches, the inner, older sand ridges and the esturine muddy deposition of rivers Yewa, Ogun and Ibu (Fig. 11). The area is generally less than 40 feet above sea level inland, and less than 20 feet above sea level on the outer beaches. The complex has been built up by marine and river deposition since the Pleistocene. The younger outer ridges are parallel with the present coastline and the recurved spits are still visible along the Badagri Lagoon. In between these ridges are shallow mud filled and marshy depressions. The Badagri and Porto Novo Lagoons occupy a depression between the outer ridges and the inner older sand ridges. The inner sand ridges are also parallel with the lagoons. The formation of these ridges and sand complexes have been discussed by Pugh (1953, 1954a, 1954b) and Webb (1958). The river estuaries appear to be drowned, but the depth of drowning involved has not been calculated. It is however, clearly evidenced by the lack of deltaic deposits at the sheltered mouths of the Yewa, Ogun and Oshun rivers, and also by the lower drowned valley of the Yewa river which gives a northward continuation of the Badagri lagoon.

The coastline is at present undergoing erosion ^{in association with} ~~from~~ longshore drifting coming from the west and this is responsible for the constant silting of the entrance to Lagos harbour. This erosional problem is discussed by Webb (1958)

Coastal Plain

The coastal plain covers the whole of Lagos State, and the southern parts of Abeokuta and Ijebu Provinces. It extends from the Dahomey border

in the west to the Oshun river in the east (Fig. 11). The southern boundary of the plain can be approximately delimited by the 50 feet contour line, but the northern boundary is less easily defined as the plain merges imperceptibly into the Southern Upland, and, east of Shagamu, into the Northern Upland. To the west of the Ogun river, the northern boundary appears to coincide with the Idiroko-Otta road, while to the east of this river, it approximates with the heads of the Owa river tributaries where the plain merges with the Ewekoro depression.

The plain is formed on the deeply weathered coastal sands. It has an average slope of 2° from its northern boundary to the coast. West of the Ogun river (Fig. 13) the plain is monotonously flat, relieved only by the wide, shallow valleys of the Owo tributaries and the steep bluffs bounding the Yewa valley. East of the Ogun river, the plain is dissected by the tributaries of the Ibu, Berre, and Owa rivers, but the depth of dissection is ~~generally~~ ^{generally} less than 50 feet, although it may reach up to 150 feet at the heads of the tributaries. Valley slopes are not steep, and except for valley heads where maximum valley slopes are up to 5° , average about 3° .

Alluvial Flats

These flats occur mainly along the Yewa, Ogun, Ibu and Oshun rivers. Along the Ogun river, the flat varies in width from 10 miles north of Lagos to 0.5 miles south of Abeokuta, and it extends about 35 miles inland from the coast (Fig. 11). The broad valley floor of the Yewa river is about 1.5 miles wide throughout its 40 miles extension inland from the coast. The alluvial flat along the Ibu river varies from about a mile in width inland for about thirty miles, to 0.5 miles near Okun Owa, while the one along the Oshun river is smaller and extends inland for only about twelve miles.

PROJECTED PROFILES

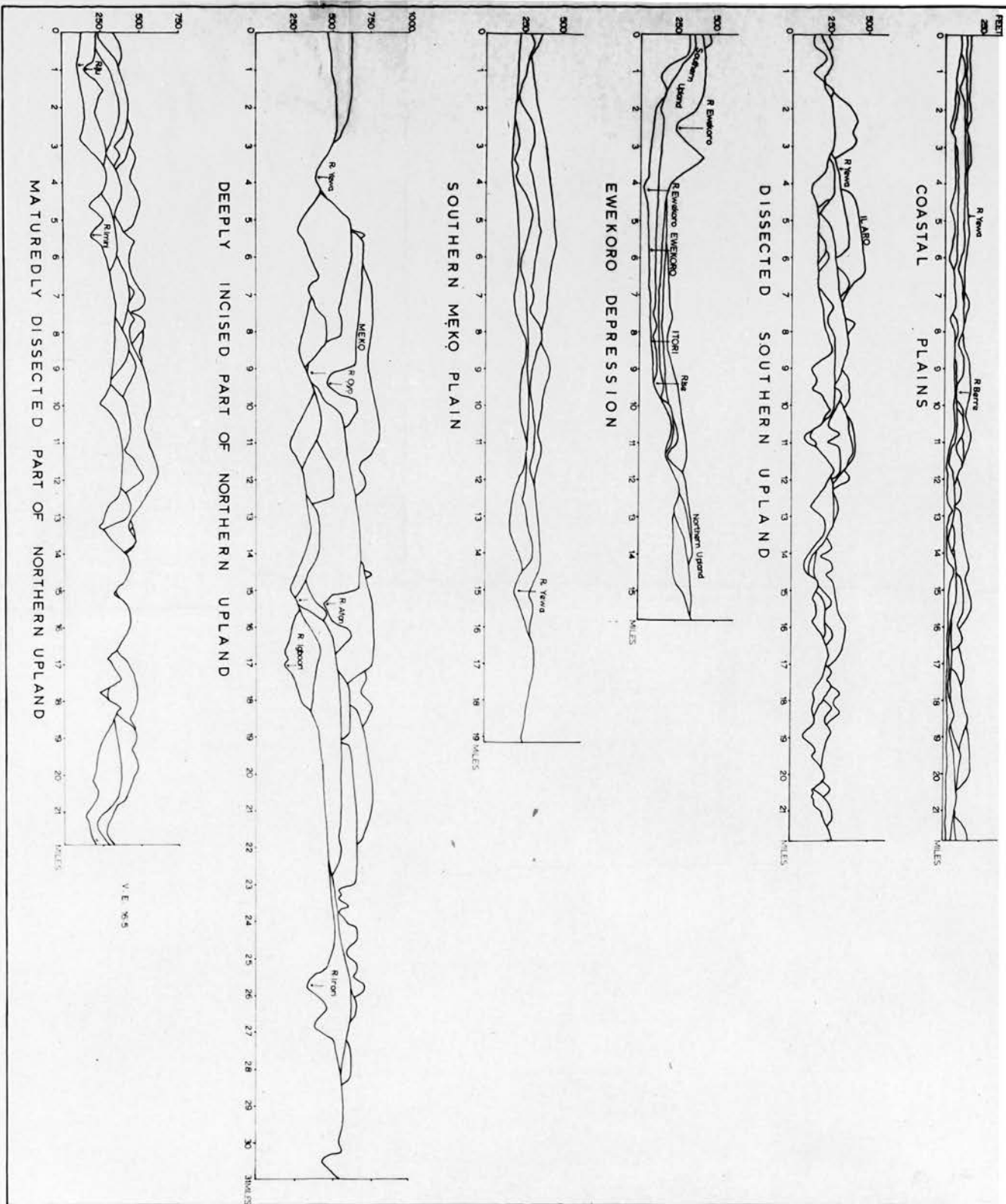


FIG. 13

Everywhere, these flats are bounded by steep bluffs. They are marshy and swampy, and old cut offs are visible on them. The composition of the alluvium has been examined in Table 6 (chapter 2). The alluvial flats along the Yewa, Ogun and Ibu rivers merge imperceptibly with the Ewekoro depression. The flats nowhere rise more than 75 feet A.S.L.

Dissected Southern Upland

This unit is called an upland not because of its altitude, but because it is a cuesta landform rising above the coastal plain to the south, and the Ewekoro depression to the north. It extends from the Dahomey border in the west to the bank of the Ibu river in the east where it fades out. The northern limit is marked by a double escarpment in the vicinity of the Yewa river south west of Ilaro (Fig. 11). North of Ilaro, and to the east, it is marked by a sharply defined scarp which, near the Ogun river, is superseded by the steep bluffs overlooking the river. The scarp is 150-200 feet above the Ewekoro depression.

The Southern upland rises from about 150 feet A.S.L. near Otta to 470 feet A.S.L. north of Ilaro, but east of the Ogun river, it is nowhere more than 350 feet A.S.L. North and east of Ilaro, the upland is in form of ^{the} summit plateau, but outside this area, it slopes at an angle of 2° to the south. It is dissected by south flowing consequent streams especially by the head streams of Berre, Owo and Ore, and by tributaries of the Yewa and Ogun. The degree of dissection, valley forms and depth depend on two factors; (a) the presence or absence of ferruginised material on the surface, (b) rejuvenation along the stream courses. East of the Ogun river where the upland surface is uncovered by ferruginised materials, and where the streams e.g. Berre, are rejuvenating, there is a deep dissection. Valley slopes are steep about 7° - 8° , and deep 100 - 150 feet. To the north and northeast of

Ilaro, the valleys within the summit plateau are shallow and flat bottomed. The area in the triangle formed between the towns of Ilaro, Ifo and Otta is well dissected because here the tributaries of the Ore, Iju, Atuwara and Ogun are being rejuvenated. The valleys of these streams are steep and deep, with maximum valley slopes between 5° and 7° , and valley depths of the range 100-150 feet. The projected profiles of this area gives an impression of wide interfluves alternating with broad, flat bottomed valleys (Fig. 13).

Ewekoro Depression

This depression occurs north of the Southern Upland. It has been traced into Dahomey by Pugh (1956) who called it the Lama-Hollis depression. He also extended it in to the Mid Western State, but in reality it seems to fade out south east of Shagamu where it merges with the alluvial flat of the Yemoji river (Fig. 11). The depression varies in width from about 18 miles near the Dahomey border to about a mile south of Shagamu (Fig. 13). It occurs on the Ewekoro formation with an inlier on the Eocene Sandstone south of Ilaro.

The Ewekoro depression varies in height from 150 feet A.S.L. near the Dahomey border to 30 feet A.S.L. near Aiyeye, and thus slopes in a NW-SE direction. In most places, it is swampy. The formation of the depression has been ascribed to erosion by subsequent streams (Pugh 1955), although Moss (1961) took the view that it was formed by marine erosion. Both opinions are questionable. The only large permanent stream within the depression is the Ewekoro which occupies a swampy, undefined channel, and appears incapable of any serious erosion. A more acceptable explanation is that of Hockey and Jones (1964) who believe it to be a structural depression, thus the rise of the Eocene escarpment above it is due to faulting. Plate 9



Plate 9. The Ewekoro depression can be seen at the middle of the plate, at the background is the Northern Upland.



Plate 10. Potholing on granite along the Ofiki river near Tapa.

shows the depression as viewed from the Eocene escarpment north of Ilaro.

Southern Meko Plain

This plain which is part of the dip slope of the Cretaceous escarpment, covers about 40 square miles SSW of Meko and west of the Yewa river (Fig. 11). It slopes from about 500 feet A.S.L. in the north to about 150 feet A.S.L. at the northern limit of Ewekoro depression. The land rises at about 40 feet per mile from the south northwards, and the average slope of the whole plain is less than 1° . The topography is flat and featureless (Fig. 13) only relieved in the southern part by broad shallow valleys with slopes less than 3° . The surface of the plain is covered by abundant lateritic debris derived from the higher upland around Meko.

Northern Upland (a) Area of Deep Incision

This is often referred to as the Meko Plateau (F.A.O. 1962), but it exists very widely in other areas (Fig. 11). Again, this unit is called an upland because it is in form of a cuesta landform rising above the Ewekoro depression to the South, and the crystalline landform to the north. It falls into two parts; the area around Meko; and the area extending east of the Ogun river south of Abeokuta to the Oshun river. The area of the former is about 200 sq. miles, while the latter covers about 400 sq. miles. The height increases from about 200 feet near the Ewekoro depression to a summit altitude of 835 feet north east of Meko. The general altitude however, is 500-750 feet A.S.L. around Meko, and 250-600 feet east of the Ogun river. The upland slopes in a N-S direction, and also in a NNW-SSE direction especially around Meko.

The northern limit is marked by a distinct scarp 150-200 feet above the crystalline area, but this feature is absent east of the Ogun river, and

reappears north of Ijebu Ode. The surface of the upland is covered by a thick carapace of laterite which is widely exposed at the steep scarp faces and at various localities on the upland. Deep incision by the headstreams of Yewa, especially the Igbo ori, Oyo and Irori often reach the underlying basement rocks. The steep side valleys are 150-200 feet deep, with maximum valley slopes exceeding 20° around Meko. In some places, the headstreams of the Yewa river have cut northwards to reach the basement complex area. South of Abeokuta and around Ijebu Ode, the valleys are also steep and deep with marked "V" profiles. The projected profiles of this physiographic unit gives an impression of wide interfluves alternating with deep, flat bottomed valleys (Fig. 13).

(b) Area of Mature Dissection

This area lies between the river Ogun and the incised section of the upland (Fig. 11) and covers about 300 square miles. It is part of the dip slope of the Cretaceous escarpment, but it is, widely dissected by the tributaries of the Ogun and Yewa, and presents a typical "ridge and valley" topography, though the "ridges" are flat topped (Fig. 13). In some parts, especially south of Aiyetoro, small, flat topped interfluves, capped by laterite may be seen, but where the laterite has been recovered, the interfluves are narrow. The land slopes in a N-S direction, varying in altitude from about 600 feet A.S.L. in the north to about 200 feet in the south. The valleys are well opened and deep. Maximum valley slopes are about 7° and valley depths vary from 50-200 feet. In some localities, noticeably near Ikereku and Ishaga, the underlying basement rocks are revealed in the valley bottoms. Towards the heads of the rivers, the valleys become shallow and flat bottomed.

(c) Dissected Margin

This area covers about 100 sq. miles extending from Abeokuta to north east of Ijebu Ode at the boundary between the crystalline and the sedimentary

rocks (Fig. 11). It occurs where the tributaries of the Ogun and the Ibu are cutting into the Cretaceous sandstone. The landscape is characterised by steep sided, tabular hills, often capped by laterite, with little vegetation cover, although the slopes are heavily forested. The hills often occur in close proximity to the crystalline domes as seen at Abeokuta. Valleys are steep and deep, with maximum valley slopes around 15° and valley depth about 150-250 feet. The projected profiles of this area gives an impression of series of hills alternating with deep valleys (Fig. 14). In several localities, the rivers have cut through the Cretaceous sandstone into the basement complex rocks below, and the unconformity is seen where the basement rock outcrops beneath the sandstone.

Dissected Terrain (a) With Low Ridges and Hills

This unit covers the largest part of South Western Nigeria (Fig. 11) and extends through parts of Abeokuta, Ibadan and Oyo provinces. The land rises northwards from about 250 feet A.S.L. at the foot of the cretaceous escarpment to about 1100 feet A.S.L. This area, described as "steeply rolling" by F.A.O. (1962) is dissected by several rivers especially by the Ogun, Ibu, Oshun and their tributaries. The landscape is monotonously uniform, with the valleys being either "bowl" shaped or "saucer" shaped except where rejuvenation heads are incised into them. Maximum valley slopes vary from about 3° - 7° near Igbo-ora to 6° - 8° near Ibadan, but are steeper where quartzitic ridges occur near the rivers. The depth of the valleys from the small and rounded interfluves to the stream lines is about 100 - 150 feet.

The monotony of the steeply rolling topography is relieved by several quartzitic ridges found mainly around Ibadan (Fig. 14). These ridges are low, rising 150 - 350 feet above the local surfaces. They are also elongated

and can be traced for several miles, although in some cases they have been reduced to chains of hills as a result of erosion; e.g. the Podo ridge south of Ibadan. The ridges are steep sided and the morphometry of some of them is shown in Table 13.

Table 13. Morphometry of some ridges around Ibadan

Ridge	Mean Slope	Standard deviation of slope	height in feet above local surface
Olokemeji I	23°	4.1°	317
Olokemeji II	19.6°	3.8°	150
Ijaiye	22.9°	4.3°	350
Arema	12.2°	2.3°	233
Ridge S.W. of Ibadan	14.9°	4.2°	340

The terrain is a reflection of differential weathering and erosion of the various rocks underlying the area, principally, schists, migmatites and quartzites. Schists and migmatites because of their weaker structure and lithology (see Chapter 2) are subject to relatively faster chemical weathering than the homogenous and resistant quartzites. Subsequent erosion thus leaves the latter as upstanding ridges, while the areas occupied by schists and gneisses become dissected.

Dissected Terrain (b) With High Ridges and Hills

This landscape type is found around Iseyin and north of Iwo in areas also underlain by quartzites and schists. The valleys are deeper and steeper than for the previous unit, however, with slopes up to 8° - 10° and depths between 100-250 feet. High ridges occur, especially north of Iwo where the quartzitic ridges are often more than 700 feet above the surrounding area. Oba Hills stand at 2,010 feet A.S.L.. Around Iseyin, the ridges are lower. The landscape shows a distinct "valley and ridge" topography (Fig. 14). Again,

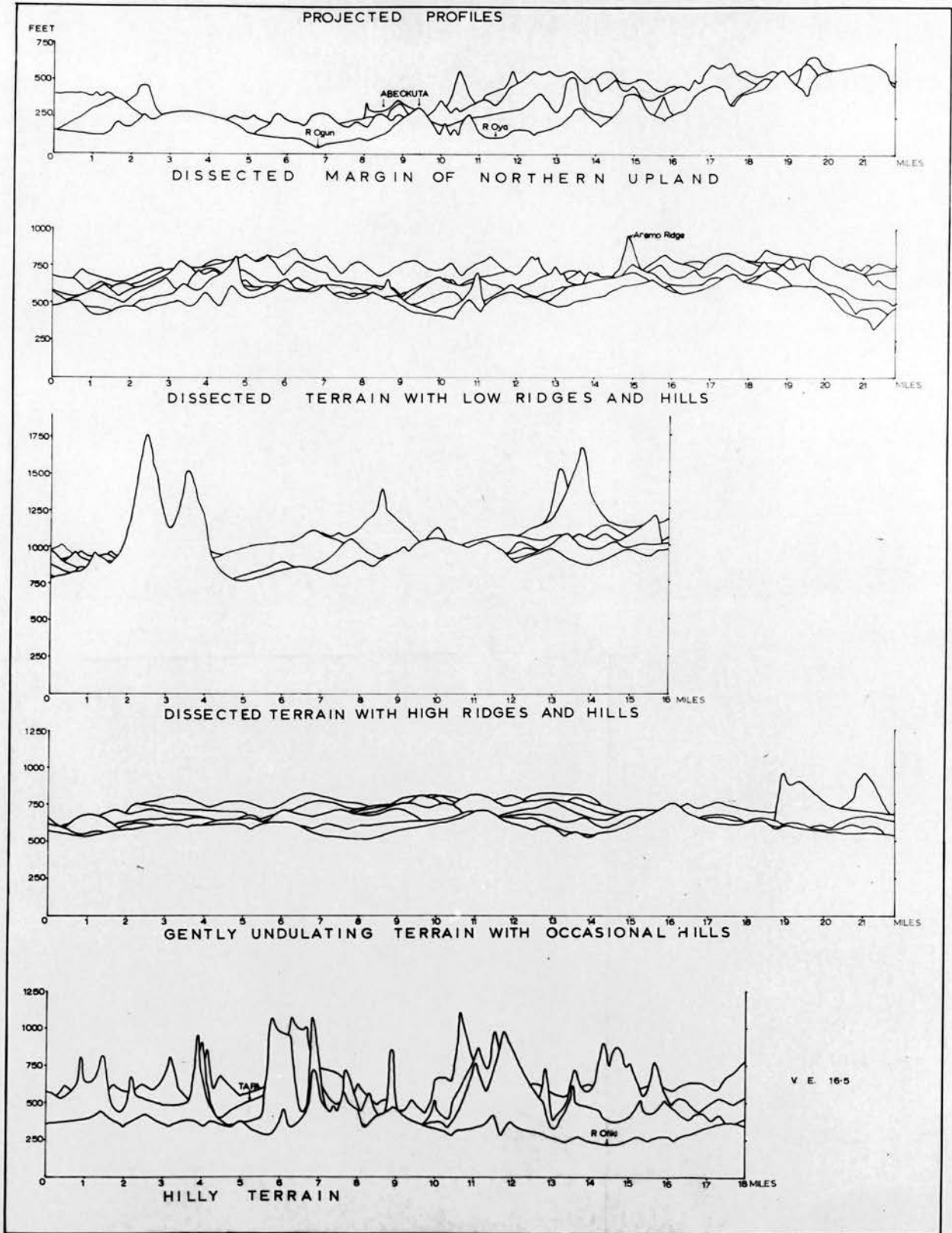


FIG. 14

this terrain is a result of differential weathering and erosion.

Gently Undulating Terrain with occasional Hills

This "gently rolling" landscape (F.A.O. 1962) is found west and south of Ijio where it extends to the Dahomey border, and also around Oyo and Iwo (Fig. 11). West of Ijio, it is about 500 - 750 feet A.S.L., but around Oyo it is about 1,000 - 1,200 feet A.S.L., while it is lower around Iwo. The landscape could be termed a plain as a large part of the terrain is uniform with broad, shallow valleys alternating with gently rounded narrow interfluves (Fig. 14). Valley depths are usually less than 100 feet, and maximum valley slopes hardly exceed 3° . The terrain is developed on schists and migmatites, both of which permit deep chemical weathering. Where rock structures and lithology are favourable, inselbergs are formed protruding above the surface to relieve the monotony of the plain.

Hilly Terrain

This category covers about 120 square miles in the aggregate, and occurs west of Igbo ora, in the Lalate - Eruwa and Ijio-Iwere areas, and around Isemi (Fig. 11). The topography is rugged (Fig. 14) and characterised mainly by large and high domes. Stream valleys between these domes are often narrow, but occasionally could be broad and flat-bottomed. Most of the terrain is in slopes. Granites and syenites, which were intruded into the relatively weaker surrounding migmatites and schists provide the foundation for this unit.

Drainage

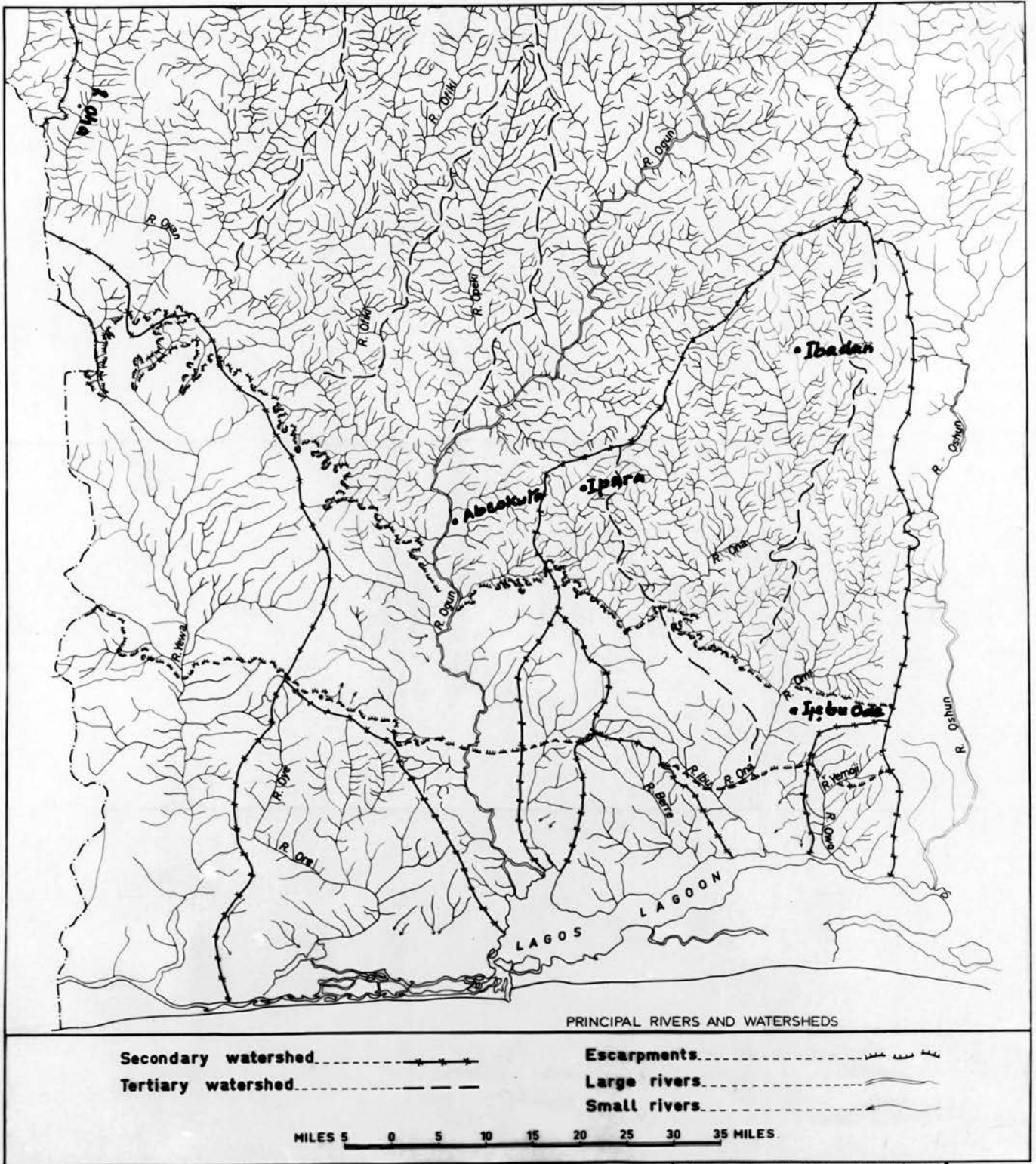
South Western Nigeria is drained by four major rivers the Yewa, Ogun, Ibu and Oshun together with their tributaries (Fig. 15). The rivers flow southwards but smaller streams on the sandstone have a slightly different orientation. The major tributaries of the Yewa flow in a NNE-SSW direction,

while the Oha/Oyan flow in a NW - SE direction near the Cretaceous escarpment. Minor rivers east of Abeokuta flow in a NNW - SSE direction near the Cretaceous sandstone.

The main watershed between the rivers of South Western Nigeria and those flowing to the Niger lies north of Shaki which is outside the region of the thesis, the other divides are shown in Fig. 15. The divides between the rivers are often not well defined. For instance the divide between the Ogun and the Yewa runs N - S on the crystalline basement through a gently undulating area, and it is only north of Meko that it is clearly distinguished by the Cretaceous scarp. The divide between the Oshun and the Ogun is defined to the north east by a series of low ridges especially northeast of Oyo, but southwards it becomes indistinct. The Cretaceous and Eocene scarps form minor divides between the consequent streams flowing to the coast and the tributaries of the larger rivers flowing northwards.

Except for the Northern Upland, the Coastal Plain and the Ewekoro depression where streams are few and far apart, the study area is well drained. Drainage density varies from place to place, and the drainage density of some areas are shown in table 14. on the next page.

Various drainage patterns can be recognised where the rocks have been deeply weathered, both on the crystalline and sedimentary areas, dendritic drainage unrelated to rock lithology has developed. Streams are relatively closer to one another on the crystalline basement where stream frequency is between 2 - 3, than on the sedimentary series where stream frequency is 0.5 - 1.2. In some localities, especially on the crystalline rocks, the dendritic pattern has been modified. This occurs where the rock structure is well marked especially where the streams cut across the quartzitic ridges. The



(Source 1:50,000 Maps)

FIG.15

Table 14 Drainage Density on some topographic Units

<u>Topographic Units</u>	<u>Drainage Density</u>
Coastal Plain (West of Lagos)	0.67
Coastal Plain (North of Badagri)	0.32
Southern Upland (South of Ilaro)	1.02
Ewekoro Depression (Ewekoro-Ibese)	0.56
Northern Upland (around Meko)	0.715
Northern Upland (around Ijebu Ode)	0.75
Dissected Terrain (North of Abeokuta)	1.9
Dissected Terrain (around Ibadan)	1.53
Gently Undulating Terrain (around Oyo)	1.85
Hilly Terrain (Tapa-Idere)	2.09

Ogun river cuts through a series of joints in the quartzite at Olokemeji and here the river is strongly rectilinear. The Ogunpa also cuts through quartzitic joints within Ibadan township and south of Ibadan across the Podo ridge, and the stream is rectilinear in both places.

Radial drainage patterns are locally developed in granitic areas, especially around Ijio, and at Eruwa-Lalate. The Ewekoro stream is trellised, flowing in a structural depression. Some of the coastal rivers e.g. river Ore show well developed rectilinear patterns. Near the Cretaceous escarpment, the tributaries of the Ibu have been superimposed through the sandstone into the crystalline basement but these streams are dendritic.

Instances of river captures in South Western Nigeria were mentioned by Wilson (1922) and Pugh (1955). The Ogunpa stream cut through the Aremo ridge along a joint and captured the Gege stream. The Ogun river ^{at Olokemeji} is captured by its own tributaries, the Otere and the Afonrin cutting through

joints in the Olokemeji Quartizitic ridge (Jeje; in press). As a result of these captures, Wilson concluded that the rivers of South Western Nigeria are still recent and not properly adjusted to rock structure. Pugh (1955) on the other hand concluded that the drainage system is old, having survived several cycles of erosion, and that these captures are modifications of the river patterns.

A striking feature of the drainage of South Western Nigeria is that nearly all the valleys, in both the sedimentary and the crystalline areas are very broad, except where rejuvenation is locally taking place. In such places the "V" of the rejuvenated valleys are incised into the older broad valley bottoms. In the dry season when the rivers have little or no water, the valleys are completely out of proportion with their present day streams; even in the wet season, the valley bottoms are never completely filled by the streams. It appears from these valley cross profile characteristics that there might have been periods of heavier precipitation in the past which gave rise to these large valleys.

Stream Regime

The pattern of stream flow does not always correspond with the rainfall pattern. In the small streams draining relatively small areas, the double rainfall maxima is always reflected in the stream regime. The streams have double height maxima in July and October as shown by the Ona river in Table 15. The larger streams show only a single height maximum in September. Data on stream flow in South Western Nigeria ^{are} ~~is~~ sparse and in several cases inaccurate. Table 15 is based on data collected from three stations by a hydrologist of the Water Corporation of the Western State using a Staff gauge.

Table 15

River RegimeRiver Ogun (Olokemeji 1968) Catchment area 3,040 sq. miles

	J	F	M	A	M	J	J	A	S	O	N	D
Height in feet	5.9	5.3	5.1	5.3	7.2	9.9	13.2	16.2	16.6	13.8	10.5	7.3
Cusecs	249.7	163.0	142.0	163.0	554.1	2022.0	5496.0	9152.0	9602.7	6803.2	2707.0	583.7

River Ofa (Iwo 1968) Catchment area 860 sq. miles

	J	F	M	A	M	J	J	A	S	O	N	D
Height in feet	2.2	2.0	1.9	2.4	3.8	6.9	11.0	12.9	15.4	9.7	5.9	2.9
Cusecs	39.23	31.1	28.3	63.6	237.0	1282.3	5633.0	7958.4	12733.3	3486.0	938.5	89.1

River Ona (Fidiwo 1967) Catchment area 580 sq. miles

	J	F	M	A	M	J	J	A	S	O	N	D
Height in feet	1.17	1.07	1.09	1.22	1.47	1.61	2.23	1.42	2.24	2.93	2.07	1.35
Cusecs	22.01	14.04	16.76	24.55	41.00	51.30	112.30	32.37	125.1	206.2	103.7	32.34

In the wet season, the streams are filled with water, linear erosion may be locally powerful where rock outcrops abound, and it is usually accomplished by potholing (Plate 10). The smaller tributaries may be dammed back for a few days as seen north of Abeokuta where a small tributary formed a small lake for three days. This damming back occurs where the speed or height of the main river is greater than that of the tributary. In the dry season, the small streams are completely dry and the large streams are reduced to low levels flowing in parts of the channels and meandering between sandy depositions; in some cases, the large rivers are reduced to chains of pools.

Generally the rivers are not important erosional agents because of their seasonality of flow, and because most of them lack the coarse rock fragments necessary for linear erosion as chemical weathering is thorough and often deep. Most of the erosion appears to be carried out by unconcentrated surface flow and rills. These geomorphic processes will be the topic of the next chapter.

CHAPTER 5

GEOMORPHOLOGICAL PROCESSES.

In the literature on landform development in tropical Africa, the Davisian peneplanation system of uplift and erosional downwearing leading to the evolution of nearly flat plains is being rejected. This rejection appears justifiable because this theory is inadequate to explain the complex system of landforms and landsurfaces present in the humid tropics. In this chapter, some theories of landform development will be examined, and the geomorphological processes in South Western Nigeria, especially the weathering processes, the pattern of weathering, base level changes and important erosional processes, will be discussed.

Several authors have attempted to explain the landforms of the tropics as a product of pediplanation. Pugh (1955,1966) took this view and explained the processes associated with pediplanation. First, the terrain is worn away laterally by parallel retreat of slope at a constant angle, even on bare homogeneous rocks. Second, new surfaces are developed from mature or old surfaces following uplift, and separated from them by scarps or zones of dissection. The drainage on the older surfaces will be more mature and better integrated than the drainage on the younger surfaces. Third, residual hills of the same rock as the surrounding plains will survive on the younger surfaces. The result of pediplanation will therefore be the production of step-like patterns of landforms.

Ruhe (1956) recognised pediplanation as the most important process in the production of the six, stepped, terracelike surfaces he described in the High Ituri in the Belgian Congo. These surfaces were produced by repeated rejuvenations and parallel slope retreat of valley sides under the influence of rills, sheet wash and mass movement. Each surface has a stone line in it,

and is covered by colluvial material from the upper surface. Ruhe admitted that in some cases, these step-like, widely concave-upward surfaces may change to convex-concave slopes, and this he believed could have been produced by changes from active pedimentation to alluviation as a result of rising base-levels. Clayton (1958) also observed a stepped series of surfaces in Kabba province (Nigeria) and ascribed their formation to pediplanation.

Such stepped, pedimented surfaces do not appear to be widespread in South Western Nigeria. To some extent, stepped surfaces are found in the lateritised upper Cretaceous and Eocene Sandstones around Meko, and Ilaro, but the processes which have created these surfaces, gave rise to more complex surfaces on the crystalline basement rocks. The latter cannot be explained by simple pediplanation. On the basement complex, especially around Oke-Iho, scarps are found which are composed entirely of syenite, and they appear to be of no cyclical importance. Rather, they result from differential weathering between the syenites forming the scarps, and the surrounding amphibolites. Footslopes also occur around inselbergs, but basically, these are not pediments as they do not cut across bare rock surfaces. The use of the word pediplain by King (1947), implying surfaces cut across bare rock surfaces as in the desert or in the semi arid area, is misleading in the humid tropics because such surfaces do not exist here. If surfaces are cut across bare rocks, chemical weathering on such surfaces under present humid conditions will make their identification difficult.

Pugh (1955) further suggested that with pediplanation, inselbergs and other erosional residuals will be of zonal distribution around cyclical escarpments. This is not seen around the scarp at Oke-Iho where most of the inselbergs occur on the tableland itself. He also asserted that inselbergs do

not mark petrological boundaries. This is true with gneiss, but does not apply to granite or syenite. Ruhe's correlation of stone-lines with particular surfaces does not appear to exist in South Western Nigeria. From this, pediplanation does not provide an explanation of the complex land-surfaces of South Western Nigeria.

Most of the exponents of the pediplanation theory fail to take into account the surficial configuration of the landsurfaces. They almost usually assume that surfaces produced by pediplanation are flat, and they regard rock outcrops on such surfaces as mere erosional survivals. The fact that they ignore the variation within the local rocks in relationship to the surficial configuration of these surfaces has led to errors in the proper appraisal of the processes responsible for creating these landforms.

Many writers have questioned the belief that series of flat, step-like surfaces are produced in the humid tropics. Wayland (1933) observed that step-like flat series of peneplains or pediplains cannot be produced from upper peneplains in an unstable area, and particularly where weathering is followed by uplift. If a lower surface develops below an upper surface, it would be formed across the weathering profile of the upper surface, and it will never be a plain, but will have low to moderate relief. Wayland termed such a surface an etchplain. Many writers have become increasingly convinced that weathered and erosional landforms in the humid tropics can best be explained in terms of the etchplain concept, and Mabbutt (1961a), Wright (1963) and Thomas (1965, 1969) have applied it to areas of widely varying lithology.

Mabbutt (1961a), working in the semi arid area of Australia, observed that antecedent weathering of the crystalline basement plateau area, followed by stripping caused by a change of base level, led to the production of an etchplain of considerable surficial configuration below the old plateau. He

noted that weathering is deeper along the valley lines on the old plateau than below the interfluves, and that the weathering front undulates in conformity with the topography. Data on the weathering pattern in South Western Nigeria does not support these observations, but this does not necessarily invalidate the theory. Mabbutt further observed that ^eesarpment recession is due to slope wash and rilling, leading essentially to the stripping of part or the whole of the weathering profile, and he noticed that rock outcrops are limited to interfluves on the lower surface.

Wright (1963) applied the etchplain concept of deep weathering and erosional stripping to explain the development of two etchplains below a sandstone plateau in the Daly river basin in the Northern Territory of Australia.

Apart from the above writers, many geomorphologists have also expressed ^{the opinion} that the landforms of the humid tropics are produced by deep weathering and subsequent erosion e.g. Birot (1968). Budel (1957) emphasised that the tropical plain is formed by deep chemical weathering and denudation, and drew attention to the existence of the "double surfaces of levelling". Denudation proceeds at the surface, and weathering progresses below on what has been variously described as "the basal surface of weathering" (Ruxton and Berry 1957), or "the weathering front" (Mabbutt 1961b). Cotton (1961) expressed ^{the opinion} that the landforms of the tropical area resulted from deep chemical weathering in a period of little surface erosion, followed by accelerated erosion under relatively drier conditions.

King (1947), expressed ^{the opinion} that different processes operate in different climatic environment to produce different landscape types, thus:-

peneplains - humid temperature

panplain and savanna - humid and semi arid areas *climates*

etchplain - humid tropics

pediplain - steppe and arid climates.

Thomas (1965, 1969) discussed the concept of deep weathering and erosional stripping leading to the production of different types of etchplains and surfaces on the Jos plateau and part of Western Nigeria (North of the field area of the present work). He defined and mapped the different types of etchplains and surfaces present in both places.

Application of the Etchplain Concept

King (1962) recognised vast erosional surfaces occurring as pediplains in the interior of West Africa and classified the surface of the basement complex of South Western Nigeria as part of the African surface. If by "surface" King means a pediplain, then this classification is inapplicable to South Western Nigeria. Near the coastal areas, such pediplains have disappeared and were replaced by erosional and weathered surfaces of considerable local relief. In the thesis area, with the exception of the Upper Cretaceous Sandstone where a fairly extensive lateritized flat surfaces are present, no pediplains can be recognised. The only location where anything approaching a pediplain can be recognised on the basement complex rocks in Western Nigeria is along the primary watershed between the rivers flowing to the Gulf of Guinea and those flowing to the Niger, and even here, only the lateritized remnants of such a surface remain. To the South of the primary watershed in South Western Nigeria, the various physiographic units composed of undulating terrains and dissected terrains, on which there are several inselbergs, tors, corestones and quartzitic ridges, appear to have been produced by the stripping of the weathered regolith of the older surface

still preserved on the primary watershed. These landforms, because of their considerable surficial configuration, cannot be regarded as pediplains. Since they have been produced by the erosion of the older landsurface further to the north, however, it is quite possible that the etchplain concept, as propounded by Wayland (1933) and as developed by Thomas (1965, 1969) can be useful in explaining, how they evolved. Thomas (1965, p. 130) emphasised that this concept is particularly applicable to West Africa, and wrote that "here between the coast and the older surfaces in the interior, there has been the production of plains from plains over a long period of time".

The most important geomorphological process in the humid tropics are undoubtedly chemical weathering and erosional stripping, and the landforms of South Western Nigeria are best explained in terms of these processes. Erosional processes may take the form of backwearing or downwearing, but each of these process by itself cannot produce the various types of landforms which are present. The various processes are examined below.

Weathering

Both physical and chemical weathering operate in South Western Nigeria, but the latter is the most important single geomorphological process. The chemical processes involved, and the pattern of chemical weathering in the humid tropics have been widely discussed (Harrison 1933, Reiche 1950, Chapman and Grenfield 1949, Ruxton and Berry 1957, 1961a, Ollier 1965 and Ruddock 1967).

Chemical weathering in a humid tropical environment takes place in form of hydration, hydrolysis, carbonation, solution, ion exchange, reduction, oxidation, base changes, and through bacterial activities. These chemical changes are encouraged by the high temperature, and the large volume of water available throughout the year (see Chapter 3). In most minerals with the exception of quartz, chemical changes lead to the formation of new, low

density minerals that occupy larger spaces than the original minerals. As these new minerals are formed, the original minerals get smaller and lose their metallic and alkali elements. In the process of forming the new low density minerals, crystalline rocks disintegrate.

Coarse grained rocks like granites usually get hydrated and suffer granular disintegration. Spheroidal weathering is also important where the rocks are well jointed. Water can permeate through the interstices between the granite or syenite crystals, and as the crystals often retain water by adsorption, hydration readily occurs. The feldspathic and metallic minerals, such as feldspars and biotite, and the joint surfaces weather quickly (plates 11 and 12). Spheroidal weathering is only checked where the joints are not opened. Metamorphic rocks, like gneisses and schists, are foliated, and where the rocks dip steeply, the cleavage planes within them allow water to move relatively rapidly through the rocks. The ferro magnesian minerals in schists and gneisses are especially prone to weathering, and this leads to a complete disintegration of these rocks. Weathering is relatively faster in these rocks than in the coarse grained granites. Quartzite being composed mainly of quartz is resistant to weathering, but where it is heavily jointed, it can be weathered. The Cretaceous and Eocene sedimentary rocks are formed as a result of weathering, transportation and deposition of other rock materials, and accordingly contain small amount of weatherable elements. The absence of structural variations in the rocks lead to uniform weathering.

In all these rocks, weathering is more pronounced in the part above the water table. Below the water table, weathering becomes less pronounced due to the absence of oxygen, although, in some instances, traces of weathering can be seen below the water table. In jointed rocks, below the water table, ferro magnesian minerals in contact with water are gradually altered into



Plate 11. Corestones in weathered syenite near Oke Iho.

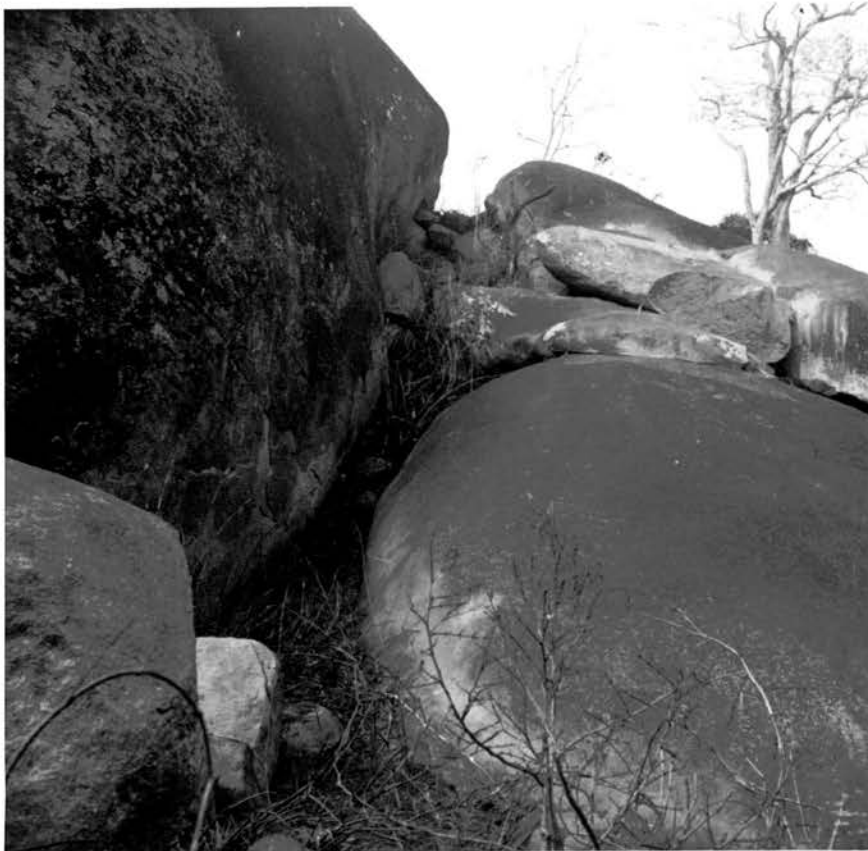


Plate 12. Spheriodal weathering of coarse porphyritic granite. The oval form of the rocks was formed subsurfacedly.

pseudomorphs. Just above the level of the water table, most weathered rocks still preserve their structure. Weathered gneiss still displays foliation and dip, while in granite, quartz persists, but biotite get changed into greenish chlorite, and feldspars become whitish and soft.

The end product of weathering of both basic and igneous rocks in the humid tropics are solution and colloid suspensions; hydrated sesquioxides of aluminium and iron, and clay minerals - illites, montmorillonites and most commonly kaolinites; unweatherable residues e.g. quartz. Solution and colloid suspension are derived mainly from chlorides, sulphates, carbonates and bicarbonates, but they are also leached from alkali bases. They are washed into streams by surface and subsurface runoffs. Hydrated sesquioxides of aluminium and iron are derived from the ferro-magnesian minerals under the seasonal tropical climate. These sesquioxides may be concentrated to form bauxite or laterite. The clay minerals are derived by hydrothermal alterations of the feldspathic and ferro-magnesian minerals. Montmorillonites are formed under alkaline ground water and in areas of imperfect drainage ~~while~~ while kaolinites are formed under acidic ground waters and in areas of good drainage. These compare with the description of Harrison (1933) that the end products of weathered rock in the humid tropics are ironstone, bauxite, pot or pipe clay and kaolin.

The significance of undisturbed chemical weathering is the accumulation of thick unweathered residue which may be porous, or impervious; and on it, erosion takes place. The weathered residue generally forms poor parent materials for soils as it lacks important bases.

The Pattern of Weathering

The pattern of weathering is determined by the following factors:-

1. The structural variation and lithology of rocks on a local and on a regional scale.

ii. A period of tectonic stability long enough to permit deep weathering

iii. Climatic stability.

The structural variation and lithology of the rocks determine the pattern of weathering and the nature of the basal surface of weathering. In chapter 2, it was observed that on the basement complex, the various granites, gneisses and quartzites resist weathering more than the weaker schists. Where schists alternate with quartzites, the differential weathering is pronounced. A good example occurs at Ibadan along the Elizabeth II Road where the quartzite is weathered to a depth of a few feet, and the adjacent schist is weathered to about 70 feet. Differential weathering of this type can also occur on a regional or a local scale due to lithological variation. Within a homogeneous granite, weathering will be more localized and marked in a well jointed section of the rock rather than in a section with few closed joints. With tectonic stability of long duration, an old landsurface will be deeply weathered probably as envisaged by Ollier (1959, 1960) over his Gondwana surface. Examples of a deeply weathered surface include that recorded by Ruddock (1967) near Kumasi in Ghana, where the weathering profile does not show core stones, and the lateritized surface on the primary watershed north of Shaki in Western Nigeria. If there is a change of base level, due to uplifting, erosional stripping will occur, and the profile of weathering will be immature.

With climatic changes especially from wet conditions to arid conditions, physical weathering will supercede chemical weathering and the profiles of weathering will also be immature. The pattern of climatic changes in the humid tropics in the past, especially in the Pleistocene-Quaternary period, is not definitely known. There is some evidence of climatic change in the

arid area of Nigeria. Old erg-dunes and wind borne deposits are found in Zaria and Kano provinces, while Grove and Pullan (1964) have used fluctuations in the extent of Lake Chad to prove climatic changes in Northern Nigeria. Oliver (1964) used beach levels and associated materials to show the sequences of Pluvial and Interpluvial periods since the Holocene along the coast of Ghana, Bruckner (1955) also used evidence of stone lines in the Accra area to postulate that arid conditions had once prevailed, and Tricart (1956) took the lateritic formations in the Guinea area to prove climatic changes in West Africa. Most of the evidence cited, especially by Bruckner and Tricart is inconclusive. Stone lines have been shown to form under wet humid conditions by Nye (1954) and others while Harrison (1933) has shown that laterites can be formed under continuously wet conditions. Budel (1959) is of the opinion that the climatic changes of the Pleistocene-Quaternary period did not affect area of the tropical forest.

It seems unlikely that the effects of climatic changes in South Western Nigeria would be as drastic as envisaged by Bruckner. What seems possible is that periods of relatively wet conditions alternated with periods of relatively dry conditions, although in the latter, the annual rainfall was still sufficient to effect deep chemical weathering especially in the forest area. It also seems likely that as the Sahara Desert advanced southwards during the interpluvial periods, the semi arid areas on the fringe would also advance southwards. Hence present day savanna area would have little precipitation, and this could have retarded chemical weathering to some extent.

The depth and pattern of weathering in the humid and subhumid areas of Nigeria were studied by Thomas (1966). In the course of the present investigations, some data not previously available to Thomas ^{were} ~~was~~ collected on these topics. The depth and pattern of subsurface weathering can be examined

from data derived from seismic investigations and bore hole drilling which have been carried out in Western Nigeria. Seismic investigation using "refraction seismology" is relatively faster than drilling bore holes, but its use in investigating the depth of weathering in Western Nigeria has been confined to selected sites suitable for dam construction. Such sites are often determined by the frequency of rock outcrops and may not give a valid idea of the weathering pattern elsewhere in the crystalline rocks. However, the number of sites justify drawing some broad conclusions from the data obtained.

Seismic traverses have been carried out along stream cross profiles. The traverses vary from 600 feet on both sides of the stream at the Owena-Ilesha Weir site, to 2,500 feet on the Oha stream near Ikirun, to several miles across the Niger at Kainji.

An objection to seismic investigation is that where corestones exist in the weathering profile, the seismic waves may not reach the unweathered parent rock, probably reaching the Zone III of Ruxton and Berry (1957). To overcome this problem, boreholes are drilled at close intervals along the seismic traverses, and observations from such boreholes often confirm the result of the seismic investigations.

Seismic investigations show that where rocks are locally shattered, such as a fracture-zone in granite, pockets of water, unrelated to the general ground water table may exist. The presence of such water often leads to deeper weathering in the shattered zones. In the Kainji area (Fig. 16), on the left bank of the Niger, the local granodiorite is heavily shattered and fractured. Along this zone of shearing, weathering has penetrated down to 52 feet while in those parts of the rock with fewer joints, weathering has only reached 20-30 feet. On Kainji Island,

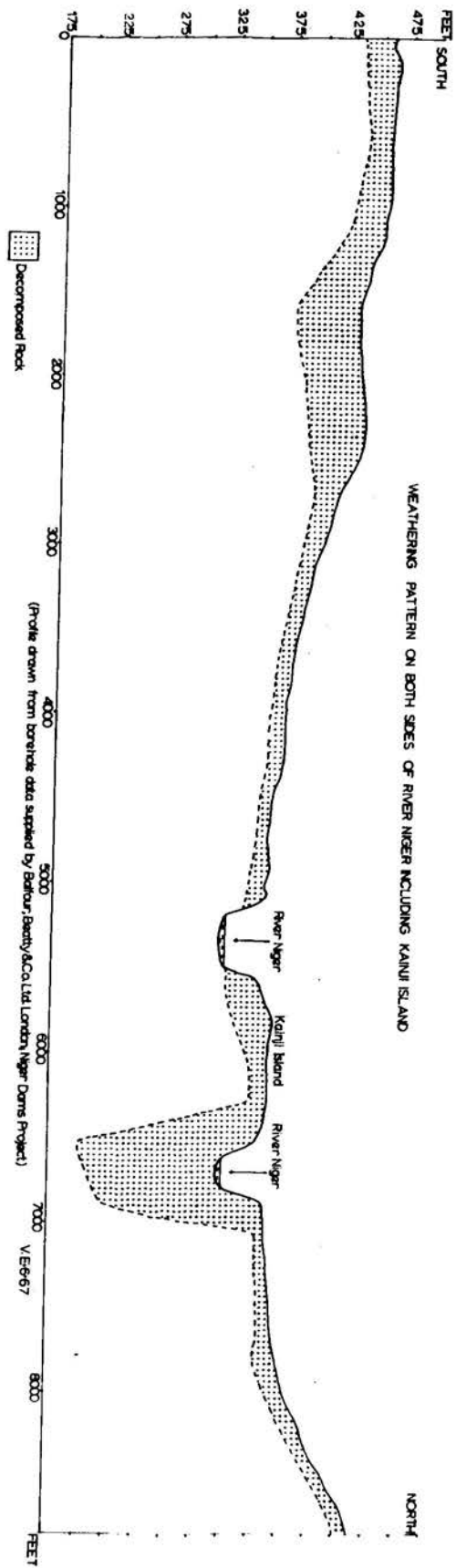


FIG.16

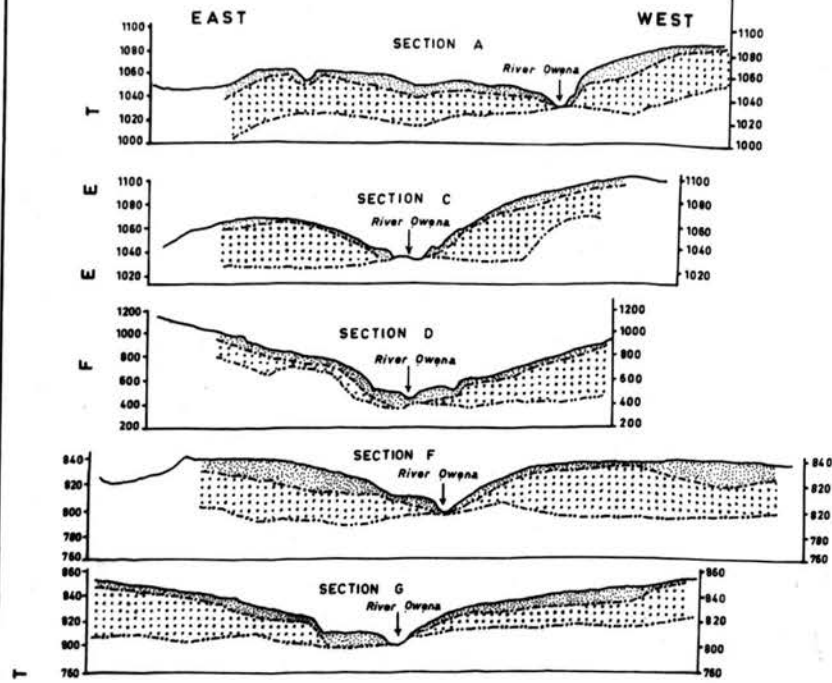
the local amphibolite is sheared and fractured by persistent vertical joints, and along this zone, weathering has reached 66-70 feet. On the right channel of the Niger, the local granite is closely jointed and fractured, and is weathered to a depth of 128.5 feet - 135 feet and here traces of chemical alterations of the rock minerals are found at 229 feet below the surface.

Along most of the traverses studied (Figs. 17, 18, 19, and 20) especially the Opeki dam site near Eruwa (gneisses crossed by pegmatites), the Otin dam site (fine to coarse gneiss) near Ikirun, and the Owena dam site (granite) near Igbara oke, about 75% of the traverses show that the local rocks outcrop along the stream channels. Away from these outcrops, weathering depth increase 30-40 feet for every 250 feet along the valley flanks, and in some cases, the depth of weathering on the interfluves reach 70 feet.

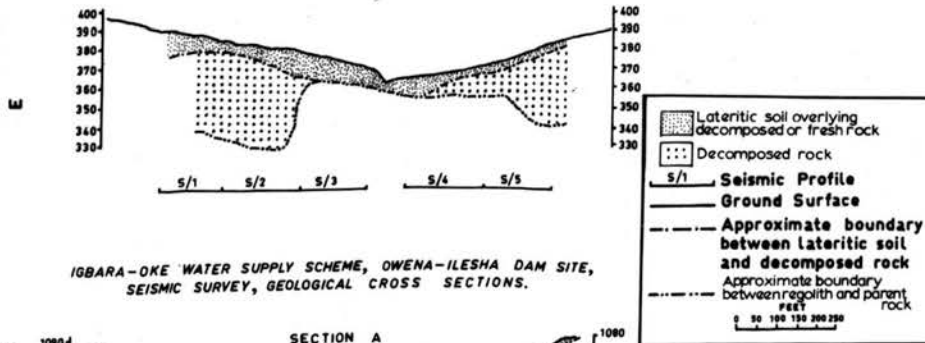
These investigations reveal an overall pattern of domical rises and basins of deep weathering along the stream cross profiles which, if continued into adjacent stream profiles, may well be the norm for the crystalline area of South Western Nigeria.

Records of boreholes drilled by the Geological Survey of Nigeria in the crystalline basement rocks show weathering depths to vary from 6-114 feet in an area of 50 sq. miles around Ilugun. Most of the boreholes are in the sedimentary areas where there is a need for water. As the sedimentary rocks are composed of pre weathered materials, it is difficult to establish the depth of weathering. The only way to determine the depth of weathering is by ascertaining the weathering profiles from the stratigraphic descriptions accompanying the records of the boreholes. Most of the boreholes passed through the upper ferruginised horizons, the mottled zones and the pallid zones of the typical weathering profiles. The following table is based on

OWENA-ONDO DAM SITE, SEISMIC SURVEY, GEOLOGICAL CROSS SECTIONS.



IGBETI WATER SCHEME, SEISMIC SURVEY, GEOLOGICAL CROSS SECTIONS.



IGBARA-OKE WATER SUPPLY SCHEME, OWENA-ILESHA DAM SITE, SEISMIC SURVEY, GEOLOGICAL CROSS SECTIONS.

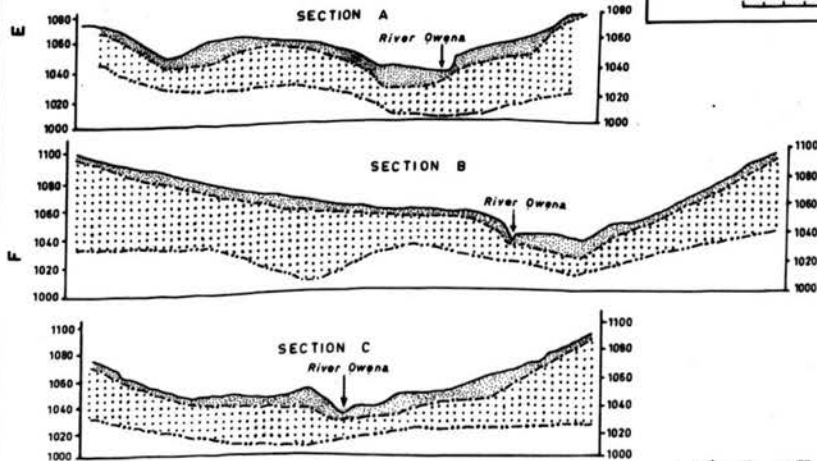


FIG. 17

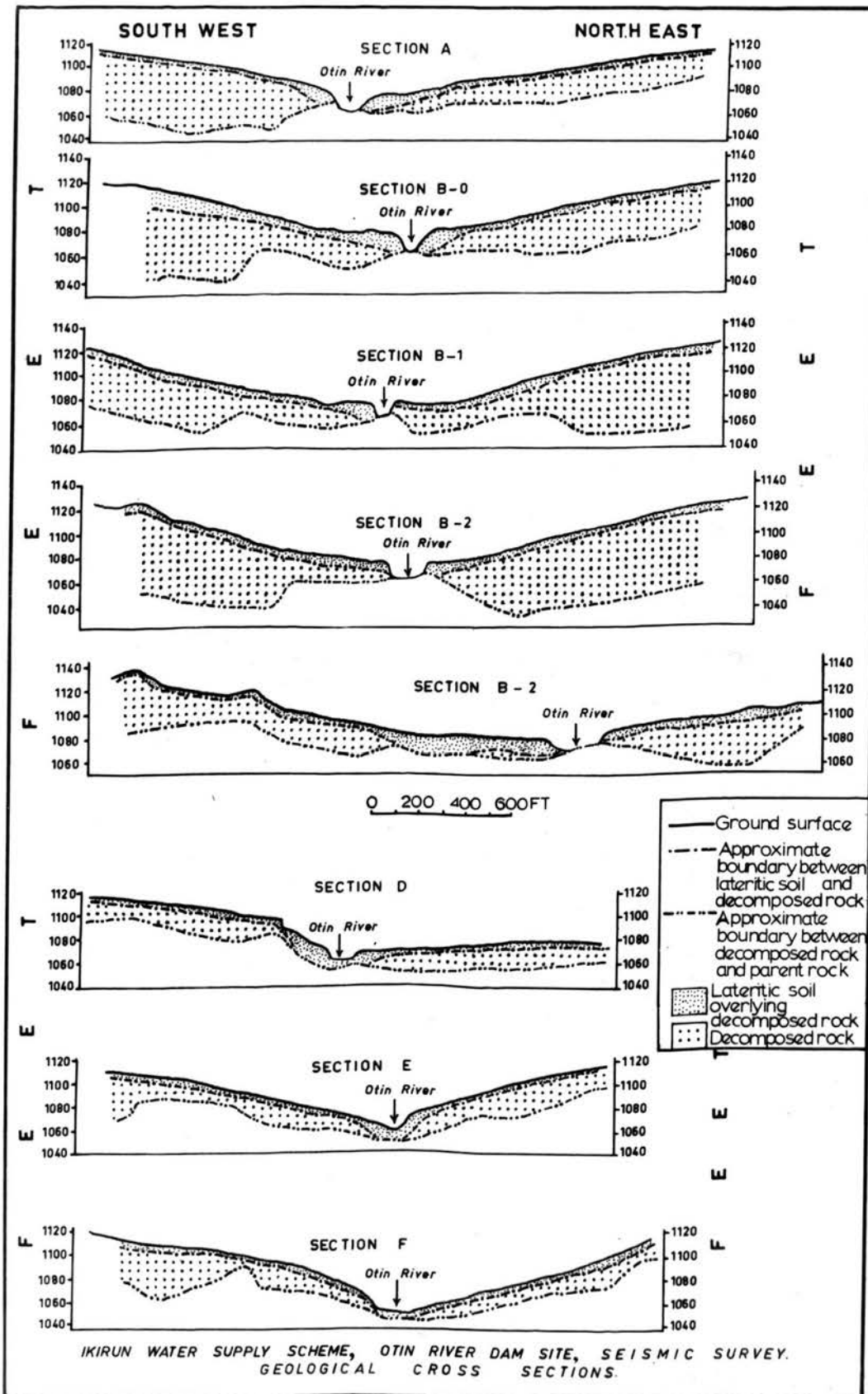


FIG. 18

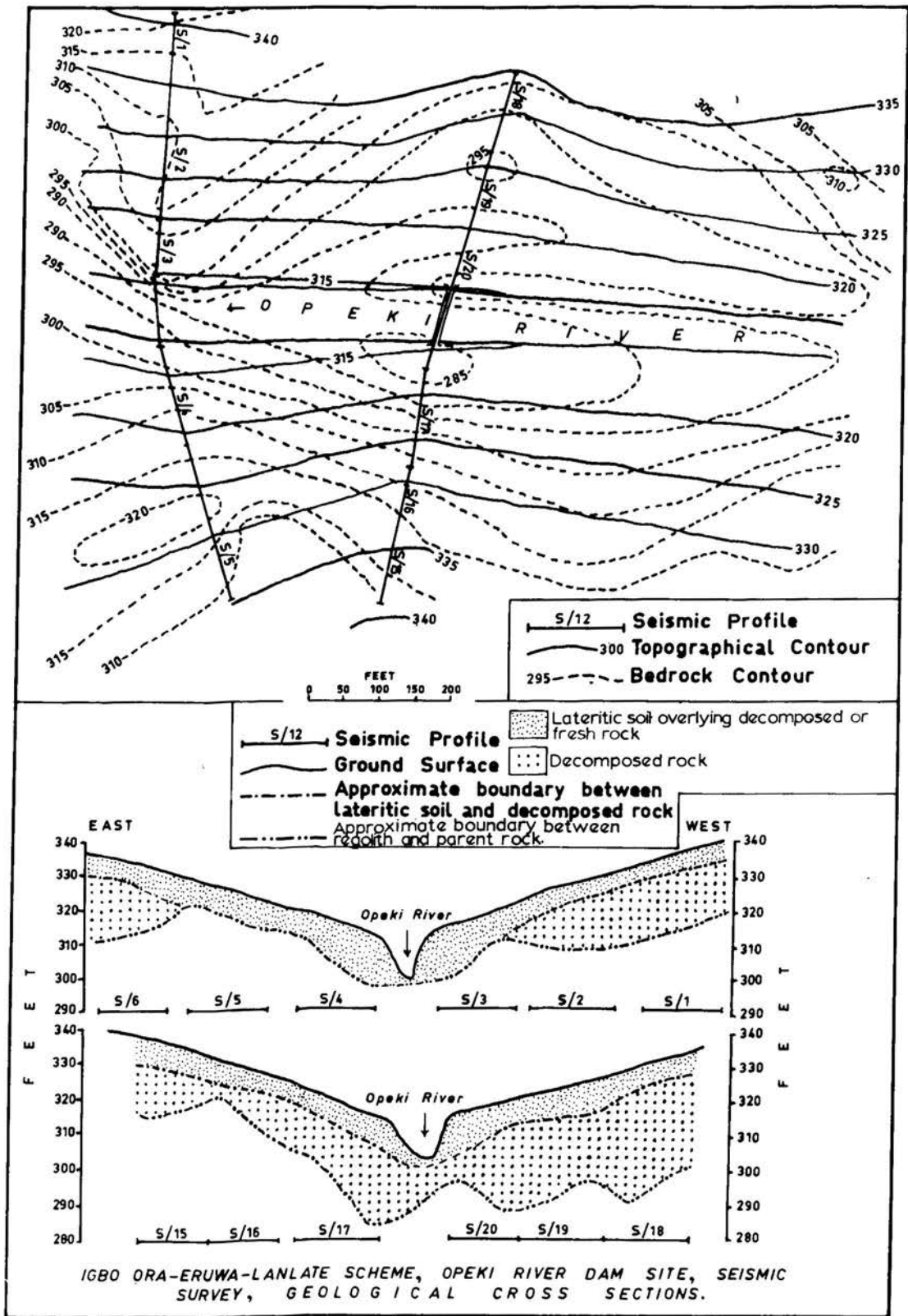


FIG. 19

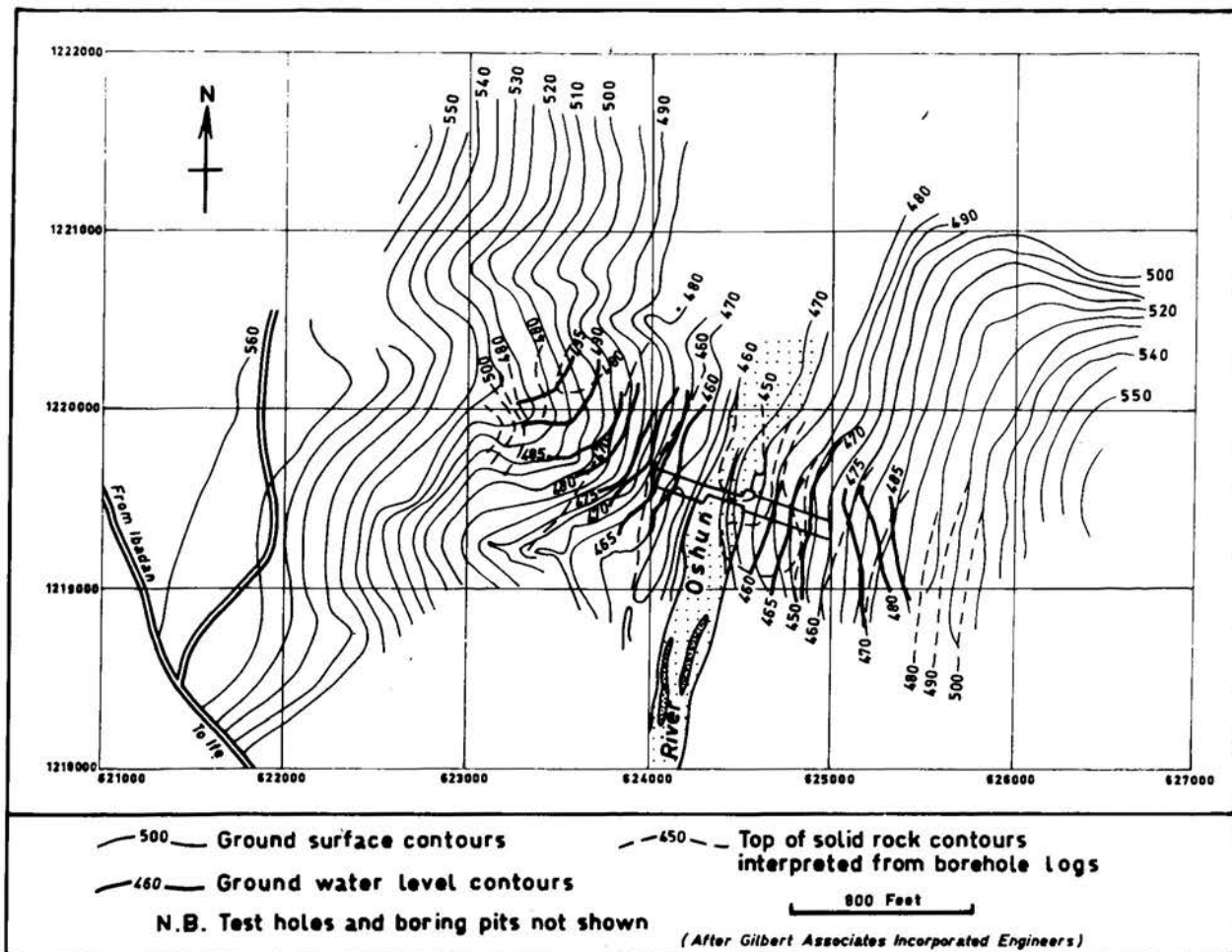
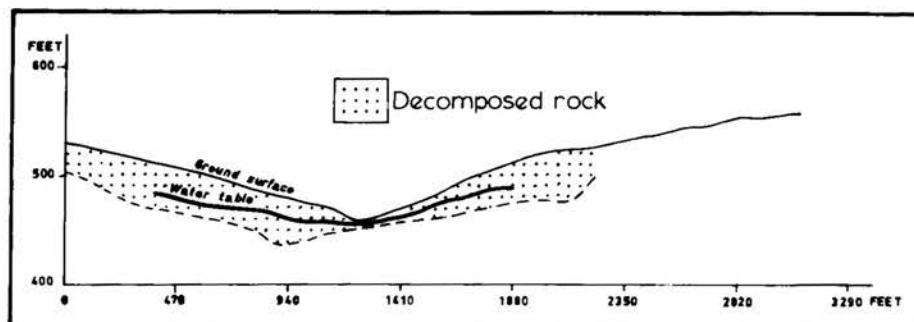


FIG. 20



a careful selection from borehole data that pass through the weathering zones listed above; and the depth of weathering is restricted to the bottom of the pallid zone.

Table 16 Depth of Weathering in the Upper Cretaceous Sandstone

<u>Location</u>	<u>Depth (in feet)</u>
Ishaga	214'
Maroko	205'
Aiyetoro	150'
Aiyetoro	210'
Meko	93'
Imushin	290'
Ijebu Ife	208'
Ijebu Ode	206'

These places are widely scattered over the sandstone, but most of them except Meko and Aiyetoro give a depth of weathering in excess of 200 feet. On the Eocene sandstone, boreholes range from 62-512 feet, but it is difficult to ascertain the depth of weathering as the records seldom include a stratigraphic description.

The great depth of weathering in sandstone may be due to the fact that it carries an old Tertiary surface heavily covered by laterite, hence stable enough to permit deep weathering below the surface. A lack of abrupt lithological changes further enhances deep weathering into the porous sandstone. Further the basement rocks below the sandstone was pre weathered before the sandstones were deposited on them, and most of the boreholes passed through the sandstone and reached the weathered basement rocks below.

The deep weathering noted above is not peculiar to Western Nigeria. Ollier (1959) recorded a depth of 200 feet in the crystalline rocks of Uganda, and Barnes (1961) noted a depth of 160 feet in the same rock. Archambault

(1960) recorded 65 feet of weathering in parts of Mauritania with 2 ins. of rainfall. Bisset (1941) recorded 100 - 150 feet depth of weathering in the Ugandan granite. Nagell (1962) observed a depth of about 300 feet in the pre Cambrian metasediments of Serra Do Navio District of Brazil. Thomas (1965, 1966) noted a depth of 180 feet on the Jos plateau and 40-60 feet for some dam sites in Nigeria. Ruddock (1967) found that in the Kumasi area, the depth of hardrock in granite, in valleys is about 20 feet, more than 25 feet in Birrimian metamorphics, and in some localities, he recorded depths of weathering up to 68 feet.

The most important point is that the basal surface of weathering is highly irregular. It also appears valid to state that weathering is deeper below interfluves than along stream valley floors. This conforms with the observations made by Thomas (1966) and Ruddock (1967) although Mabbutt (1961a) had contrary evidence. Deep weathering below interfluves is explained by Thomas (1966) as due to the lateral movement of groundwater beneath interfluves towards the valley lines as a result of the dissection of an old surface. In places where the interfluve is covered by laterite, the valley sides are protected from serious erosion while weathering goes on unimpeded beneath the interfluves. Most of the data on the depth of weathering in Western Nigeria is derived from such dissected areas, but there ^{is} are no clear evidence to show old erosion surface remnants. According to Ruddock (1967) what appears significant in the formation of this type of weathering is the movement of water below the interfluve towards the stream channel. Groundwater moves vertically downwards beneath interfluves, and also laterally towards the stream line and this leads to deeper weathering beneath interfluves.

Basal Surface of Weathering

The form of the basal surface of ^{the} weathering ^{zone} is important in relationship

to the landform that will result when the superincumbent regolith is stripped off. There is no consensus of opinion among the several authors about the form of the basal surface of ^{the} weathering^{zone}, Ruxton and Berry (1957) are of the opinion that in crystalline rocks, corestones (Zone III) often separate the parent rock from the weathering profile, in which case the basal surface of weathering is well marked. Mabbutt (1961b) believes that an abrupt change from the soft pallid zone to hard fresh rock is common, in which case the basal surface of weathering will be transitional between thoroughly weathered and unweathered rocks.

The type of basal surface of weathering that will develop in any rock depends on the lithology and structure, and on the length of time during which weathering has taken place. In the granitic terrains of Oke-Iho, Tapa-Idere, and Eruwa-Lalate, corestones and tors are common on the ground surface (Plate 13), and in road cuts, corestones are frequently seen (Plate 11). Where weathering has been prolonged over a long time, the corestones are destroyed (Plate 14), but the weathered rock above fresh bedrock will preserve its structure, though it is very soft. Thus in a well jointed granite or syenite, if the weathering sequence is disturbed, the profile will be immature, and the weathering front may be like that envisaged by Ruxton and Berry (1957). If weathering continues over a long period, the corestones will disappear. In other rocks, especially gneisses, schists and other schistose rocks, corestones are always absent. In a few weathering profiles, small rafters of rocks could be seen, but as a general rule such rocks have become hydrated and soft. Schistose rocks due to their foliation and cleavage planes are weathered regularly (Plate 15) and do not display the transitional zone of corestones as seen in granites and syenites. In the sandstones, the basal surface of weathering will merge imperceptibly



Plate 13. Corestones and tors on the ground surface near Lalate.



Plate 14. Corestones being destroyed in the weathering profile - observed near Eruwa.

with the parent rock and this is due to the absence of pronounced structural and lithological variations.

There are still problems arising from the present observed pattern of weathering. Is the present pattern of weathering and the resultant landforms a product of relict weathering and subsequent exhumation of part of the basal surface of weathering? Does the present pattern result from concurrent weathering and erosional stripping over a long period of time? To answer these questions, the base level changes that have occurred in South Western Nigeria have to be discussed.

Base Level Changes Leading to Erosional Stripping

King (1962 p. 240 & 300) is of the opinion that the interior part of the Guinea Coast suffered monoclinical cymatogenic inflexion at the end of the Cainozoic age, and records of deep sediment deposit along the Nigerian coastline seem to support this claim. Precisely what form this tilting took, however, is still difficult to understand. For this purpose, a few theoretical considerations may be examined about the periodicity of cyclical uplifts and base level changes that could have produced the pattern of landforms of South Western Nigeria.

King postulated that following the tilting southward of the hinterland of the coast of Guinea, the old African erosion surface became inflexed and was eroded to produce the Post African surface. This simple assumption is difficult to sustain if it is accepted that when there is a tilting of the land, a positive change of base level must take place, i.e. the mouths of the rivers and the coastal areas will become areas deposition. Since no vertical uplift is involved at the coast, there can be no cyclical erosion of the tilted land area. Thus this simple monoclinical inflexion cannot explain the erosional history of South Western Nigeria unless it is assumed

that ^{while} only the coastline was downwarped ^{there was also} with the concomittant uplift of the hinterland.

Kennedy (undated) is of the opinion that the coastal basin of West Africa "must have formed as a result of pronounced and continued basement downwarping with or without concomittant faulting". This view is especially valuable in assessing the geological history of South Western Nigeria. Records of deep boring by the Mobil Oil Exploration Group show sediment deposits 7,000 feet thick at the coastline near Badagri. Inland, the total thickness of the sedimentary series over the basement rock is less than 600 feet. These observations suggest that with the deposition of sediments in the downwarped coastal basin, the hinterland of this basin will be isostatically uplifted. Thus both the pre Cambrian basement rocks and the sedimentary rocks overlying them would be uplifted right from the coastline. The amount of isostatic compensation is not known, and the nature of the uplifts involved cannot be easily assessed, but there is evidence which suggests that the uplift has been considerable since the formation of the sedimentary rocks. Before assessing the nature of the uplift, some consideration of the initial surface of South Western Nigeria especially on the basement complex is required.

Initial Surface

The present surface of the basement complex rocks slope ^{is} in a N - S direction from the primary watershed north of Shaki to the base of the upper Cretaceous escarpment. The older surface from which this evolved may be reconstructed if it is assumed that remnants of such a surface may exist on tops of hills and ridges in a N - S direction, though differential erosion on these hills and ridges present difficulties. Following this assumption, six profiles were drawn to pass through the tops of the hills and ridges in a

N - S direction at intervals of 45 minutes (Fig. 21). The profiles slope gently from the Northern boundary to the Upper Cretaceous sandstone, but near the sandstone, they exhibit pronounced inflexions. The Oba hills north of Iwo do not fit into the profiles and probably belong to an even older surface.

Theoretically, in an area of heterogeneous rocks like the pre Cambrian basement, if this sloping surface is continuously uplifted, there will be no stable base level at any period, erosional stripping will closely follow on chemical weathering. The result would be the exposure of convex bare rock surfaces over most of the pre Cambrian basement. This is not the case in South Western Nigeria.

On the other hand, if this sloping surface undergoes periodic uplift, during the intervals there would be stable base levels which would permit deep chemical weathering to operate on the surface. With uplift and rejuvenation of streams, a sloping and undulating surface may be produced below the old sloping surface, and in some places, part of the basal surface of weathering of the old erosion surface may be exposed. Towards its upper limit, the new surface will be developed along the drainage lines of the older surface. The period between the uplifts is thus important. If uplifts are frequent, the erosional stripping that will result will telescope several surfaces together to produce irregular surfaces exhibiting varying amount of basal rocks; if uplifts are widely spaced, it is possible that several distinguishable surfaces will be produced.

In South Western Nigeria especially over the crystalline basement rocks, no distinctive widespread surfaces can be recognised, and the configuration of the landsurface varies tremendously. This suggests that the uplifts which led to cyclical rejuvenation and erosional stripping of the weathered material

of the pre-existing sloping surface could have occurred at frequent intervals. Field evidence from the Cretaceous and the Eocene formations appear to bear out this assumption. In these formations, there is an increase in the vertical separation of the stream beds and the crest bevels from the coast to the valley heads. Here also, two or three pronounced breaks of slope on valley cross profiles were recognised, with each slope break marked by valley benches on which laterite deposits are found. In the area north of Aiyetoro and around Meko, the depth of stream incision with their breaks of slopes total 150 feet - 200 feet. Each break of slope appears cyclical, denoting an uplift, hence there have been at least three periods of uplift since the Early Tertiary after the formation of the sandstone. The resultant rejuvenation of the south flowing drainage on the sandstones led to regressive erosion and the breaching of the divide between the sandstone and the crystalline basement along the Yewa river. The pre Tertiary pattern of uplift is not yet known but it appears to be aperiodic as seen from local surfaces found on the basement complex.

These various uplifts, base level changes and their accompanying rejuvenation and erosion could have produced the various weathered landforms, and landforms exhibiting varying degrees of erosional stripping present in South Western Nigeria.

Present Pattern of Erosional Stripping

Not much is known about the pattern of erosional stripping in the past. Indeed, there is considerable controversy about the pattern of erosion in the humid tropics. Pugh (1955, 1966) and Ruhe (1956) are foremost in maintaining that erosional stripping in the humid tropics is in form of "beveling" i.e. the slopes retreat parallel to themselves at a consistent declivity ^{until} ~~the~~ the upstanding masses are consumed. King (1957), in his ^{discussion of} ~~his~~

uniformitarianism principles, also implied that parallel erosion goes on all over the world including the humid tropics. Pugh (1966) later reiterated that backwearing and downwearing are not mutually exclusive, because dependent on the particular rock type involved, surface wash and creep can combine to produce downwearing in a zone behind advancing cyclic front.

Holmes (1955) believed that both downwearing and backwearing can operate in the same area, even on a single slope profile, dependent on whether the slope facets are wash slopes (affected by downwearing) or gravity slopes (affected by backwearing); but that eventually downwearing will become increasingly operative. On p. 387 he wrote that "the progressive elimination of the small gravity slopes with concomittant extension and integration of the wash slope units gives the overall effect of decreasing angle of valley side slopes as downwashing of the divide goes on".

From field evidence, it appears that both processes of downwearing and backwearing are operating in South Western Nigeria. Backwearing processes appear to be important in the scarp zone of the Upper Cretaceous Sandstone. The scarp appears to be retreating backward under gully and rill erosion (see Chapter 13). The scarp is laterized e.g. between Imala and Obada^(Fig. 62), and the crust produces the free face below which the laterite rubble and blocks give rise to a constant slope. The length of the waning slope element below the constant slope depends on the location of the individual slope profile. It is very short where the scarp is deeply dissected by gullies, and long elsewhere. Free surface runoff undermines the cap rock which breaks up into large blocks, thus the cambered laterite edge wears back. At re-entrants, the constant slope is undercut by lateral erosion and thus the whole slope profile appears to retreat parallel to itself. On such profiles over a large area, the values of maximum slope angle are nearly the same (Chapter 13).

and this confirms the impression of backwearing.

Parallel slope retreat is also common at gully heads and sides because spring sapping at gully heads lead to block slumping and headward extension of the gully, while lateral erosion at the gully sides lead to slumping at the sides. On artificially-cut steep slopes (Plate 16) free fall of runoff on such slopes lead to basal scouring and slumping from above, giving an impression of backwearing. Rills are also capable of causing parallel retreat (Plate 17). These rills eat into the slope at a constant rate. Thus where the lithological variation is suitable or where lateral erosion and spring sapping occur in South Western Nigeria, backwearing will result. This does not, however, mean that backwearing is the dominant erosional process.

Data on sedimentation ^{are} is limited and insufficient to elucidate the amount of linear erosion in South Western Nigeria. From observations, it seems that linear erosion by streams is weak along most of their courses. The materials derived by surface runoff and carried into the streams are rather fine, so that except where rejuvenation is active, linear incision is unimportant. Occasionally, outcrops along stream channels are potholed, but this is very localised and confined to where the basal surface of weathering is exposed along the stream courses.

Eluviation is an important process both under forest and Savanna, and the type of mechanical eluviation that can occur in the tropics have been discussed by Ruxton and Berry (1961b p. 29). Mechanical eluviation involves the movement, vertically downward, and laterally, of fine soil particles through the interstices of larger ones as a result of sub surface water flow. The effect of tropical thunderstorms on exposed soil is not only to disperse fine materials, but also to drive finer clay and silt particles further down into the soil concentrating the larger particles on the surface. Under consistently intense rainfall, the finer particles are rapidly concentrated



Plate 15. Weathered gneiss near Asejire, at the bottom of the plate, to the right, the regolith is seen to lie directly on unweathered parent rock.

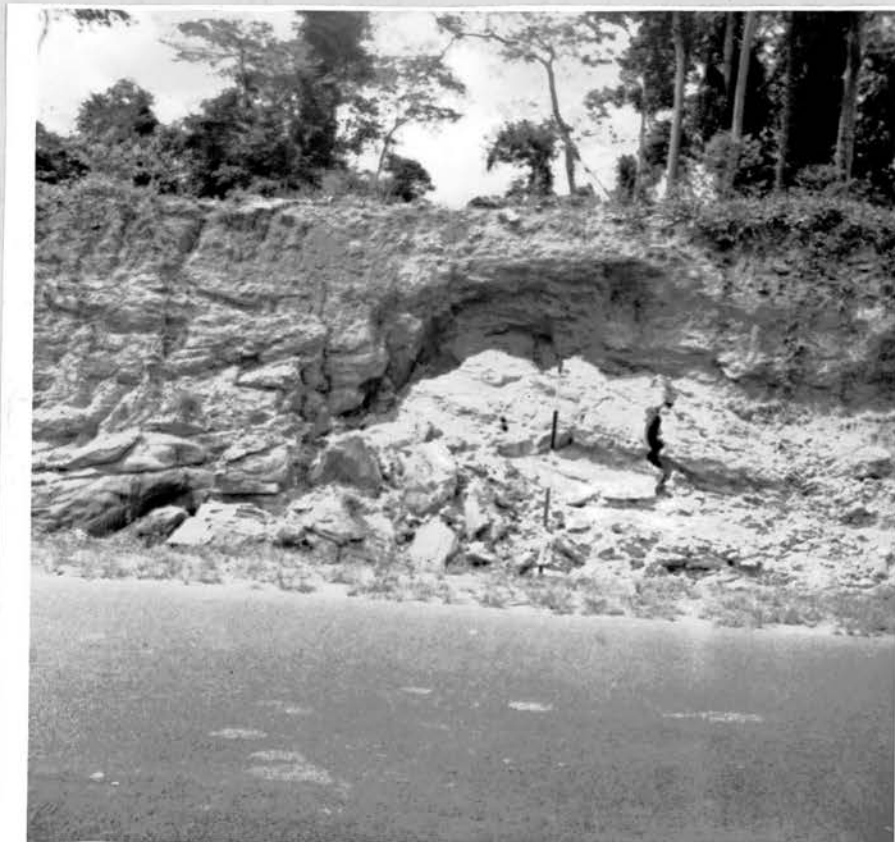


Plate 16. Slumping of the relatively weak, pallid material on a steep artificial slope - near Oru.

to form a clay rich lower soil horizon (B horizon). On slopes these finer particles are washed into the soil by influent seepage and percolation of water moving down slope under the influence of gravity. The finer particles may be washed into the river by effluent seepage. Eluviation is geomorphologically important. In the savanna area, it leads to increased slope wash of the unconsolidated material in the Upper (A) Soil horizon. Under the forest, soil materials are removed by subsurface lateral flow especially as groundwater moves towards the streams. This leads to a gradual and almost imperceptible lowering of the ground surface.

Slope wash is important both in the forest and in the savanna area and usually starts with rain drop erosion. In both the forest and savanna area, unconcentrated slope wash starts when the rain water saturates the ground surface especially during the heavy short periods of rain fall. Where the forest has been cleared, direct rain drops rapidly destroy the top soil. As the ground surface gets saturated, wash becomes concentrated and more erosive. Unconcentrated wash is more effective in the savanna because there is little leaf litter to absorb the rain water, and the grass stems occur as separate tufts leaving exposed surfaces between them. As observed on footslopes of inselbergs, such unconcentrated sheet flow pack finer materials downslope. Here, as the water moves downslope it gets concentrated especially where it gets obstructed by grass stems. The water becomes turbulent and is concentrated into rills which scour the ground surface. This can occur on any kind of slope even as flat as $\frac{1}{2}^{\circ}$ as, for example, around Oyo.

Rills are effective in eroding the land surface especially where such surfaces are exposed as a result of deforestation. They also cause headward extension of streams as seen in two cases around Ibadan airport where the

amphitheatre-like heads of two minor streams are being rilled (Plate 18).

The rate of rill development was studied on a newly deforested surface along Ite-Ojdo road between March 1969 and July 1969. An area of 120 feet by 255 feet was cleared on a slope of 4° and part of the top soil was removed for road making. With the onset of the rainy season in March the cleared surface was still free of rills, but by May, these were evident four 3rd order rills were developed on the surface. The length of the overland flow was 55 feet, about 1/5th the length of the exposed surface. The factor responsible for channelling the flow was mainly the irregularity of the surface configuration.

The table below shows the rill numbers and their average depth and width.

Table 17 Rill Numbers, Average Depth and Width

Rill	Order	Number	Average Depth	Average width
First	1	5	3 ins.	9 ins.
First	2	2	9 ins.	2 ft.
First	3	1	15 ins.	3 ft.
Second	1	6	3 ins.	7 ins.
Second	2	2	7 ins.	1 ft. 10 ins.
Second	3	1	13 ins.	2 ft. 8 ins.
Third	1	8	5 ins.	11 ins.
Third	2	2	9 ins.	2 ft. 5 ins.
Third	3	1	15 ins.	3 ft. 4 ins.
Fourth	1	4	1.7 ins.	5 ins.
Fourth	2	2	4 ins.	11 ins.
Fourth	3	1	7 ins.	1 ft. 6 ins.



Plate 17. Rills on a steep artificial slope near Oke-Iho.



Plate 18. Headward erosion by rills and small gullies of small streams near Ibadan airport.

The interfluvial spaces between them vary from 7 ft. - 9 ft. in width. The rills developed by headward erosion and lateral undercutting, and, between May and July the 1st order rills extended headward between 2 - 4 ft. The surface was disturbed in Mid July and the study discontinued, but it serves to demonstrate the rapidity with which exposed surfaces are eroded.

Gullying and spring sapping are found to be related (Plate 19). With the exception of the several gullies found on the face of the escarpment around Oke-Iho, gullies are never found to a large extent on the crystalline basement, thus confirming Savigear's (1960) observations. Where found, gullies occur irrespective of slope angle. Those on the crystalline basement are found mainly on footslopes of inselbergs and also within the towns, where they occur as a result of drainages from the roofs. The gullies on the crystalline basement are not deep, they rarely exceed 10 feet in depth, but they could be very wide. In almost all those observed on the crystalline basement, subsurface seepage at the heads of the gullies bring out fine soil materials and this causes basal sapping and headward erosion. In contrast to the crystalline area, gullies are common on the surface of the Cretaceous escarpment, but their erosional activities are rather intermittent and are discussed in Chapter 13. Gullies are absent on the scarp face and on the dip slope of the Eocene sandstone except where deforestation has occurred as at Shasha Training Camp some miles east of Ijebu Ode. The area was deforested in 1963, and by 1965, three ^{gully} systems of ~~gully~~ ^{had} ~~have~~ developed and when measured in 1968, they averaged 35 feet in depth, and 160 feet in length. They are eroding backward by basal sapping of the ferruginised sandstone, and laterally by undercutting and slumping. Generally, gullies cause occasional and spectacular erosion, but their work is intermittent and not very important in the overall evaluation of erosional stripping.



Plate 19. Seepage, basal sapping and slumping at the head of a shallow gully near Idere.



Plate 20. Stone line observed north of Abeokuta.

Soil creep is an important erosional process as it involves the transfer of fine soil material from the upper parts of slopes to the middle and the lower parts, but it is extremely slow. Evidence of soil creep were seen in several places especially in road cuts all over the crystalline basement. The most impressive evidence is the thin stone lines found on moderate slopes. Soil creep appears to occur mostly on deeply weathered gneisses and schists whose weathered regolith contain a large proportion of clay. The depth of the migratory soil layer above the stone lines observed in road cuts is always less than 3 feet. Quartz veins which have survival chemical weathering got broken up at the base of the migratory soil layer, and the broken fragments move downslope to form the thin (about 6 ins.) stone lines (Plate 20). Nye (1954) is of the opinion that the stone line may be formed by termites and ants bringing up fine materials from the subsoil to cover the surface gravels. This however, does not seem to be the case on most of the road cuts where stone-lines were observed. Usually the soil material above the stone lines are rather coarse - (Plate 20). On slopes developed in the sandstone area, especially where loose soil is seen along the slope, mounds of sand often bank up against the lower parts of the tree stems, with the sand on the downslope sides of such tree stems eroded away.

Slumping occurs particularly under two circumstances (a) on a steep slope, lateral erosion may occur at the base of the slope, and once the basal material is removed, the upper material will slump down. This is seen mainly on the laterite covered steep scarp of the Upper Cretaceous Sandstone (b) On some steep slopes, runoff often occur on such slopes as free fall, and this leads to the basal scouring of the softer and less consolidated material below with the upper part slumping down (Plate 21).

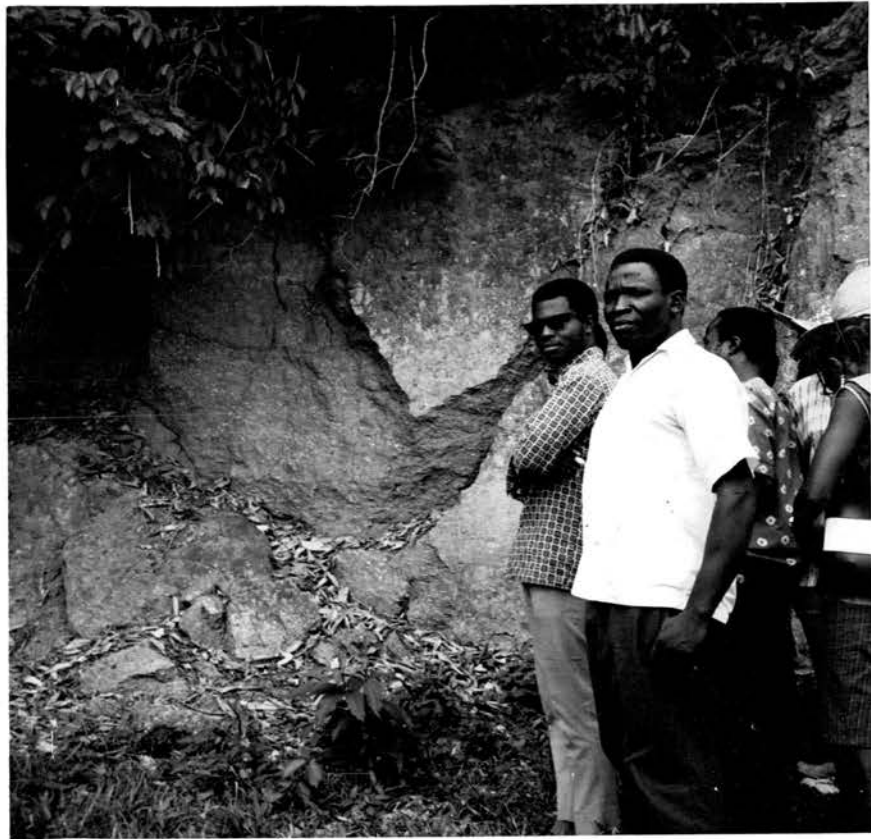


Plate 21. Slumping of the harder ferruginised upper horizon after the erosion of the softer lower materials, observed near Ikirun.

The above are the erosional processes stripping off the weathered regolith over both the sedimentary and the crystalline basement rocks in South Western Nigeria. The combination of these processes could lead to either backwearing or downwearing depending on the lithology of the weathered regolith in a particular area. The results of this erosional stripping are the complex landforms of South Western Nigeria which are discussed in the following chapter.

CHAPTER 6
LANDFORMS

In Chapter 5, it was mentioned that landform development in the humid tropics can be explained with the etchplain concept of deep weathering and erosional stripping. This will be further amplified in this chapter. In Australia, Mabbutt (1961a) and Wright (1963) recognised that younger etchplains are developed ^{on the surface} ~~across~~ the weathering profile of an older plateau-like surface. The younger etchplains have moderate local relief and irregular surface configuration, and are separated from the older surface by scarps. This type of landform development whereby older plains are separated from lower etchplains by scarps was also reported from Nigeria by Thomas (1965). They are typical where the older surface was flat and featureless. This is not the case in South Western Nigeria.

The initial surface in South Western Nigeria as discussed in chapter 5 was inclined to the Gulf of Guinea, however, and the exact configuration is unknown. If it is assumed that an inclined surface is weathered, and then uplifted, a new surface or etchplain will develop along the river valleys, and will not be separated from the older surface by a cyclical scarp. With further weathering and repeated uplifts, newer surfaces will develop within the pre existing surfaces, but it is unlikely that cyclical scarps will occur between them. Such scarps may occur locally where there is differential weathering, but these features will be structural rather than cyclical. This seems to have been the sequence in South Western Nigeria where no definite widespread erosion surface can be recognised especially on the pre Cambrian basement rocks. Instead there are different types of weathered and erosional landforms, with the degree of erosion and the basal surface of weathering exposed on the landforms, varying from place to place.

These have been produced by repeated uplift and stripping away of the weathered regolith of the older surface whose lateritised remnants are still preserved on the primary watershed north of Shaki. The nature of the different landforms depend on the following factors:

- a) the amount of base level changes involved and the pattern of base level changes affecting the older surface,
- b) the amount of weathering in the periods between the base level changes,
- c) the amount of erosion in the periods between the base level changes,
- d) the amount of basal surface of weathering exhumed,
- e) the contemporary pattern of weathering and erosion:

The first three parts were examined in Chapter 5 and will not be repeated here, the last two points are discussed below in considering the different landforms.

Thomas (1965, 1969) has shown how different categories of etchplains and etchsufaces have been produced from the old weathered surface on the basement complex rocks in Western Nigeria, and it is unnecessary to elaborate on this here. These landforms are also found in the sedimentary area. The basal surface of weathering in the sedimentary rocks is indistinct and definitely not in form of domical rises and basins as in the crystalline rocks. In this case erosional stripping might be expected to produce pediplains especially as the surface of the sedimentary rocks are lateritized. To some extent, wide valley benches representing incipient pediplanation can be recognised in the sedimentary areas, but these do not give the impression of widespread plains. Rather than exhibiting such plains, the sedimentary areas show a gradation from a relatively undissected lateritized surface to well dissected surfaces which may be termed etchplains and etchsufaces.

The etchplains and etchsufaces developed in South Western Nigeria exhibit varying amounts of interfluve areas, lateritic cover and rock outcrops. The primary criteria established by Thomas (1965) for recognising these landforms are (i) the amount of basal surface of weathering exposed i.e, the amount of rock outcrops, (ii) the amount of laterite present on the interfluves, and (iii) the amount of dissection that has taken place within the exposed basal surface of weathering. These criteria will not apply in all individual cases e.g. in the sedimentary area where there are no rock outcrops. Using the above criteria, the following landforms have been recognised in South Western Nigeria (Fig. 22).

Sedimentary Area - 1. (Partially Dissected) Lateritized Plain

- ii. Dissected and Partially Stripped Etchsuface
- iii. Zone of Dissection and Partial Stripping
- iv. Aggraded Plain
- v. Partially Dissected Coastal Plain

Crystalline Base-
ment Area

- 1. Partially Stripped Etchsuface
- ii. Dominantly Stripped Etchplain
- iii. Dominantly Stripped Etchsuface

There ^{is} are some correspondence between these landforms and the physiographic units. The major difference is that the landforms are classified according to their surface material, while the physiographic units are classified according to their surface configuration. On the sedimentary rocks, the Partially Dissected Coastal Plains is the same in both cases, the Aggraded Plain corresponds with the Ewekoro Depression, while the Dissected and Partially Stripped Etchsuface is nearly the same as the Maturedly Dissected parts of Northern and Southern Upland. The (Partially Dissected) Lateritized Plain corresponds with the Incised section

of the Northern Upland, and the Meko Plain, while the Zone of Dissection and Partial Stripping is the same as the Dissected Margin of the Northern Upland. On the crystalline basement rocks, the Partially Stripped Etchsurface covers nearly the same area as the Dissected Terrain except for the Western part, while the Dominantly Stripped Etchplain corresponds with the Gently Undulating Terrain around Oyo and Iwo. The Dominantly Stripped Etchsurface corresponds with the Hilly Terrain and the Dissected Terrain with High Hills and Ridges.

Mapping the different Landforms

It is difficult to map the landforms from the 1:40,000 airphoto series of Western Nigeria. The two criteria of laterite cover and the amount of basal rocks exposed present problems of identification on airphotos. In the sedimentary areas, the laterite is clearly visible, being both widespread and thinly covered by vegetation, in the crystalline area, lateritic outcrops are very small, and the forest vegetation makes the identification difficult. Under both savanna and forest, however, all the large rock outcrops stand out distinctly under the mirror stereoscope.

All rock outcrops visible from the airphotos were delimited and marked on the 1:50,000 topographic maps. Some areas were traversed especially at Oyo-Fasola, Ibadan, and Iseyin-Ado Awaiye, on the crystalline rocks, and Abeokuta, Aiyetoro-Meko, and Ilaro on the sedimentary rocks. Rock and lateritic outcrops along the traverses were mapped and identified. About 10 per cent of each landform area was traversed. The maps derived were subjective because the delimitation into the different landform categories was done on visual inspection of the field maps, and there is a degree of unavoidable overlap from one landform type to the other.

Quantitative Description

For each landform type, attempts have been made to quantify some

measurable properties. These include the percentage of rock outcrops on the different landforms, calculated for sample areas from airphotos, and the amount of lateritic outcrops in each landform from observations.

Thomas (1969) has argued against using the properties of the drainage systems within the landforms to quantify the different landforms. He contents himself with the "Incidence of streams", Drainage Density, and mean valley width for each landform. He also mentioned that since third and fourth order drainage basins often cut across lithologic and geomorphological boundaries, they may not necessarily be representative of individual landforms. Wigwe (1966), however, used drainage basin analysis to establish some ^{degree} ~~degree~~ of difference between the etchplains and etchsides he recognised in parts of Northern Nigeria.

Analysis of drainage basins presents difficulties as a diagnostic criteria for the different landforms, especially when streams extend beyond the boundaries of individual landforms. Moreover, the accuracy of the stream properties measured will depend on the scale of the available maps and airphotos. However, since the different etchplains and surfaces produced from an older surface will depend on geology and, more particularly, on the intensity of local erosional stripping, it seems feasible that drainage basin properties within the individual landforms will differ. For instance the older and less dissected landforms will have fewer streams than the younger and more dissected landform. The stream properties which often reflect the degree of erosion are: length of the 1st order streams, stream number, drainage density, stream frequency, Constant of Channel Maintainance and length of overland flow. These are directly related to the stage of stream development and therefore to the erosional properties of such streams (Horton 1945).

The Percentage Hypsometric Curve designed by Strahler (1952) is perhaps of greater importance. Strahler designed the curve in order to assess the amount of erosion and the stage of landform development within the drainage basins. It is drawn on a dimensionless basis in order to make comparison possible between drainage basins located on different geology and in different landforms, the higher the value of the hypsometric integral, the relatively undissected such a landform. Strahler gave the following hypsometric integral values for the following landforms:-

- i. above 60% for relatively undissected landform
- ii. below 60% for youthful to mature landform
- iii. 35% and below, for plains with monadnocks

For each landform type recognised in South Western Nigeria, all the 4th order streams occurring within the landforms were delimited from the 1:40,000 airphotos. The number of such streams varies from 1 in the Dominantly Stripped Etchsurface to 6 in the Dissected and Partially Stripped Etch-surface. For each drainage basin, the stream properties enumerated above were analysed, and the hypsometric integral calculated from the 1:50,000 maps.

For purposes of abbreviation in later discussions, the following symbols are used.

- \bar{A} - Total Area of stream basin
- \bar{L} - Total length of stream
- N_s - Stream Number
- N_s^1 - Number of 1st Order Streams
- $\bar{X}L^1$ - Mean lengthth of 1st Order Streams
- $\bar{X}A^1$ - Mean Area of 1st Order Streams
- B.R - Bifurcation Ratio
- Dd - Drainage Density

Dd1 - Drainage Density of 1st order streams

CCM - Constant of Channel Maintenance

SF - Stream Frequency

L.O.F - Length of Overland Flow

Relationship between the landforms and the Geology

The ^{general} ~~general~~ morphology of an area is a reflection of the geomorphic processes, and more important, of the broad geological outline. The detailed form elements of the landforms are determined by the absolute lithology of the underlying rocks. This is the case in South Western Nigeria where the landforms are mostly determined by the broad geology, the lithology of the different rock groups and the varying degree of erosional stripping of the differentially weathered rocks.

The sedimentary rocks have a west to east zonation, with the rivers cutting diagonally across them in a north to south direction, especially the rivers developed on the dip slopes. The Upper Cretaceous Sandstone (Abeokuta Formation) occurs further to the north than the other sedimentary series. It is heavily lateritized, and on it is developed the partially stripped lateritized plain. This landform is deeply weathered. To the south, at the middle courses of the dip slope rivers is the more dissected and stripped etchsurface. This pattern is repeated on the Eocene Sandstone (Ilaro Formation) to the south, where the lateritized and relatively undissected landform is found on the upland north of Ilaro, and the more dissected landform is found at the middle course of rivers Berre and Ore. The partially dissected coastal plains occur further to the south.

On the crystalline basement, the rocks show a strong North to south zonation as reflected in the disposition of the quartzite bands and the gneisses. The interaction between the lithological patterns of these rocks

and the geomorphic and tectonic evolution, appear to have produced irregular West to East zonation of the landforms except for the dominantly stripped etchsurfaces developed on the north to south trending quartzites and granites.

On the basement complex, particular types of etchplains or etchsurfaces appear to be associated with certain rock types. The dominantly stripped etchplain is found mainly on migmatite; the dominantly stripped etchsurface is locally developed on granites and more widely developed on quartzites and schists; while the partially stripped etchsurface is developed on schists and migmatites. This association of landforms with particular rock types reflects the susceptibility of such rocks to differential weathering and erosion; and this will be examined when individual landforms are discussed.

One outstanding problem is that both the partially stripped etchsurface and the dominantly stripped etchsurface are to a large extent developed on migmatites. The reason for this will be apparent when the zonation of the landform is discussed.

Zonation of the Landforms

The landforms have an apparent W - E zonation (Fig. 22) which is associated with the drainage pattern on the sedimentary rocks, but not easily explained on the crystalline basement rocks. Here, the dominantly eroded landform lies north of the partially eroded type. This zonation suggests that erosional stripping is more active to the north than to the south. There are some reasons for this, it is quite possible that since the two landforms evolved, weathering has been more intensified on the partially stripped etchsurface because of the greater amount of rainfall and vegetation cover, but this particular landform type occurs both in the forest and in the savanna. The main reason may be due to drainage on the

different landforms. To the north, the rivers are more youthful and more erosive than to the south, hence more eroded landforms would be found to the upper courses of these rivers than on their lower courses. The landforms on the watershed of these rivers is the lateritized and partially dissected plain recognised by Thomas (1969), hence the dominantly stripped etchplain present in South Western Nigeria is really at the middle courses of these rivers, while the partially stripped landform to the south is on the lower courses of these rivers. Thus the zonation of the landforms are related to the drainage on the basement rocks. This is similar to the sequence on the sedimentary rocks.

Climatic and vegetation influences also appear to influence the zonation of the landforms. The dominantly stripped landforms are mainly in the savanna, while the partially stripped landforms, are mainly in the forest. As mentioned in Chapter 5, the influences of past climatic changes were felt more in the semi arid area and the savanna fringes than in the forest. In the savanna area, the smaller amount of precipitation in the drier periods would lead to a decreased vegetation cover and as the intensity of rainfall was high, there would be more sheet erosion in the savanna than in the forest, hence landforms in the savanna will be more eroded.

The Landforms

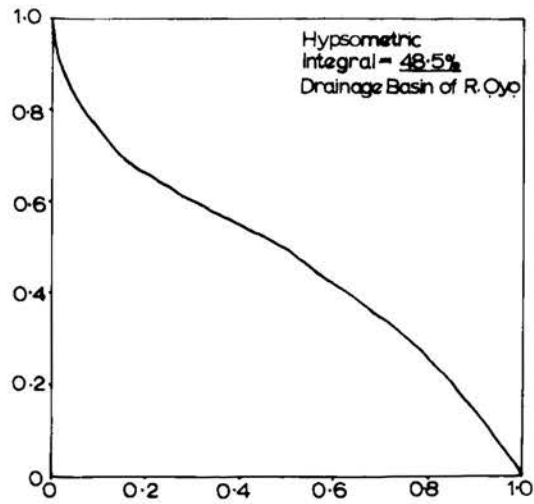
(Partially Dissected) Lateritized Plain. This landform is developed on the upper Cretaceous Sandstone and on the Eocene Sandstone. It is found on the upland surface between Aiyetoro and Meko, south of Abeokuta as far as Ijebu Ode, and north of Ilaro. ^{surface of the} The landform, which is gently sloping, shows little surface relief (of the order of 50-100 feet). Deep weathering has penetrated through the sandstone formations to the underlying gneisses,

as seen at Obada. A typical weathering profile where the plain is deeply dissected shows:-

- a) 0.6 ins. - loose greyish surface soil,
- b) 6 ins. - 35 feet - thick vesicular brownish red laterite,
- c) 35 feet - 40 feet - soft clayey zone with lateritic concretions,
- d) 40 feet - 120 feet - mottled zone composed of clayey, sandy, reddish material,
- e) 120 feet - pallid zone, whitish grey and clayey.

The lateritized plain is deeply dissected by the headstreams of the Yewa river. The plain is probably an old erosion surface of early to mid Tertiary age. Below it, along the stream valleys are wide valley benches which are still being widened by erosional backwearing. Unit landforms on the old surface consist of the sloping, upper, laterite covered, extremely wide interfluves and the valley slopes. Laterite covers about 50% of the interfluve areas between Aiyetoro and Meko, but it is seldom present in the Abeokuta-Ijebu Ode area except on the upper slopes of river valleys. The valley slope profiles usually consist of the cambered edges of laterite occurring as free faces, followed by a straight slope of 16° - 25° often covered by laterite blocks. Below the steep constant slope is the terrace-like bench at 2° - 6° on which detrital laterite is often found; this slope may be followed by a short, steep, rejuvenation slope of up to 45° .

The only 4th order stream found on this surface is the Oyo river. The drainage basin shows a hypsometric integral of 48.5% (Fig. 23) which compares favourably with the dissection index worked out for this landform in Chapter 4. The low value of the integral is not truly representative of the amount of dissection on the landform, however, because the river



PERCENTAGE HYPSONETRIC CURVE OF
A 4th ORDER DRAINAGE BASIN ON THE
LATERITISED PLAIN.

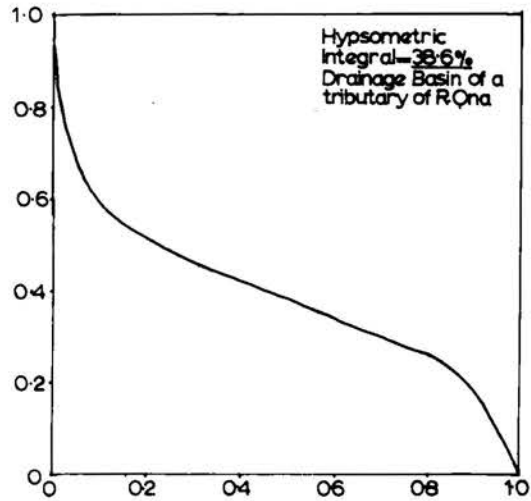
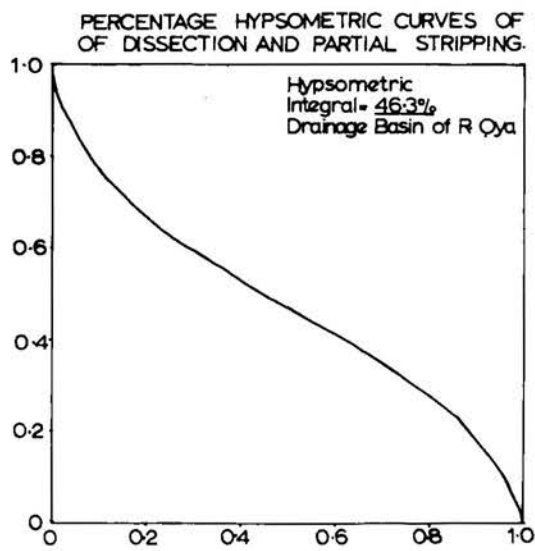


FIG. 23

has expanded headward into the crystalline rocks to the north in some areas. Nevertheless it indicates that the landform is still not maturely dissected. The Drainage Density, within the drainage basin, is 1.1. This is low because of the widespread occurrence of laterite on the old plain and because the underlying sandstone is porous. The porosity of the sandstone is also responsible for the low stream frequency which is 0.99 per square mile. The 1st order streams are long, with a mean length of 0.8 mile, while the length of the overland flow is 0.449 mile. The reason for this is that most of the water on the surface either percolates into the sandstone before streams can develop or is retained on the surface of the laterite leading to the noticeable widespread waterlogging between Idi-Emi and Meko during the rainy season. The morphometric properties of river Oyo are shown in Table 18, and the frequency distribution of the stream lengths and areas are shown in Fig. 24.

Table 18 Morphometric Properties of River Oyo

River	Rock Type	Stream Order	Ns	\bar{A} (sq. mls.)	\bar{L} (mls)	Ns1	$\bar{X}L1$ (mls)	$\bar{X}A1$ (sq. mls.)	B.R.	Dd	Dd1	CCM (sq. mls.)	Sf	L. of (mls.)
Oyo	Upper Cretaceous Sandstone	4	101	101.69	113.2	79	0.81	0.76	4.32	1.1	1.064	0.9	0.994	0.449

Dissected and Partially stripped Etchsurface This landform is developed on the Dip slopes of both the Upper Cretaceous and Eocene sandstone. It is mainly found between Aiyetoro and Wasimi in Abeokuta Province, and also in the basins of Ore and Berre rivers. The landform resulted from the dissection and erosional stripping of the lateritised surface discussed above. Its relative relief is about 150-200 feet. On the upper Cretaceous sandstone, thick vesicular laterite occurs on the narrow interfluves, but on the Eocene sandstone, the interfluves carry ferruginised material.

LATERITISED PLAIN(PARTIALLY DISSECTED)
 FREQUENCY DISTRIBUTION OF STREAM LENGTHS
 (IN MLS)AND STREAM AREAS(IN SQ.MLS)

R. Oyo

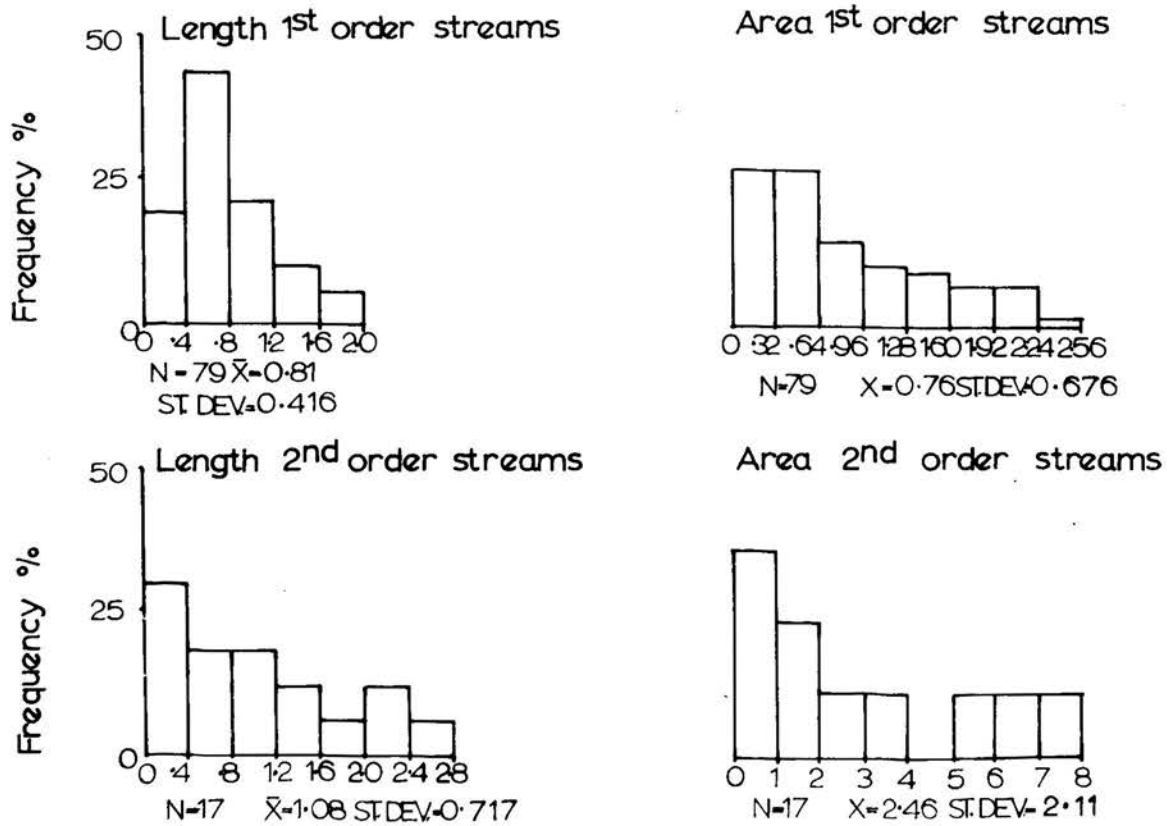


FIG.24

In the Aiyetoro-Wasimi area, the landform is intensively dissected by the tributaries of Ogun and Yewa and in several places, the basement complex rocks below the sandstone are exposed. In spite of this dissection, remnants of an old erosion surface are still preserved on the interfluves by the vesicular laterite at 475feet-525feet. A younger surface at 275feet-380feet is developed along the valley floors and valleybenches which are often covered by detrital laterite. On the Eocene Sandstone south of Ilaro, the same pattern of surfaces occur. The upper surface is preserved on interfluves at 250feet-300feet while the lower surface occurs at 125feet-250feet on wide valley benches.

Unit landforms in the dissected and stripped landform consist of the upper laterite covered, narrow interfluves, followed by the free faces formed by the vesicular lateritic outcrops. Lateritic outcrops cover about 10% of the landform. The straight valley slopes below the lateritic outcrops vary from 3° - 7° and these are often followed by wide valley benches $\frac{1}{2}^{\circ}$ - 3° . The valley floor is very wide and often mantled by thick alluvial deposits.

Several 4th order streams are found in this landform and six of the drainage basins were analysed. The hypsometric integral and the hypsometric curves of the drainage basins are shown in Fig. 25. The former varies from 32.4% for the basin of Onigbongbo river to 45.0% for the basin of Berre river indicating a mature dissection of the landform. The Drainage Density is low, ranging from 0.8 for the basin of the Eripa river to 1.2 for the basin of the Iju river. Stream frequency is low, about 1 per sq. mile. The mean length of the 1st order streams varies between 0.69 mile to 1.14 mile. The length of overland flow varies from 0.4 - 0.6 mile; while the constant of channel maintainance is high varying from 0.9 - 1.0 sq. mile to

PERCENTAGE HYPSOMETRIC CURVES OF 4th ORDER DRAINAGE BASINS IN THE DISSECTED AND PARTIALLY STRIPPED ETCH SURFACE.

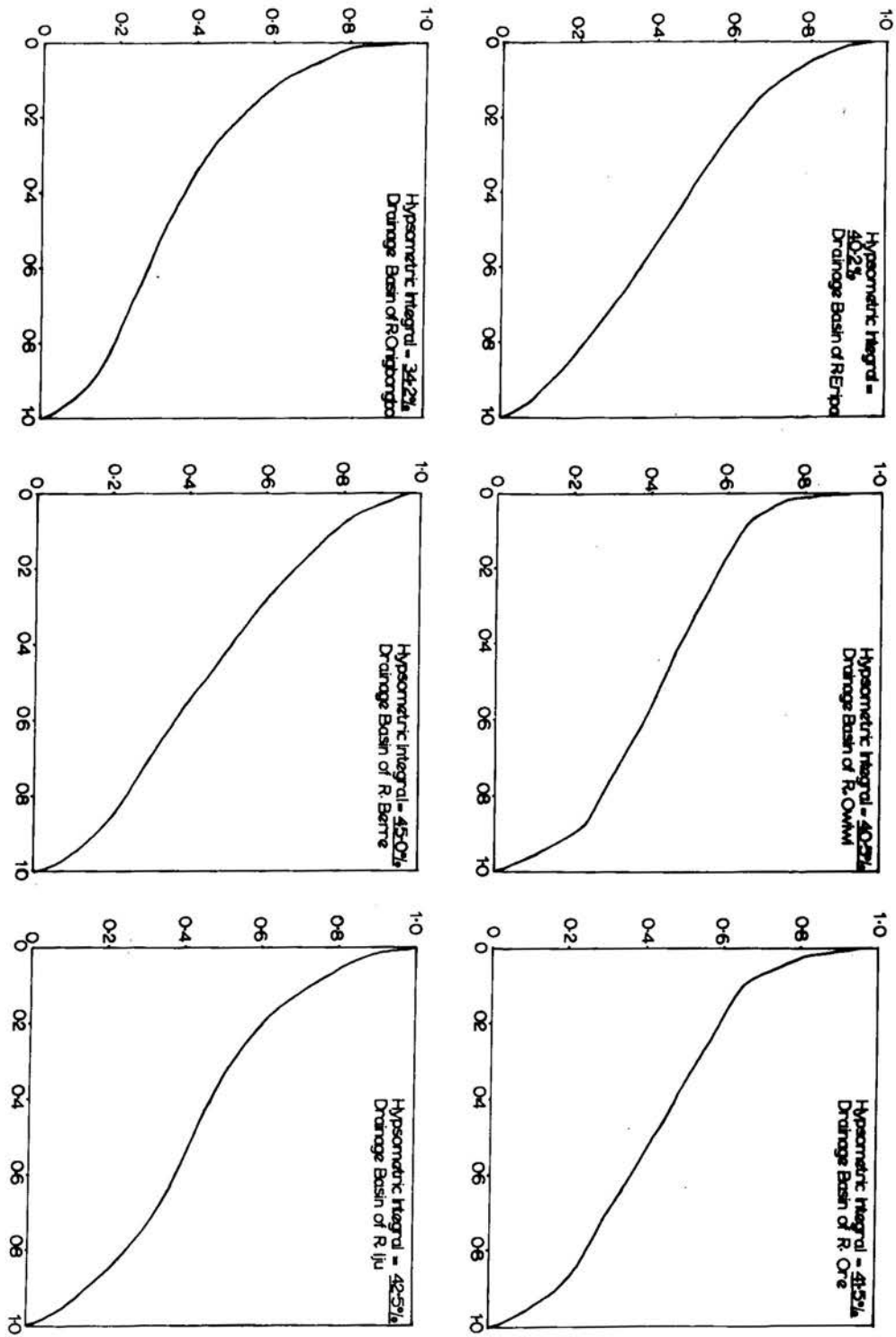


FIG. 25

1 mile of stream channel. These stream properties are summarised in Fig. 26, and in table 19. The stream properties are much the same as for river Oyo, on the older landform to the north, and further reflect the porosity of both the Cretaceous and Eocene Sandstones.

Table 19 Morphometric properties of some 4th order rivers on the Dissected and Partially Stripped Etchsurface

Rivers	Rock Type	Stream Order	Ns	\bar{x}_A (sq. mis.)	\bar{x}_L (mis.)	Ns1	\bar{x}_{L1} (mis.)	\bar{x}_{A1} (sq. mis.)	B.R.	Dd	Dd1	CCM (sq. mis.)	Sf	$\frac{L}{S}$ (mi.)
Eripa	Upper Cretaceous sandstone	4	36	85.28	66.84	26	1.14	1.27	3.1	0.78	0.894	1.276	0.442	0.638
Onigbongbo	"	4	31	29.77	32.00	22	0.78	0.75	2.9	1.75	1.04	0.931	1.07	0.465
Owiwi	"	4	37	35.11	39.28	26	0.75	0.60	3.08	1.11	1.253	0.894	1.054	0.465
Berre	Eocen sandstone	4	72	70.95	77.80	57	0.69	0.71	4.0	1.09	0.979	0.912	1.015	0.456
Ore	"	4	121	157.62	157.2	99	0.91	1.01	4.26	0.99	0.912	1.002	0.77	0.501
Iju	"	4	158	128.54	157.08	125	0.71	0.60	5.2	1.22	1.186	0.819	1.23	0.409

Zone of Dissection and Partial Stripping This landform occurs east of Abeokuta at the contact zone between the upper Cretaceous sandstone and the pre Cambrian basement rocks. The sandstone is dissected by the tributaries of Ogun, Ona and Ibu rivers into well spaced mesas with tabular surfaces covered by laterite. The local relief is between 150 feet and 250 feet. The laterite is exposed as flat pavements on top of the erosional remnants. The basement complex rocks outcrop over a wide area near Abeokuta.

Field investigation shows definite surface remnants on top of the sandstone residuals at 400-550 feet. Unit landforms are composed mainly of laterite covered mesas and the valley slope. The free face of the vesicular laterite on the residuals is rarely seen as it is often masked by a replacement slope composed of laterite rubble. The steep slopes of the residuals near Abeokuta vary from 10° - 25° . Below the steep slopes are long

DISSECTED AND PARTIALLY STRIPPED ETCHESURFACE
 FREQUENCY DISTRIBUTION OF STREAM LENGTHS(MKS) AND STREAM AREAS(SQ.MS.)

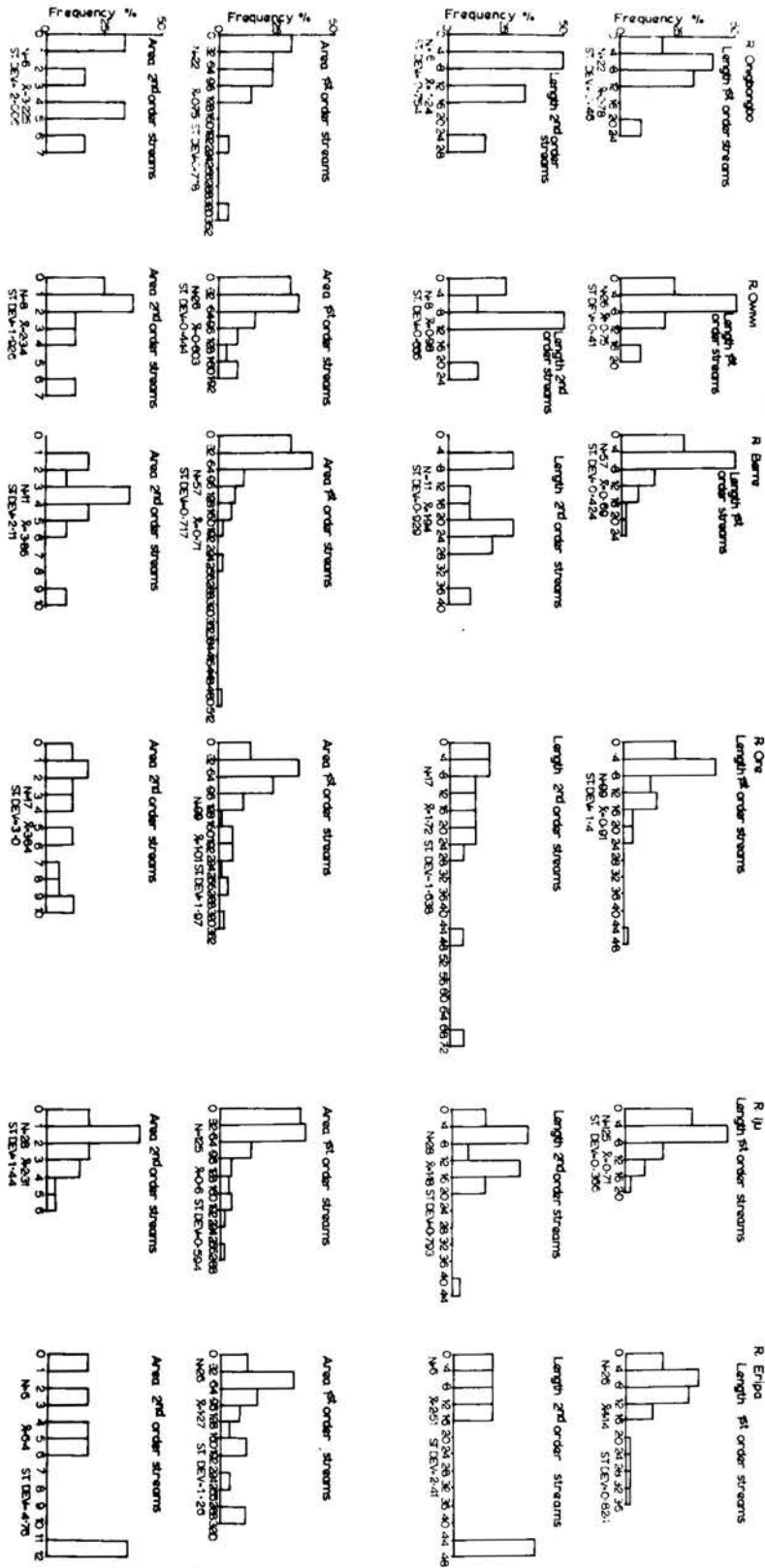


FIG. 26

footslopes 2° - 6° on which ferruginised materials and recemented laterite occur. These footslopes are often intruded by low convex rock outcrops. Lateritic outcrops cover about 10% of the landform area, but the individual rock outcrops are small and their total area is negligible.

Only two 4th order streams occur within this landform, R. Oya south of Abeokuta and a tributary of R. Ona north of Ijebu Ode area. The hypsometric integral of the Oya basin is 47.3% and that of the Ona basin is 38.6% (Fig. 23). The former is not truly representative because of the large flat topped residuals within the basin, while in the basin of the Ona tributary, the residuals are small and conical. The hypsometric integral of the Oya indicates an early mature dissection, while that of the tributary of the Ona indicates a late mature dissection.

The landform is well drained probably because the removal of the porous sandstone leads to more drainage development on the relatively non porous underlying basement complex rocks. Drainage Density varies from 1.1 for the Oya basin to 1.92 for the basin of the Ona tributary. Where dissection is still not well advanced, the 1st order streams are long, with a mean length of 1.2 miles for the Oya river, but they are relatively short, 0.6 mile, for the Ona tributary (Fig. 27). Length of overland flow varies from 0.26 mile in the well dissected section to 0.45 mile in the poorly dissected section. Stream frequency is low, 0.76, in the latter, but high, 2.64, in the former. The constant of channel maintainance is 0.91 sq. mile to 1 mile of drainage line within the Oyo basin, and 0.521 sq. mile to 1 mile within the drainage basin of the Ona tributary. These drainage characteristics are summarised in Table 20.

ZONE OF DISSECTION AND PARTIAL STRIPPING
 FREQUENCY DISTRIBUTION OF STREAM LENGTH
 (IN MLS.) AND STREAM AREAS (IN SQMLS)

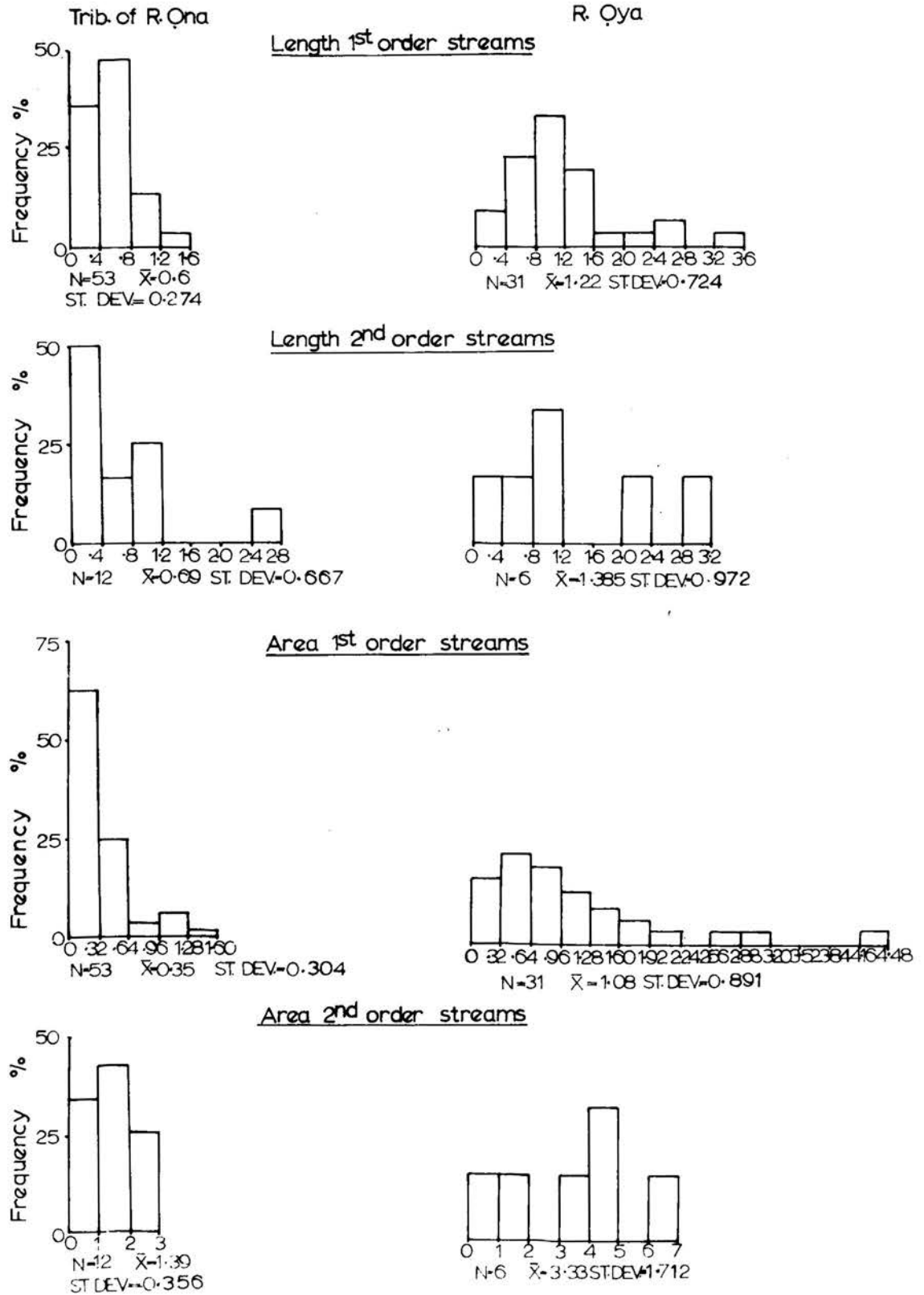


FIG. 27

Table 20. Morphometric properties of some 4th order streams within the zone of Dissection and Partial Stripping

River	Rock Type	Stream order	$N_s \bar{x}_A$ (sq. mls.)	\bar{x}_L (mls.)	NS_1	$\bar{x}_L 1$ (mls.)	$\bar{x}_A 1$ (sq. mls.)	B.R.	Dd	Dd1	CCM (sq. mls.)	Sf	L of (mls.)
Onatrib	Upper Cretaceous sandstone and	4	69 26.16	50.24	53	0.6	0.35	3.8	1.92	1.72	0.521	2.64	0.261
Oyo	basement complex rocks	4	40 52.41	57.68	31	1.22	1.08	3.4	1.1	1.13	0.91	0.76	0.455

Aggraded Plain This landform occupies the Ewekoro Depression discussed in Chapter 4. The depression was formed probably as a result of faulting which also led to the formation of the Eocene scarp to the south. The depression was covered by a shallow lagoon in the Pleistocene - Quarternary period - (Moss 1961), and the thin shale found within it confirms this opinion. Since its formation, it has served as a basin of deposition for materials eroded from the scarp of the Eocene sandstone and from the dip slope of the Upper Cretaceous Sandstone. The drainage and surface configuration were discussed in Chapter 4.

Partially Dissected Coastal Plain This landform has been discussed in Chapter 4 and will not be repeated here.

On the basement complex, the landforms are:

Partially Stripped Etchsurface This covers the largest area of all the landforms. It extends northwards from the base of the Upper Cretaceous escarpment to the northern boundary of the area in the west at Dakomey boundary. It has been called an etchsurface rather than an etchplain because of its surface configuration which is highly irregular. Local relief on it varies from moderate to high, about 100 feet to 350 feet. The landform is mainly developed on migmatites and schists, but quartzitic ridges are common on it.

There are few rock outcrops. In an area of 250 sq. miles around Ilugun, only 0.66% of the area is covered by rock outcrops, and 1.2% formed by quartzitic ridges. Around Ibadan, 0.8% of the surface is covered by rock outcrops and 8% formed by quartzitic ridges.

The degree of rock weathering on the surface varies from area to area. For instance near the Upper Cretaceous escarpment, the weathering profile is truncated and consists of about 3 feet of upper sandy, clayey red soil, below which is a 10 foot pallid, whitish grey zone, overlying partially weathered gneiss. In most places where the weathering profile is not truncated, it is often shallow, but deep basins of weathering are also common. Along Ijebu Ode - Idi Ayunre road, all the complete weathering profiles examined were less than 30 feet in depth. A typical weathering profile on an interfluvium would be an upper 30 ins. of soil composed of fine clayey material and unsorted quartz fragments and concretions, separated from the mottled zone below by a layer of gravel 6 ins. thick. The mottled zone is 9 ft. thick and is composed of reddish brown clay. The pallid zone is about 6 ft. thick and is composed of gritty clayey material, whitish grey with streaks of red. The pallid zone is separated from the underlying gneiss by a partially weathered layer of gneiss. From observations it appears that weathering profiles on schists are deeper and contain more lateritic concretions than weathering profiles on gneisses.

Unit landforms include the quartzitic ridges with their steep sides; these ridges invariably form interfluviums. The ridges are covered by thin layer of flaggy quartzite fragments. The weathered convex interfluviums cover about 25% of the landform area. Massive vesicular laterite is rarely seen on these interfluviums, but detrital laterite and lateritic concretions are frequently seen on the lower slopes. Few inselbergs and rock pavements occur,

and most of them are under forest and often carry superficial regoliths. The inselbergs are low, often less than 150 ft. above the local surface. Below the quartzitic ridges, moderately dissected footslopes, 2° - 5° occur, and these lead to the valley slopes below.

The valley slopes are mainly concavo-convex, and show no important slope breaks. Valley heads display a remarkable amphitheatre-like appearance as seen around Ibadan, and this shows that rejuvenation has progressed to the head of these rivers.

Several 4th order streams occur within this landform, but only four of them occur largely on uniform rock types. Two were selected from migmatite and two were selected from schist areas. The hypsometric integral of the drainage basins are uniform (Fig. 28). Where there are no ridges within the drainage basins, the hypsometric integral varies from 43.2% - 46.5% indicating a mature dissection, but it is lower - 31.5% in the basin of Oso river where there are hills and ridges.

The landform is generally well drained, but the drainage varies from rock type to rock type. On migmatite it varies from 1.7 - 1.9, while it is about 2 on schist. Stream frequency is higher on schist, 2.5 - 3 than on migmatite, 1.9 - 2.6. The mean lengths of the 1st order streams on schists are shorter 0.55 mile than on migmatite 0.65 - 0.73 mile (Fig. 29). The length of overland flow on schists is also shorter 0.25 mile than on migmatite 0.275 - 0.296 mile. The constant of channel maintainance is smaller on schists 0.46 - 0.52 sq. mile than on migmatite 0.55 - 0.59. The slight differences noted in these drainage properties on the different rock types reflect the different lithology and structure of the rocks. Schists are weathered relatively faster than migmatite, and the weathered residue of schists is mainly clayey and non porous while that of gneiss is sandy. It

PERCENTAGE HYSOMETRIC CURVES OF 4th ORDER DRAINAGE BASINS IN THE PARTIALLY STRIPPED ETCH SURFACE

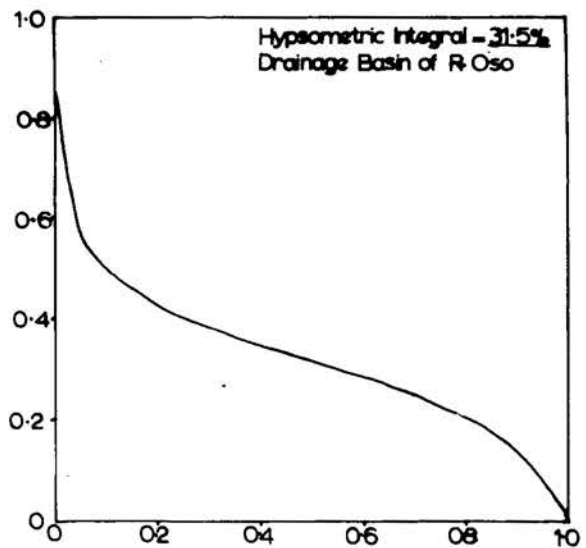
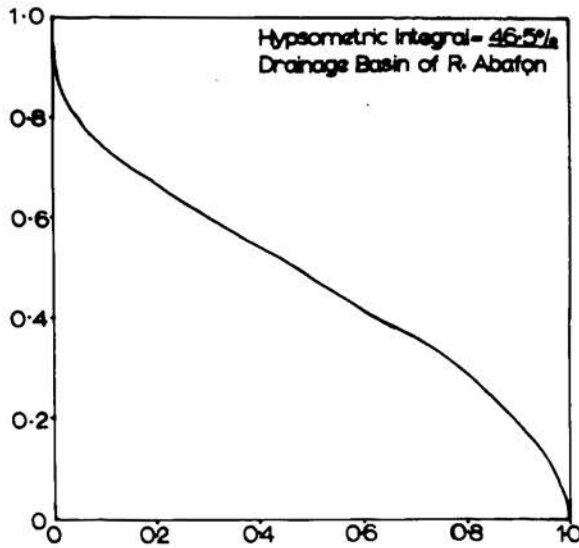
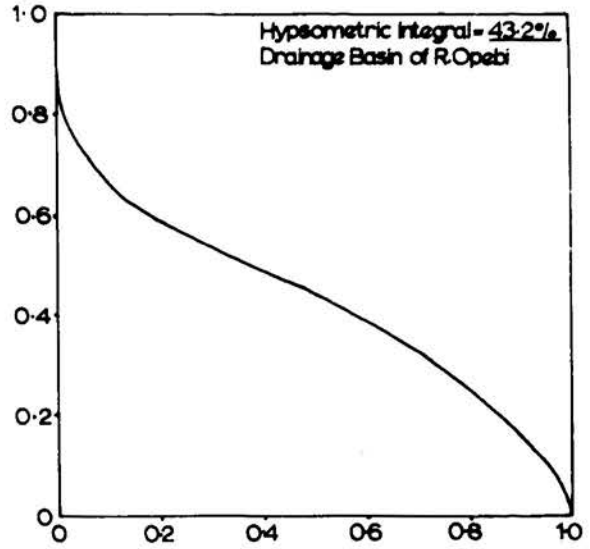
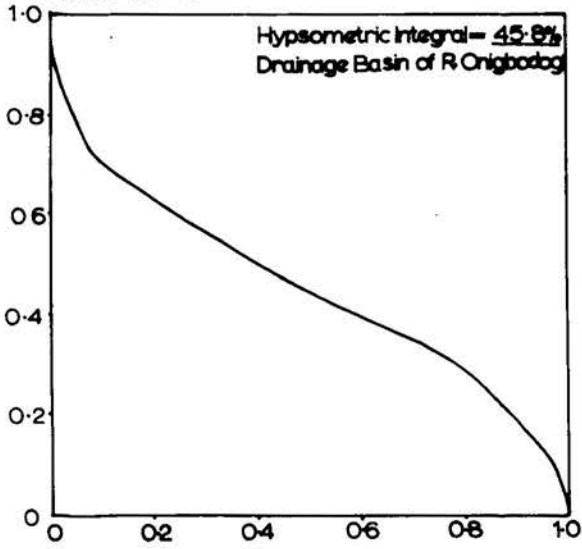


FIG 28

PARTIALLY STRIPPED ETCHSURFACE.
 FREQUENCY DISTRIBUTION OF STREAM LENGTH (IN MLS) AND STREAM AREAS (IN SQ MLS).

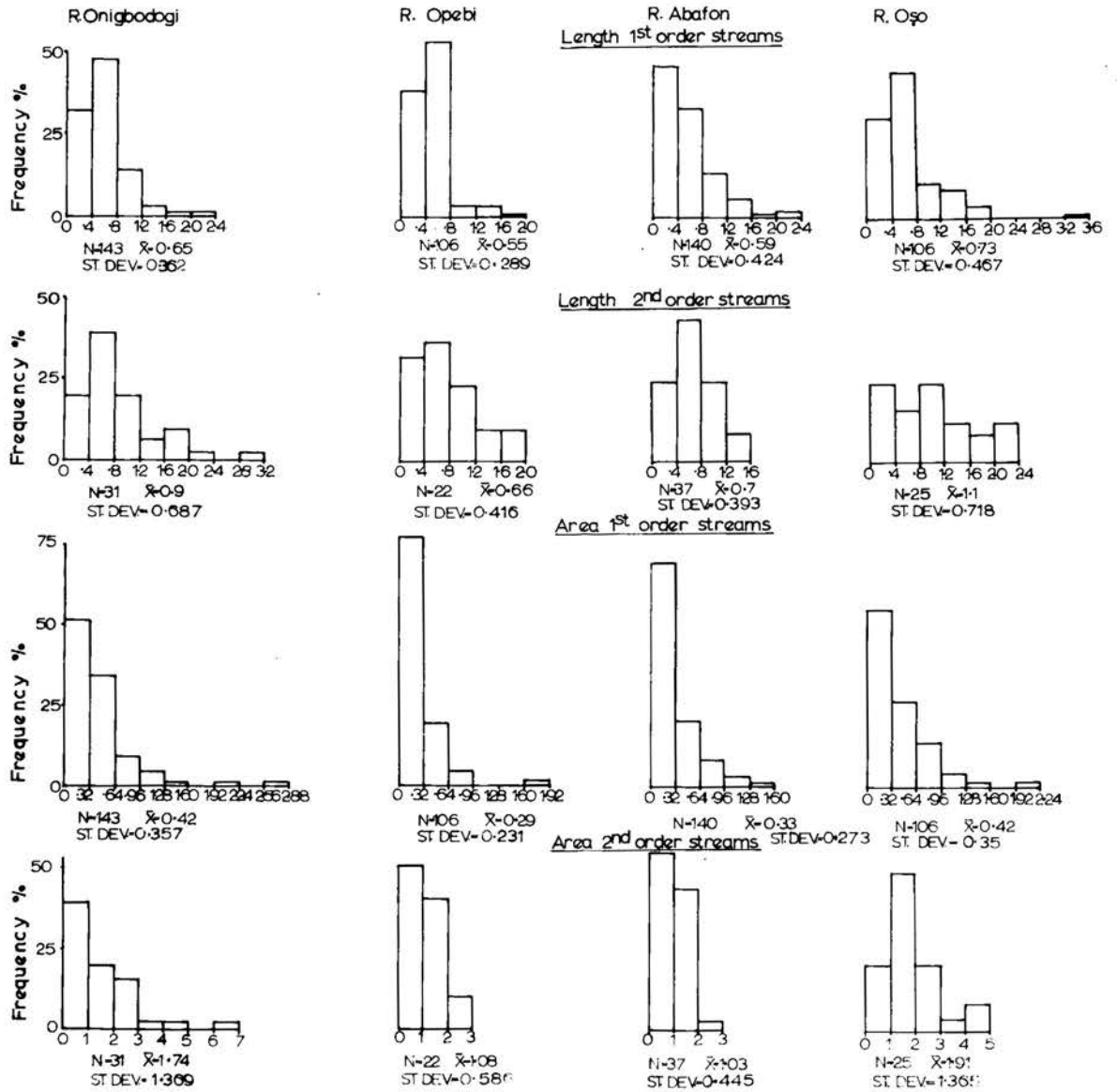


FIG. 29

is possible that streams would develop relatively faster on the weathered residue of schists than on migmatite. The morphometric properties of the streams are shown in Table 21.

Table 21 Morphometric properties of some 4th order streams in the
Partially Stripped Etchsurface

Stream	Rock Type	Stream Order	Ns	\bar{A} (sq. mls.)	\bar{L} (mls.)	Ns1	$\bar{L}1$ (mls.)	$\bar{A}1$ (sq. mls.)	B.R.	Dd	Dd1	CCM (sq. mls.)	Sf	L of (mls.)
Ouigbodogi	Migmatite	4	183	94.82	160.04	143	0.65	0.42	5.6	1.69	1.54	0.59	1.93	0.296
Oy	Migmatite	4	138	73.03	132.92	106	0.73	0.42	4.8	1.82	1.73	0.55	1.89	0.275
Opebi	Schist	4	133	43.11	93.88	106	0.55	0.29	4.8	2.12	1.91	0.45	93.01	50.243
Abafoa	Schist	4	185	73.87	141.38	140	0.59	0.33	5.4	1.91	1.81	0.52	32.49	0.255

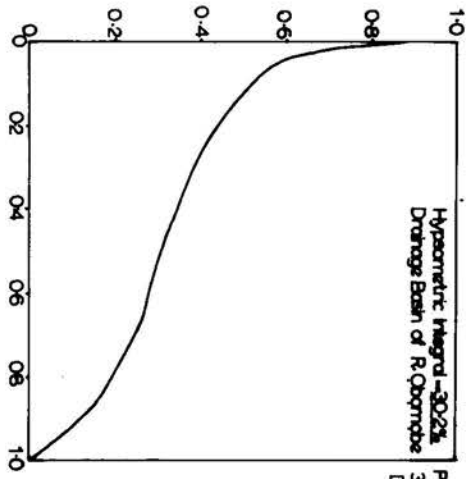
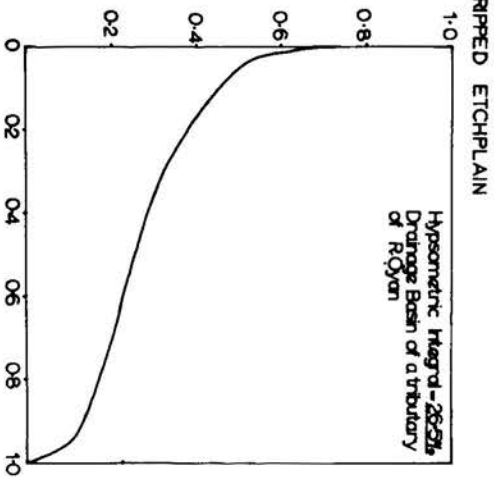
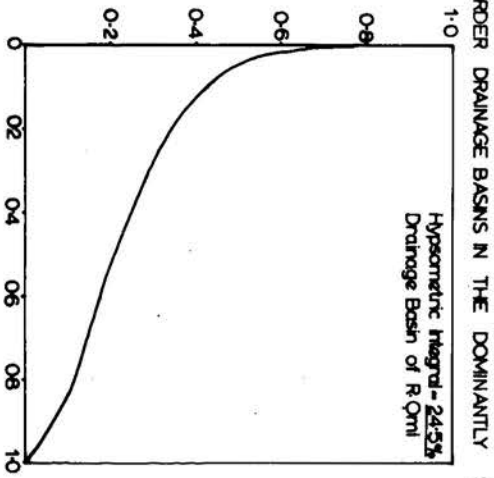
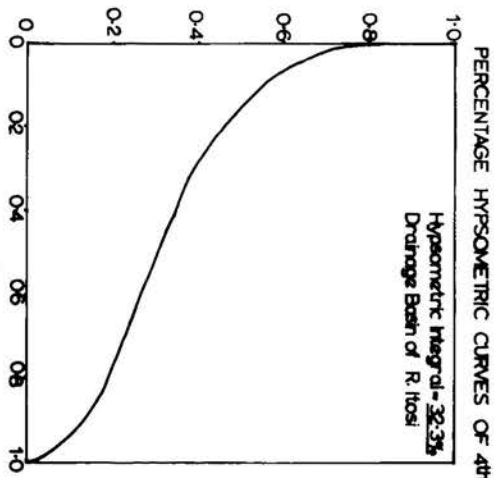
Dominantly Stripped Etchplain This landform is found mainly around Oyo, and Ado-Awaiye-Ijio-Iseyin area (Fig. 22). The two areas are separated by the etchsurface around Iseyin.

The landform is developed mainly on migmatite and to some extent on schist. The local relief is low around Oyo being 50-100 feet, and moderate between Ado Awaiye and Ijio area at 50-150 feet, hence its designation as an etchplain. Over most of the landform, weathering depth is shallow. The percentage of rock outcrops within the landform varies from area to area, but generally a large part of the basal surface of weathering is exposed on the landform. In the Ado-Awaiye-Ijio-Iseyin area, the rock outcrops are larger and much more frequent (Fig. 22) and cover 6.55% of the area, compared with 2.6% around Oyo. Rock outcrops occupy a larger percentage of the landform than revealed by the above figures because several low rock outcrops, not easily identified from airphotos, occur over a large area.

Important landform units include the gently convex interfluves on which

detrital laterites frequently occur. On the amphibolite schist near Igangan, vesicular laterites are occasionally seen on the interfluves. Inselbergs are common, and are high, usually 100-400 feet above the local landsurface, although they may be up to 700 ft. to 1057 ft. above the local surface as at Ado Rock and Ilele Hills. Low rock pavements are common especially on interfluves. Corestones and tors are rarely seen in the migmatite area, but are common on the syenite near Oke-Iho. Footslopes around inselbergs are gently sloping, $\frac{1}{2}^{\circ}$ - 7° , but are often intruded by low rock outcrops. The footslopes are long where the inselbergs are located on interfluves, but short where inselbergs are located on valley slopes. The valley sides are gently inclined, with maximum valley slope less than 5° , and are often covered by laterite concretions. They show no evidence of multicyclic incision.

Few 4th order streams occur within this landform. The hypsometric integrals of the drainage basins vary from 24.5% - 32.3% (Fig. 30) showing the monadnock stage of landform development discussed by Strahler (1952). The hypsometric integrals reveal that landform dissection has reached the old age stage when monadrocks (inselbergs) become frequent within the drainage basins. The landform is well drained with drainage density approximately 1.9 in all the drainage basins. Stream frequency varies between 2-3 per sq. mile. The mean length of the 1st order streams is about 0.55 mile (Fig. 31) while the length of the overland flow is about 0.28 mile. All these indicate that the landform is well dissected and eroded. Some properties of the drainage basins are shown in Table 22.



PERCENTAGE HYPSONETRIC CURVE OF A 3rd ORDER DRAINAGE BASIN IN THE DOMINANTLY STRIPPED ETCH SURFACE

FIG. 30

DOMINANTLY STRIPPED ETCHPLAIN.
 FREQUENCY DISTRIBUTION OF STREAM LENGTH (IN MLS)
 AND STREAM AREA (SQ MLS).

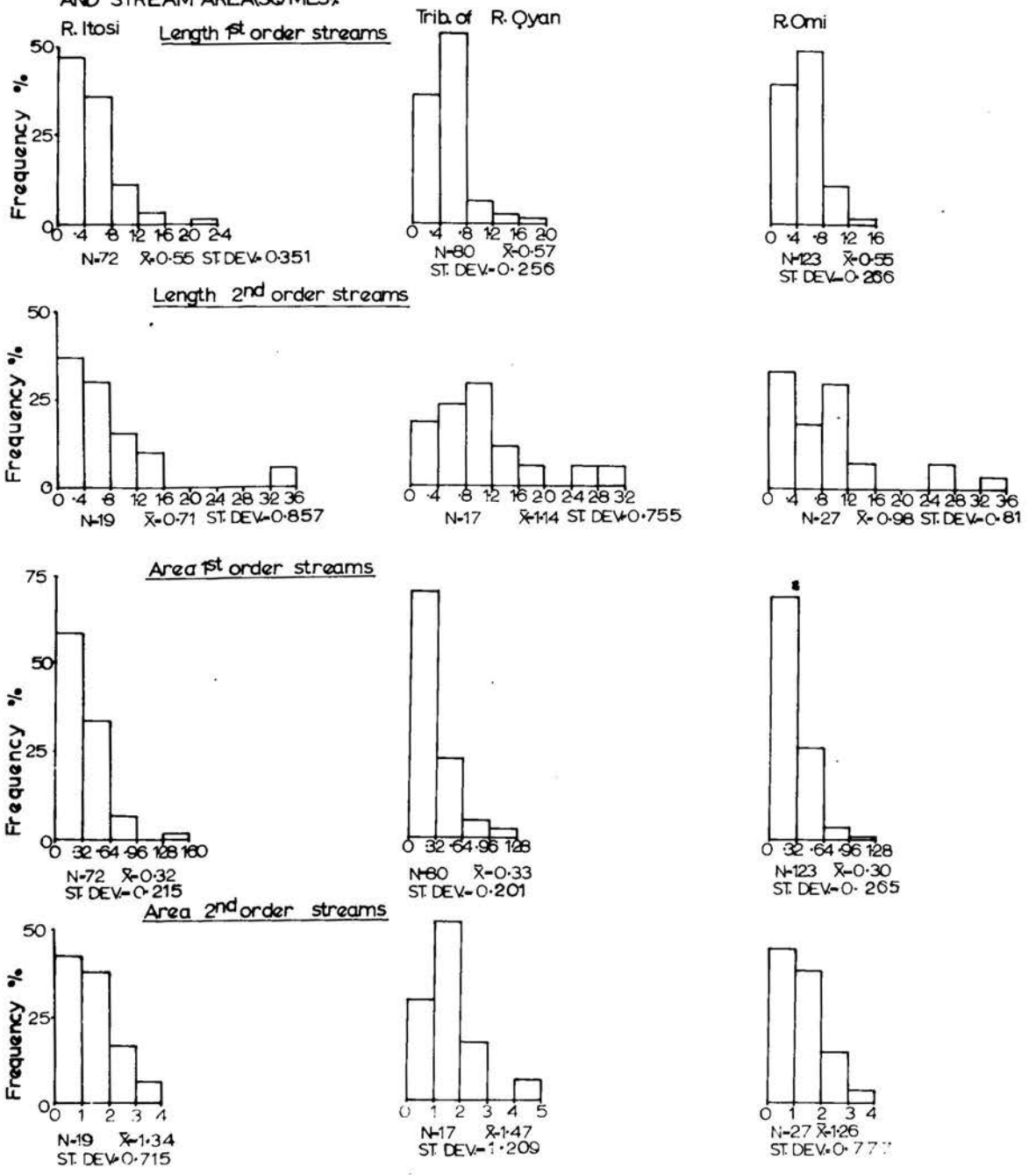


FIG. 31

Table 22 Morphometric properties of some 4th order rivers on theDominantly Stripped Etchplain

Rivers	Rock Type	Stream Order	Ns	\bar{A} (sq. mls.)	\bar{L} (mls.)	Ns1	$\bar{L}1$ (mls.)	$\bar{A}1$ (sq. mls.)	B.R.	Dd	Dd1	CCM (sq. mls.)	Sf	L. of (mls.)
Itosi	Migmatite	4	98	35.93	68.48	72	0.55	0.32	4.3	1.91	1.73	0.525	2.73	0.263
Oyan- trib.	Schist	4	101	42.86	80.02	80	0.57	0.33	4.4	1.87	1.73	0.536	2.36	0.268
Omi	Schist	4	157	64.26	122.8	123	0.55	0.30	5.1	1.91	1.87	0.523	2.44	0.262

Dominantly Stripped Etchsurface This landform is developed on quartzite and schists around Iseyin and north of Iwo, and on granite in Abeokuta, Eruwa-Lalate, and Idere-Tapa areas. It is a landform that particularly demonstrates the effects of differential weathering and erosion. In Iseyin area, the schists have been deeply weathered and are occupied by broad valleys while quartzite bands stand out as N-S trending ridges. North of Iwo, the quartzites form elongated high ridges and high hills. In the granitic areas, the landform is characterised by large whalebacks and inselbergs.

Local relief on the landform is high being about 150-350 ft. in Iseyin area, over 700 ft. north of Iwo, and 300-500 ft. in Idere-Tapa area. No evidence of erosional surface remnants have been seen, but small local surfaces are preserved on granitic area at Eruwa-Lalate area. Weathering depth is shallow and the profiles are often truncated. In Abeokuta and Idere-Tapa area, the top soil is thin and sandy, and below the soil is a zone composed of whitish grey material in which hydrated feldspar and quartz fragments predominate. In several cases, the structure of the underlying granite is still well preserved in the weathered material above the parent rock. In Iseyin area, the quartzite bands often outcrop over a wide area as the weathered material above them is thin.

Major landform units include the large monolithic domes which vary from 200-600 ft. above the local surface in Idere-Tapa area, but are lower in Eruwa-Lalate, and Abeokuta area. The domes are frequently covered by rock blocks. Tors, corestones and rock pavements are frequent and in places, form a continuous rock surface. In Idere Tapa area, rock outcrops cover 30% of the whole landform, in Abeokuta, they occupy 20% of the landsurface, and in Eruwa-Lalate area comprise 12% of the landsurface. Valley slopes consist mainly of footslopes of the inselbergs and their maximum inclination is 4° - 5° . The valleys are broadly "V" shaped in cross profile except where modified by recent incision. In Iseyin and north of Iwo, the quartzitic ridges occupy 22% and 26% of the landforms respectively. In all the areas, no lateritic outcrop is seen, but hardpans are frequently seen in Abeokuta.

No 4th order stream is seen here because the landforms are relatively small, consequently a third order stream was analysed. The hypsometric integral of the Obomobe basin is 30.2% (Fig. 30) which shows a late maturity to old age dissection of the landform and particularly indicates the presence of erosional residuals. The landform is well drained with drainage density of 2.71. Stream frequency is high, 2 stream segments per sq. mile. The length of overlandflow is less than 1000 ft. The high drainage density, stream frequency, and the low figure of the length of overlandflow are due to the fact that the landform contains several contiguous bare inselbergs which allow rapid surface runoff. The 1st order streams hardly exceed 0.7 mile (Fig. 32) The morphometric properties of the river is shown in table 23.

DOMINANTLY STRIPPED ETCH SURFACE.
 FREQUENCY DISTRIBUTION OF STREAM LENGTHS
 (IN MLS.) AND STREAM AREAS (IN SQ. MLS.).

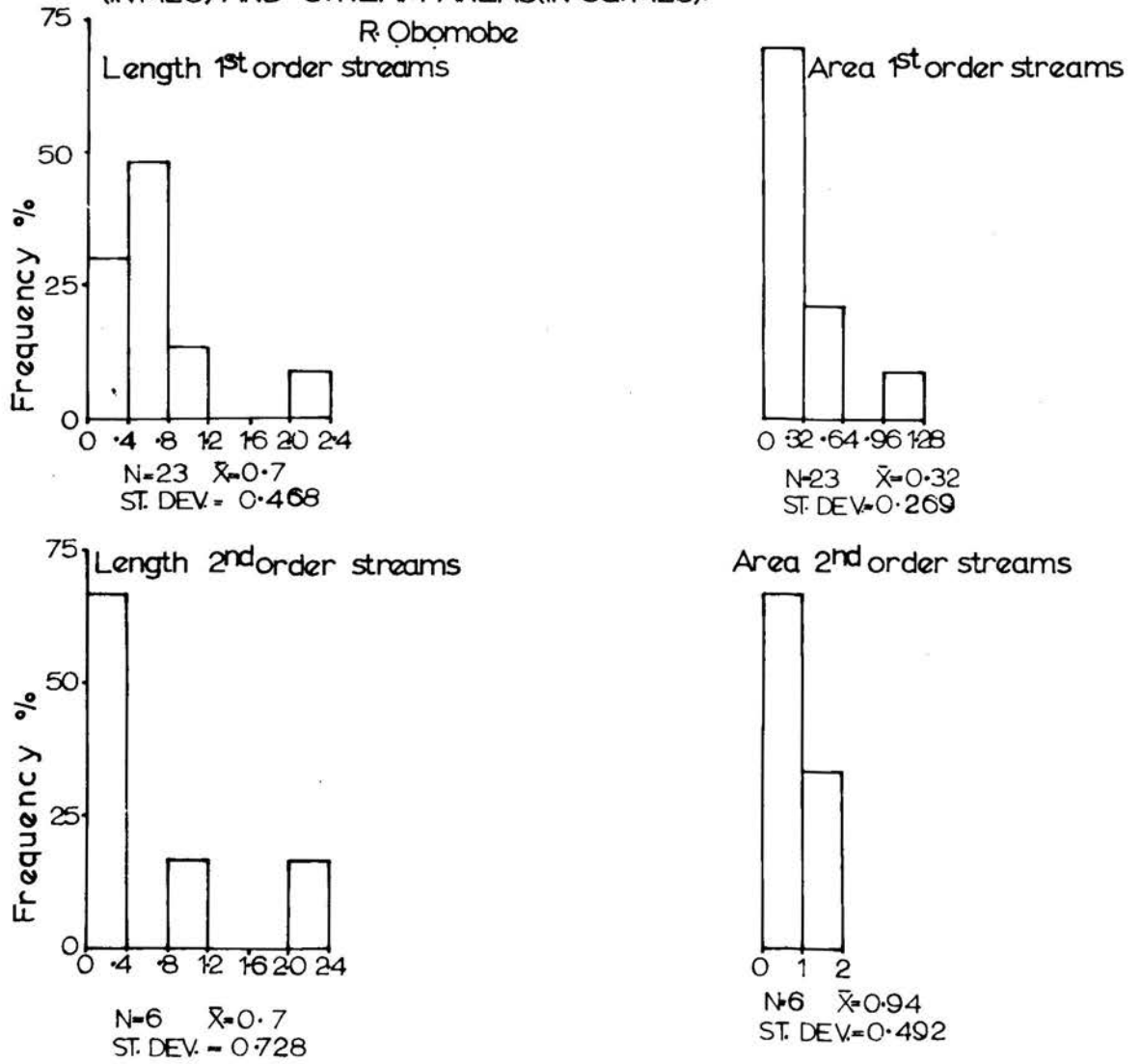


FIG. 32

Table 23 Morphometric Properties of R. Obomobe

River	Rock Type	Stream Order	Ns	$\bar{x}A$ (sq. mls.)	$\bar{x}L$ (mls.)	Ns1	$\bar{x}L1$ (mls.)	$\bar{x}A1$ (sq. mls.)	B.R.	Dd	Dd1	CCM (sq. mls.)	Sf (sq. mls.)	L.of (mls.)
Obomobe	Coarse Porphyritic Granite	3	30	10.48	28.4	23	0.7	0.32	5.9	2.71	2.15	0.377	2.15	0.189

Discussion on the Morphometric properties of the Drainage Basins of the different landforms

A summary of the means of some drainage properties (Table 24) indicates the differences in the intensity of erosional activities within the drainage basins of the different landforms.

Table 24 Means of the Means of some properties of Drainage basins within the different landforms

Lanforms	(mls) xL1	(sq. mls.) xA1	(mls.) Dd	(mls.) CCM	(mls.) Sf	(mls.) L.of	Hyps- Integral
Sedimentary Area							
Partially Dissected Lateritised Plain	0.81	0.76	1.1	0.9	0.994	0.449	48.6%
Dissected and Partially Stripped Etchsurface	0.83	0.82	1.05	0.97	0.93	0.489	40.35%
Zone of dissection and Partial Stripping	0.91	0.72	1.5	0.7	1.7	0.308	42.9%
Crystalline basement Area							
Partially Stripped Etchsurface	0.605	0.365	1.9	0.5312	2.08	0.267	40.25%
Dominantly Stripped Etchplain	0.56	0.32	1.9	0.5282	2.51	0.264	27.9%
Dominantly Stripped Etchsurface	0.7	0.32	2.71	0.3772	2.15	0.189	30.2%

The most important point is that the properties of streams developed on the sedimentary areas are different from those developed on the crystalline basement, although the hypsometric integral of the partially stripped

etchsurfaces in both areas are identical. This can only be explained by the differences in the structure and lithology of the sedimentary and crystalline rocks.

However, the most significant point about these landforms is that they are produced by deep weathering and erosional stripping irrespective of their underlying geology. For instance a deeply weathered lateritized surface is present on the crystalline basement on the primary watershed north of Shaki, and is also present on the Cretaceous Sandstone as discussed in this chapter. On both the sedimentary and the crystalline rocks, the deeply weathered, lateritized landforms, have low drainage density, low stream frequency, and the 1st order streams are long. This is so because in both areas, whatever may be the nature of the regolith, the surface laterite precludes the development of surface drainage. Once dissection increases in both areas and the surface laterite is removed, the differences in the rock character will become apparent on the drainage development. Thus more streams will be developed on the basement rocks than on the sedimentary rocks. As erosion continues, and more basal surface of weathering is exhumed, drainage density and stream frequency will increase at varying proportions on the different rocks.

It can thus be concluded that the evolution of the weathered and eroded landforms of South Western Nigeria dependson the nature of the rocks, the amount of weathering on the rocks, the pattern of drainage development, and the base level changes that initiated differential erosion within the drainage basins developed on the different landforms. Of some importance are the effects of the different vegetation covers and the past climatic changes in affecting the evolution of the different landforms.

CHAPTER 7

EROSION SURFACES

In chapter 6, it was mentioned that there are no widespread erosion surfaces in South Western Nigeria. This will be examined further in this chapter. An erosion surface has been defined by Rich (1938) as a surface of very low relief, often featureless, produced by sub aerial erosion. Geyl (1961) describes it as an area of relatively flat land formed by the process of normal erosion during a period of baselevel stability, the surface which stands above present baselevel, is in a process of destruction by retrospective erosion. The concept of erosion surfaces in the literature suggests that such surfaces are usually flat land, but it appears that such flat surfaces cannot be found anywhere. There are also arguments about the processes involved, the manner in which these surfaces were formed, and how these surfaces can be determined on the field and on maps. Basically, erosion surfaces are said to be produced by peneplanation (Davis 1902) or by pediplanation (King 1953). The present chapter aims at reviewing some current literature on erosion surfaces in Western Nigeria, and in Nigeria as a whole, examining the methods used to determine these surfaces, and then discussing the surfaces identifiable in South Western Nigeria using field evidence and morphometric analysis.

Pugh (1955) used superimposed profiles, derived from the 1:125,000 map series of Nigeria, to demonstrate the presence of four erosion surfaces in parts of Western Nigeria and advanced a theory that these surfaces were produced by pediplanation and scarp retreat operating from the coast into the interior following changes of base level. Later, in 1966, he modified his view by stating that scarp retreat could proceed from the valley lines and not directly from the coast. Pugh maintained that these surfaces are

are separated by cyclical scarps e.g. Oke-Iho scarp, or by belts of dissected land which he identified as stretching from north of Meko, eastwards to the Ibadan area. Pugh gives the impression that the four erosion surfaces which he recognised in parts of Western Nigeria occur in a stair-case pattern with the three upper surfaces occurring as bevels on inselbergs or as intermontane plateaux. He advanced the theory that inselberg bevelling may be produced by "a flattening of the external face in the case of smaller domes or in form of small 'intermontane plateaux' in the larger masses". His conclusion was that the older erosional surfaces in Western Nigeria have been destroyed as a result of repeated tilting towards the coast and the reduction of the land surface by scarp retreat northwards from the sea and southwards from the Benue trough.

This work deserves close examination because it is the only one purporting to recognise the overall pattern of erosion surfaces in Western Nigeria. The use of superimposed profiles for identification of these surfaces is open to question. The 1:125,000 map series of Nigeria are extremely inaccurate and sketchy with the contour lines imposed according to a few accurately determined spot heights. Superimposed profiles are useful in demonstrating the grain of a terrain, but are of marginal value in determining the existence of erosion surfaces. Several geomorphologists have objected to this method e.g. Rich (1938) who noted that "the projection of hill tops, ridges and sloping surfaces in both foreground and background on to one vertical plane, unduly emphasises the appearance of horizontality, hence it is as deceptive as a view from a hill top with its accompanying psychological errors". A similar warning was given by Craft (1933) when he wrote that "the characteristic feature of the scenery as an even skyline which gives an appearance of horizontality

is often deceptive as changing distance and perspective mask undulations or gradual slopes over a long distance".

The Oke-Iho scarp is taken by Fugh as a cyclical escarpment separating two different surfaces, such a cyclical escarpment, if the bevelling theory is to be believed, must not mark a petrological boundary. The Oke-Iho scarp, however, is a structural scarp formed by the differential weathering and erosion of the syenite forming the scarp and the local amphibolite and schists surrounding the syenite. On its western and southern sides, it forms a continuous rock surface marking a discontinuity between the syenite and amphibolite and schist. There is also a structural scarp at Eruwa which marks a petrological boundary between granite and schist.

The pediplanation and bevelling theories, involving either a retreat of cyclical scarps from the coast or along the valleys, take no cognizance of the importance of deep chemical weathering and differential erosion in Western Nigeria. In the humid tropics, if cyclical scarps are produced in a weathered regolith, they will be quickly destroyed unless a resistant caprock like laterite develops on the regolith to prevent the rounding off of the top of the scarp. If a cap rock does develop, erosion will undermine it, especially lateral stream erosion and spring sapping; the slope below the caprock will be steepened and will retreat parallel to itself. The scarp will thus be preserved till the lateritic cover is completely destroyed. Where no caprock develops, rilling and free flow of runoff coupled with soil creep will destroy the upper slope, the slope will lose its steepness and be replaced by a flatter slope. Thus the pediplanation theory can only be sustained where laterites develop extensively on a flat or gently sloping, deeply weathered initial surface. This was demonstrated by Ollier (1959) in Uganda.

The bevelling of inselbergs mentioned by Pugh does not appear to be of any cyclical significance. Such bevels can be formed where vertical joints in inselbergs open up, as a result of physical tension, leading to a collapse of the dome in a process whereby an inselberg is transformed into Castle Kopje (see Chapter 9). Ollier (1961) explained that a series of bevels on an inselberg can be produced by a succession of unloaded sheets, with each sheet leaving a basal step after its destruction. The 'intermontane plateaux' bevelling noted in Oke-Iho area by Pugh, can also be explained as a result of differential weathering and erosion along converging joint planes as observed by Thorpe (1967). Some inselbergs in Western Nigeria e.g. Ado Rock, exhibit bevels on their sides, but several others like Ilele (1057 ft.)*, Agidan (250 ft.) and Aseke (225 ft.) developed in granite, and migmatite do not show bevels on their convex surfaces which extend from the summit to the base (Plate 22). The concept of inselberg bevelling is therefore difficult to sustain on the basis of observations made in South Western Nigeria.

The most important factor that can lead to notching at the base of an inselberg is deep weathering and erosion, undercutting the feature. Deep chemical weathering occurs due to the large amount of surface runoff from the face of the inselbergs. When the weathered regolith is removed, an inselberg may have a deep recess at its base or its lower face may be steepened. This does not suggest that inselbergs' surfaces retreat parallel to themselves, and thus the observations by Pugh appear inapplicable to South Western Nigeria.

Moss (1961) used lateritic outcrops on crest bevels and on valley benches, and slope breaks on valley cross profiles to recognise four local erosion surfaces on parts of the Northern Upland, Southwest of Abeokuta. The surfaces stand at 210-250 ft., 340-360ft., 430-470ft. and 510-525ft.

* Their heights are given above their local surfaces.

On the Southern Upland, he recognised five local surfaces at 120-155 ft., 225-275 ft., 330-350 ft., 395-415 ft., and 450-475 ft. The altitudinal intervals between these surfaces vary from 35 ft. to 70 ft. The recognition of surfaces at such close intervals must require accurate levelling.

De Swardt (1953) recognised three surfaces in ^{the} Ilesha area: the Older, the Intermediate and the Younger surfaces. He did not mention the altitude at which these surfaces occur, but he disclosed that the interval between them is about 100 ft. The older surface is capped by primary laterite while the intermediate surface is covered by detrital laterite derived from above, and the younger surface is found along the streams. These surfaces are separated by scarps, and De Swardt ascribed their formation to base level changes following changes of climate in the past.

Wigwe (1966) used evidences from knickpoints along valley long profiles, and breaks of slopes on valley crossprofiles together with morphometric analysis to identify six surfaces in parts of Western and Northern Nigeria. The surfaces occurred at 500-550 ft., 950-1000 ft., 1000-1050ft., 1150-1200 ft., and 1300-1400 ft. He ascribed these to baselevel changes and climatic changes.

Clayton (1958) recognised five surfaces in Kabba Province: the Post Gondwana surface which he identified from six peaks at about 2000 ft., the African surface of Pre Miocene age at 1200-1400 ft., the Niger surface at 750-900 ft., and 800-1200 ft., and the lowest surfaces at 400 ft. and 250 ft. He mentioned that the African and Niger surfaces were developed across wide concave pediments covered by thick layers of ironstone. The surfaces are separated either by scarps or by dissected zones. Clayton did not explain how these surfaces were formed, but from their descriptions it would appear that these surfaces are pediplains.

For Nigeria as a whole, several erosion surfaces have been recognised. King and Pugh (1952) recognised the Gondwana surface preserved on the Younger Granites on Jos Plateaux at 4000-5800 ft; the Post Gondwana surface preserved on the Fluvio-Volcanic series in Jos district at 3600 ft. to 4700 ft; the African surface at 2200-2500 ft., and the Post African surface at about 1600 ft. King (1962) further recognised four degradational surfaces and two aggradational surfaces in Nigeria; the Gondwana and Post Gondwana of Jurassic-Cretaceous age on the Jos Plateau; the African surface of early Tertiary on the Hausa Plains and the primary watershed of Western and Eastern Nigeria; the Post African surface of late Tertiary identified on the basement complex of Western and Northern Nigeria, and the Congo surface of the Quaternary age found along the major rivers of Nigeria. King identified a Post African aggradational surface on the Cretaceous and Eocene sandstones, and a recent aggradational surface along the coast.

The various surfaces identified by these authors cannot be correlated from one part of the country to another because they were recognised at different localities and on different rock types. These surfaces are summarised in table 25.

Table 25

Erosion Surfaces in Nigeria

Moss R.P. (1961)		Wigwe G. (1966)	Clayton C.D. (1958)	King L.C. & Pugh J.C. (1952)
Northern Upland	Southern Upland	Part of Western & Northern Nigeria	Kabba Province	Nigeria
Altitudes (ft)	Altitudes (ft)	Altitudes (ft)	Altitudes(ft) Age	Altitudes (ft) Age
510-525	450-475	1300-1400	Over 2000	Post Gondwana 4000-58000 Gondwan Jurassic
430-470	395-415	1150-1200	1200-1400	African- Pre Mio- cene 3600-4700 Post Gondwana Cretaceous
340-360	330-350	1000-1050	800-1200	Niger 2200-2500 African- Early Tertiary
210-250	225-275	950-1000	750- 900	1600 Post African- Late Tertiary
	120-155	750- 850	400	
		500- 550	250	

From the abundant literature on erosion surfaces it appears that the recognition of surfaces depend, more or less, on the following points:-

- i. association of particular types of laterites with specific surfaces - De Swardt (1946, 1953).
- ii. association of stone lines with erosion surfaces - Ruhe (1956).
- iii. separation of surfaces by cyclical scarps or by zones of dissection; such scarps often show the typical waxing slope, the free face, the constant slope and the waning slope - Pugh (1955), King (1953) and Pallister (1952).
- iv. surfaces are limited to the divides of the major rivers and are separated by slopes varying from 45° - 60° - Ruhe (1956).
- v. old surfaces are found as remnants on hills and ridges, so that accordance of summits on different rock types show that such summits are remnants of a surface - Pugh (1966).
- vi. the above are supplemented by analysis of the longitudinal and cross profiles of valleys, with breaks of slopes unrelated to lithological and structural control used as diagnostic of cyclic and epeirogenetic events. Morphometric analysis from maps is also carried out to demonstrate the presence and nature of erosion surfaces.

The above criteria for recognising erosion surfaces have various limitations. It is quite possible that erosion surfaces may be preserved where ferruginous material (laterite) has developed on deeply weathered rocks - Crosbie (1956). Steep scarp slope can develop below such caprocks as mentioned earlier in this chapter. The steep slope will retreat parallel to itself while the caprock exists, and a newer surface will develop below. Such surfaces are not necessarily flat, and they almost invariably slope

in the direction of the drainage lines. This relationship between lateritic occurrence and sloping surfaces is observable in South Western Nigeria on the Cretaceous and Eocene Sandstone. The fact that surfaces always slope towards drainage lines means that accordance of summits does not appear to be of much use in recognising erosional surfaces. Hill tops, ridges, spurs and shoulders are subjected to differential weathering and erosion within an erosion cycle, and they are bound to suffer differential loss of altitudes not easily calculated. The amount of differential lowering will depend on the nature of the rock concerned and its resistance to weathering.

Stone lines can occur in relationship to erosion surfaces. This happens where the ferruginous material covering an upper erosion surface is broken up and its fragments deposited on the newer surface below. The fragments are later covered by colluvial material from the upper surface and are buried within the soil profile on the lower surface. But there are other factors responsible for the formation of stone lines. Stone lines are frequently found where quartz veins that are not weathered persist in the soil profiles especially in areas of gneiss and schists. The veins are broken up and move downslope under the migratory soil layer on the slope. Thus stone lines by themselves are not always diagnostic of erosion surfaces.

What perhaps makes the recognition of erosion surfaces difficult in South Western Nigeria is the nature of the landsurface coupled with the effects of differential weathering and erosional stripping. South Western Nigeria is composed of several rock types, and the whole area is tilted towards the sea. As noted in Chapter 2, the crystalline rocks of South Western Nigeria was arched up in the Pliocene period along the present

primary watershed north of Shaki between streams flowing to the sea and streams flowing to River Niger, so that inherently the land surface slopes from north to south. The effect of deep weathering and erosion on the different rock types of the inclined surface is the production of a complex assemblage of landforms referred to as etchsurfaces and etchplains in the preceding chapter. Hence there can be no question of any flat erosion surfaces existing in South Western Nigeria. Recognition of erosion surfaces is best done from area to area by intensive field work and the results synthesised to give a regional pattern. In this study, local recognition of surfaces is based on field evidence supplemented by morphometric analysis from maps.

Field Evidence

South Western Nigeria covers approximately 9,000 sq. Miles and it was impossible within the available time to cover it all by traverses. Evidence was collected from areas of detailed field work shown in Fig. 2. This was concentrated on the Northern Upland, the Southern Upland and some localities on the crystalline basement. On the sedimentary rocks, investigations were based on an area of about 100 sq. miles around Meko, some 150 sq. miles around Aiyetoro, and another 80 sq. miles around Ilaro. In Meko and Aiyetoro district, 50 traverses were recorded from the river lines to interfluves especially along the rivers Irori, Igboori, Oyo, Afon and Yewa. Several traverses were recorded across the Cretaceous escarpment to the north. In Ilaro district 10 traverses were recorded across the Eocene escarpment and 10 from river lines to the interfluves.

Along the traverses, important breaks of slope on the valley cross profiles were noted, and the causes studied especially where they are associated with ferruginised material. The altitudes at which these breaks occur were measured with altimeters. The data were then plotted and

correlated from one area to the other to determine the presence or absence of erosion surfaces.

On the crystalline basement area, four areas totalling, about 500 sq. miles were investigated in Oyo-Fasola, Ibadan, Igboora, and Eruwa-Lalate districts. Similar methods were used. Valley benches on the crystalline basement prove to be so narrow that they are virtually useless in determining cyclical changes along the streams. The majority of the valley slopes are either convex-concave or straight. Detrital laterites are commonly found on these sloping valley sides, but vesicular laterites are infrequent on the interfluves. The implication is that vesicular laterites are usually associated with an older surface whether such a surface is flat or sloping; detrital laterites are associated with lower surfaces. This relationship holds good on the sedimentary rocks, but on the crystalline rocks, no such association was seen.

Analysis of the data on breaks of slopes on valley crossprofiles and the associated ferruginised material suggests the presence of two local erosion surfaces on the Cretaceous Sandstone (Fig. 33). The upper surface occurs on the divides of the streams flowing on the dip slope of the Cretaceous Sandstone and the obsequent streams flowing on the scarp slope of the sandstone. The surface slopes from about 800 ft. near the scarp north of Meko to 500 ft. south of Meko at a gradient of 15 ft. per mile. It also slopes in a NNW - SSE direction towards the Ogun river. North of Aiyetoro this surface occurs at between 400-600 ft. sloping N-S. The surface is terminated to the north by the scarp of the Cretaceous Sandstone, and to the south by the steep valley of the Yewa and a narrow zone of dissection between the Yewa river and Aiyetoro. The same surface occurs east of the Ogun river south of Abeokuta to Ijebu Ode area at an altitude of 300-550 ft. Here it

EROSION SURFACE REMNANTS ON THE SEDIMENTARY ROCK

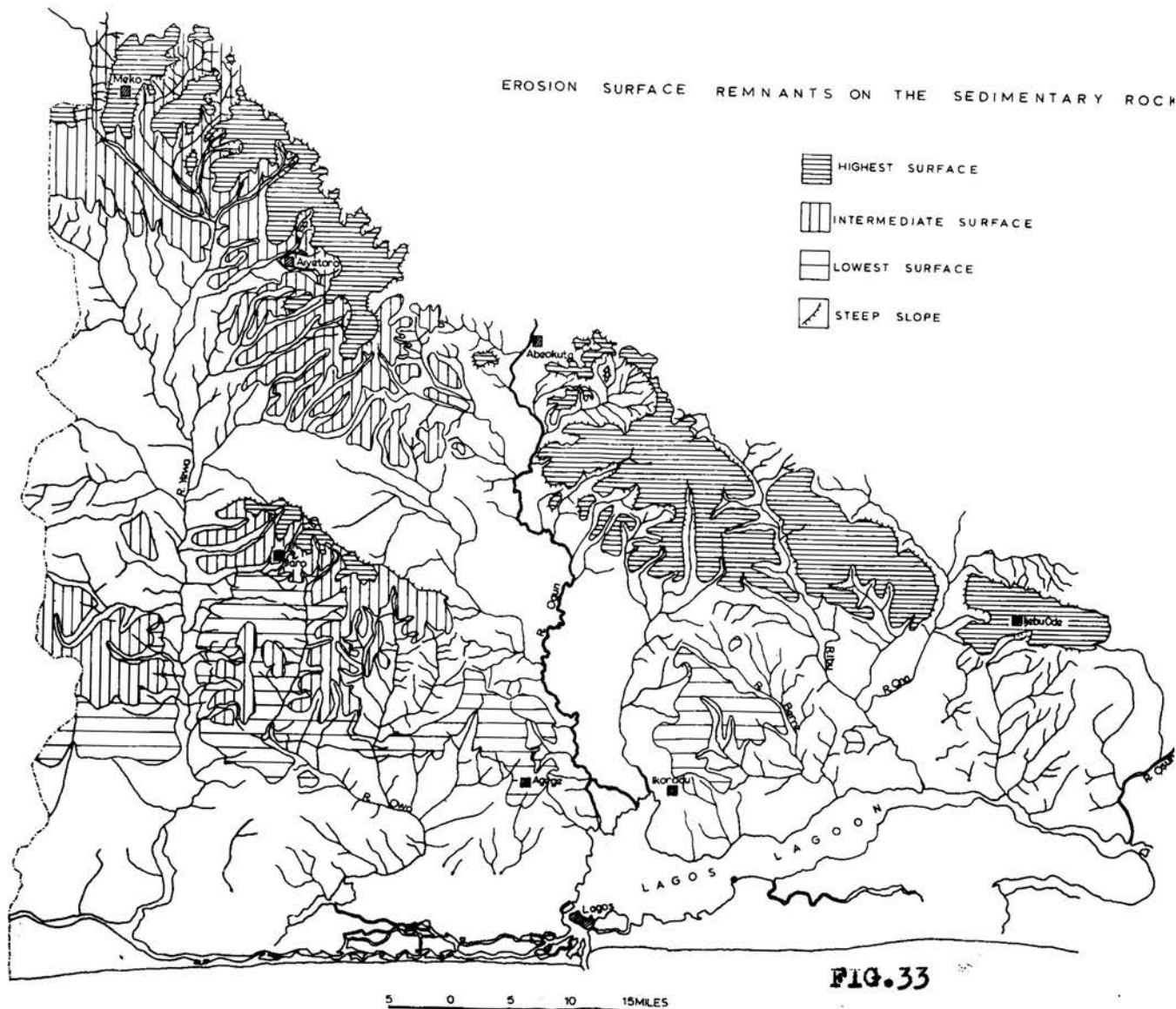
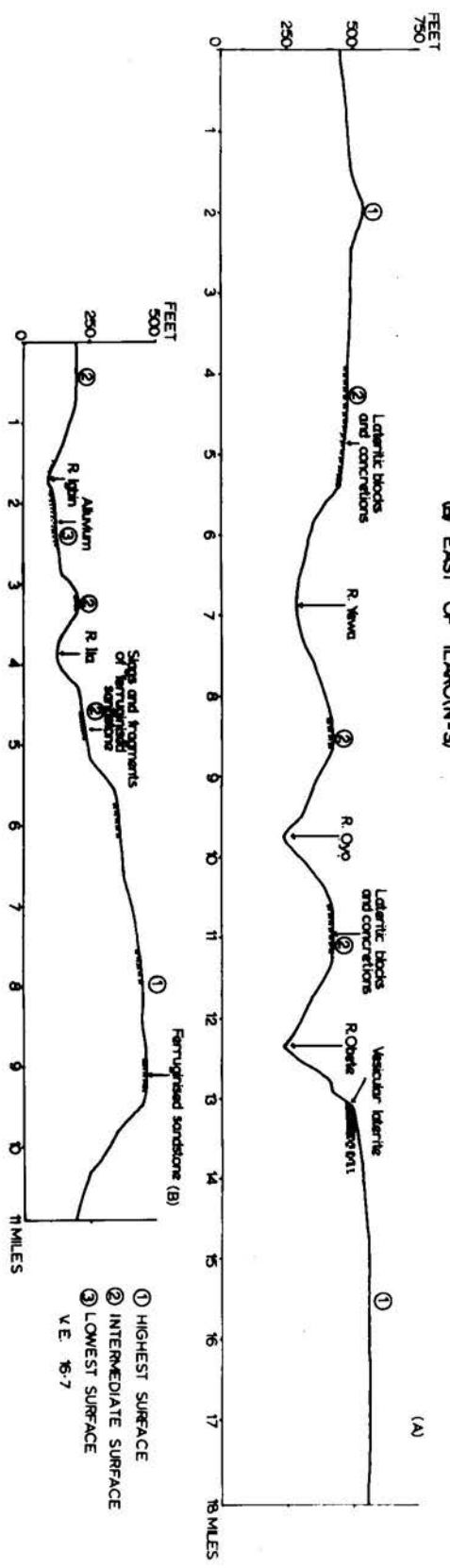


FIG. 33



RELATIONSHIP BETWEEN THE EROSION SURFACES
 (A) SOUTH OF MÈKOUÉ-W)
 (B) EAST OF ILARON-S)

FIG. 34

slopes mainly in a N-S direction and is terminated by the depression formed by the convergence of the valleys of Ibu, Ona, and Ewekoro depression.

Below the upper surface, a lower surface has developed as a small plain south of Meko, but mainly as wide valley benches and narrow interfluves between the Ogun and Yewa rivers. The valley benches in the areas traversed are 500-1500 ft. wide, sloping at 2° - 6° towards the rivers. The altitude at which this surface occurs ^{varies} vary from one area to the other, in Meko area, it occurs at 475-650 ft., south of Meko it is 300-500 ft., but near Aiyetoro it is at 275-380 ft. The lower surface is separated from the upper surface by steep valley slopes.

On the Eocene Sandstone around Ilaro, (Fig. 33), three local erosion surfaces were recognised. The uppermost surface occurs at 400-475 ft. north, and northeast of Ilaro at the head of streams flowing southwards on dip slope of the Eocene Sandstone. The surface is terminated to the north by the Eocene scarp, and to the south by a narrow zone of dissection. The two lower surfaces occur as valley benches near Ilaro, but southwards, the intermediate surface occurs on broad interfluves at 250-385 ft. The lower surface is found between 125-260 ft. Table 26 gives a summary of these surfaces and their associated ferruginised materials.

Table 26 Local Erosion Surfaces on the Cretaceous and Eocene Sandstones.

Area	Upper Surface	Associated Ferruginised Material	Intermediate Surface	Associated ferruginised Material	Lowest Surface	Associated Ferruginised Material
Northern Upland	500'-800 ft. 400'-600 ft. 300'-550 ft.	Hard Vesicular laterite outcrops widely over the surface	475-650 ft. 300-500 ft. 275-380 ft.	Covered by detrital laterite and laterite blocks	-	-
Southern Upland	400-475 ft.	covered by ferruginised sandstone which outcrops as wide pavements over the surface	250-385 ft.	Covered by small blocks and pebbles of ferruginised material which are uncemented dark, hard slugs are also common on the surface	125-260 ft.	Occasionally some fragments of ferruginised material are seen on this surface

The various surfaces have been correlated over a large area because of the particular material associated with each one. It should be noted, however, that the vesicular laterite associated with the upper surface does not outcrop as wide pavements between the Ogun and Ijebu Ode area, but occurs mainly on the upper parts of valley slopes.

The relationship observed between local erosion surfaces and occurrences of laterites in the sedimentary area does not apply on the crystalline basement vesicular laterites are absent on the interfluves. Breaks of slope on valley cross profiles, often associated with the presence of lateritic concretions occur at 510-560 ft. in Ibadan, area, 650-800 ft. between Oyo and Iseyin, and at 475-550 ft. in Eruwa-Lalate Eruwa. The data obtained are too few and not comparable from one area to the other for use in determining cyclical events on the basement complex. Nonetheless, small surfaces associated with particular rock types do occur on the basement complex. Both in Eruwa and Lalate area, small local surfaces are developed on weathered granite. These surfaces are covered by detrital laterite and in some places strewn with corestones. They occur at 650-750 ft. and are separated from the surrounding areas by irregularly dissected escarpments composed of partially weathered and unweathered granite.

Morphometric Analysis

Supplementary evidence was obtained mainly from maps. The methods employed were: (i) analysis of stream longitudinal profiles to determine the presence of knickpoints and examination of corresponding stream cross-profiles to see whether such knickpoints coincide with breaks of slopes on the valley sides; (ii) examination of the generalised contour map; (iii) altimetric analysis; and (iv) areal analysis.

Stream Long Profiles, Cross Profiles and Knickpoints

Knickpoints along stream courses can be produced in two ways. First, grading of stream slope may be arrested due to resistant rocks alternating with weaker rocks in a downstream direction. In this case the stream profile will be irregular and the breaks are regarded as structural knickpoints. Second, knickpoints are produced along stream long profiles where rejuvenation is progressing headward along such streams. The rejuvenation could be triggered off by a negative change of base level, by uplift of the land surface or by climatic changes. On a tilted landsurface, like that of South Western Nigeria, knickpoints of this type will progress rapidly upstream and may not be stable enough as base levels for the widespread development of erosion surfaces. These knickpoints can only be protected from degradation by the structural influence of hard rocks along the stream long profiles, and in such cases they are of no use in deciding cyclical changes.

Breaks of slopes on stream cross profiles as a result of rejuvenation are rapidly destroyed except where they are protected by the development of laterite on the terraces, as in the sedimentary areas. The valleys become convex-concave in cross profiles as seen on the partially stripped etch surface discussed in Chapter 6. In some cases where valleys are developed across resistant rocks, as at Olokemeji, the terraces may not be rapidly destroyed, and there is the typical "valley-in-valley" cross profile.

With the above limitations in mind, the long profiles of the Ogun (Fig. 35) and its main tributaries, the Ona-Ibu system and the Yewa rivers were analysed to determine the presence of knickpoints (Fig. 36). The profiles were compared with the underlying geology to determine whether the observed knickpoints were structural or cyclical. The summary of the observations is given below. Knickpoints considered to be structural are

marked with 'X', those that do not coincide with zones of hard rocks are marked with 'C'. The heights are given in feet.

Table 27 Knickpoints along the long profiles of the rivers analysed

River Ogun	River Ogbara	River Ose	River Opeki	River Oso	River Awon	River Oyan	River Ofiki	River Trib	River Ona	River Onigbodogi	River Omi	River Opebi	River Irori	River Oyo
200C	-	-	200C	-	-	-	-	-	250C	-	200X	200C	200C	-
300X	-	-	-	-	-	300X	-	-	400C	400C	-	-	-	-
500C	550C	550X	-	-	-	-	500C	500C	500X	-	550C	-	-	-
650C	-	700X	650C	650C	650C	-	-	-	700C	-	-	-	-	600C

The knickpoint at 200 ft. along the Omi is structural occurring where the river cuts through schist into quartzite. Similarly the 300 ft. knickpoints on the Ogun and Oyan are structural occurring where the Ogun cuts through schist into quartzite at Olokeseji, and where the Oyan cuts through granite gneiss into augen-gneiss. The 550 ft. knickpoint along the Ona and Ose are also structural, the former where the river is dammed near Ibadan and the latter where it cuts through a quartzitic ridge. The 700 ft. knickpoint along the Ose occurs where the river cuts through schist into quartzite northwest of Ijaiye. The remaining knickpoints appear to be cyclically formed.

Examination of the valley cross profiles where these knickpoints occur suggests that in some cases no significant break of slope occurs in association with them. Significant breaks of slope occur where "valley-in-valley" profiles of rejuvenation have formed. This is noticed at the 200 ft. knickpoint along the Ogun river near Iyano-Eruwa, along the Opeki and the Opebi, and in each case, the "valley-in-valley" profiles are developed for about 3-4 miles. There is also a break of slope associated with the 250 ft. knickpoint along the Irori near Aiyetoro, and along the Ona, with composite cross valley profiles developed for three miles in each case. There is no

significant break of slope related to the 300 ft. knickpoints along the Ogun and Oyan rivers. The 400 ft. knickpoint is associated with significant breaks of slope and well developed "valley-in-valley" cross profiles along the Ona for over 6 miles, but this is poorly developed along the Onigbodogi river. There is a break of slope associated with the 500 ft. knickpoint along the Ogun river for about 5 miles. The 550 ft. knickpoints and their associated breaks of slope along the Omi, and the Ogbara are confirmed on the field. The 650 ft. knickpoint with its associated "valley-in-valley" profile was seen along the Ogun, the Awon and the Itosi rivers in Oyo - Fasola district.

These knickpoints show that base level changes occurred at infrequent intervals in South Western Nigeria and each change was insufficiently stable to permit the development of widespread erosion levels on the basement complex rocks. Nevertheless the knickpoints and their accompanying "valley-in-valley" profiles suggest that sloping surfaces may occur locally at 200-250 ft., 300-400 ft., 500-550 ft. and 650-700 ft., on the sedimentary and crystalline rocks. These to some extent coincide with the sloping surfaces found on the upper Cretaceous and Eocene Sandstones.

Generalised Contour Map

This was used in an attempt to reconstruct the whole landscape before dissection took place. The method has been employed by King (1966) to show erosion surfaces in the Howgill Fells area of the Lake District in England. It eliminates all the minor dissection of the landscape and thus reveals both the horizontal and the sloping surfaces. The main advantage is that it gives a picture of the significant stages in the development of the landscape, but it does not offer conclusive proof. The most prominent limitation is the subjectivity required to eliminate the minor valleys.

All the same it has value in indicating the nature of surfaces present in a tilted area such as South Western Nigeria (Fig. 7). It appears that large areas of sloping landsurfaces occur at 100-300 ft. on the Southern upland on the dip slope of the Eocene escarpment. Such sloping surfaces also occur on the dip slope of the Upper Cretaceous escarpment at 200-400 ft. and 500-800 ft. On the crystalline basement, there appears to be a sloping surface occurring at 500-900 ft. These observations confirm the findings derived by other methods and may be true of the basement complex where Morgan (1960) claimed to observe only one sloping surface at 300-950 ft.

Morphometric Analysis

The use of morphometric analysis to demonstrate the presence of erosion surfaces, and the different types of morphometric methods in use have been criticised by Clarke and Orrell (1958) and Clarke (1966). Their three main points of objection are that morphometric analysis is said to be objective while the maps on which the analysis is based are inherently subjective, that morphometric analysis wastes a lot of time and gives results of minimal value, and that morphometric analysis depends on the subjective judgement of the operator.

These criticisms, important as they are, still do not preclude the use of morphometric analysis in demonstrating the presence of erosion surfaces as the methods are absolutely independent of subjective visual impressions in the field. Further, if the methods are carefully used, they can indicate the presence of erosion surfaces which can then be confirmed in the field. In this study, altitudinal analysis and areal analysis were used. Geyl (1961) has proposed the use of the Shoulder, Summit, Col (SSC) method to demonstrate the presence of erosion surfaces. Though admirable, this is impractical

because of the difficulty of assigning values to the length and areal units involved.

Altitudinal Frequency

The use of altitudinal frequency to demonstrate the presence of erosion surfaces presupposes that the highest parts of the landscape are always the last to lose the remnants of former erosion surfaces as dissection spreads up the valley. Two methods can be used; (i) the number of the closed contours on maps can be counted, each closed contour given one unit, and the total number of closed contours occurring at specific altitudes grouped together; (ii) the sampling method can be used, whereby grids are superimposed on the maps and the highest points within the grids, especially spot heights and closed contours, are recorded and grouped together. The latter method is preferable because in the former, both large and small areas enclosed by contour lines are given equal values and undue emphasis will be laid on dissected areas.

The limitation to the use of both methods is that they presuppose the initial surface to be flat. This is not always true and remnants of such surfaces will occur at different levels as a result of differential weathering and erosion of the different rocks. Further, only a small part of the total landscape is taken into account. The methods are used in this study for demonstration purposes. The grids imposed on the maps are at a mile interval as this is considered suitable by Clarke (1966) for use in a moderately dissected terrain.

The altitudinal frequency of the closed contours is shown in Fig. 37. The graph shows maximum bulges at 500 ft, to 900ft, and 100 ft. to 400 ft. The altitudinal frequency of the Grid sampling was drawn for the whole of South Western Nigeria (Fig. 37) and for the Ibu / Ona river system which

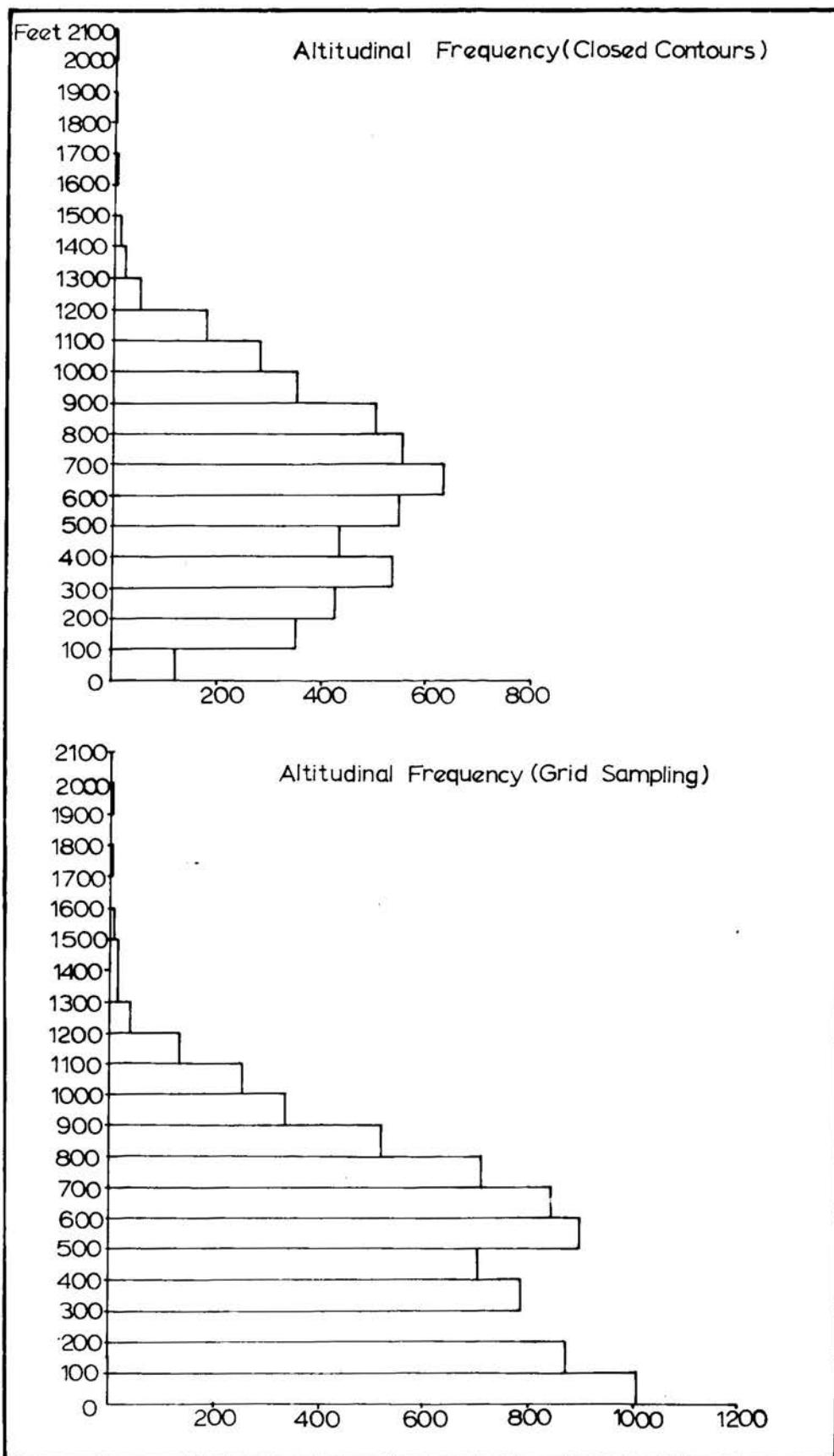


FIG.37

is the only complete large river basin present (Fig. 38). In the Ibu Ona basin, the graph shows a maximum bulge at 500 ft. to 700 ft., while for the whole of South Western Nigeria the graph shows maximum bulges at 100-200 ft., 300-400 ft., and 500-700 ft. The 500-700 ft. bulge is common to both. Thus the altitudinal analysis shows that sloping surfaces may be found at the altitudes indicated by maximum bulges on the altitudinal graphs.

Areal Curve

Areal analysis shows an interrelationship between area and altitude, showing the absolute or relative areas of land between adjacent contours. This method is preferable to the altimetric analysis in that it is not confined to units of height alone. It is also particularly useful in correlating erosion levels from area to area.

The obvious problem is how to calculate the inter-contour areas. This can be done with a planimeter, or, as suggested by Clayton (1953b), the maps could be cut along the contour lines after testing for equal paper quality throughout; the strips are then weighed and the intercontours areas computed. Where several maps are to be analysed, both approaches are impractical. The quickest method is mesh sampling. A series of vertical lines are drawn at mile intervals on the maps, and along each line, the distance between successive contour lines is measured. The value along each strip for the different intercontour distances are summed and cumulative totals derived for all the vertical lines. For South Western Nigeria, (Fig. 39) and for the Ibu/Ona river basin, (Fig. 38), the resultant curves show maximum bulges at 100-300 ft, and 500-700 ft; 300-400 ft. and 500-700 ft. respectively.

The table below gives a summary of the levels at which erosion surfaces were observed with the different methods used.

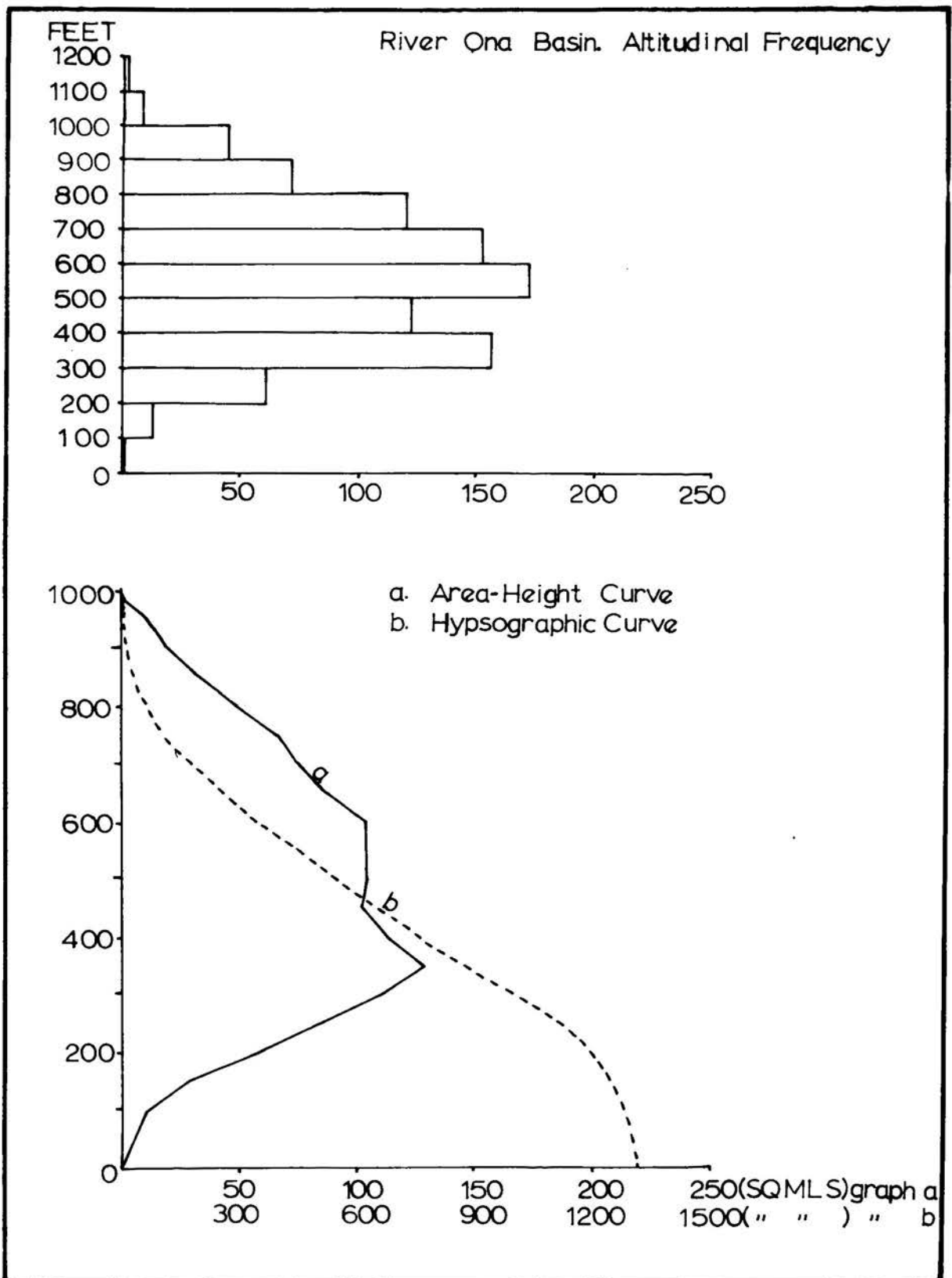


FIG. 38

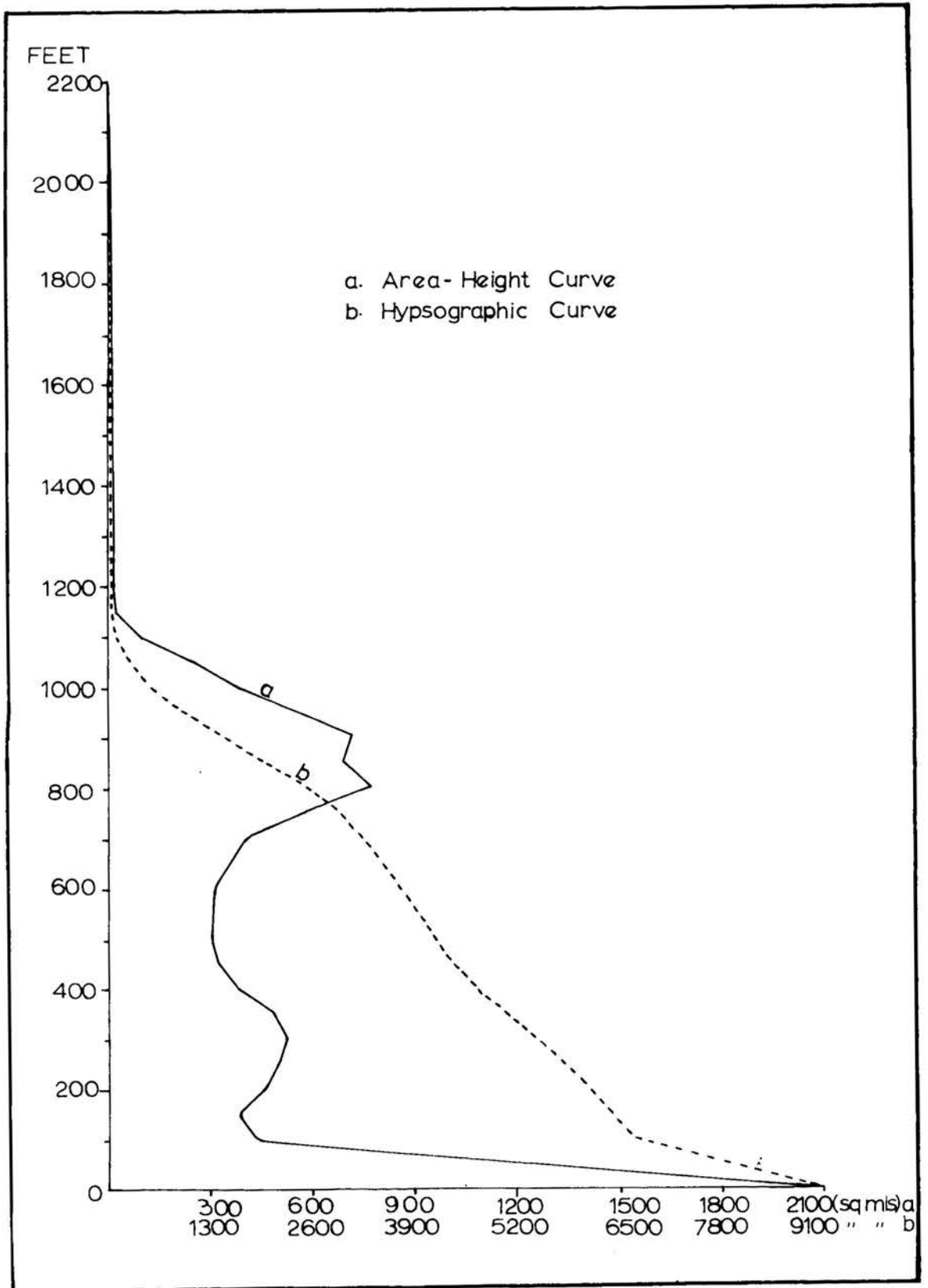


FIG.39

Table 28Different methods and Erosion Surfaces observed

Field evidence	Long profiles of streams	Generalised Contour	ALTIMETRIC CURVE		Areal Analysis
			Closed Contours	Grid Sampling	
<u>Northern Upland</u>	S.W. Nigeria	S.W. Nigeria	S.W. Nigeria	S.W. Nigeria	S.W. Nigeria
500-800ft)Upper surface	650-700ft	500-900ft	500-9--ft	500-700ft	500-700ft
400-600ft)at different localities	500-550ft	200-400ft	100-400ft	300-400ft	100-300ft
300-550ft)localities	500-400ft			100-200ft	
475-650ft)Intermediate surface at different localities	200-250ft			Ibu/Ona Basin	Ibu/Ona Basin
<u>Southern Upland</u>				500-700ft	500-700ft
400-475ft Upper surface north and north east of Ilaro					300-400ft
250-385ft Intermediate surface around Ilaro					
125-260ft Lower surface south of Ilaro					

It is difficult to correlate all these surfaces, but in all the methods used, three surfaces appear consistently. The highest one occurs between 500-900 ft. and is best developed on the Upper Cretaceous Sandstone, it is also locally found on the crystalline basement where it is developed on deeply weathered rocks and covered by detrital laterite, or where it is etched out between granite outcrops as near Lalate. This surface is lower east of the Ogun where

it lies between 300-550 ft. and also on the Eocene sandstone north of Ilaro where it lies between 400-475 ft. a.s.l.

The intermediate surface occurs between 275-650 ft. on the upper Cretaceous sandstone, and at 250-385 ft. on the Eocene sandstone. In both places, it is mainly developed as wide valley benches, but it is also found on interfluves. Traces of this surface are found on the crystalline basement where it occurs as narrow terraces e.g. along the Ogun near Olokemeji or along the Ona on the Lagos-Ibadan road.

The lower surface occurs between 100 ft. and 300 ft., mainly on the Eocene sandstone as wide valley benches, but it is also developed on broad interfluves within the basins of Berre and Ore streams. This surface appears to be absent on the crystalline basement rocks. These surfaces and the relationship between them are shown in figs. 33 and 34.

The nature of the surfaces

The highest surface recognised on both the upper Cretaceous sandstone and the Eocene sandstone is gently sloping. On the upper Cretaceous sandstone it slopes from N-S at about 15 ft. per mile, but also slopes in a NNW-SSE direction towards the Ogun river which acts as a local base level. On the Eocene sandstone, the surface slopes in a N-S direction.

The surface on the Cretaceous formations is covered by vesicular laterite which outcrops mainly at the upper valley slopes, but also as wide lateritic pavements. Laterite is invariably present in soil profiles at depths varying from 6 ins to 18 ins. The surface is dissected by tributaries of the Yewa, through headward erosion following rejuvenation, and the valleys of these streams are deep and steep. On the Eocene sandstone, there is a cover of thin ferruginised material, especially where the forest has been removed. It is also

dissected by the head streams of the Ore river, but their valleys are shallow and wide-bottomed.

The intermediate surface occurs as a sloping plain south of Meko where it is covered by widespread lateritic blocks. These are also found within the soil profiles. Elsewhere, the surface occurs as wide valley benches covered with detrital laterite, lateritic blocks and concretions, below the upper surface. The relationship between the two surfaces is shown in Fig. 34. South of Aiyetoro it occurs on the lateritic covered narrow interfluves, although the cover is rapidly being destroyed. Near Meko, the slope separating the upper from the lower surface varies from 10° - 25° , but east of Aiyetoro the slopes vary from 7° - 12° . On the Eocene sandstone, this surface occurs mainly as broad valley benches below the upper surface, and, in several places, it merges imperceptibly with the upper surface. The benches are covered by detrital, ferruginised sandstone derived from the upper surface and occasionally large masses form wide ferruginised pavements. This occurs especially where deforestation has taken place.

The lowest surface occurs as valley bottoms covered by alluvial material, south of Ilaro where it was studied, but it also occurs as wide interfluves in the basins of Ore, and Berre where thick forest growth precluded close investigations. The surface slopes in a N-S direction.

Formation

The formation of these surfaces involves both climatic changes and base-level changes. Evidence for climatic change in South Western Nigeria ~~are~~ *is* neither conclusive nor convincing and the only pointer to past climatic changes is the lateritic deposit on the upper surface. Tricart (1956) is of the opinion that the laterites of the Guinea Coast were formed as a result of climatic changes in the Tertiary-Pleistocene period. Some aspects of the climatic changes

have been mentioned in Chapter 5 and are also discussed by Bond (1962). What is significant is that there is no evidence of desertic conditions alternating with very humid conditions in South Western Nigeria as Tricart implies for the Guinea Coast. Sivarajasingham et al (1962) have pointed out that laterites can readily form where there are alternations of periods of heavy rainfall with periods of relatively low rainfall either over a long geological period or within one seasonal cycle. This appears to have been the conditions in the Pleistocene-Quaternary period in the humid tropics.

The vesicular laterite covering the upper surface could have been formed during the Pleistocene-Quaternary period in which case the surface itself was a pre-Pleistocene surface. Since the formation of the laterite, the upper surface has been dissected and the lower surfaces produced by lateral backwearing of the valley sides. What is not clear in this situation is the connection between lateritic formation and the dissection of the upper surface. If a deeply weathered surface is dissected, laterite tends to form at the upper parts of the slopes of dissection. On the upper surface laterite occurs on the upper parts of the river valleys and also occur as broad pavements on the surface. Lateritic formation on the surface could have resulted from the effects of changes of climate and erosional dissection of the surface.

The dissection of the upper surface involved base level changes. The amount of base level changes involved since the upper Cretaceous (Senonian) times when the older sandstones (Abeokuta Formation) were formed is difficult to calculate. Davies (1964) has calculated that the sea level in West Africa was at -90m (297 ft) to -100m (328 ft) from the present sea level before the Quaternary Ice Age, and he identified the 55m (171.5 ft), 22-25m (72.6-81.5ft), 9-13m (29.7-42.9ft), 3-6m (9.9-19.8ft) and 1.1-5m (3.3-5.0ft) terraces at Cape Three Points in Ghana. It has also been variously calculated that since

the end of the Ice Age, the level of the sea has risen by 6-8m (19.8-26.4ft) leading to the drowning of the present coastline. From what can be seen at the headstreams of the main consequent rivers developed on the upper surface, the amount of incision is of the order of 150-200ft which shows that since these rivers were developed, probably in the early Tertiary, there have been changes of base level of this order. The pattern of change is not clear however, whether it was the land which was being uplifted or whether it was the sea level that was subsiding, both would produce the same result.

As laterite was developed on the upper surface forming a cap rock, with base level changes and rejuvenation the lower surfaces would be formed by parallel retreat of slope. The lower would then be covered by laterite blocks derived from the upper surface.

Age

King (1962) has recognised that the oldest degradational surface i.e. primary watershed north of Shaki, in Western Nigeria is early Tertiary. The next lower surface is of late Tertiary, followed by another of Quaternary age. There is no way of knowing the absolute ages of the surfaces recognised in South Western Nigeria, but it appears that the dating by King, with slight variations, fits in well with the recognised surfaces. The higher surface developed on the sandstones can be tentatively assigned to the mid Tertiary i.e. Oligocene-Miocene period; the intermediate surface can be tentatively assigned to the Pleistocene-Quaternary pluvial and interpluvial periods, while the lowest surface can be regarded as Recent. No such chronology can be attempted for the basement complex area where no large scale erosion surfaces can be identified, but King has dated the whole of the dissected landform here as late Tertiary.

Part IILANDFORM ELEMENTS:CHAPTER 8INSELBERGS.

A REVIEW OF SOME THEORIES OF INSELBERG FORMATION.

The word "inselberg" is derived from the German language, and it means "island mountain". This word correctly describes the domical convex rock outcrops commonly found on the basement complex of Nigeria (Plate 22). Inselbergs are of varying shapes and sizes, perhaps the best known being the symmetrical types referred to as bornhardts. From Falconer (1911) to present writers, nearly all of the opinion that inselbergs are formed from crystalline rocks, both igneous and metamorphic, but Cotton (1947) goes further and suggests that they can even form on schist and basalts, quoting examples from Western India. Holmes and Wray (1912) and King (1949) differ slightly in saying that inselbergs are formed on plutonic rocks alone, especially granites, granodiorites and diorites.

Inselbergs are widely distributed. They occur in the forested humid tropics in Africa, Brazil, Australia and India, and they are also present in the grassland savanna of Africa and Australia. They are further found in the tropical deserts. Inselbergs are less evident in the forest zone, however, and this has led to a belief that they occur only in the savanna. This prompted Cotton (1947) to designate "the savanna landform" as one typified by inselbergs and plains. The realisation that the distribution of inselbergs is not so localised made Cotton (1961, 1962) change his earlier views, and he wrote that inselbergs could have originated in the hot humid climate of the forest belt, and that inselbergs now found in the savanna area were probably formed when the present savanna area was more humid. It has been realised that the formation of inselbergs and tors require deep

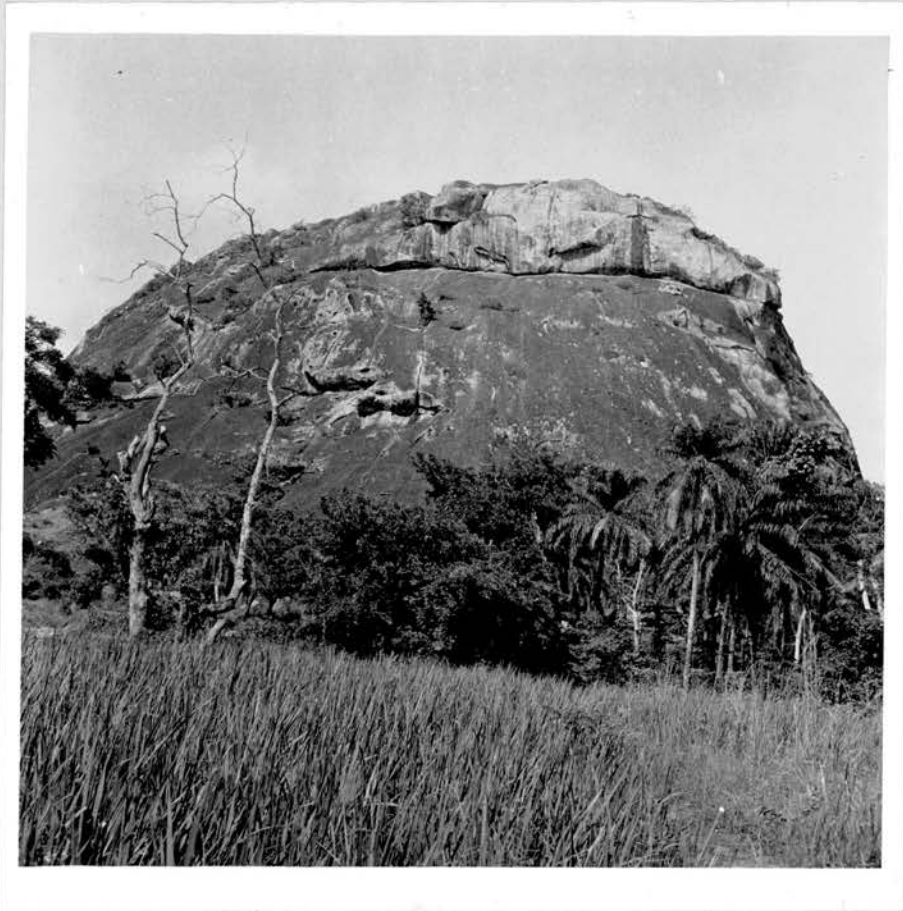


Plate 22. An inselberg formed in syenite near Oke-Iho.

weathering. Linton (1955, 1964) writing on the tors of the South Western Coast of England stated that deep weathering occurred in the crystalline rocks of Britain in the pre-Pleistocene period when the climate was warm, and that exhumation of the weathered regolith followed in the interglacial periods. This theory of deep chemical weathering and subsequent exhumation following changes of base level has been advanced in Chapter, 5 and 6 to explain the evolution of the major landforms in South Western Nigeria, and it appears to be equally applicable in explaining the formation of inselbergs and tors in varying geomorphic environments.

There are as many theories as there are writers on inselbergs. The aim of this chapter is to classify these theories on inselberg formation, and to examine each category in the light of present knowledge. An attempt will then be made to show why some of these theories are inapplicable to the inselberg landform of Western Nigeria. Many of these theories may be applicable in different geomorphic environments because as Doornkamp (1968, p. 154) has pointed out, it is quite possible that similar types of features may result from different processes. It can be added that this will especially be the case for the contrasting climatic areas where most of the observations and deductions have been made.

The Theories

There are three principal categories:

- Group I: The theory that inselbergs result from sharp changes of climate; these are referred to as "relict hypothesis theories" by Cotton (1947)
- Group II: The theory that inselbergs result from ph colithic or from large plutonic intrusions, subsequently dissected by rivers and each compartment retreating parallel to itself to form inselbergs.
- Group III: The theory that inselbergs result from deep weathering,

followed by a period of exhumation under a second cycle of erosion.

At this stage, the hummocky basal surface of weathering is exposed to give rise to the present inselberg landform.

Within each group, different writers express ideas which, in most cases, only slightly differ one from another.

Group 1: Passarge (1895) appears to be the first writer to postulate the relict hypothesis theory. He suggested that tropical inselbergs were formed under arid conditions in the Mesozoic period when the present savanna areas were deserts. Wind scour was deemed responsible for widening and deepening the hollows between the rocks. This hypothesis is doubtful, because in the first place, as pointed out by Cotton (1947, p. 90), it is very difficult to prove that the savanna areas have ever been under desertic conditions. Although the Sahel Savanna areas of Northern Nigeria have accumulations of seif and erg dunes, it is not recorded that wind-scour is of any significance there. Second, there is no conclusive proof that the humid tropics of Western Nigeria has ever been under desertic conditions as pointed out in Chapter 6, even in Northern Nigeria, weathering depth of about 150 ft. has been observed in Kano (Thomas 1965). Third, from what is known of erosive processes in the desert, windsour is not an effective agent of erosion. The later modification of this concept by Passarge (1904) that the inselberg landform is the result of alternation of humid periods when deep weathering occurred, followed by dessication when aeolian agents operated, did not improve the hypothesis.

Bornhardt (1900), from ^{whom} the symmetrical type of inselberg takes its name, believed that inselbergs result from the superposition of more than one cycle of erosion triggered off by sharp climatic variations. Although modern workers such as Thomas (1962, 1965) and Ollier (1960) share his idea of multiple erosional phases, they do not agree with the second aspect of

sharp climatic variations. Further Bornhardt failed to explain the mechanism responsible for the evolution of inselbergs.

Falconer (1911, 1912) postulated deep chemical weathering on an initial plane level of granites and gneisses under humid to subhumid conditions. This process was then followed by stripping to produce irregular hollows between the outstanding rocks. Later, with a change of climate and probably following a downwarping, the hollows were filled by drift accumulation. This contrasts with the windsour theory of Passarge. It is equally unexpected from Falconer who observed inselberg distribution from the humid Abeokuta area to the semi arid areas around Kano. Certainly, there may be drift accumulation in the Kano area, but this is not true of Western Nigeria.

Group II: Holmes and Wray (1912) wrote that "inselbergs mark the position of phacolithic or batholithic intrusions of igneous rock below. It would seem that dome-like intrusions have been the primary cause in determining the sites occupied by the present inselbergs, the contrast of surface relief brought about by weathering and erosion being the external expression of internal structure". This implies that inselbergs are formed on granites and granodiorites and indeed about half of those examined in South Western Nigeria are composed of such rocks. Others, however, are composed of various types of rocks of which gneiss is predominant. Apart from mentioning that the intruded rocks form domes, nothing is stated about the mode of formation of inselbergs.

King (1949), in his theory of bornhardts, asserted that inselbergs are formed from plutonic igneous and metamorphic rocks. He also recognised that inselbergs do not express petrological differences in the landscape. The importance of rock structure, especially joints, in the plutonic

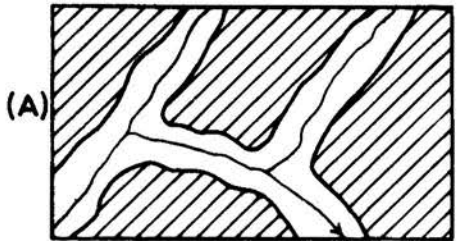
intrusions was stressed as a factor in the formation of inselbergs. It was assumed that the initial surface of such intruded masses would be level, with streams developing along the vertical joints. With a change of base level, such streams were incised and the initial mass divided into compartments along the joint system, as illustrated in Fig. 40. Each compartment then commences to shrink by scarp retreat and pedimentation. The rounded forms of inselbergs are later imparted by exfoliation, due to unloading. In 1966 (p.97) he restated his theory and emphatically refuted the idea that the evolution of inselbergs involves deep weathering as he could not envisage this process penetrating to depths of 1000-1500 ft. Thus he stated that inselbergs have "developed beneath the sun and wind of the open sky".

A discussion of King's theory leads to a wider field including the problems of parallel retreat and downwearing as they affect slopes. It is sufficient to observe with Dury (1959, p.62) and Savigear (1952) that most of the assertions regarding backwearing and downwearing have been made with insufficient grounds or with inadequate observation; thus observations made in the semi arid areas of South Africa need not hold true for other climatic areas. In applying King's theory to the inselbergs of South Western Nigeria, there are several objections:

i) While parallel retreat may be an important geomorphic process in a semi arid environment, this is not necessarily true of the humid tropics. In South Western Nigeria (see Chapter 5) backwearing occurs under certain lithological and structural conditions especially where laterites have been formed on deeply weathered surface, but it does not constitute the overall erosional process.

ii) King, in his earlier paper, did not explain how back-wearing and parallel retreat occur. Later, in his "Canons of Landscape Evolution" (1953)

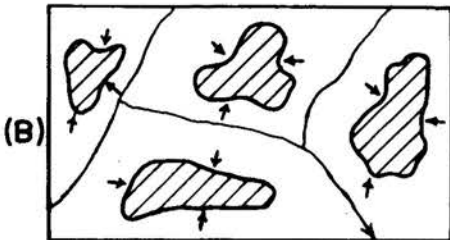
EVOLUTION OF INSELBERGS
(L.C.King1949)



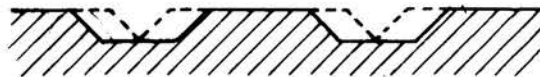
A Plutonic landform incised along the joints by deep valleys.



A cross section of the initial incision.



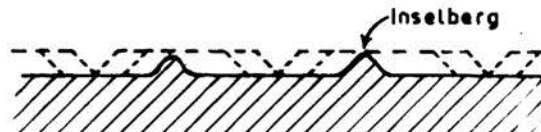
Pedimentation has caused the landform to secede into separate large blocks.



A cross section of the pedimented landform.



Further pedimentation has led to the formation of inselbergs on the plain



A cross section of the inselberg landform

FIG.40

he attributed parallel retreat to weathering, exfoliation and rill action on the free face of slopes, and laminar flow on the waning slope. Not all geomorphologists agree ^{on} with the slope elements that led to the propagation of this theory because, except where rock structure is favourable, his combination of slopes is not widely recognised except perhaps in deserts. In the humid tropics several writers e.g. Thomas (1962) and Savigear (1960), claim to recognise more convex features than others. Thus King's mode of inselberg evolution is open to question, especially the processes of parallel retreat on homogeneous rocks.

iii) Further, the rock cut pediments recognised by King, are not found in Western Nigeria where drilling has revealed pockets of deep weathering around nascent inselbergs (Thomas 1966). His theory fails to take into account the most important geomorphological process in the humid tropics - deep chemical weathering, and this makes the theory inapplicable to Western Nigeria. Birot (1968) believes that it is more appropriate in the semi arid and arid areas.

Following King, Pugh (1954c, 1955) recognised scarp retreat and pedimentation as important factors of inselberg formation in Nigeria. He observed that inselbergs decrease in frequency away from a scarp or areas of youthful dissection and are thus zonal in distribution. Pugh assumed an initially uplifted erosion surface, with scarp retreat or a belt of youthful erosion destroying the existing surface right from the coast. Where scarp retreat is checked locally by resistant rocks, inselbergs will be left above the new plain. He then ascribed the evolution of the dome shape to concentric exfoliation. In these earlier works, Pugh failed to stress the importance of joint pattern in producing inselbergs as King did, nor did he recognise the importance of deep weathering as affecting the evolution of inselbergs. Further, he did not mention the mechanics of scarp retreat.

Pugh (1966) later assigned some importance to deep weathering and indicated that the basal surface of weathering is an important factor in the evolution of tropical landform. He postulated that in a period of tectonic stability, deep weathering would occur, and, with a change of base level, a new cycle of erosion is initiated, streams are incised and the land is divided into compartments by the large rivers and their tributaries; each compartment shrinks by parallel retreat of the slopes. This compartmental shrinking would lead to the evolution of inselbergs. Pugh explained the process of slope retreat as due to surface wash and soil creep assisted by gullying and basal spring sapping which contradicts the rill flow and laminar flow theory of King (1953). Parallel slope retreat by surface wash, soil creep, gullying and basal stripping can only operate where lithological and structural variations are suitable, definitely not on all the slopes.

Essentially, this proposition is a restatement of King's view with slight modification of weathering introduced. Pugh did not explain the factors that will isolate the surviving rock kernels from weathering. The modified theory may help to some extent in understanding the evolution of inselbergs but it is difficult to see how compartmentalised shrinking of weathered regolith can occur when no cap rock is present on such regolith.

Twidale (1964) followed King's hypothesis and recognised the importance of the primary joint pattern in the formation of inselbergs. Unlike King, however, he was of the opinion that it is the spacing and type of joints and deep weathering that determine the occurrence of inselbergs. Twidale also pointed out that in areas with closely spaced joints, total weathering may occur to leave corestones behind, in areas with joints more widely spaced, weathering may produce tors and inselbergs.

He further explained that it is the hardness of rocks that decide whether inselbergs will be formed, postulating that only the younger granite can produce tors and domes. This observation may be true of ^{the} Jos Plateau (Northern Nigeria) as corroborated by Thomas (1962), and of Australia's best known to Twidale, but it is not true of Western Nigeria where inselbergs are formed on the older granites, migmatites, granites and gneisses.

Moreover, Twidale mentioned that large blocks of rocks are weathered into compartments along the master joints, and later valleys are developed along such lines. The sides of such valleys will recede parallel to themselves to produce inselbergs. These inselbergs, are then rounded by curvilinear sheeting of large blocks 1-20 ft. thick. This view has been disputed by Thomas (1962, 1965) who argued that roundness is imparted by chemical weathering ever before domes are exhumed and further, that any sheeting is in response to the pattern of weathering on the pre exhumed domes. This view is reinforced by the weathering pattern shown in Figs. 17-20. The implication of Twidale's theory is that inselbergs in a given area, and within the same erosion cycle will be of uniform altitude which is never the case. Further, his concept of parallel retreat of valley slopes on base rock surfaces is difficult to substantiate. In any event, it is difficult to see how compartmentalised weathering, stream incision and erosion can occur within one cycle of erosion.

Group III: For a long time, many writers have recognised the importance of deep weathering and the basal surface of weathering on all types of crystalline rocks in relationship to the formation of inselbergs; and the following have exploited this idea in various ways to explain how inselbergs are formed:

Theile and Wilson (1915) wrote that "during a prolonged period of

weathering at a time when stream activity was at a minimum on account of the country having reached base level, the rocks became decomposed to a considerable, but varying depth. Subsequent elevation produced a rejuvenation of streams when they swept away the loose rock, leaving the resistant parts which had escaped decomposition as isolated hills." This theory though relevant, fails to explain some problems about inselbergs evolution. For instance it neither explains the factors responsible for causing weathering to operate to varying depths to isolate resistant rock parts, nor the pattern and processes of exhumation.

Bain (1923) recognised two types of inselbergs in Nigeria, viz., the symmetrical dome shaped with steep sides which he associated with coarse textured porphyritic granite-gneiss, and the elongated asymmetrical type which he associated with various types of gneisses. He believed that climate, rock structure and weathering are the most important factors in producing inselbergs from an assumed initial undulating surface whose hollows coincide with areas of joints, ^{and} he postulated that weathering will proceed in depth along the joints during the wet season, and streams will be aligned along such joints. Later the resultant regolith is stripped off by such streams and a constant repetition of this process leads to the formation of deep gorges separated by long narrow ridges. As time goes on, minor joints in the ridges are opened up by weathering and subsequently the ridges are dissected up into separate hills. Further reduction of these hills would be caused by exfoliation, triggered off by expansion and contraction.

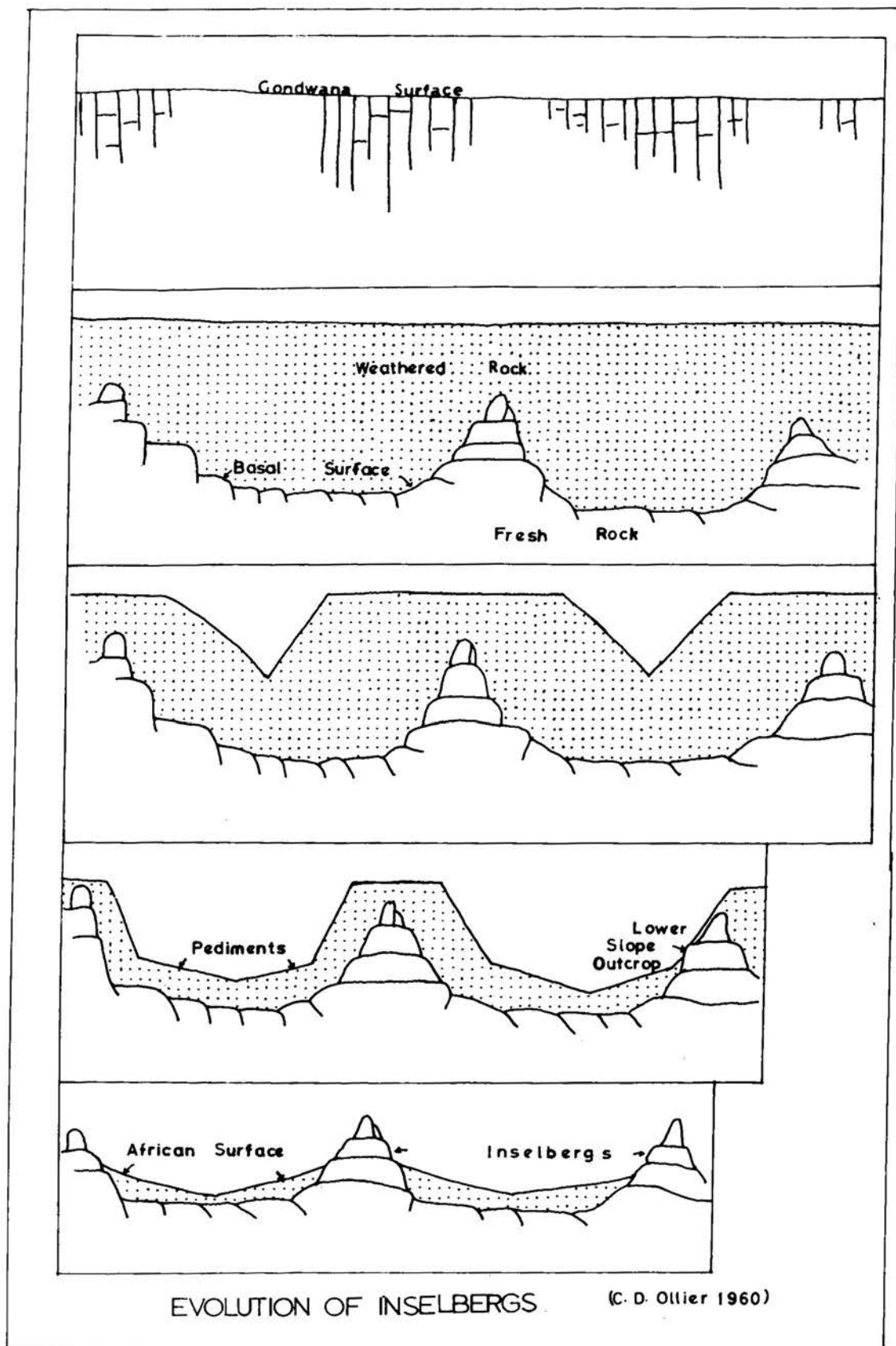
There are several flaws in this theory. In the first place, inselberg forms are not particularly related to any rock type, and in the second place, there are no known examples of such ridge and gorge topography. The

production of such features is difficult to envisage as master joints in rocks are never oriented entirely in two directions; they occur in several directions in any crystalline rock. Even if it is accepted that such joints exist, however, weathering cannot be entirely localised within them, so that by the time the ridge and gorge topography could be produced, the ridges themselves would also have been carved up into separate hills.

Cotton (1947) states that inselbergs are found in the savanna belts of West and East Africa with a height of 1,000-2,000 ft. In reality, only a few inselbergs are within this altitudinal range. Like Bain, he assumed an initial peneplain or pediplain on which there is a contemporaneous operation of weathering and erosion so that as erosion progresses under a single cycle, hummocky features and low residuals will start to appear. For the really large inselbergs, Cotton postulated an elevation of the land which he claimed leads to an intensification of erosion. He concluded that plains around inselbergs are very flat, with gentle slopes, and such plains are extended by pedimentation and lateral planation, or by the migration of streams at the basal depressions towards the bases of the inselbergs. In 1961, Cotton modified his earlier views. He assumed an initial level surface on which weathering operates and stressed that the basal surface of weathering is irregular. After weathering, erosion is followed by down-wearing and by lateral planation of the rivers till the "up-jutting unweathered salients of the unevenly decayed deep floor have merged as a result of a general ablation or erosional lowering of previously bevelled savanna plains". An examination of Cotton's hypotheses show them to be essentially the same. Both involve a cycle of erosion. Cotton's assertion, that after weathering, erosion starts within the same cycle, with no climatic

changes or base level changes involved is difficult to substantiate, ^{especially near the coast.} This can only occur if runoff is weak at the period of weathering or if linear erosion is non-existent, but later on there is a period of increased runoff to cause erosion i.e. this can only occur if there is a sharp climatic variation. Cotton's theory that lateral planation causes a general downwearing is reminiscent of Crickmay's (1933) idea, and may appear true for the semi arid areas with sparse vegetation, but it is not true for the humid tropics area with its thick cover of forest.

Ollier (1960) writing on the inselberg landform of Uganda mentioned that inselbergs are found on interfluves, on top of subdued relief, in rugged areas, and on lower slopes. His illustration shows that inselbergs are distributed in a somewhat consistent relationship with the drainage pattern, and his explanation as to the mode of inselberg formation agrees with this. Thomas (1962, 1965) has denied any consistent relationship between inselberg distribution and the drainage pattern, and field experiences have convinced the present author that Ollier's observations are not always substantiated. Ollier assumed an initial undulating Gondwana surface on crystalline rocks with several primary joints criss-crossing the surface. Weathering will occur on such a surface following the pattern of jointing and produce an irregular basal surface of weathering. In the second cycle of erosion, following an uplift, the streams formed are aligned on the deepest weathered area, but this relationship is not found to be true by the examination of the weathering pattern on crystalline rocks in South Western Nigeria. The streams having been incised, develop narrow valleys which are later widened out by parallel retreat to form pediments and pediplains. Wherever bevelling comes across hard rocks in the basal surface of weathering, inselbergs will emerge. The sequence of pedimentation is shown in Fig. 41.



EVOLUTION OF INSELBERGS

(C. D. Ollier 1960)

FIG.4I

Ollier's theory is difficult to apply in South Western Nigeria; where, as, demonstrated later, (Chapter 9) the physiographic location of inselbergs does not confirm the observations. Further, there is nothing to show that streams are ever aligned along deeply weathered areas; if anything, the contrary holds true as illustrated in Figs. 17-20. Ollier did not explain how parallel retreat can occur in a weathered regolith in the absence of cap rocks especially laterite.

Jones and Hockey (1963) gave a less detailed explanation of the formation of inselbergs, stressing subsurface weathering controlled by the joint pattern in rocks, the production of an irregular basal surface of weathering, and the subsequent erosion that exposes the irregular basal surface. They stressed that after erosion, the upstanding crystalline rocks will be immune to weathering especially as the joints on them are unopened, while the lower areas will continue to be weathered and stripped, hence the inselbergs continue to grow.

Thomas (1962, 1965 and 1966) agreed broadly with Bain (1963) Pugh (1966), Twidale (1964) and Ollier (1960) as to the importance of the influence of climate, joints, and joint pattern, and weathering pattern in the evolution of inselbergs. He observed that inselbergs are formed on both igneous and metamorphic rocks. Like Twidale, Thomas stressed that joints divide crystalline rocks into variable sizes; weathering may entirely consume the shattered and much fractured rocks to produce corestones, while less fractured rocks with fewer joints are reduced to tors, with inselbergs forming where the joints are far apart. He emphasised that weathering affects all the exposed parts of the rock, but proceeds fastest along the joints where it may penetrate down to 200 ft. Thomas explained that stripping of regolith is by surface wash and creep where cap rocks are absent and by parallel retreat where

cap rocks are present. Stripping will reveal the unweathered "kernels" as inselbergs in a second cycle of erosion. Writing on the curved surfaces of inselbergs, he disagreed with the exponents of exfoliation. He stressed that jointing in crystalline rocks is three-dimensional with weathering more pronounced at the edges of the cuboids into which joints have divided the crystalline rocks. The cuboids so weathered assume rounded form, and due to loss of coherence and loss by solution consequent on weathering, expansion will occur to produce exfoliation slabs in sympathy with the curved surface of weathering. The domed form has thus been produced ever before erosion reveals the inselbergs. In support of this, Thomas showed examples of high domes that show no exfoliation slabs on them.

In 1966, Thomas discussed the pattern of weathering in the crystalline rocks of Nigeria and tried to correlate this with the formation of inselbergs. In the crystalline areas, he found the basal surfaces to be irregular in the form of basins and domical rises much as in Figs. 17-20. Thomas observed that the depth of weathering increases away from the river to the interfluves and that drainage lines are in several places superimposed on underlying domical areas, and not on the deeply weathered zones postulated by Ollier (1960). He therefore suggested that in some cases, the uniclinal shifting of valleys on weathered rock after coming into contact with subsurface domes is responsible for the stripping and exposure of domes, aided by creep and surface wash. This hypothesis needs further amplification as it is difficult to conceive how such could occur since several inselbergs occur not only on valley slopes, but also on major interfluves.

In 1911, Falconer noticed the proximity of several low inselbergs and rocky outcrops to the escarpments of the sedimentary rocks in Sokoto and Lokoja area. Savigear (1960) elaborated on this and asserted that such

inselbergs could evolve as the sedimentary scarps retreat to show that the underlying basement rocks have undergone deep but differential weathering.

After reviewing the various theories, it is obvious that opinions are still widely divergent about inselberg formation. In the following chapter, the physiographic location of inselbergs and their pattern of distribution in South Western Nigeria is examined. Inselbergs will also be related to their parent rocks in order to determine their mode of evolution in the different rock types.

CHAPTER 9The Processes of Inselberg Evolution

The study of inselbergs was approached in three ways: first, the physiographic locations were determined in order to establish the pattern of distribution viz-a-viz drainage channels. This was intended to indicate whether the evolution of inselbergs is related to "compartmental shrinking", pedimentation and erosional bevelling, or whether it is due to weathering in rocks along lines or weaknesses followed by fortuitous exhumation of the basal surface of weathering. The nature of the foot-slopes below inselbergs was also briefly examined. The study of the distribution of inselbergs over the crystalline rocks of the basement complex was succeeded by detailed work on their location on specific rock types, especially granite and migmatite. Second, inselbergs were related to their parent rocks in order to assess the effect of lithological variations in their evolution. The morphometric properties of inselbergs produced by different rock types were defined and compared in terms of:

- a) elongation index calculated for the different forms;
- b) frequency of occurrence;
- c) height; and
- d) size.

Third, local studies of inselbergs were carried out in specific areas. In the first phase, all the inselbergs visible on the 1:40,000 air photos covering the crystalline basement area of South Western Nigeria were plotted on the 1:50,000 maps. Except where forest cover precluded examination, each identification was confirmed in the field during the dry season of 1968/9. In several cases, low convex rock outcrops or small domes were discovered which had not been revealed from the airphotos using the mirror stereoscope. The area of each

inselberg was calculated from the airphotos, and the elongation of their long axes was measured. Samples of the parent rocks were collected and identified in the Geological laboratory of the University of Ife. The physiographic location was mapped from airphotos and confirmed in the field. Heights were measured with altimeters which are particularly useful when climbing steep rocks and are also convenient when the sample population is large (see chapter 1). Inselbergs less than 50 feet high were disregarded as low convex rock outcrops. In the second phase, four areas were studied in details:

- i. The granitic terrain of Eruwa-Lalate;
- ii. the granitic terrain of Idere-Tapa;
- iii. the migmatitic area of Ado Awaiye-Ijio-Iseyin;
- iv. the migmatitic area between Oyo and Fasola.

Physiographic Location and Distribution of Inselbergs

The implication of the pedimentation and erosional bevelling theory is that inselbergs are old age erosional forms (hertlungs) in the landscape. If so, they would be expected to occur on interfluves surrounded by extensive pediments sweeping in a concavity towards adjacent stream lines (Fig.40) as visualised by King (1949). They should also have a zonal distribution and occur close to cyclical escarpments. Ollier (1960) in particular asserts that inselbergs are mainly found on interfluves (Fig. 41) or as subsky line features because the erosional stripping which produced them was by pedimentation and parallel slope retreat. Thomas (1966) disputed the view that inselbergs are distributed in a consistent relationship with the drainage pattern, especially in Western Nigeria, and concluded that there is an "absence of consistent relationship between stream lines and patterns of weathering" which produced these inselbergs. However, Thomas never analysed the physiographic location of inselbergs on a regional scale.

Before examining the physiographic location, it is worth repeating the warning of Doornkamp (1968, p.154) that "it is quite possible that similar features may result from different processes operating in different areas". Thus the following analysis is confined to conditions in South Western Nigeria, and need not apply elsewhere. For the purpose of analysis, four physiographic locations were identified:

- a) main interfluves of greater than ^{third} ~~third~~ order streams;
- b) lesser interfluves;
- c) valley sides; and
- d) dissected areas.

It should be noted that inselbergs often generate first order streams, thus, except where they are small, they will invariably occupy one interfluve or another. This brings out the importance of differentiating between those occupying the principal watersheds of the larger rivers, and those on lesser interfluves. Three important geomorphological regions were recognised on the basement complex area, and the analysis of the physiographic location within each geomorphological region is shown below.

Table 29

Physiographic Location of Inselbergs

DOMINANTLY STRIPPED ETCHPLAIN

	Location 3rd order Interfluve	Location 3rd order Interfluve	Location of valley side	Location in a dissected area
Number	52	110	43	15
As % of all	24	50	19	7

PARTIALLY STRIPPED ETCHSURFACE

Number	7	10	4	-
As % of all	33	48	19	-

(continued on next page)

DOMINANTLY STRIPPED ETCHSURFACE

	Location order	3rd Interfluve	Location order	3rd Interfluve	Location of valley side	Location in a dissected area
Number		12		44	12	81
As % of all		8		30	8	54

SUMMARY

As % of all		19		42	15	24
-------------	--	----	--	----	----	----

In the migmatite area around Ado Awaiye, 25% of the 52 inselbergs (Fig. 42) occur directly on valley slopes, 28% on the principal interfluve between Ofiki tributary and the Opeki river, and the remaining 47% occur mainly on 1st and 2nd order interfluves. In the migmatite area around Oyo (Fig 43) only about 45% of the inselbergs occur on the principal watersheds, while the rest are found on valley slopes and on lesser interfluves.

At the regional scale in table 29, there does not appear to be any consistent relationship between the physiographic location of inselbergs and the drainage pattern. If this relationship existed, most should occur on the principal watersheds, but in fact only 19% are so located. The majority (42%) occur on less than third order interfluves. Locally, migmatite inselbergs display no absolute relationship between their physiographic locations and the drainage channels. Thus strictly speaking, these inselbergs are not "hertlungs" on the landscape.

Granitic inselbergs occur mainly in areas of dissection where the streams have incised into the regolith between the domes. All the same, these inselbergs are not really on the principal interfluves. Those near Idere-Tapa lie on the general slope of the Ofiki river, with the area being dissected by the Ofiki tributaries. The main interfluve between the Ofiki and the Opeki river lies about fifteen miles to the east. The inselbergs in the Eruwa-^{Lalate}~~Late~~ area are on

PHYSIOGRAPHIC LOCATION OF INSELBERGS

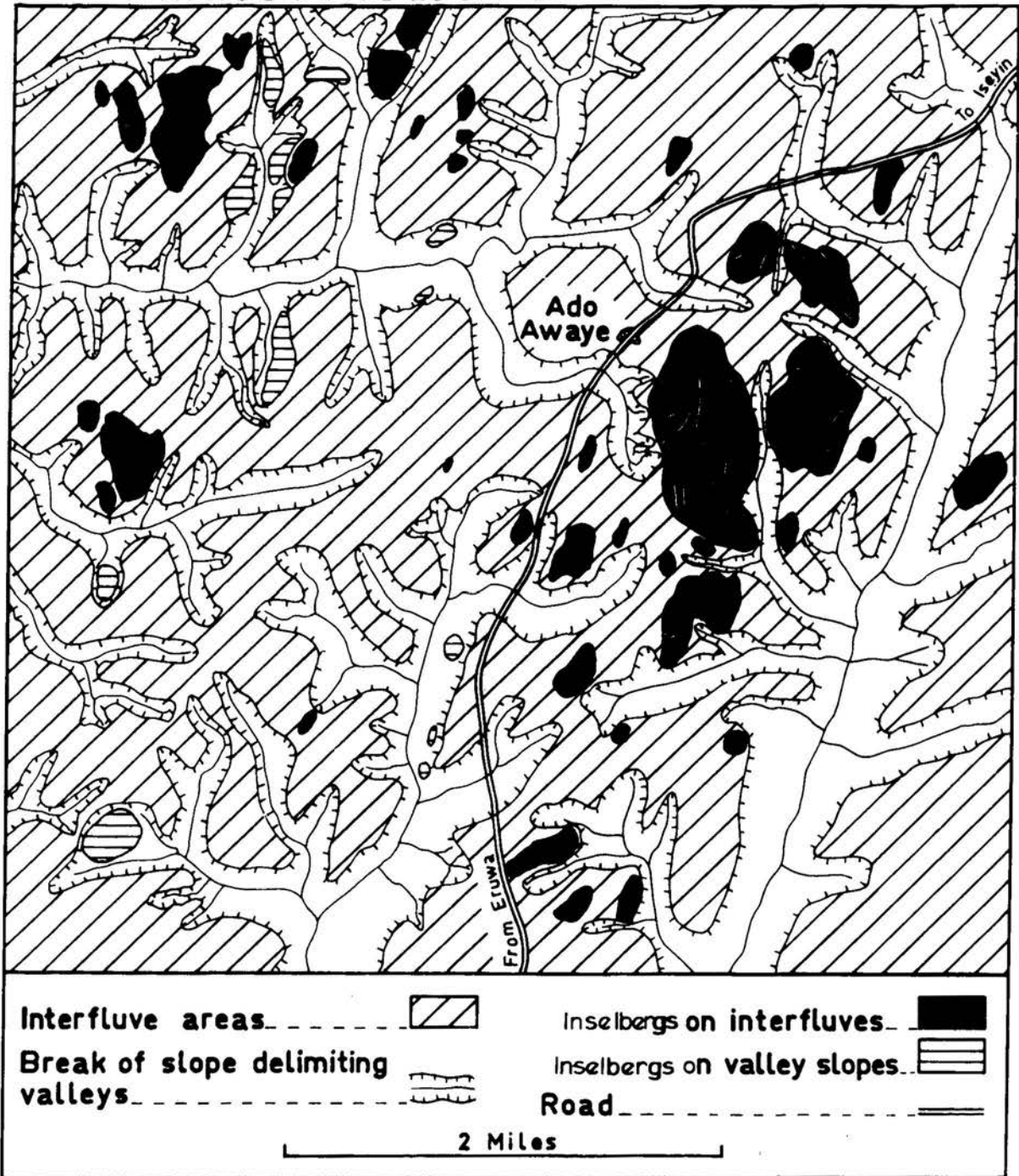


FIG.42

RELATIONSHIP BETWEEN INSELBERGS AND DRAINAGE LINES ON THE PLAIN AROUND OYO

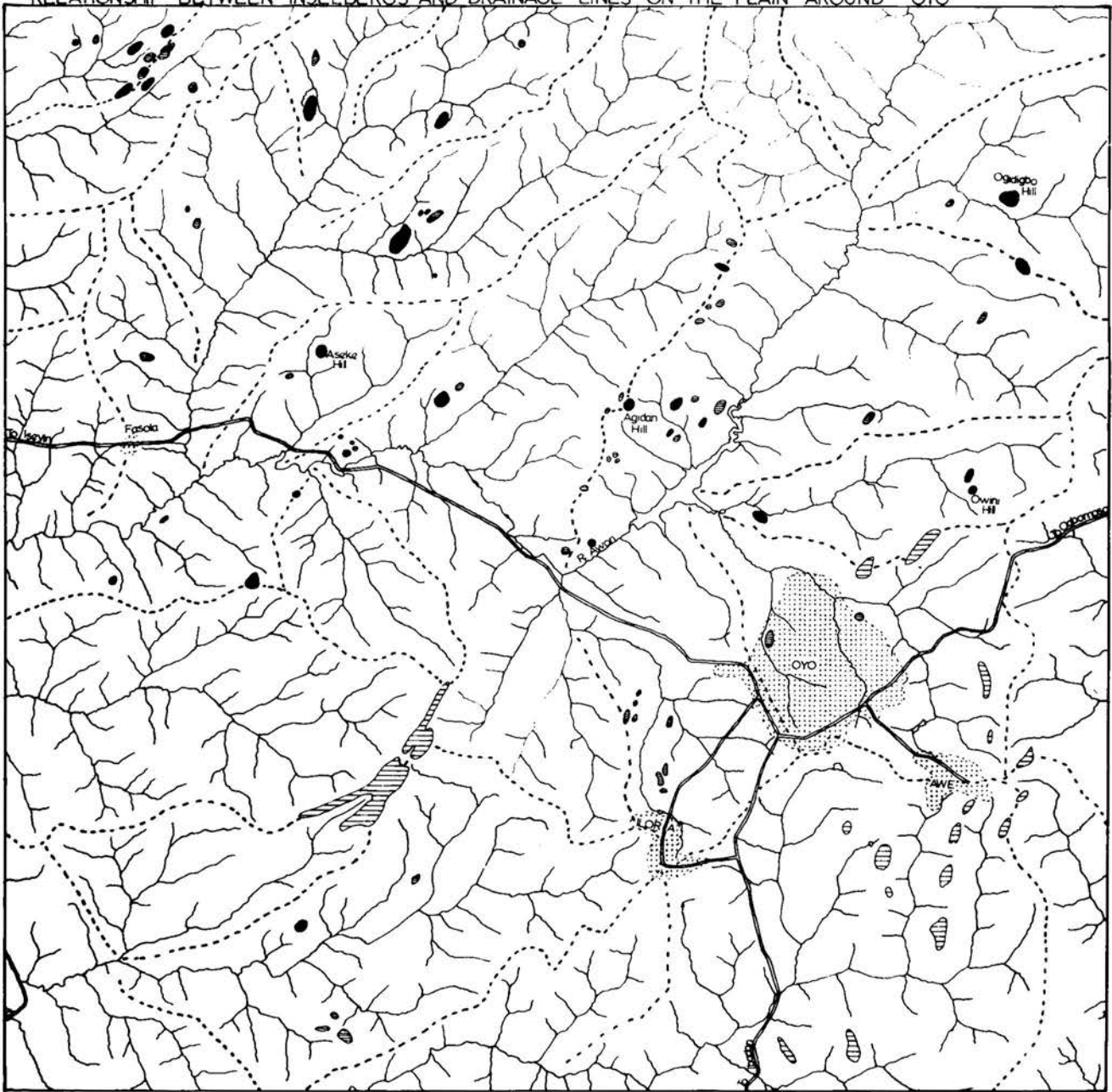



FIG.43

0 1 2 3 4 MILES

- | | |
|---|--|
|  INSELBERGS |  PRINCIPAL WATERSHEDS |
|  LOW ROCK OUTCROPS |  MAIN DRAINAGE LINES |
|  QUARTZITIC HILLS |  IMPORTANT ROADS |

the general slope of the Opeki river. Thus granitic inselbergs show no absolute relationship to the regional stream pattern.

From the above analysis and field observations, it appears that inselbergs are mainly azonal in distribution even though a few may be found near structural escarpments as at Oke-Iho. Inselbergs occur where structural conditions favour their existence and this is best illustrated between Ado Awaiye and South of Iseyin (fig. 44). Here the migmatite foliation and joints trend in NNE-SSW and N-S directions and most of the inselbergs trend similarly. Granitic and syenitic inselbergs are often elliptically arranged (Figs. 45, and 46) as seen around Ijido and Oke-Iho, or may display a compartmentalised arrangement (Fig. 47) e.g. in the Eruwa-Lalate area, which suggests that they were formed from deeply weathered and dissected batholiths.

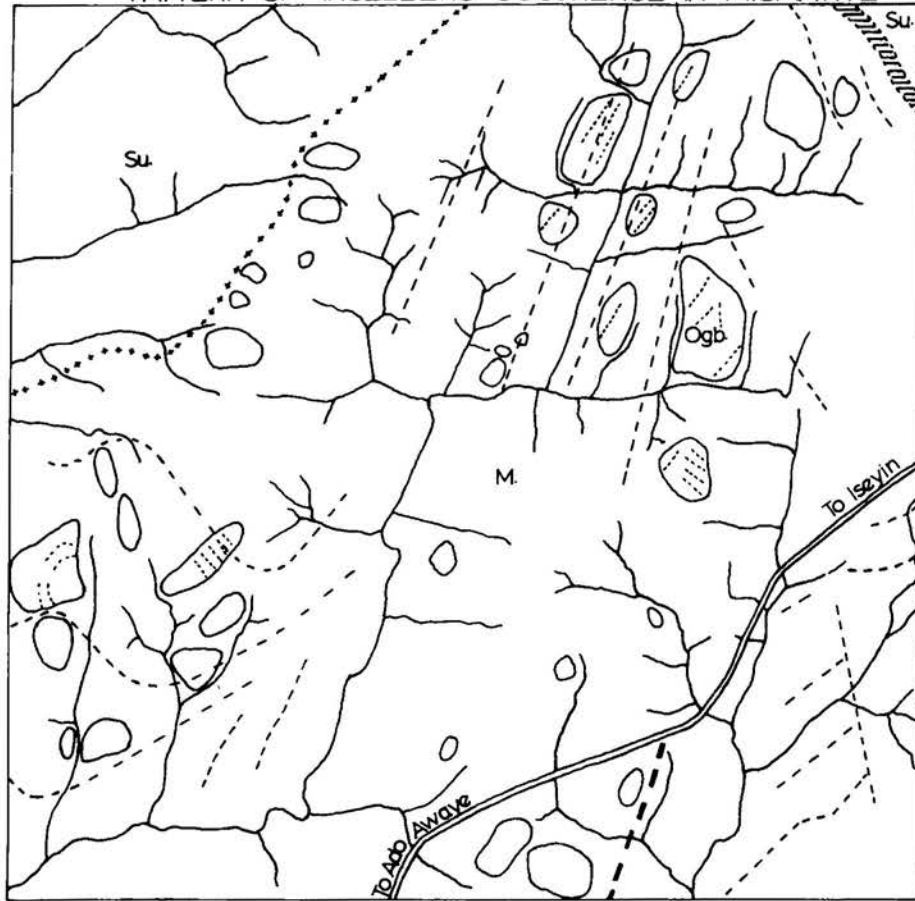
All these observations invalidate the theories of King, Pugh, and Ollier in respect of South Western Nigeria, even though they may hold good elsewhere.

Pediments

King (1949), Pugh (1955) and Ollier (1960) believe that pediments are produced by parallel retreat of slope, but while the former two believe that the process can operate across bare rock surfaces, the latter believes that pediments are cut across regolith. The mere use of the word "pediment", as noted in Chapter 5, requires qualification because of differences in interpretation. The word "footslope" appears less ambiguous, but pediment is retained for the purposes of this discussion.

If pediments are produced by parallel slope retreat, the implication is that pediments grow younger away from the main stream line to the foot of the inselberg. Assuming that pediments are cut across bare rock or across regolith, in the humid tropics, the rapid rate of chemical weathering precludes the preservation of such rock cut features. It would be expected however, that the

PATTERN OF INSELBERG OCCURENCE IN MIGMATITE



(Geology after Jones+Hockey 1964)

0 1 2 3 4 Miles











- | | | | |
|---|---|---|---|
|  | Inselbergs. |  | Structural trend-line. |
|  | Migmatite. |  | Fault assumed. |
|  | Undifferentiated gneiss complex,
probably mainly schist. |  | Trend of vertical joints in inselbergs. |
|  | Coarse-porphyrific, biotite- and
biotite-muscovite-granite |  | Boundary between migmatite and
schist. |
|  | Quartzite and quartz-schist |  | Rivers |

FIG.44

OCCURENCE OF INSELBERGS IJIO AREA

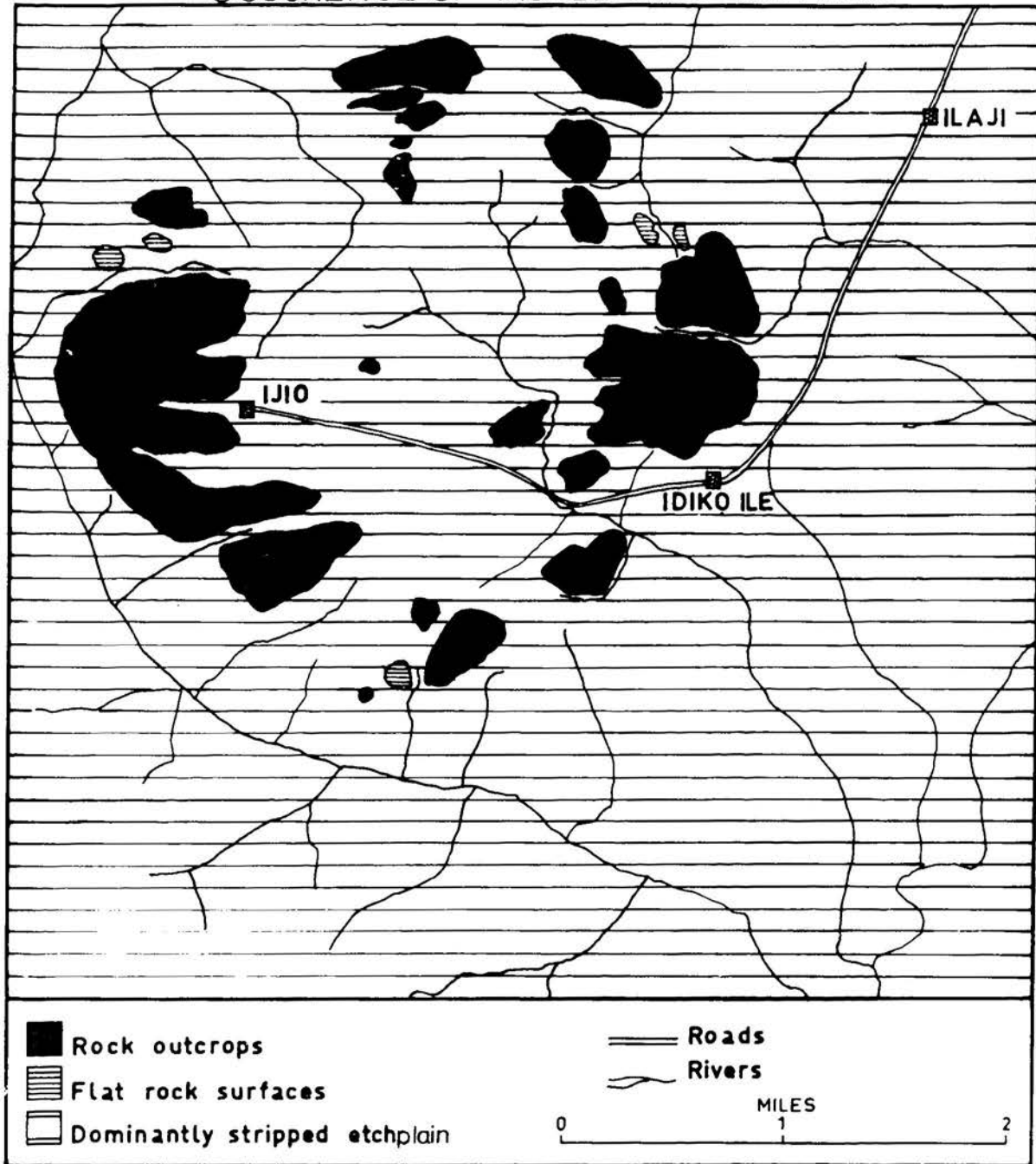


FIG.45

OCCURENCE OF INSELBERGS OKE-IHO AREA

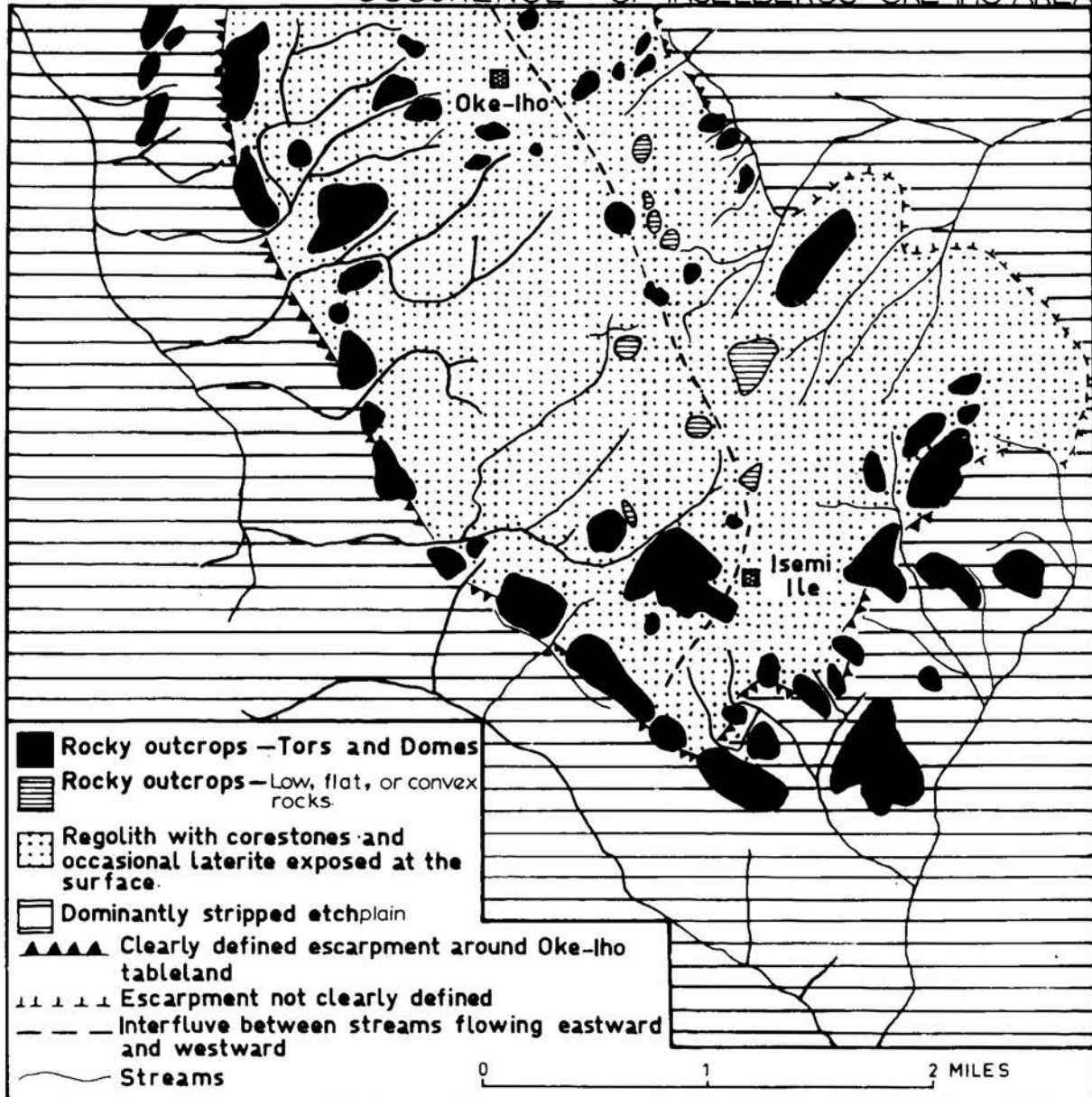


FIG.46

PATTERN OF INSELBERG OCCURENCE IN COARSE PORPHYRITIC GRANITE



(Geology after Jones & Hockey 1964)















- | | |
|---|--|
| <ul style="list-style-type: none">  Inselbergs and low rock outcrops  Migmatite  Coarse porphyritic, biotite- and biotite-muscovite-granite  Porphyroblastic gneiss  Augen-gneiss  Pegmatite or quartz-vein  Undifferentiated gneiss complex, probably schist | <ul style="list-style-type: none">  Structural trend line  Fault assumed  Vertical joints assumed  Approximate geological boundaries  Geological boundary  Rivers  Important roads |
|---|--|

FIG.47

depth of weathering would increase regularly away from the inselberg foot to the stream line. This is not always true, however.

As observed by Doornkamp (1968), the theory of pedimentation and parallel slope retreat will not stand if pockets of deep weathering are found near inselbergs. It will also fall if it can be shown that the sides of inselbergs mark petrological boundaries between the rocks producing the inselbergs and the country rocks. The pattern of weathering around inselbergs is complicated by the fact that surface runoff from inselbergs seep into the base of the inselbergs below the screes to cause subsurface weathering. Nevertheless, there is indicative evidence.

Records of boreholes in dam sites (Figs. 17-20) show that the basal surface of weathering in the crystalline rocks of South Western Nigeria is in ~~form~~^{the form} of basins and domical rises with pockets of deep weathering alternating with domes. Thus when erosional stripping occurs, areas near domes have pockets of deep weathering. The depth of weathering below stream lines is often shallow, increasing in depth towards the interfluves. In a pedimented landscape, the expected, depth of weathering would be deepest along the stream line, becoming shallower to the interfluve.

From field study, it is evident that pediment surfaces are in several areas intruded by low convex rocks especially in the migmatite areas, while ⁱⁿ the granitic areas, such pediments are often littered with corestones and tors. These do not suggest pedimentation. The same processes of erosional stripping of weathered regolith have produced the tors, corestones and the adjacent inselbergs. Where gullies, about 10 feet deep, have developed on pediments, no fresh rocks were seen at the gully bottoms.

In the areas of migmatite, there are no petrological boundaries between inselbergs and the adjacent country rocks; and this lends some credence to the

the pedimentation theory. In areas of granite and syenite, however, the steep sides of the inselbergs mark the petrological boundaries between them and the country rocks. The wide pediments at the western sides of inselbergs at Eruwa are developed on schists, while those surrounding the outer sides of the inselbergs around Oke-Iho are developed on amphibolite, and the pediment at the western side of the Ijio inselberg is developed in schist.

There is little then to suggest that pediments are produced in South Western Nigeria by parallel retreat of bare rock surface or by being cut across regolith by parallel slope retreat. On the strength of field observations, it is justifiable to reject the theory of pedimentation and erosional bevelling.

Inselberg Form

In ground plan, inselbergs are mainly elliptical, rounded or complex. In profile and appearance, inselbergs are either rounded and symmetrical - bornhardts, or elongated and symmetrical or elongated and asymmetrical. These various forms are related mainly to rock structure and lithology, and particularly

- i) whether the rock is foliated or not
- ii) the direction of foliation and angle of dip
- iii) the presence of bounding joints.

Granitic inselbergs are often elongated and symmetrical, but some like the Ilele Hill at Ijio, have pronounced asymmetry. Migmatite inselbergs are elongated but may be either symmetrical or asymmetrical. These characteristics are determined by the foliation, the direction of the strike and the angles of dip of the foliation. Where the dip and strike of foliation coincide, the inselbergs are mainly elongated and symmetrical e.g. the Ado Rock, where the strike of the foliation is 340° NNW and the dip is vertical. The analysis of the long axes of the elongated migmatite inselbergs show that they are mainly elongated in a NNE-SSW, N-S, and NNW-SSE direction (Fig. 48). Where the

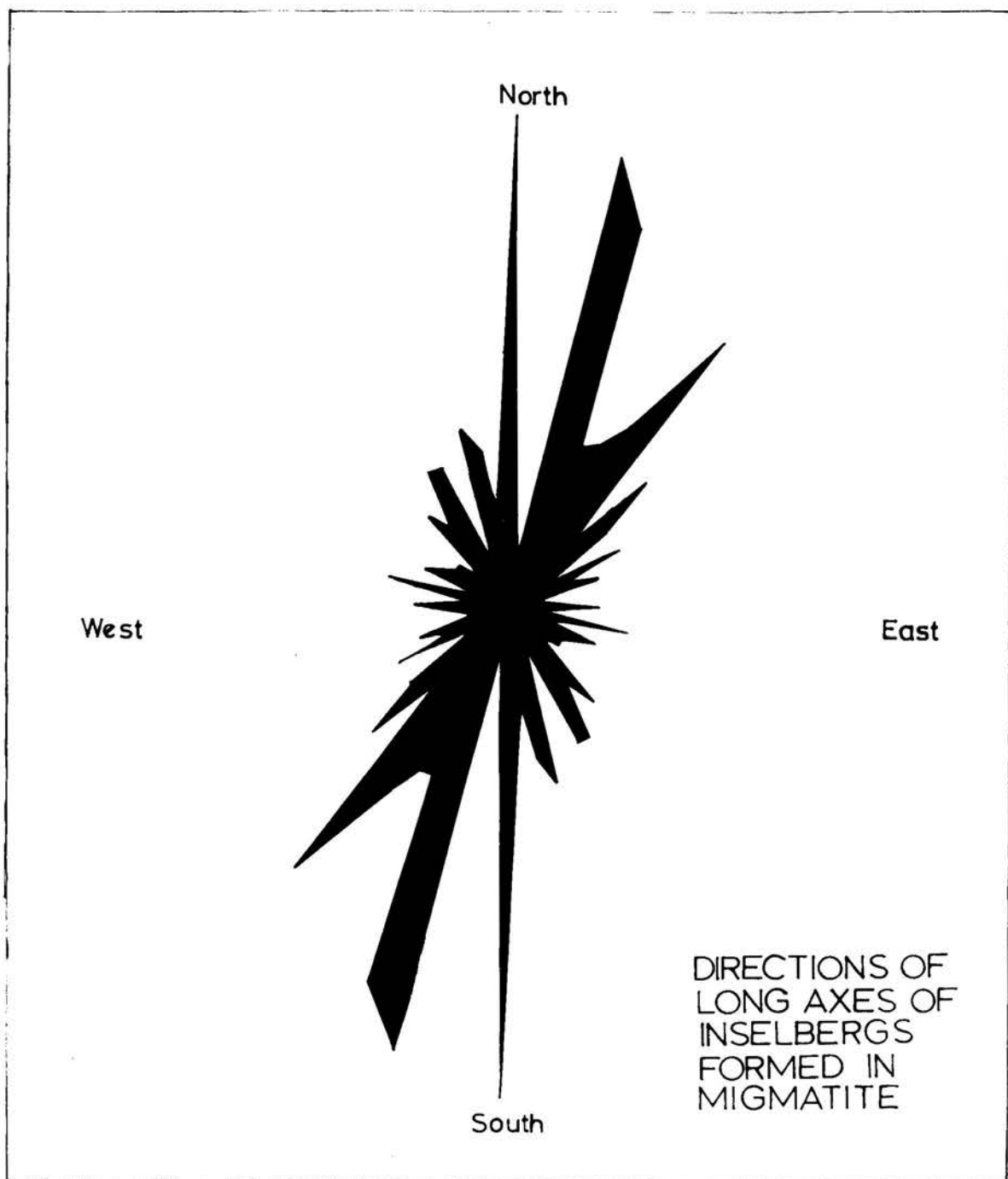


FIG.48

vertical joints cut across the dip of foliation, the asymmetry is much pronounced as seen on an inselberg near Egbeda about ten miles north of Fasola. In most cases, inselbergs have extremely steep bounding slopes on one side, and gentle slopes on the other. Only occasionally are the slopes uniformly steep around an inselberg. The steep bounding slopes are often emphasised by sub-surface rotting and stripping at the base of the inselberg, and this leads to formation of convex slopes or overhangs (Plate 23).

Inselbergs forms may be conveniently classified according to their ground plan pattern which is recognisable from airphotos. Large and elongated inselbergs are termed whale backs, while smaller and elongated types are referred to as shield inselbergs. Oyawoye (1960) favours the term "turtle back" instead of shield inselberg, and this has been adopted in this study because there has been much controversy regarding the formation of shield inselbergs. When inselbergs are rounded, they are called bornhardts. Castle kopjes are also subrounded to rounded in ground plan, but were differentiated from bornhardts in the field by their conical and often castellated profiles. Several inselbergs do not fall into this simple pattern and are referred to as complex.

The main problem lies in differentiating between whalebacks and turtle backs. The parameters used are the ratio between the short and long axes, and their areas. The ratio between the short and long axes of whale backs varies from 1:2.2 to 1:4; for turtle backs, it varies from 1:1.5 to 1:1.8. Whalebacks are often twice as large as turtlebacks. Elongation index calculated for the various types show:

	Whaleback	Turtleback	Bornhardt	Castle Kopje
Elongation Index	2.6	1.6	1.1	1.3

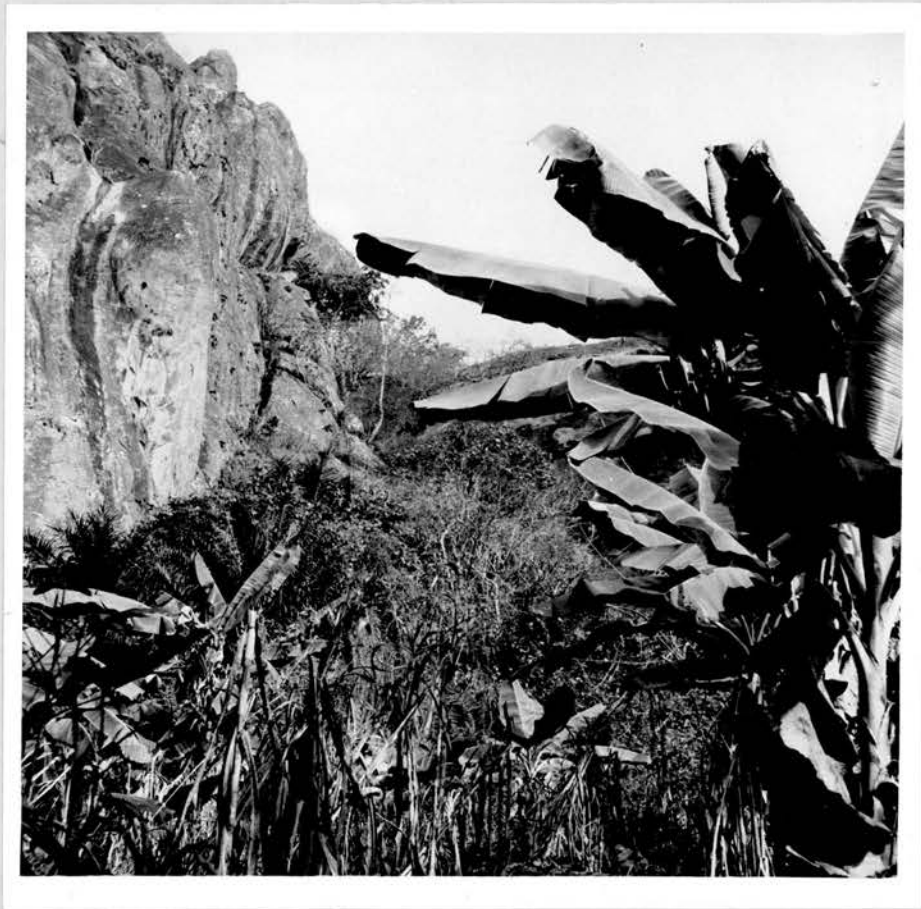


Plate23 - To the left of the plate, is the steep, overhanging
slope of an inselberg near Eruwa.

Each of these various types may occur devoid of any regolith cover, but this is exceptional. Granitic inselbergs are often covered by rock blocks of various dimensions while those ~~developed~~ ^{developed} in migmatite often carry small blocks and skeletal soils which may partially cover them. On most of them, unloaded blocks occur in various dimensions. They may also be entirely or partially covered by vegetation.

An analysis of the various types of inselbergs in relationship to their parent rocks in South Western Nigeria is shown in Fig. 49, and in table 30. The percentage of occurrence is in the horizontal.

Table 30 Inselberg Form related to Parent Rocks

Rock Type	Whaleback	% Occurrence	Turtleback	% Occurrence	Bornhardt	% Occurrence	Castle Kopje	% Occurrence	Complex	% Occurrence
Coarse Porphyritic Granite	50	31.85	66	42.04	21	13.28	8	5.10	12	7.63
Migmatite	21	13.71	96	62.75	21	13.71	-	-	15	9.80
Older Granite	3	12.00	15	60.00	4	16.00	-	-	3	12.00
Syenite	4	26.66	2	13.33	1	6.66	2	13.33	6	39.99
Porphyroblastic Gneiss	3	30.00	6	60.00	-	-	-	-	1	10.00
Granite Gneiss	-	-	2	66.66	-	-	1	33.34	-	-
Augen Gneiss	1	100.00	-	-	-	-	-	-	-	-
Muscovite Tourmaline Granite Gneiss	-	-	1	100.00	-	-	-	-	-	-

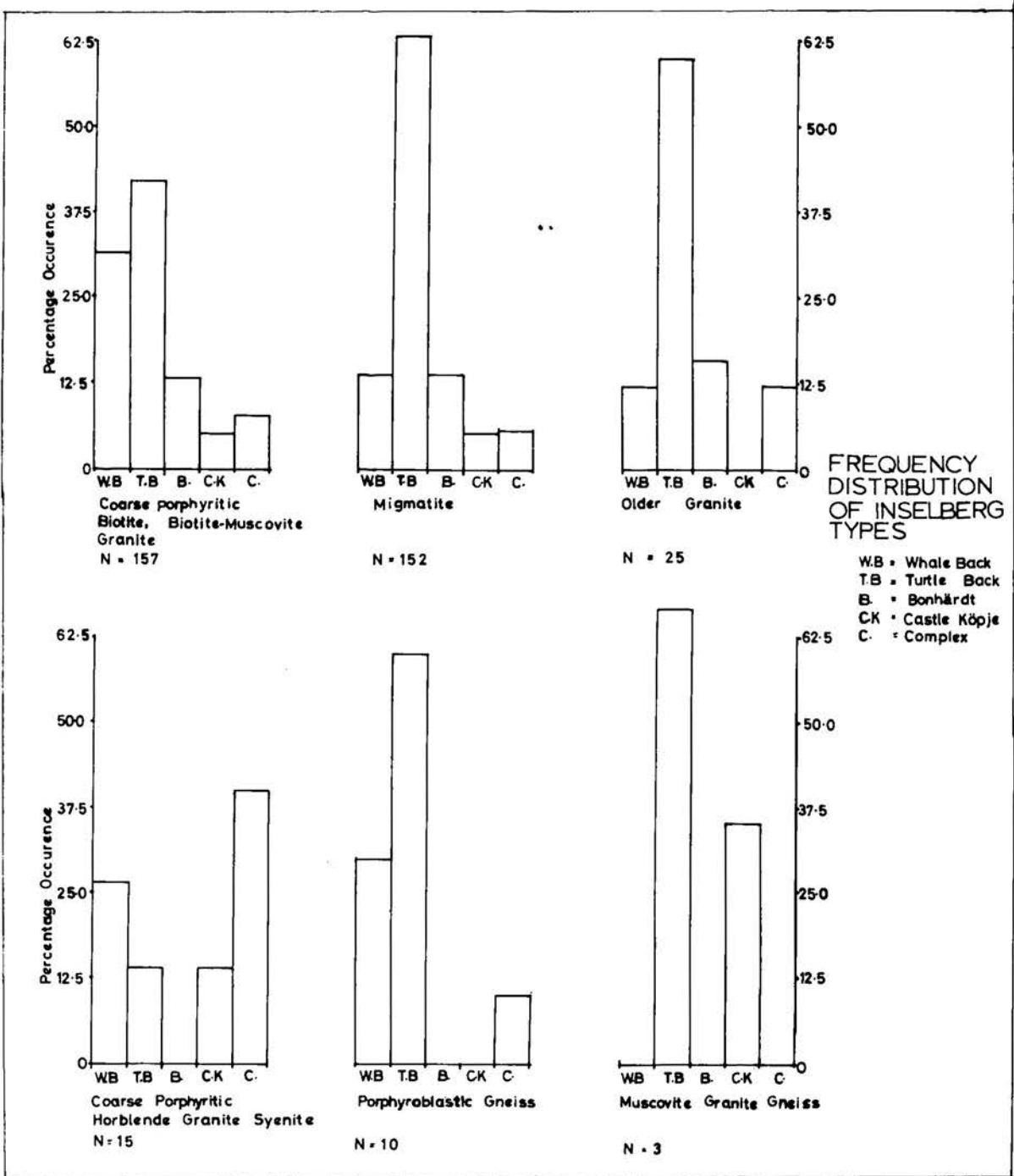


FIG.49

Elongated inselbergs of moderate size are commonest on all rock types, but coarse porphyritic granite gives rise to larger inselbergs than all the other rocks. Bornhardts are equally numerous in both granite and migmatite, but this is of no special significance as the occurrence is fortuitous. The significant point to be noted is that granite consistently gives rise to larger inselbergs than the gneisses. This difference in size is a reflection of the basic differences in the structure and lithology of the rocks which must have affected the mode of inselberg formation.

Frequency of Inselbergs in Relationship to Parent Rock

In areal extent, migmatite occupies an area considerably larger than that occupied by all the other basement rocks combined (Fig. 3). Coarse porphyritic granite which occurs as large emplaced bodies occupies a lesser area, but it gives rise to the largest number of inselbergs (table 31).

Table 31

Frequency of Inselbergs in Relationship to Parent Rock

<u>Rock Type</u>	<u>Number</u>	<u>% of Occurrence</u>
Coarse Porphyritic Granite	157	43.13
Migmatite	152	41.76
Older Granite	25	6.86
Syenite	15	4.12
Porphyroblastic Gneiss	10	2.75
Granite Gneiss	3	0.82
Augen Gneiss	1	0.27
Muscovite Tourmaline Granite Gneiss	1	0.27

The above point can be clarified if the frequency of inselberg occurrence is examined at different localities. In the granitic terrain at Eruwa-Lalate,

and Idere-Tapa, inselbergs occur at a rate of 1 per sq. mile; in the migmatite area around Ado Awaiye, inselbergs occur at a rate of 1 per 2.5 sq. miles, but around Oyo they occur at a rate of 1 per 6 sq. miles; in the Syenite and Older Granite terrain at Oke Iho and Iwera areas, they occur at a rate of 2 per sq. mile.

Height and Size in Relationship to Parent Rocks

The histograms of the frequency distribution of inselberg heights (table 32) and size (table 33) in the different rock types are skew (figs. 50 and 51). For comparative purposes, the modes are therefore used.

Table 32 Inselbergs' Heights in different Rock Types

Class Interval (soft)	<u>Coarse Porphyritic Granite</u>		<u>Migmatite</u>		<u>Older Granite</u>		<u>Syenite</u>	
	Number	%	Number	%	Number	%	Number	%
51-100 ft	26	16.56	46	30.07	4	16	1	6.63
101 - 150 ft	33	30.02	36	24.18	6	24	2	13.33
151-200 ft	21	13.38	29	18.95	7	28	1	6.66
201-250 ft	23	14.65	18	11.77	2	8	3	20.00
251-300 ft	15	9.55	6	3.92	1	4	-	-
301-350 ft	14	8.92	7	4.58	1	4	1	6.66
351-400 ft	5	3.19	4	2.62	-	-	2	13.33
401-450 ft	5	3.19	1	0.66	-	-	1	6.66
451-500 ft	4	2.55	1	0.66	3	12	2	13.33
501-550 ft	2	1.27	1	0.66	-	-	-	-
551-600 ft	1	0.64	1	0.66	-	-	-	-
+600 ft	6	3.83	1	0.66	1	4	-	-

Inselbergs formed in Coarse Porphyritic Granite have a mode of 101-150 ft., compared to 151-200 ft. in the older Granite, 201-250 ft. in Syenite, and the much lower value of 51-100 ft. for migmatite.

FREQUENCY DISTRIBUTION OF INSELBERGS' HEIGHTS

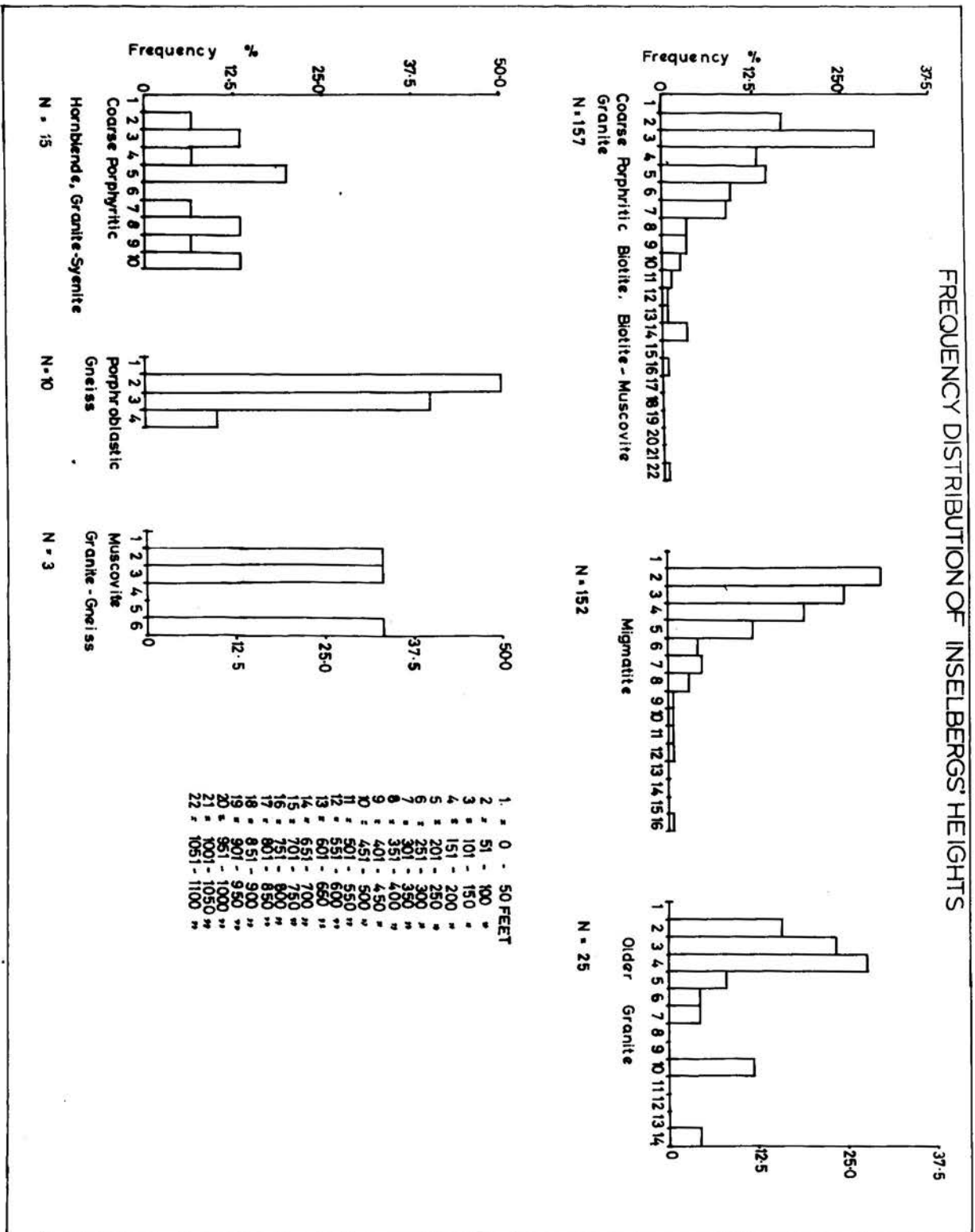


FIG. 50

Table 33

Inselbergs' Sizes in different Rock Types

Class Interval (0.0320 sq ml)	Coarse Porphyritic Granite		Migmatite		Older Granite		Syenite	
	No.	%	No.	%	No.	%	No.	%
0.0-0.0320 sq ml	29	18.48	54	35.53	25	20	2	13.3
0.0321-0.0640 sq ml	41	26.11	53	34.87	27	28	3	20.0
0.0641-0.0960 " "	28	16.56	19	12.50	6	24	4	26.7
0.0961-0.1280 " "	22	14.02	10	6.58	3	12	1	6.7
0.1281-0.1600 " "	7	4.46	2	0.66	-	-	2	13.3
0.1601-0.1920 " "	5	3.19	4	1.32	1	4	-	-
0.1912-0.2240 " "	5	3.19	-	-	1	4	1	6.7
0.2241-0.2560 " "	4	2.55	2	0.66	-	-	2	13.3
0.2561-0.2880 " "	3	1.92	2	0.66	1	4	-	-
0.2881-0.3200 " "	1	0.64	2	0.66	-	-	-	-
0.3201-0.3520 " "	1	0.64	2	0.66	-	-	-	-
0.3521-0.3840 " "	-	-	-	-	-	-	-	-
0.3841-0.4160 " "	1	0.64	1	0.33	1	4	-	-
0.4161-0.4480 " "	-	-	-	-	-	-	-	-
0.4481-0.4800" "	3	1.92	-	-	-	-	-	-
+0.4800 " "	7	4.46	1	0.33	-	-	-	-

Inselbergs formed in Coarse Porphyritic Granite and the older Granite have a mode of 0.0321-0.0640 sq. ml., while those formed in syenite have a mode of 0.0641-0.0960 sq. ml. These are larger than those formed in migmatite with a mode of 0.0-0.0320 sq. ml. These observations show that granites produce larger inselbergs than migmatites.

Some inferences may be drawn from the morphometric properties listed above. Granitic inselbergs are larger and higher than those developed on gneiss; and their frequency of occurrence is greater than those on migmatite. These variations do not necessarily suggest a difference in the evolutionary pattern of these inselbergs; they only reflect the response to the same process by different structures. This is important if the mode of inselberg evolution is to be properly interpreted.

There are several factors which make it possible to conclude that the inselbergs of South Western Nigeria have resulted from deep chemical weathering and erosional stripping within several cycles. Primarily, there is a consistent and close association between tors, corestones and low convex rock outcrops.

In the granitic terrain of Idere-Tapa, and Eruwa-Lalate, inselbergs and low convex rock outcrops occur in close proximity, and these often carry tors, corestones and skeletal soils. A mile north of Tapa, a low convex rock outcrop has a large corestone precariously perched on it (Fig. 52), and remnants of the supporting regolith are still present. East of Lalate, there is an area of about two sq. miles entirely covered by low convex rocks, tors, corestones and a few domes (Fig. 53). These features are also present around Eruwa where the valley separating the inselbergs are narrow, and the valley slopes carry a large number of tors and corestones. The eastern side of the Oke-Iho scarp has several tors and corestones, but only a few domes are present. Near Idere, several of the inselbergs carry tors on their upper surfaces (Plates 24 and 25). In the migmatite area, especially between Oyo and Fasola, domes occur adjacent to convex rock pavements, both on the valley slopes and on the interfluves, and the low domes (Plate 26) exhibit the same features as the high bornhardts around. Low convex domes are especially numerous between Agidan Hill and Oyo waterworks;

CORESTONES LYING ON LOW CONVEX GRANITIC
OUTCROP NEAR TAPA.

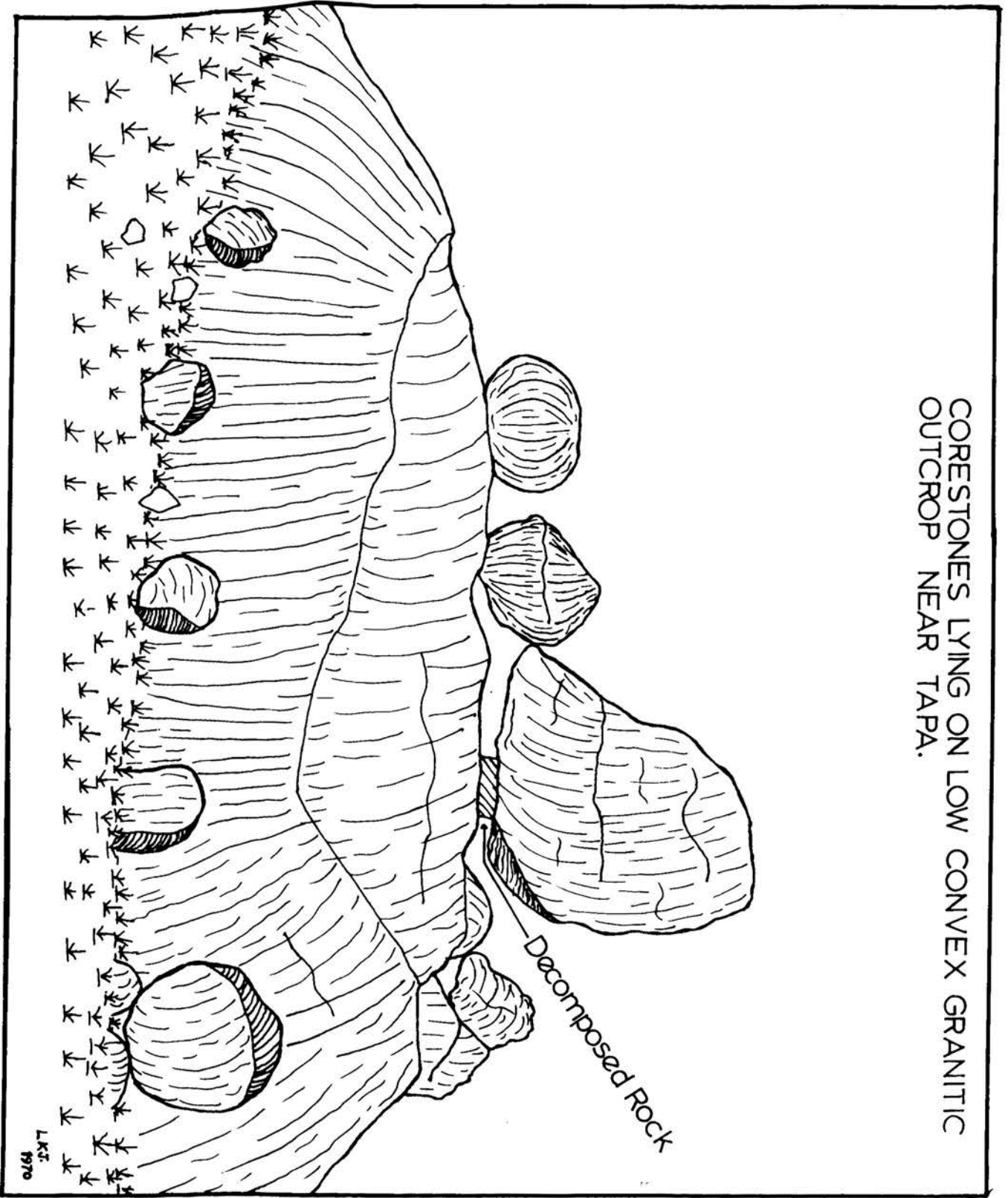
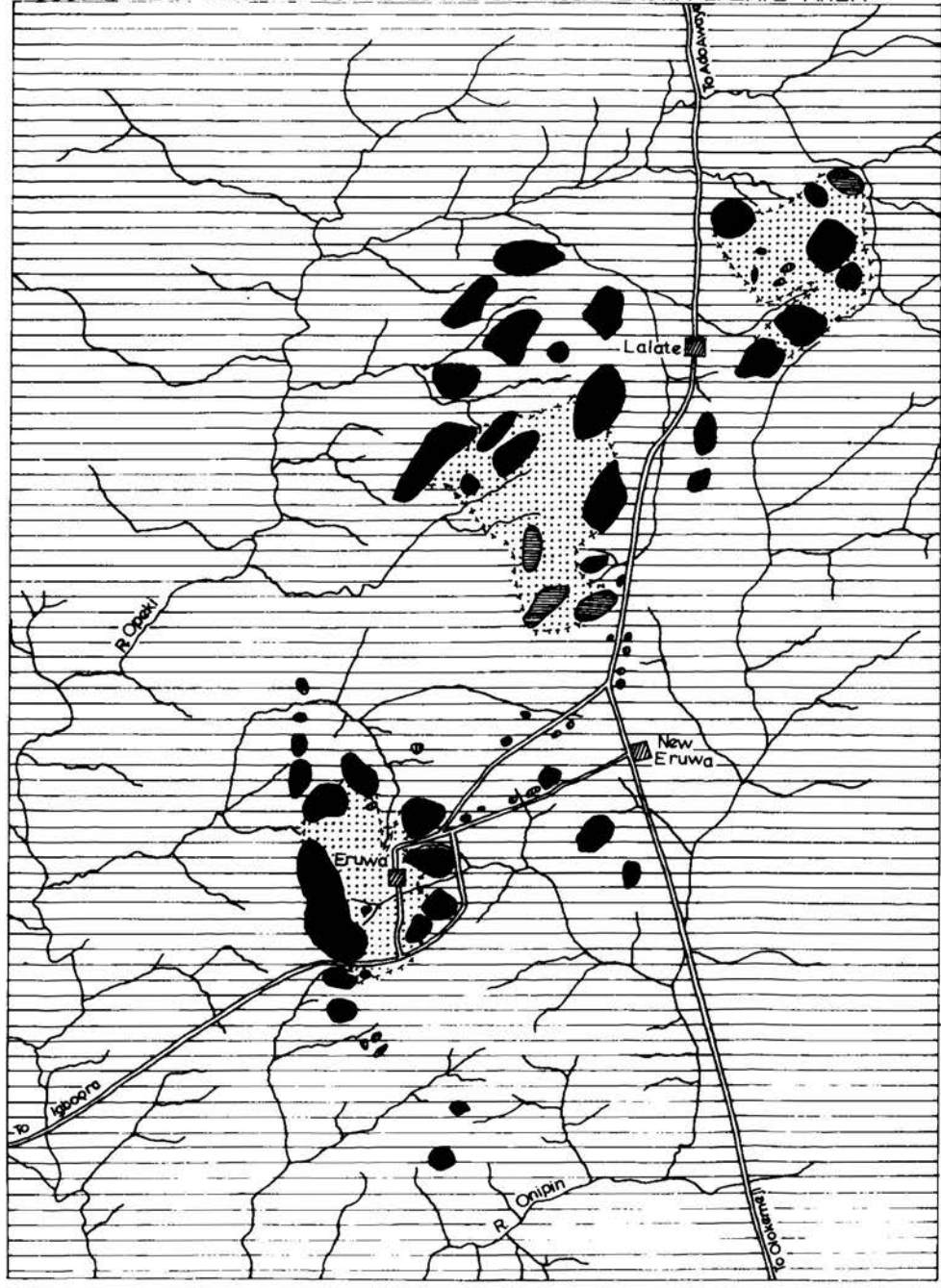


FIG. 52

OCURRENCE OF INSELBERGS AND LOCAL SURFACES ERUWA-LALATE AREA



- | | |
|--|---------------------------------|
| Bare Inselbergs | Partially stripped etch surface |
| Inselbergs partially or totally covered by regolith | Irregular scarpline |
| Small convex or flat rock outcrops | Important roads |
| Regolith undergoing erosional stripping
Tons corastones and laterite often present on its surface | Rivers |

FIG. 53



Plate 24 - A tor about 20 ft. on an inselberg near Idere

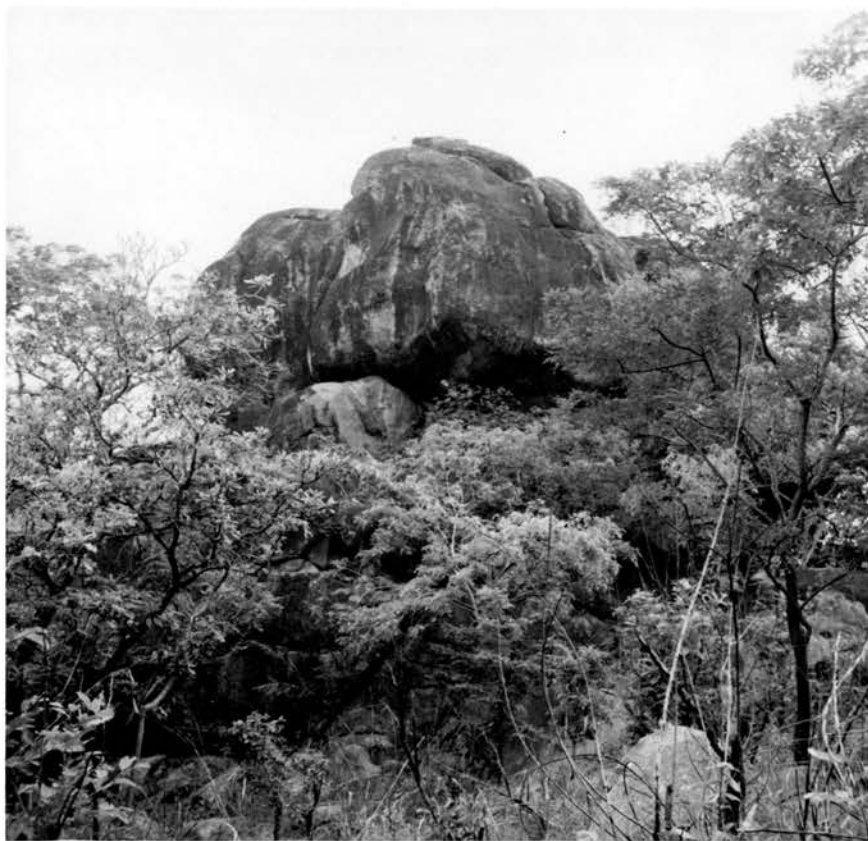


Plate 25 - Another tor about 25 ft. high on the same inselberg

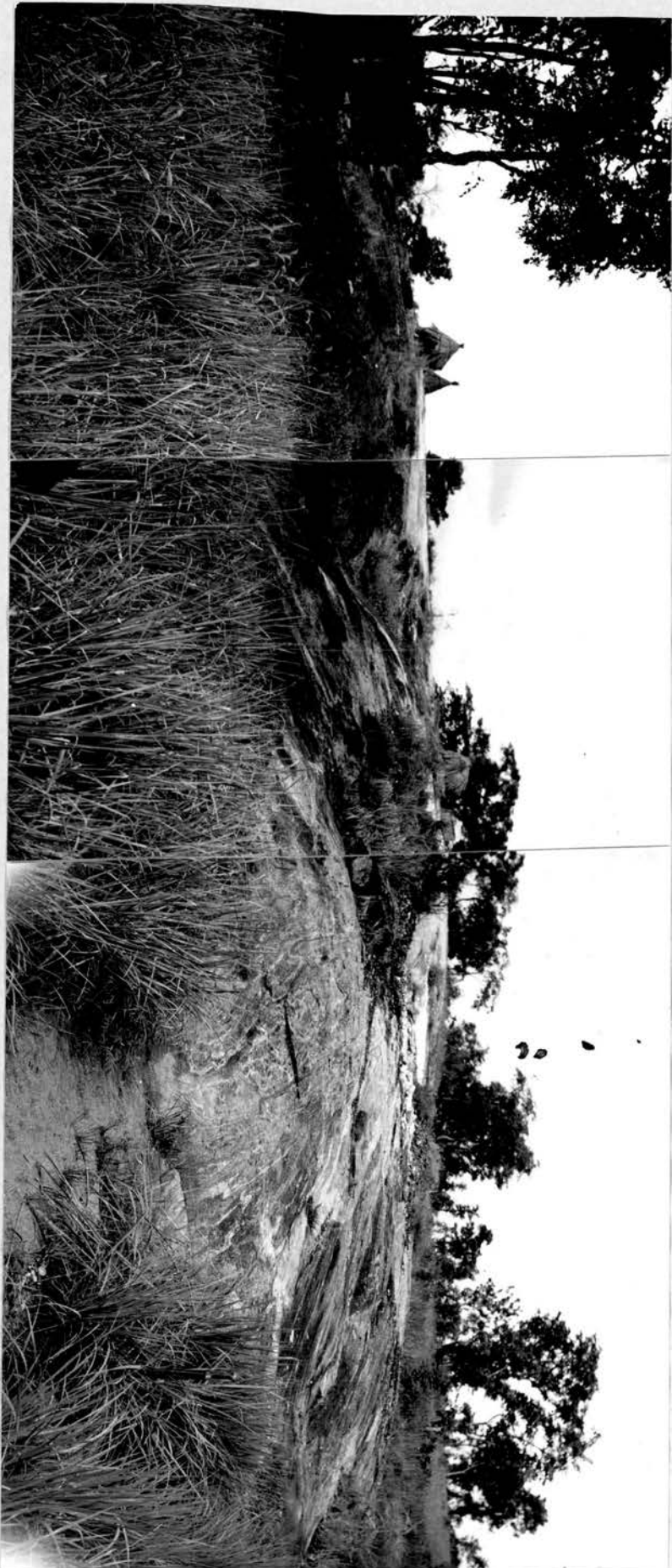


Plate 26 - A low dome between Agidan hill and Oyo waterwork, note the perfectly domical surface.

there are 25 in an area of about 1 square mile.

The contiguity of these low convex rocks, corestones, tors, and large domes in all these types of rocks, suggest that these features have been produced by the same process within the same cycles. They can only be satisfactorily explained as a result of deep chemical weathering and erosional stripping, but not necessarily as envisaged by Ollier (1960) or Pugh (1966).

Rock Structure and Lithology: Importance of Joints

Most authors agree that the presence of joints determine the frequency of inselberg occurrence in any type of crystalline rocks. Where joints are relatively unopened and far apart, large inselbergs are often formed; where the joints are closer together and relatively open, weathering will penetrate, destroying the smaller blocks by reducing them either into regolith if advanced enough, or to corestones. Thus zones of fissuring and shattering in crystalline rocks may be marked by tors, corestones and small rock outcrops. Where inselbergs are distributed close to one another, as in the granitic area, this is a reflection of the joint pattern, and where irregularly distributed, this can be traced to spatial variations in the structure and lithology of the rock as in the case of migmatite.

Inselbergs in the Eruwa-Lalate area show a definite compartmentalisation (Fig. 47) similar to those in Idere-Tapa area. This suggests that the emplaced granites which gave rise to these inselbergs were divided into large, subrectangular compartments by a regularly spaced vertical joint system which now appears as shatter zones. Migmatite does not show this type of compartmentalisation, but some sort of joint control may be apparent, e.g. at Ado Awaiye where a fault line exists between Ado Rock and an adjacent inselberg. The joint patterns in both inselbergs can be traced from one to the other. Unfortunately, joint systems cannot be traced in the regolith once weathering has taken place in a

crystalline rock, hence the above observations are tentative. Both Thorpe (1967) and Thomas (1966) have associated deep weathering with areas of joints on the Jos Plateau. The migmatite inselbergs show a structurally controlled trend making the rock weaker and less able to resist chemical weathering than granite. Further, granites are composed of closely interlocked crystals with corresponding low porosity whereas migmatite is foliated and relatively porous making it more susceptible to chemical disintegration. Thus the morphometric differences noted in the various inselbergs reflect the spatial variations in the distribution of joints in the different rocks, and also reflect their relative weatherability.

Differential Weathering In Granite and Migmatite

The distribution of the granitic inselbergs (Fig 47) suggest that the joints are few and far apart. Chemical weathering penetrates along these joints ^{and} rapidly destroys the shattered rocks between them and this often gives rise to a weathering basin in which a local water table, unrelated to the regional water table, develops. Weathering to some extent goes on below this local water table. Along the joints, spheroidal weathering is especially pronounced, so that the large sub-rectangular blocks into which the granites are initially partitioned are reduced to semi oval and rounded forms. Thus, as emphasised by Thomas (1962, 1966) the domed shape of granitic inselbergs would have been produced by subsurface weathering ever before the overlying regolith is stripped away. The basal surface of weathering in granite is often marked by corestones, and it has greater undulation than that in gneisses.

In migmatite, chemical weathering is relatively fast. With medium to high porosity, water can seep through the foliation bands; the darker minerals are destroyed first, after which there is a granular disintegration of quartz which often forms up to 70% of the minerals in migmatite. As migmatite is more friable than granite, often no corestones are produced. The basal surface of

weathering is undulating as shown by seismic survey and boring across the Opeki river between Igbo Ora and Eruwa (Fig. 19).

Regolith Stripping and Inselberg Evolution

Inselbergs in South Western Nigeria appear to have been produced by the erosional stripping of differentially weathered rocks. Many authors e.g. Ollier (1960) claim that the initial surface on which weathering started was flat and featureless with very little relief. These claims are difficult to substantiate, but they often help to simplify the problems of weathering and base level changes. In South Western Nigeria as noted in Chapter 5 and 6, the initial surficial configuration is unknown, but geological history suggests that the area was tilted southwards to the Gulf of Guinea from the primary watershed.

The evolution of inselbergs depends on the following factors:

- i. the total depth of weathering between the cycles of erosions;
- ii. the height differences between the base levels connected with the cycles of erosions;
- iii. the depth of stream incision within the current cycle;
- iv. the periodicity of cyclical uplift and base level changes.

These have been used in producing a schematic pattern of inselberg evolution in fig. 54, and are discussed below.

Base level changes

The evolution of the high inselbergs observed in South Western Nigeria requires multi-cyclic phases, but it is not possible at present to give a comprehensive record of the base level changes involved. An attempt has been made to reconstruct the base level changes involved from observations made at the inselberg terrains of Eruwa-Lalate (Fig. 53) and Idere-Tapa area. The deductions are based on the local surfaces and the heights of the inselbergs. The use of this type of data has some

WEATHERING AND EROSIONAL STRIPPING OF GRANITE

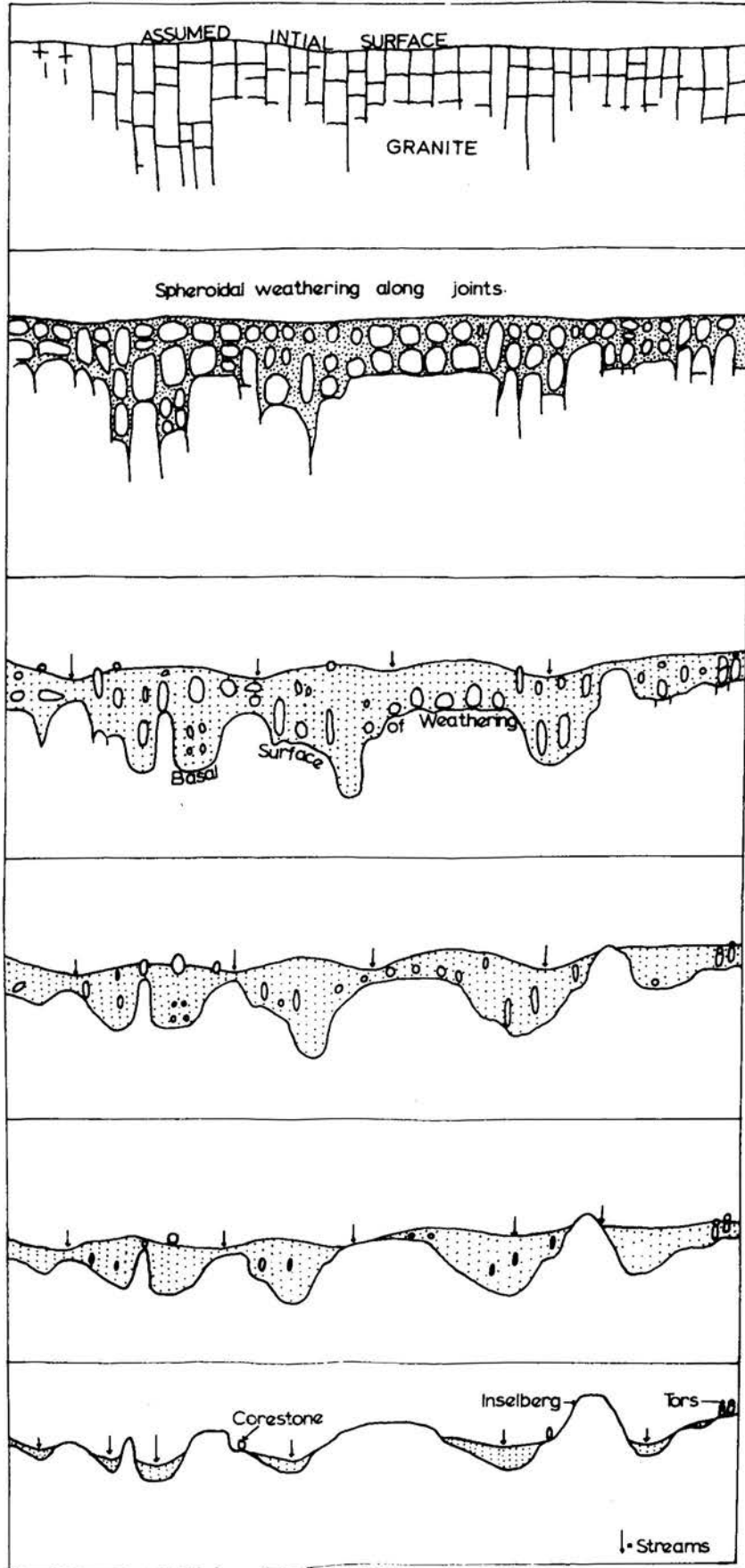


FIG. 54

limitations. First, it is uncertain that the depth of weathering was the same over all the inselbergs before they were exhumed. Second, since exhumation the domes have suffered differential lowering, hence accordance of summit may not be relevant. Third, the different dome levels do not necessarily indicate that they were produced under different cycles. With these limitations in mind, the observations can be discussed.

Field evidence suggests the presence of three local surfaces in Eruwa-Lalate area at 450-550 ft, 650-750 ft and 800-950 ft. The lowest surface is developed on schist lying between the granite, and the surface is in form of broad valley slopes. There are pisolithic and detrital laterites near the streams where recent incision has occurred as seen near Lalate. The upper surface is on the weathering profile of the granite. It is covered in some places by detrital laterite as seen within Eruwa township, and littered with corestones and tors. It is separated from the lower surface by an irregular scarp formed by partially weathered granite (Fig. 53). 21% of all inselberg occurrences lie between the lower (450-550 ft) surface and the upper surface (650-750 ft). The highest surface represented by the inselbergs' tops is at 800-950 ft, and these inselbergs constitute 69% of all the inselbergs occurring in Eruwa-Lalate area. There is thus an overall local relief of about 500 ft between the lowest surface and the highest surface which implies an erosional stripping of that extent.

In Idere-Tapa area, four local surfaces can be recognised. The lowest is between 300-425 ft occurring close to the Ofiki river where it carries tors, corestones and rock pavements. The next occurs between 500-550 ft, and is also covered by tors, corestones, and rock pavements. 10% of all the inselbergs occur between these two surfaces. There is another surface at 600-650 ft, and between this, and the lower one (500-550 ft) 15% of all the inselbergs occur. The highest surface represented by the tops of the inselbergs is at 700-950 ft, and

these inselbergs constitute 60% of all the inselbergs. The local relief is about 650 ft.

In Abeokuta area, the inselbergs at less than 500 ft are lower than the Cretaceous escarpment at 500-625 ft a.s.l. The Ogun valley forms the local baselevel at about 100 ft. a.s.l. The local relief is 400-500 ft.

From these observations it appears that the baselevel changes involved in the evolution of the inselbergs of South Western Nigeria could be estimated at 400-650 ft. While this may be used to explain the height of most of the inselbergs, it cannot apply to those at Ijio and Idanre whose heights are respectively 1,057 ft and more than 2,000 ft above the local surfaces. These latter inselbergs appear to be considerably older than others and have undergone greater changes of base levels.

The most important problem about base level changes is to determine the amount of uplift involved in every change of base level, and to calculate the number of baselevel changes that occurred. Geyl (1961) has ^{proposed} ~~propounded~~ that base level changes all over the world as shown by erosion surfaces analysis will be about 200 ft. within each cycle of erosion. This is difficult to apply in South Western Nigeria. As shown in Chapter 5, since the Tertiary period, there appears to have been two or three uplifts amounting to 150-200 ft as seen at the headstreams of rivers in Meko-Aiyetoro area. This in effect means that the pre-Tertiary baselevel changes would amount to 250-400 ft, and several of the inselbergs are pre-Tertiary. There is no doubt that the low inselbergs in Abeokuta area are Tertiary or much later as they were produced when the Upper Cretaceous sandstone was eroded (Chapter 13).

Erosional Stripping

The courses of the pre-Tertiary rivers responsible for the erosional stripping appear to be similar to the courses of the present rivers, and there is nothing to

suggest that they were ever aligned on areas of deep weathering as Ollier(1960) pointed out in Uganda. Thomas (1966) is inclined to believe that rivers may align on the top of the still nascent domes and that when the rivers cut down to the tops of the domes, they shift unclinally to the sides of the domes. Although attempts have been made to show that many of the rivers of South Western Nigeria have changed their courses, (Pugh (1955) Wilson and Bain (1922), Jeje(in press)), there is nothing to indicate that uniclinal shifting is responsible for all the inselbergs. What is apparent is that the location of streams before and after change of baselevel has nothing to do with the irregularity of the basal surface of weathering unless such rivers initially occupy lines of faults or other structural weaknesses.

The amount of stream incision that will occur with a change of base level depends on the ^{sea level} ~~vertical uplift~~ involved, and the deduced base level changes appear commensurate with the heights of most of the inselbergs in South Western Nigeria. The pattern of erosional stripping of the weathered regolith is fortuitous. Where there is a suitable lithological arrangement whereby laterite overlies the regolith, erosional processes would lead to parallel slope retreat, but where such an arrangement is absent, it appears that downwearing will prevail. Unfortunately, no old weathering profile could be observed in the field (on the basement complex in the thesis area), and the amount of laterite present is negligible. All over South Western Nigeria's basement complex, there is a paucity of what can be considered as primary laterite in the sense indicated by Du Preeze (1949). Instead detrital laterites are often found on interfluves, and these might have been formed by the disruption of an older laterite lying on higher elevations. The older weathering profile then could have been stripped by erosional backwearing. At the present time, most of the slopes on the basement complex are convex-concave in profiles, and where detrital laterites occur,

they ^{do not} give ~~rise~~ to free faces that could have encouraged erosional backwearing. The present slopes appear to be modified by surface wash, and to some extent by gullying, rilling and creep. Thus whatever process might have occurred in the past, today the dominant erosional process in the inselberg terrain is not backwearing but that of surface wash leading to the downwearing of the regolith in between the inselbergs.

In areas of migmatite, weathering is more thorough and the basal surface of weathering is rather sharp and regular; with base level changes, erosional stripping will reveal lower and smaller inselbergs than in granite. Where fracture zones have delimited large cuboids of rock, however, the inselbergs would be large. Migmatite inselbergs are fortuitously exhumed depending on the intensity of local erosion, and on the amount of the basal surface of weathering revealed within each erosional cycle. Hence extremely low domes often occur adjacent to high domes. Inselbergs in migmatite show no petrological boundaries between them and the local rocks.

In the granitic areas, the development of inselbergs closely follow the joint pattern which divides the original rock into large cuboids. The basal surface of weathering in granite is highly irregular and with the stripping of the overburdening regolith, large and often high inselbergs are juxtaposed with corestones and tors and in some cases, the tors and corestones occur on the inselbergs (Plates 24 and 25). Inselbergs in granite are not fortuitously exhumed. The pattern of stream development in the granitic areas is markedly radial or rectangular (Figs 45 and 47) indicating that these streams initially occupied zones of weakness in these rocks, and it is along these zones of weakness that weathering is concentrated. Thus the pattern of erosional stripping is probably compartmentalised, but this in no way indicates that each compartment shrunk towards itself by parallel slope retreat. The steep sides of granitic inselbergs

almost invariably mark the boundaries between granite and the weaker surrounding rocks. It can be concluded that inselbergs basically are products of differential weathering and erosion under multi-cyclic phases.

Further Evolution of Inselbergs (Disintegration)

Quite a large number of the inselbergs of South Western Nigeria have existed since the pre-Tertiary period surviving several cycles of deep weathering and erosional stripping around them. Between these cycles, some inselbergs are destroyed with their destruction related to the opening of the tight joints within the rocks which initially ensured their survival from subsurface weathering.

After the exhumation of inselbergs, the joint system within them still controls their mode of evolution. The closed joints within inselbergs are often opened up by weathering agencies especially by rain water seeping into them and initiating chemical weathering. (Plate 27). In as much as such vertical joints divide the inselbergs into large blocks, when the joints are widened by weathering, the individual blocks tend to collapse outwards (Plate 28). This has two effects. In low domes, with this collapse, the dome is destroyed and replaced by large piles of angular blocks; in medium to high domes, the central block may survive surrounded by large debris (Plate 29) to form the typical castle kopje. The upper domical convexity of the former inselberg can still be seen on top of such castle kopje (Plate 28). Thomas (1962) is of the opinion that castle kopjes are formed when an inselberg reaches a critical but undefined height, and its internal cohesion is overcome by tensional splitting along the joints, leading to outward collapse of the blocks. It is difficult to envisage how the concept is applicable since several inselbergs rise from over 400 ft. to 1,000 ft. above their local plains with no tensional splitting along their joints. Most castle kopjes observed are between 120-250 ft. above their surrounding plains, and they occur

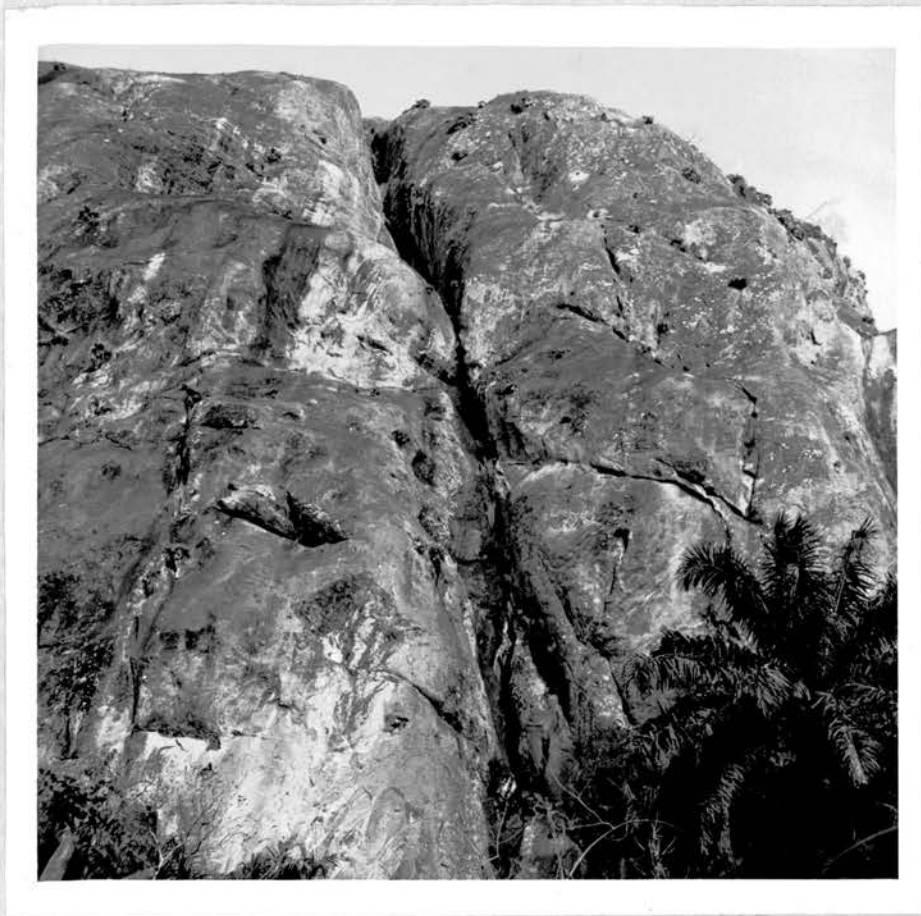


Plate 27 • Vertical joint being opened up by weathering.



Plate 28 - The vertical joints within the low granitic dome at the centre of the plate have opened up, and the blocks collapsing outwards. Note the upper convexity and the steep sides.

mainly in granite and syenite. It appears that their formation is related more to parent rocks than to any critical height. When granitic inselbergs are exhumed, the vertical joints within them are opened up by weathering agencies making their conversion into castle kopjes relatively faster than in other rocks. No example of a castle kopje was seen in the migmatite area.

Pugh (1955, 1966) has noted the phenomenon of dome-on-dome feature in inselbergs and attributes their formation to erosional bevelling within more than one cycle of erosion. This feature has been observed in the field on both granitic and migmatite inselbergs. The formation of the feature is related to the horizontal joint pattern within the rocks. Smaller domes are found on large domes near Eruwa, the vertical joints within the smaller domes have been opened up and the domes are tending to collapse outward. This shows that they were not formed by erosional bevelling. The dome-on-dome feature is noted strongly on a low migmatite inselberg near Ado Awaiye, and on a granitic inselberg near Igangan. The impression of the dome-on-dome feature arises because of the curvilinear joints present in these domes. These joints do not entirely cut across the inselbergs, so that while a part of the inselberg gives the impression of a dome-on-dome, the other side gives the impression of a single convex slope (Plate 30). If the feature is due to erosional bevelling, then all the inselberg's sides must be equally affected.

Physical and chemical weathering continue to affect the evolution of inselbergs after their exhumation. Unloading is an important aspect of the physical disintegration of inselbergs. This is a phenomenon whereby large sheets 3025 ft. thick are produced on inselbergs when the overburdening regolith has been removed. The sheets are said to be produced when internal compressional stresses within the rocks are released vertically and horizontally as a result of erosional stripping (Twidale 1964). Twidale (1964) and Mabbutt (1952) observed that the



Plate 29 - A castle kopje developed in syenite near Oke-Iho. Note the central surviving block.



Plate 30.- An inselberg near Ado Awaiye. To the left is the "dome-on-dome" feature, but to the right, the slope is continuous. Note the horizontal joint below the upper "dome".

degree of curvature of the sheets decrease with depth, and others believe that the unloaded sheets are curvilinear all round like onion skins. These observations are not always seen in the field. The form of the unloaded sheets appear to vary in different rock types. On most of the coarse porphyritic granite inselbergs, the sheets are curvilinear following the contours of such inselbergs (Plate 31). On migmatite, unloaded sheets assume various shapes and forms, but never this curvilinearity. They may often be horizontal, thicker at the middle, and taper away at the edges; where they develop along foliation lines they are oval shaped and massive; they may also be platy with their sides sharply truncated.

Unloaded sheets often cut across the vertical joints and the grain of the rock minerals. The speed at which they are broken up depends on the nature of the rocks forming them. Generally migmatite inselbergs are surmounted by few blocks, but at their bases, large screens are present. Granitic inselbergs are in several cases covered by large blocks. It could be that disintegration of unloaded sheets is much faster in migmatite than in granite or this may simply reflect the different times at which unloading occurred.

Thick exfoliation sheets 9 ins. - 2 ft. thick are found more frequently on the convex and straight slopes of the gneissic inselbergs than on the granitic types (Plates 32 & 33). They are formed as a result of chemical weathering penetrating along the foliation lines. The rock then split off like onion skins. These occur more rapidly than unloading.

Superficial exfoliation producing sheets 0.5 ins. - 3.0 ins. thick is common on all the inselbergs. Locally these thin slabs concentrate in gullies on the inselbergs, but they are usually deposited at the base of the flatter slopes. On granitic inselbergs, most of these small slabs are completely



Plate 31 - Granitic inselberg near Aiyete covered by an unloaded sheet which is breaking up into large blocks.



Plate 32 - Exfoliated sheet on granite-gneissic inselberg near Igangan.

disintegrated before reaching the base of the inselbergs. Field observations show that several new slabs were formed on gneisses between March and June of 1969 (Plate 34). A possible explanation of their formation lies in the high insolation intensity of March (hottest month of the year) coinciding with the period of bush burning. Also at this time there were occasional rains that could chill the extremely hot surfaces of these rocks leading to the exfoliation of the thin slabs.

There can be no separation of chemical and physical weathering but it is convenient to isolate them for discussion. All the large blocks and small slabs are weathered in situ either lying on the inselbergs or lying on the footslope. They suffer hydration (Plate 35) and granular disintegration. Examples of case hardening were noted in granite gneiss blocks (Plate 36); with the outer parts of the blocks being hard while the inner parts were soft. Ollier (1965) has suggested that this may be due to chemical addition to the outer layer of these blocks and leaching from the centre. Deep weathering pits variously referred to as taffoni or oricangas are developed on inselbergs. These are different from the grinding pits common on most inselbergs. Weathering pits are found on the flatter upper slopes, but could also be found on the steep convex slopes (Plates 37 & 38). They may hold water as seen on the Ado Rock. Weathering pits are formed where weaker intrusions are present in the main rock, or may be formed where pre weathering occurred along convergent joint lines. The one on Ado Rock is found at the point of convergence between N-S and 50° - 220° (NE-SW) joints. They may also form along the foliation planes (Plate 38). In some cases, the reason may not be apparent. Where the pits are favourably located, they are widened and enlarged by pot holing.

Both gneissic and granitic blocks often have their surfaces etched (Plate 39). The rough surfaces of such blocks often accumulate dust or may



Plate 33 - Exfoliated sheet on migmatite inselberg south of Iseyin.



Plate 34 - Fresh superficial exfoliation on granite-gneissic inselberg near Igangan. The rock pile to the left was broken up by the author. To the right the exfoliation was not disturbed.



Plate 35 - A block of granite undergoing weathering in situ. The rock is soft and can be broken with gentle taps with a hammer.



Plate 36 - A block of granite-gneiss which is case hardened.

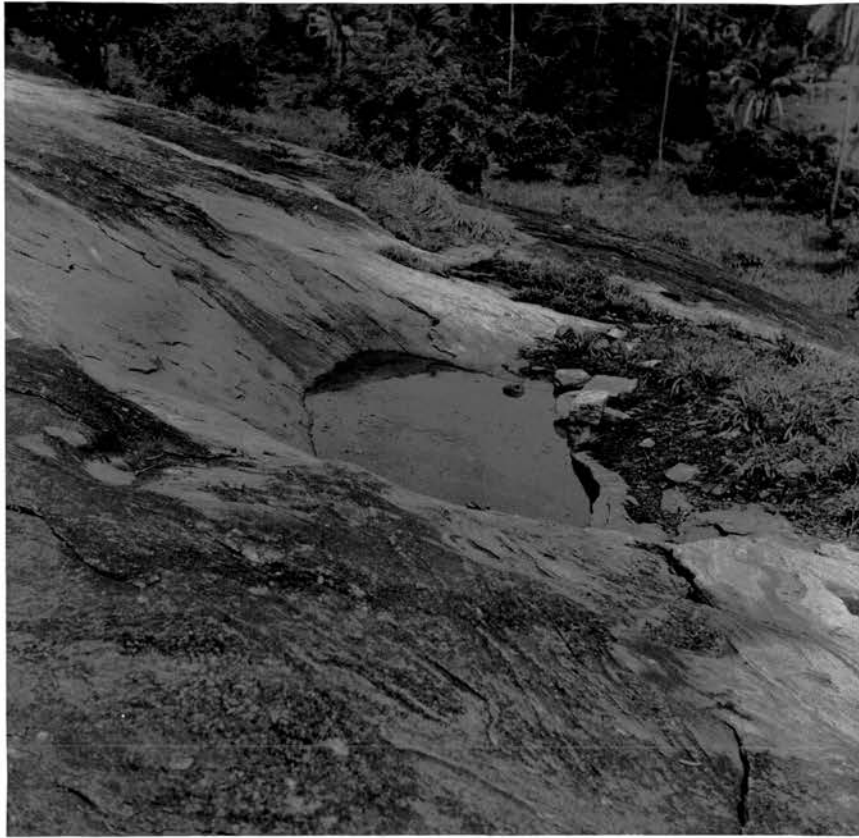


Plate 37 - Weathering pit on the convex slope of a migmatite inselberg near Fasola.



Plate 38 - Weathering pit along the foliation planes of the Aseka Hill (migmatite).

be colonised by lichens, mosses, and algae. After some time, they are further colonised by hardy grass e.g. Cylindrica Imperata which are capable of trapping more dust to lead to more grass growth. These plants produce humic acid when they rot, and this acid reacts with rain water to cause subsurface rotting of these blocks. In an extremely dry season, the grasses and micro flora die, their roots no longer retain the soil, it is blown away to reveal irregular hollows on the blocks.

Trees can also grow between joints to cause physical and chemical disintegration. Thick exfoliation sheets are often delimited by superficial joints along which hardy grass and plants grow; as the roots of the plants develop, they widen the joints and the exfoliation sheets are broken up. Deeper joints in the main inselbergs are also opened up by chemical weathering and gets colonised by grass and trees. Foliation planes are also equally colonised with consequent weathering. The enlargement of such joints and foliation planes causes deep grooves on inselbergs and can initiate gullies (Plate 40).

Rain water falling on inselberg's surface, runs off, often in sheets which seep into the scree at the base of inselbergs to effect subsurface weathering. Where such weathering coincides with horizontal joints deep niches are formed at the base of the inselbergs. It is not surprising to see cultivation localised on the scree slopes in the savanna area as water often seeps out from the base of the slopes even in the middle of the dry season. With erosional stripping of the weathered regolith at the base of the inselberg, the typical basal concavity results. There is nothing to show that such overhangs may collapse as suggested by Twidale (1964) unless vertical joints are present. This phenomenon referred to as basal sapping or foot rot - Ruxton and Berry (1961a) is common to all inselbergs whether granite or migmatite.



Plate 39 - Etched blocks lying on an inselberg near Odo-Ogun



Plate 40 - A gully developing along a weathered joint plane.

The net effect of both physical and chemical weathering on inselbergs are these: (i) a general but slow decrease of inselbergs' heights and areas will occur. This may, to some extent, affect the pattern of local precipitation over a long period. When inselbergs are very high, as the Ilele Hill (1,057' above its local surface), they often cause local orographic rainfall when warm air is forced to rise, but with their steady decrease in height, this pattern will change. (ii) More important, replacement slopes are built around inselbergs where unloaded blocks fall around them building screes (apron drift) (Plate 41). This reflects the balance between waste production from inselbergs and the destruction of such waste materials by weathering and mass movement at the base of the inselbergs. (iii) Skeletal and occasionally deep soils are developed on inselbergs and this leads to vegetation colonisation of the inselbergs. The waste matter from these vegetation often react with rain water to further effect the chemical destruction of such inselbergs. (iv) Subsurface weathering of inselberg's bases coinciding with the opening up of vertical joints near the bases lead to a steepening of the inselbergs' sides.

Weathering is not as important as surface run off and gullies in destroying inselbergs. Direct surface runoff on inselbergs' surfaces is the most efficient way of disposing of the large amount of water falling on the inselbergs in the rainy season, and some 80% is removed in this way. Run off transports away the particles of weathered material and the exfoliated rock flakes to produce the typical rough inselbergs' surfaces (Plate 42). Usually no channels result, but permanent channels may be developed where there is a concentration of runoff along pre weathered foliation planes in gneisses. This is especially common on the steep faces of the Ado Rock where a system of rills have developed on the western face which perhaps induced Pugh (1955) to conclude that the steep slope is retreating parallel to itself. After the



Plate 41 - Scree at the base of an inselberg near Eruwa.



Plate 42 - Run off has transported away the weathered particles and the exfoliated slabs to make the surface of this inselberg rather rough.

rains, some of the water may be retained in patches of soil on the slopes, with drainage some 3-4 days after the rain. Some water seeps directly into joints (Plate 43) to appear at the base of inselbergs as springs, but such springs are incapable of causing spring sapping.

Gullies are present on all the inselberg types and as correctly observed by Savigear (1960) they are responsible more than other agents for destroying inselbergs. Gullies may divide inselbergs into two or more parts e.g. Agidan hill near Oyo (Plate 44) and they are more common on migmatite than on granite. On the Ado Rock, eight gullies occur on the eastern side alone. The gullies are often very large. On a migmatite inselberg near Iseyin, one fully measured 300 ft. in length, 150 ft. in width, and 100 ft. in depth, and near Odo Ogun village another measured 300 ft. in length, 30 ft. in width and 20 ft. in depth on a migmatite inselberg. Those on the Ado Rock are of ^{very large} immeasurable dimensions (Plate 45).

Gullies can be initiated by several causes.

- (a) They can form where weaker dykes of pegmatite intruded into either granite or migmatite. The dykes weather more rapidly than their host rocks and form depressions along which run off is channelled. The depressions gradually get enlarged into gullies. This is common on the granitic inselbergs around Eruwa.
- (b) Gullies form more commonly along joints in all the rocks as a result of expansion and widening of the vertical joints by weathering (Plate 40).
- (c) On migmatites gullies are initiated along the foliation planes. This may explain why gullies are more common on migmatite inselbergs.
- (d) Gullies may originate at the top of inselbergs where pre weathering along convergent joints created a "trough-like" feature. Such features are



Plate 43 - Water seeping out at the lower part of an inselberg, from a vertical joint. (Feb. 1969).

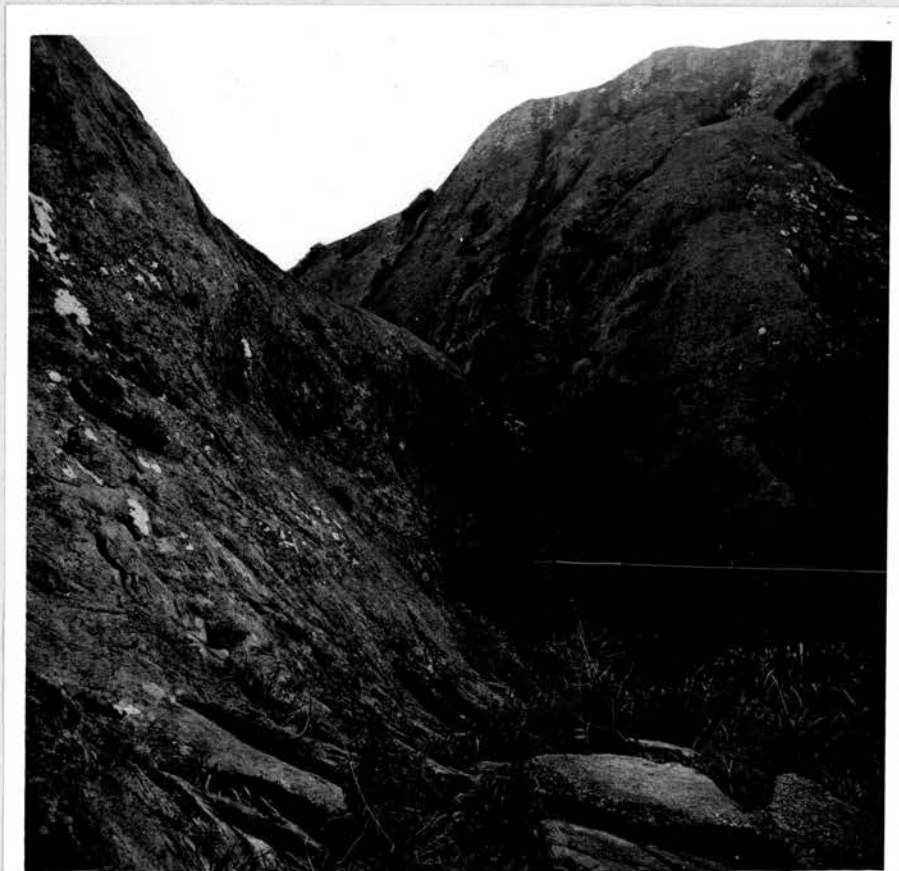


Plate 44 - Agidan Hill near Oyo divided into two parts by a gully.



Plate 45 - One of the large gullies on Ado Rock (Ado Awaiye)

common on both migmatite and granite. On Ado Rock, such a trough measured 100 ft. in length, 15 ft. in width and 6 ft. in depth. Water is channelled away by these troughs, and the transported boulders deepen the channels, subsequently creating deep gullies.

After initiation, gully development is by headward erosion along the joints and the foliation planes. Erosion is preceded by weathering, runoff removes the weathered material and ~~gets~~^{is} incised into the weathered plane. Lateral development is by exfoliation and spalling of rock slabs. Downcutting is effected by pot holing with the fast runoff using the exfoliated slabs as erosional tools. Most of the gullies observed are still downcutting, but some are choked with debris which are rotting in situ (Plate 46). Spectacular as the gullies are, their development is relatively slow, and rather intermittent.

The rate of operation of all these destructive agencies is relatively slow both in time and space, and this makes it possible for many inselbergs to have survived several erosional cycles since the pre-Tertiary period. There are still some features connected with inselbergs e.g. basal knicks and depressions not mentioned in this chapter, they will be examined in the succeeding chapter.



Plate 46 - Gully filled with debris rotting in situ (south of Iseyin).

Chapter 10

Pediments

Pediments constitute important landform elements on the crystalline basement complex of South Western Nigeria. Descriptions of pediments occur persistently in the literature on inselbergs, but with the exception of Pallister (1956) no attempt has been made to show the different slope units found on pediments. In this chapter, the following will be discussed:

- a) the extent of pediments around the different types of inselbergs,
- b) the slope units constituting the pediments and the material associated with these slope units,
- c) differences in pediment declivity in different vegetation zones,
- d) characteristics of the abrupt junction between inselberg's base and the pediment's head, and
- e) the nature of the footslope depressions found at inselbergs' bases.

Methods of Study

Slope measurement was based on the slope mapping system suggested by Savigear (1956) and later revised in 1965. The different slope units were recognised in the field and measured orthogonally across the contour lines from the adjacent streams to the bases of the inselbergs. An Abney level was used to take slope readings, ranging rods and a measuring tape were used to measure the distance between the slope breaks. Pediments were measured in different geomorphological regions, especially on the dominantly stripped etch surface, and the dominantly stripped etch plain, and in different vegetation zones. The latter included the forest around Ife, forest/savanna area around Ohq and Idere-Tapa districts, and the savanna area between Oyo and Fasola, Ado Awaiye - Iseyin and Eruwa-Lalate districts.

Around each inselberg, attempts were made to measure slopes on a N, S, E or W, or on a NE, NW, SE or SW pattern wherever possible. In several cases, however, this proved impossible either because of the physiographic location of the inselberg (i.e. where located on a valley slope) or because of thick vegetation around the inselberg which made the cutting of traverses difficult and expensive. The number of pediments measured in the forest area were few because of inaccessibility. For each slope segment or element, the material composing the slope was investigated based on three categories (i) whether it is composed of mainly unweathered material, usually coarse rock fragments, (ii) whether it is composed of weathered or partially weathered material immersed in soil matrix (iii) or whether it is composed mainly of soil with or without a few rock fragments.

Pediment: Sensus Stricto

Due to the difficulties of interpretation, many geomorphologists have avoided using the term "pediment" especially in the humid tropics e.g. Savigear (1960). Ruxton and Berry (1961a) prefer to use non-genetic terms to describe the slope facets below inselbergs. They divide the slope profiles into plain, plinth (footslope) and hillslope. The major problem lies in deciding where each type begins and ends, and this may not be possible. In an earlier paper (1958) Ruxton and Berry used the words "piedmont angle" to delimit the inselberg slope and its associated scree slope from the lower slope units, calling the slope above the piedmont angle, the upper pediment. The use of these non-genetic terms can lead to further confusion and so it seems advisable to retain the word pediment and use it with some caution. The term could be applied to footslopes below inselbergs wherever they occur, notwithstanding the processes that could have produced them. It is best used as a descriptive rather than as a genetic term, thus in this work, the word has no genetic significance.

Delimitation of the upper and the lower limits of pediments

The delimitation of the lower limits of pediments presents no problem as most pediments are bounded by streams. Where such streams are absent, pediments are often terminated where the land starts to rise to other neighbouring inselbergs. The upper limit of pediments is more difficult to determine. Huxton and Berry (1958) state that the pediment is separated from the inselberg and its associated scree slope by a distinct piedmont angle, and this view is shared by Cotton (1947) and Rahn (1966). Savigear (1960) did not make this distinction, but established that both steep and relatively flat footslopes can occur together depending on the nature of the constituent material and the erosional processes. Most of the examples cited by these authors are from the semi arid areas. In the humid tropical area around Oyo, Thomas (1967 p. 251) has shown that even around a single inselberg, there are different types of slope breaks between inselberg and the surrounding footslope.

In this study, the delimitation of the upper limit of the footslope is based on the recognition of the gently or sharply concave slope element which often separate the scree slope from the flatter slope below. Where no scree slope exists, this concave slope element is well marked (Plate 47). However, it must be noted that in several cases, the inselberg slope itself may merge imperceptibly into the footslope with hardly any change of slope especially where the asymmetry of the inselberg as delimited by its bounding joints, foliation planes and dip of foliation is well marked.

Relative sizes of Pediments

The impression gained from the literature is that pediments are extremely wide, often several miles in length from the inselberg to the neighbouring stream lines and are regularly concave away from the inselbergs. This may be true for areas where pedimentation and erosional bevelling are important geomorphological

processes, but it is not necessarily true for the humid tropical area of South Western Nigeria.

The relative longitudinal extent of pediments from the stream line to the limiting scree slope at the base of the inselberg depends on the physiographic location of the inselbergs. Where inselbergs are located on valley slopes close to the streams, pediments are very short or non-existent. The average length of pediments of this type is about 700 ft. Where inselbergs have been produced by compartmentalised weathering and erosion as in the granitic areas of Eruwa-Lalate, Idere-Tapa, Oke-Iho-Iwere, pediments are very short averaging 500 ft., although a few may be up to 2,000 ft. long (Figs. 55 and 56). Where the sides of the inselbergs mark petrological boundaries with the country rocks, and the footslopes are developed on weaker rocks like schist or amphibolite, e.g. at Eruwa, pediments could be more than 2,200 ft. long. Where inselbergs are located on the principal watersheds, the pediments are very long often reaching 300 ft.

Pediment slope units and materials associated with the slope units

The terminology used here is based on Savigear (1956) and are shown below.

Slope profile - all the slope units within a longitudinal section traverse
from the stream to the inselberg slope.

Slope unit - slope segment or slope element.

Slope segment - a rectilinear ^{portion} portion of a slope profile.

Slope element - a curved portion of a slope profile whether convex or concave.

Convex slope element - this increases continuously in angle downslope.

Concave slope element - this decreases continuously in angle downslope.

A slope sequence - a portion of a slope profile consisting successively of
a convexity, a maximum angle segment and a concavity.

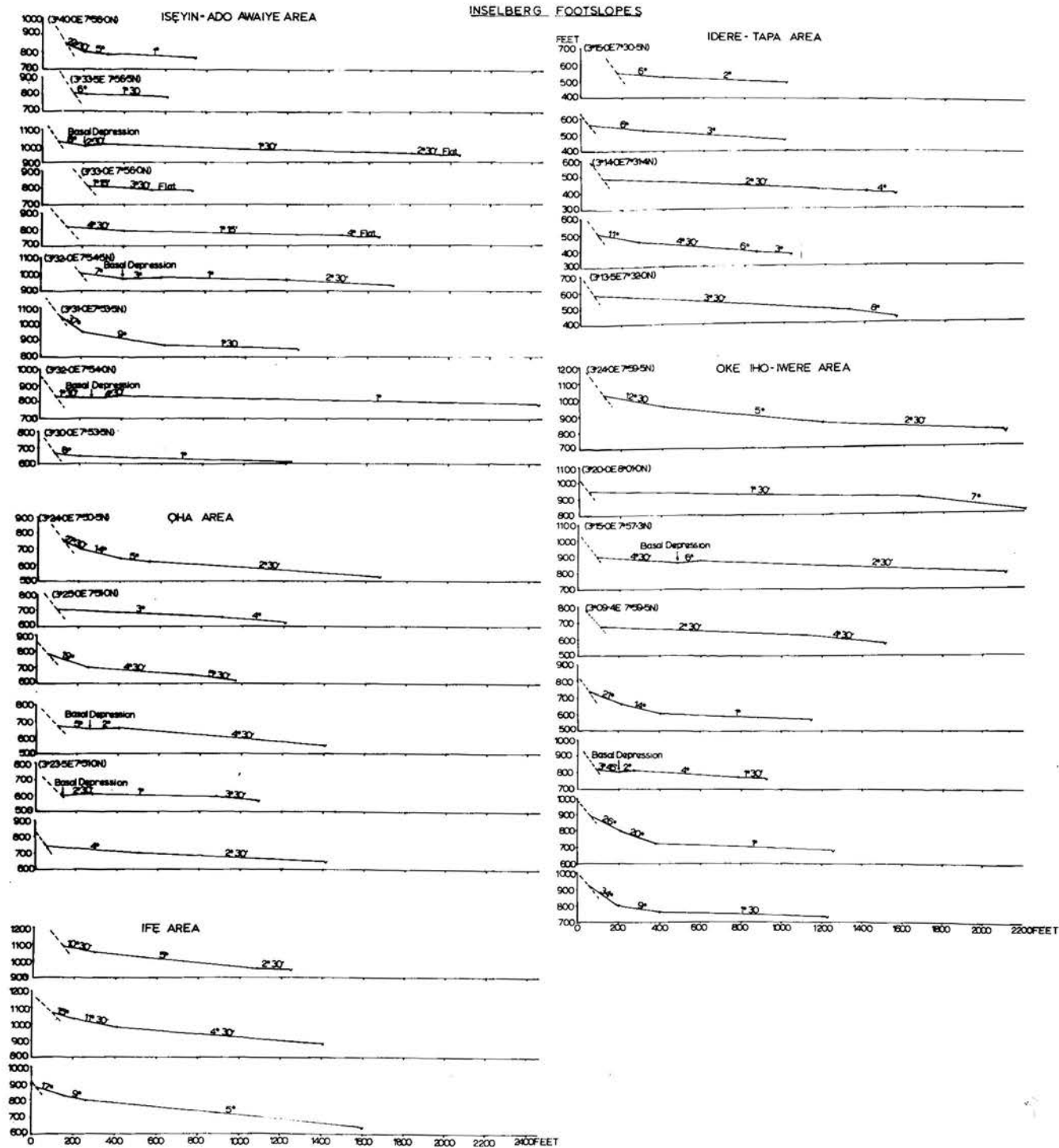


FIG. 56

All the pediment slope profiles measured can be conveniently grouped into three types;

a) The concave profiles: These constitute 80% of all the slope profiles measured. The slope starts imperceptibly from the stream line rising gradually to the scree slope and the side of the inselberg. They occur mainly where there has been no recent stream rejuvenation. The profiles usually consist of 2 - 4 slope segments and elements (minus the inselberg's slope), but the most typical are those consisting of two slope segments and one slope element. The first segment away from the inselberg is the scree slope which varies from 10° - 37° in both granitic and gneissic areas; the length of the segment varies from 25 ft. to 150 ft. (Figs. 55 and 56). The declivity of this slope is mainly determined by the coarseness of the material shed by the parent rock, and most of the scree slopes are steep because the materials composing them are large, coarse, blocks of varying dimensions which may be partially weathered, or fresh. These scree slopes are often associated with the steep sides (30° - 85°) of inselbergs, but this association does not hold in all cases.

The next segment is rectilinear, but could be concave at times. It is often separated from the main scree slope by a sharp break, or in a few cases, the point of separation may be imperceptible. The slope of this segment varies from $2\frac{1}{2}^{\circ}$ - $11\frac{1}{2}^{\circ}$, and the length varies from a few feet to more than 100 feet. It is composed either of completely or partially weathered blocks (more than 50% of the constituents) immersed in soil, or, at times of coarse fragments of quartz and felpars mixed with finer soil constituents. In several cases, this particular slope unit has replaced the steep scree slope. Two independent processes could have been responsible for the formation of this slope unit. First, the materials composing the slope segment could have been washed out in a sorting process from the scree slope above by rill action. This is the process favoured by Savigear(1960)

Second, the materials composing the slope segment could have been derived from the inselberg by exfoliation, washed down slope in the form of debris, and stream deposited at the base of the inselberg where it will undergo weathering and down slope mass movement. This second explanation will be valid where no large debris slope is present. The above slope unit is often considered as the pediment head as it separates the scree slope from the footslope below.

The lower pediment slope unit is the most important because it is always present around inselbergs. Its declivity depends on the physiographic location of the parent inselberg. Where inselbergs are on valley slopes, this slope unit varies from 3° - $6\frac{1}{2}^{\circ}$, elsewhere it is rarely above 6° . The slope is mainly composed of weathered regolith with laterite occasionally occurring on its surface, but in many instances, low convex rock outcrops, corestones and tors may diversify its surface. As this slope occurs regularly around most inselbergs, it appears most useful as a measure of comparison from area to area.

b) Concave - Convex Profiles.

These constitute about 11% of all the pediment slope profiles measured (Figs. 55 and 56) and are commonly found in areas of recent stream rejuvenation. The profiles consist of 3 - 5 slope units, but the typical type consists of 4 units. All the segments and elements discussed above are present and not essentially different. The fourth slope unit is the convex slope element near the river which varies from a few feet to several hundred feet. Its declivity varies from $2\frac{1}{2}^{\circ}$ - 7° . The surface of this slope element is often masked by pisoliths of laterite and is also occasionally scoured by rills. It is almost invariably followed by a flat slope unit near the river, composed of alluvial material.

c) Complex Profiles

These have the slope units discussed in the Concave, and the Concave-Convex

Profiles, but are diversified by minor slope units near the inselberg bases (Figs. 55 and 56). The scree slope is absent and is replaced by a flatter slope unit of 1° - 4° . This slope is followed downhill by another slope unit 2° - 6° and the two together constitute the basal depression at the base of the inselberg. (Figs. 55 and 56). These are then followed by the other slope units previously discussed.

Pediment Angle under different Vegetational/Rainfall Regimes

In chapter 5, it was emphasised that erosional processes, especially surface wash, are more pronounced in the savanna than in the forest because of the differences in the ~~length of the rainy season~~ ^{vegetation cover}. The implication of this is that footslopes in the forest will be steeper than those in the savanna. Before comparing footslope declivities in the different vegetation zones, it is necessary to note that there are other factors governing footslope steepness. They are the nature of the parent rock, and the stage of erosional stripping of weathered material by runoff and other agencies. In the field, differences in parent rocks have not affected the declivity of the footslopes and these produced around granitic inselbergs have the same slope units and angles as those produced around migmatite inselbergs. This is especially marked where measurements are carried out in the same landform category e.g. Oyo-Fasola (migmatite) area, Oke-Iho-Iwere (granite and syenite) area. To solve the problem of differences that may occur as a result of differences in the stages of landform development, slope profiles were also compared for the dominantly stripped etchsurface, and the dominantly stripped etchplain in the savanna. Both show no basic differences.

The three vegetation zones in the survey area are the Derived Savanna, the Forest/Savanna transition zone and the Forest. Some work was carried out in the forest around Ife. The derived savanna resulted from the long term effects of

shifting cultivation and annual firing, as exemplified in Oyo district where the area has been in use over 200 years. In the forest-savanna area, where patches of forest occur in the savanna and vice versa, settlement and cultivation is still recent. Since the vegetation types and length of deforestation in both areas are different, pediments would not be of the same declivity. The savanna area will have flatter slopes while the pediments in the savanna/forest zone would be steeper, and those in the forest will be steepest. The table below shows a summary of the observations made under the different vegetation zones.

Table 34: Pediment slopes in the different vegetation zones

Number	Vegetation		0°-0.9°	1.0°-1.9°	2.0°-2.9°	3.0°-3.9°	4.0°-4.9°	5.0°-5.9°	6.0°-6.9°
48	Derived								
	Savanna	%	-	56.25	16.7	10.4	8.3	6.25	12.10
11	Savanna								
	Forest	%	-	9.0	27.0	37.0	27.0	-	-
3	3	Forest	%	-	-	-	-	33.4	66.6

The following analysis also tend to confirm the relationship between slope and vegetation. In the derived savanna, the slope declivity has a range of 1°-6° with a mean of 2.25° and a standard deviation of 1.39°. In the savanna/forest area the range is 1°-4½° but the mean is 3.1° and the standard deviation is 1.17°. Both measurements show no normal distribution. In the forest area, the data is regretably few, but slope measurements in places 15 miles apart show a range of 4½°-5° with a mean of 4° 50'.

The chi-square method is employed to test the observed values of pediment slopes in the forest/savanna and the derived savanna area. The X^2 value is 152.35 and the Degree of Freedom is 5. From the Table 5 of the Cambridge Elementary Statistical Table by D.V. Lindley and J.P. Miller, it can be seen that the difference between the slope categories is significant even

at 0.1%. The data for the forest area ^{are} ~~is~~ not enough to permit the analysis of variance for all the slope categories, but it appears that it is also significantly different from the other areas. More systematic survey of these slope units under the different vegetation zones is still necessary in order to make available a larger body of data to permit of more rigorous testing. The hypothesis that can be advanced is that although factors like rock type, stages of landform development and erosion, and the physiographic location of inselbergs affect pediment slopes, the angles of footslopes are more fundamentally affected by the vegetation prevailing on the footslopes. Footslopes in the savanna are generally flatter than those in the forest.

Basal Knick

Many authors have referred to the fact that sharp knicks often separate the slope of the inselberg from the footslope below it and several theories have been advanced to explain this phenomenon. Ollier and Tuddenham (1961) attributed the formation of the basal knick to unloading of the "onion-skin" -like exfoliation sheets regularly from the inselberg. King (1949) attributed the formation to the absence of scree at the base of inselbergs. Twidale (1962), Savigear (1960) and Ruxton and Berry (1961a) state that the basal knick could be formed by chemical weathering at the base of inselbergs and selective erosion by unconcentrated wash which removes the finer grains from the coarse blocks of the upper scree slope to build a flatter slope. Rahn (1966) believes that the basal knick is formed by the lateral erosion of streams at inselbergs' bases, and that such knicks, once developed, are maintained where the inselbergs shed coarse material to the inselbergs' bases. Pugh (1966) ascribed the basal knick to lateral stream erosion at the foot of an inselberg.

With a few exceptions, most of these authors have observed basal knicks in semi-arid environments and formed their conclusions accordingly. The most obvious

problem is to decide precisely what is the basal knick? Ruxton and Berry (1961a) described it as a sharp piedmont angle between the scree slope and the upper pediment. This is not always seen in the field, and there seems two possible definitions: either as the point where the inselberg's steep side slope abuts directly on the pediment with no masking scree present (Plate 47) or as the point where the steep scree slope abuts sharply on the gentler slope formed by the weathered and partially weathered smaller blocks. Thomas (1967) has shown that around a single inselberg the point of junction between the slopes of the inselbergs and the footslope below varies and concludes that "the hill does not always adjoin the surrounding plain at an abrupt 'piedmont' angle, and the distinction between hill and the plain is not always straight forward".

Basal knicks, by the second definition are fairly common around inselbergs because the steep scree slopes, composed of large blocks are often separated sharply from the lower slopes composed of weathered material. The reason for this is apparent; the angle of inclination of the coarse material comprising the steep scree slope is different from the angle of inclination of the weathered material forming the gentler slope below. With the first definition, the basal knick is very difficult to explain as it implies that the gentle footslope merges abruptly (at a sharp angle) with the steep slope of the inselberg, and there is a complete absence of scree cover. This type of basal knick occurs infrequently either associated with basal depression at the foot of a large inselberg, or with no association with a basal depression. For example, around a migmatite inselberg at Egbeda near Fasola, no scree slope was present at the eastern side of the inselberg (Plate 48) and runoff, especially free fall from the almost perpendicular face of the inselberg kept its base free of debris. The point where the base adjoins the surrounding slope is sharply marked. In this particular instance, the theory of King (1949) is substantiated. Nevertheless, this form of

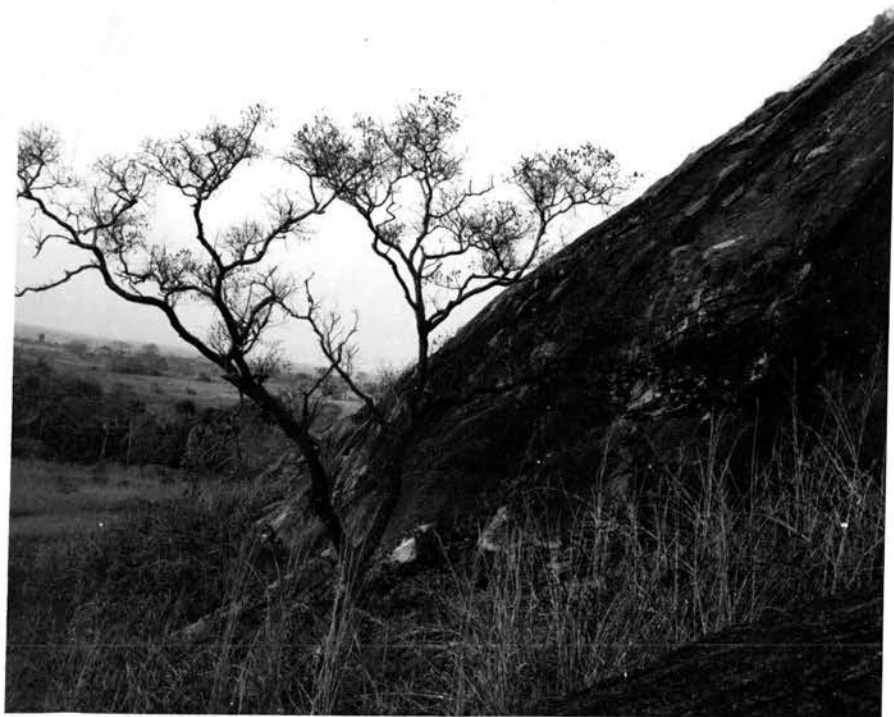


Plate 47 - The eastern slope of the Aseke inselberg is convex and merges abruptly with the footslope.



Plate 48 - The perpendicular slope of this inselberg merges abruptly with the footslope and shows a distinct basal knick. There is no scree slope at the base of the inselberg.

sharp basal knicks can only be explained in relation to the formation of the basal depressions.

Basal Depressions

Basal depressions are not always present around inselbergs. They occur more frequently around large whalebacks than around smaller inselbergs. The depression may occur just beneath the base of an inselberg or may be separated from it by a small narrow threshold composed of partially weathered rock fragments embedded in soil matrix. The depressions vary in depth from 25-50 ft., but their widths are much larger, often up to 200 ft.

Many theories have been advanced to explain how basal depressions are formed. Cotton (1947) ascribed the formation to lateral stream planation, with the stream moving against the base of the inselberg as the inselberg's slopes retreat backward, and the outer bank of the stream being colonised and stabilised by grass whose roots trap soil. Pugh (1956b) took the view that it was formed by lateral stream erosion at the base of inselbergs. Following the break up of an older erosion surface, the streams coming from the old surface on reaching the lower surface gets deflected laterally by alluvial fans and have to flow against the sides of the inselbergs. Clayton (1956) believed that the basal depression was formed by spring sapping on the pediment and the headward progression of the springs along the weathered zone surrounding the inselbergs. When rejuvenation occurred, the depression was deepened. Savigear (1960) mentioned that the depression could have been formed as a result of convergence of surface water draining the inselberg slopes or due to the emergence of spring water. Thomas (1967) said that the depression could have been formed by runoff from the dome surface becoming concentrated at the base to form the depressions. An important point to note however, is the importance of weathering at inselbergs' bases. This has been discussed in Chapter 9, and it is only necessary to emphasis here that chemical

weathering goes on throughout the year around most inselbergs. The presence or absence of basal depressions around inselbergs will depend on (i) the depth of weathering around inselbergs and the amount of local erosion on the weathered zone around inselbergs by direct runoff from the surface of the inselbergs; (ii) the pattern of surface and subsurface movement of water around the inselberg and on the pediment.

Where inselbergs are located on valley slopes with their long axes parallel to the slope, or on a general slope that controls the local surface and subsurface pattern of hydrological movement, direct surface runoff from the inselberg's slopes can form basal depressions. If these inselbergs are devoid of superficial debris, rain water is often rapidly discharged in sheets down ~~the~~^{their} steep slope. At the base of the inselberg, the runoff is forced to move downslope hugging the foot of the inselberg. Part of the runoff will seep into the soil below, but the greater part flowing on the surface is capable of removing the superficial debris at the base of the inselberg, often using the debris to cut a channel for itself. Weathering is continuous at the base of the inselberg, and erosion takes ^{place} ~~place~~ in the wet season. This process when repeated over a long period can lead to excavation of a depression at the base of an inselberg. These depressions are found on both sides of an inselberg near Oha (near Ado Awaiye), and they coalesce into one at the downslope spur end of the inselberg. This type of basal depression does not occur around all inselbergs located on valley slopes; they were observed only around two elongated inselbergs. Clayton (1956) rejected the view that basal depressions could be formed by direct runoff from inselberg's surface as envisaged above. He based his objection on his observations that the depressions around inselbergs are always of the same size, and as the inselbergs vary in mass, runoffs from them would not produce similar depressions. Clayton did not give the dimensions of the depressions he observed, but the present work shows that

basal depressions are of varying dimensions and their dimensions are often related to inselberg sizes. Clayton's objection that direct runoff from inselbergs' surfaces cannot produce basal depressions cannot be sustained.

In some places where large gullies are developed on inselbergs, it is possible for basal depressions to occur where the water from these gullies is discharged on to the footslope. King (1949) observed that "where waters emerge from deeply funnelled gully, their scouring effect is distinctively puny, scouring only shallow gullies across the narrowly surrounding pediment which stands between the basal knick and the lowest line of depression into which they run." This observation, made in the semi arid area of South Africa, is essentially correct because in such a place, alluvial fans are likely to be deposited at the mouth of the gully and the water from the gully gets dispersed and cannot effect linear erosion on the footslope. This has also been observed around some inselbergs in South Western Nigeria; where the gullies' mouths were choked with debris, no channelled flow occurred on the footslope, but in other cases individual gullies often continue across the footslope e.g. around Ado Rock.

Where debris is absent at gully mouths, and where several joint-aligned gullies converge to discharge their water on the footslope, such discharge often cuts deep channels. The stream flows close to the base of the inselberg in a downslope direction to the nearest higher order stream. Examples of such basal depressions were seen near Odo Ogun village between Iseyin and Ado Awaiye. In such cases, except at the point where the gullies discharge their water directly on the footslope there is often a small threshold separating the basal depression from the inselberg's base, and the length of the threshold varies as the basal stream moves away from the inselberg's base. At the base of such an inselberg the basal knick may be indistinct as it is often masked by debris.

The third process noted is the development of gullies in connection with basal depressions. On some footslopes, runoff from inselberg surfaces especially where large scree is absent at the inselberg base, can be channelled into rills scouring the surface of the footslope. Either as a result of micro-piracy or direct convergence the rills often develop into gullies up to 6 ft. deep and 4 ft. wide, cutting across the footslope to the adjacent streams. This was especially noticed in the granitic area of Tapa-Idere. Here, at the height of the dry season, water continued to seep out at the gully heads. Some of the gully heads are in the form of small amphitheatres which is strongly suggestive of spring sapping. It appeared that these gullies were progressing headward towards the weathered bases of the inselbergs along the line of subsurface flow of water from the inselbergs' bases. Only one was observed to have reached the base of an inselberg. There is no doubt that all of them may progress headward to their respective inselbergs where they would form basal depressions. A few of the inselbergs have basal depressions deeper than these gullies and contain stagnant pools of water in the dry season. The basal knick below the inselbergs is well marked in the floor of the depressions. The same processes producing the basal depressions could have formed the basal knicks.

Present Pattern of Pediment Evolution

As mentioned in chapters 5 and 9, pedimentation by backwearing and parallel slope retreat do not appear at present to be important landform process on the crystalline basement complex. If backwearing and parallel slope retreat were responsible for the formation of the pediments, it would be expected that pediments in the same stage of landform development would have a relatively narrow range of slopes. Most of the pediment slopes measured in the dominantly stripped etch-plain and the dominantly stripped etch-surface in South Western Nigeria show wide variations, and it cannot be concluded that these pediments were produced by

backwearing from distant stream lines.

The pediment slope profiles often show the hydraulic curve associated with stream flow, and there is no doubt that the slope profiles are being modified by the present pattern of runoff across them. However, there is no evidence that this pattern of runoff can produce these pediments and the cross grading of pediments as King (1951) envisaged. At the present time, the pediments are being modified by subsurface weathering and by surface runoff.

In both the savanna and the forest area, surface wash is important on the pediments, although it is more emphatic in the former. Water runs off mainly as sheet flow from the surface of the inselberg. At the base of the inselberg, part of the water flows across the pediment head in form of tiny runnels which anastomise downslope to form rills. Often, water also seeps into the base of the inselberg, and by the end of the rainy season, the local water table around the inselberg may rise and reach the surface, when water seeps out in unchannelled flow across the pediment. The effect of the sheet wash and the rills is to lower the declivity of the footslope as they wash finer surface material downslope. Subsurface flow also occurs, as water from inselberg's base moves downslope to the river line, both in the savanna and in the forest. The lateral eluviation involves the transporting of finer material downslope. The effects of both surface and subsurface erosion on pediments is the imperceptible lowering of the pediment.

Gullies are not frequent on pediments, but where present, greater erosion is accomplished. Old gullies which have become graded to the local streams, and whose sides have widened out smoothly, mainly carry water and small debris across the pediment. The gully sides have not been cross graded as envisaged by King (1951).

Where streams delimiting the pediments have been rejuvenated, the bounding slopes of the newly incised valley are quickly flattened. This occurs as a result

of concentrated rilling and surface wash at its top. Where laterite has developed at the top of the incised slope, it is too thin to form any free face. This perhaps is the reason why rejuvenation knicks are not well preserved in the crystalline basement area of South Western Nigeria. The present pattern of runoff both at the surface, and drainage below the surface will invariably lead to the downwearing of the pediments, and these processes could have been important once the old weathering profile lost its protective cover of laterite. As the pediment downwears gradually, chemical weathering will go on below. If both downwearing at the surface and chemical weathering below ~~process~~^{process} at the same rate, a balance will be maintained, and the depth of weathering in the pediment constant; but with any change of baselevel, erosion may become more emphasised at the surface to reveal the basal surface of weathering. The gradual basal and surface lowering under several erosional cycles will lead to the further emergence of inselbergs and the pediments will be preserved.

Conclusion

It can be concluded that inselbergs are formed by deep weathering and differential erosion under multicyclic phases in all the different rock types, but the variations in size, form and heights of the various inselbergs is a reflection of how the different rocks respond to the same process as conditioned by their texture, structure and lithology. Inselbergs and pediments are closely related in that both are produced by erosional stripping. Pediments vary in declivity as a result of parent rocks, stages of landform development and most especially varying vegetation environments.

Chapter 11

Valley Cross Profiles

Pediments form a very small ^{element} part of any landform type, and the characteristics of different landforms are best understood by an examination of the valley cross profiles. These constitute a large part of any landform type.

The stream valley characteristics are based on measurements of slope of third order stream valleys. Such streams are easily identified in the field, while first and second order streams are either too small or fail to make any impression on the landscape. Data ^{was} collected from sample areas which were considered representative of typical landforms. Valley slope profiles were measured from the stream line to the top of the interfluvial crest. This was not always possible, however, especially in the sedimentary areas where interfluvials are extremely wide; in this case, measurements were confined to small portions of the flat interfluvials. The slope units across the profiles were identified and the erosional processes on the profiles were noted. It must be emphasized that it was extremely difficult to locate the points at which the slopes change in some instances. The number of measurements in the forest area was limited due to problems of cutting traverses across the stream valleys.

Valley Types

Broadly speaking, valley cross profiles on the basement complex areas are convex-concave, while those on the sedimentary rocks are multi-faceted and concave. Variations exist where locally determined by the lithology and erosional processes. A descriptive rather than a genetic classification is used because a genetic classification assumes a-priori knowledge of how these valleys were formed.

On the basement complex, two valley types appear to predominate; i.e. "saucer-shaped" valleys, and broadly "V" shaped valleys. Both types often have

narrow to broad valley floors, but the former have relatively steep bounding valley walls which the latter lacks. On the sedimentary rocks, three valley types appear characteristic, i.e. a multi-concave type best described as a "valley-in-valley" type; a deep "V" ^{shaped} forms, and those with broad valley floors, but with steep bounding valley slopes resembling a 'bowl'. On each rock type, these valley types grade into one another, and short stretches of one may be seen in any particular location.

Valley Types on the Crystalline Basement Rocks

The "saucer-shaped" Type: These valley cross profiles are found mainly in the forest area from north of Ibadan to north of Ijebu Province. They are also present in the forest-savanna boundary west of Abeokuta province. This valley cross profile gives to the area an appearance of dissected topography. Local relief along the valleys varies from 50-150 feet. The valley profiles are not limited to 3rd order streams, but also occur along streams of higher orders varying from the 4th order Ogunpa stream to the 10th order Ogun river. Sometimes, the valley form may be changed slightly where recent rejuvenation has led to stream incision with the stream cutting narrow, shallow gorges e.g. along the Ogunpa in Ibadan, and along the Ona 12 miles to Ibadan.

The valley slopes are seldom symmetrical (Fig. 57). On one side there may be three slope units, and on the other, four or five. The slope units on the opposite sides of the valleys often occur at different heights. The upper part of the valley consists of a low curvature $0^{\circ} 30'$. This is followed by a short maximum slope segment $4^{\circ}-9^{\circ}$ which in turn is succeeded by a concavity. The slope on the valley floor varies from $0^{\circ} 15' - 2^{\circ}$ (Fig. 57). The upper slope is about 500-700 ft. long, while the maximum slope segment is about 100-150 ft. long and the convex inflexion between them is about 50 ft. long. Laterite rubble occasionally occurs on the upper slope units and on the maximum slope. The slope

VALLEY CROSS PROFILES(PARTIALLY STRIPPED ETCHSURFACE: BADAN AREA)

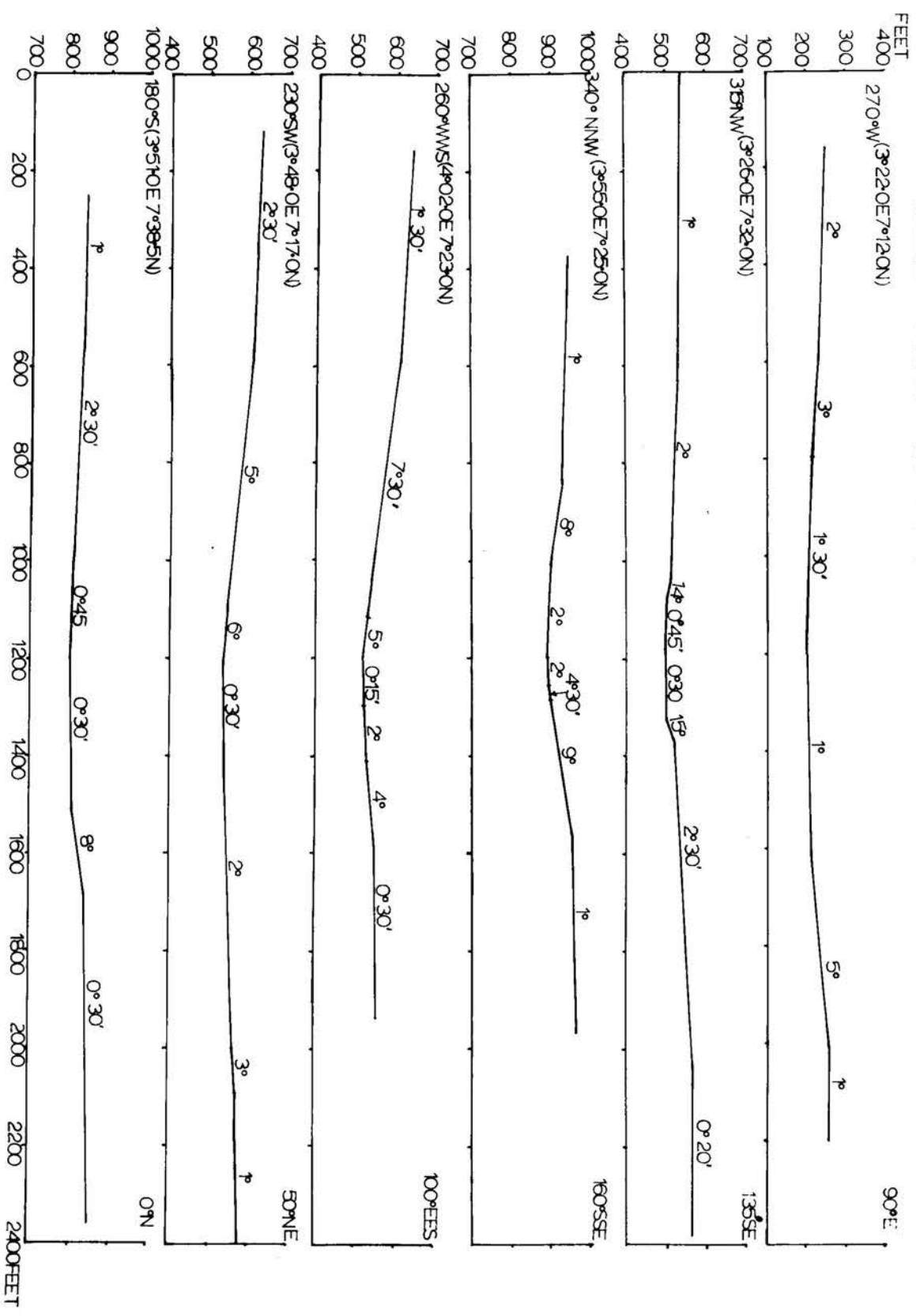


FIG. 51

crest is undergoing erosion by surface wash. Surface wash continues downslope for some distance, and on the maximum slope, some of the runoff may be channelled into shallow rills. Rills occur mostly where the slope is deforested. The valley floors are wide, dependent on the size of the river, and along third order streams they may be up to 500 ft. Alluvial deposits on the valley floor may often have hard pans composed of cemented quartz fragments over them.

This valley type appears to be found where rejuvenations and stream incision has progressed as far as the heads of even the smallest tributaries. The valley heads are deep 'trough ends' e.g. around Ibadan airport and near Olaoyo village at mile 15 on Ibadan-Lagos road. On such steep valley heads, stream headward extension on the bounding slopes is by rilling and spring sapping (Plate 43).

The Broadly 'V' Type: These profiles are found mainly in the savanna area from north of Iwo across to Oyo Fasola and Iseyin - Ado Awaiye area. The sample area lay between Oyo and Fasola where this particular type of valley profile occurs along both small and large streams. The valley form could be changed where recent rejuvenation e.g. along the Awon (near Oyo waterworks), has led to stream incision below the narrow valley floors. The broadly 'V' valley forms are associated with a gently undulating topography, and the local relief along the valleys hardly exceeds 100 ft.

The valley profiles are more symmetrical than the 'saucer-shaped' types and consist of two or three slope units (Fig. 58). The upper slope is convex to flat with angles varying from $0^{\circ} 30'$ to $1^{\circ} 15'$. It is often interrupted by low domes, and detrital laterite occasionally occurs on it. This slope joins the valley slope in a broad convex inflexion, often 100-200 ft. in width. The main valley slope is straight and long, extending to 1,000 ft. even along 2nd order streams. The slope varies from $0^{\circ} 30'$ to 5° , but it is often interrupted by

VALLEY CROSS PROFILES (DOMINANTY STRIPPED ETCH PLAIN: OYO-FAŞOLA AREA)

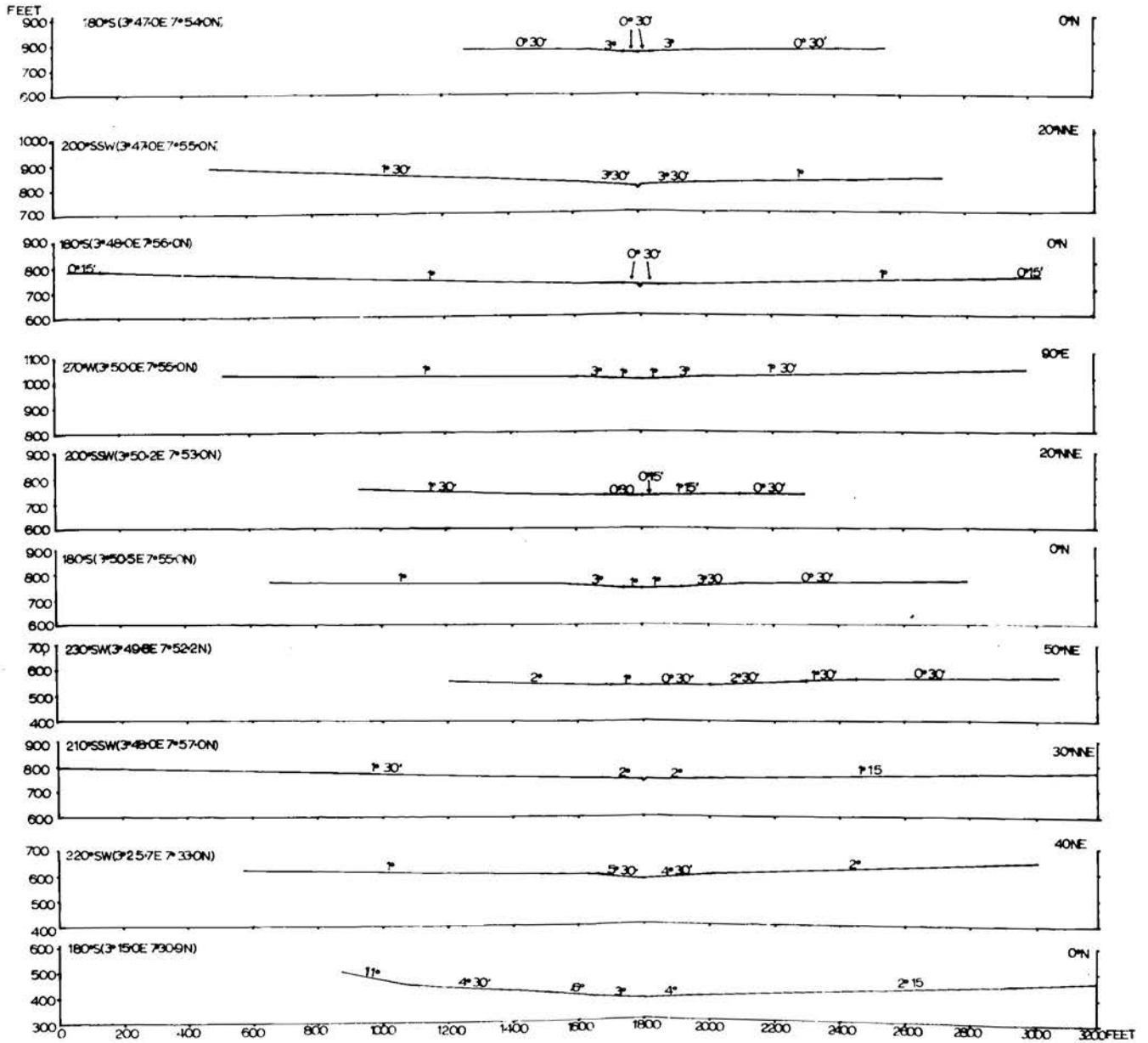


FIG. 50

rock outcrops. This slope may continue to the river line or it may be succeeded by a short valley floor slope composed of alluvial material. In incised sections, the valley floor slope may be up to 6° .

Runoff on the slope units from the crest to the valley floor is by sheet flow, but where the slope profile is interrupted by rock outcrops, runoff becomes rilled. Surface wash and rilling appear to be the most important erosional agents and this essentially means that the valley slope is being gradually flattened. Where detrital laterite occurs on the interfluvial crest, it does not form significant slope breaks.

Valley Types on the Sedimentary Rocks

The 'valley-in-valley' type: These are found along the third order streams draining the dip slopes of the cretaceous and eocene formations; especially along the Irori, Igboori, Afon, Obete and Oyo. They also occur along larger streams like the Ogun south of Abeokuta and Yewa, north and south of Meko. The valley walls are thickly forested while the interfluvial areas are covered by derived savanna. The valleys are deeply incised and the local relief from valley floor to interfluvial varies between 150 - 250 ft.

The profiles are remarkably symmetrical (Fig. 59). The steep upper slope units mark old stream incision and valley widening, while the lower steep slope units mark recent stream incision. In some places, the lower steep slope units have widened out and broad valley floors have developed. Valley profiles contain 4-5 slope units. The interfluvial slope varies from $0^{\circ} 15'$ to 3° and is often very long. The break ^{between} ~~between~~ the interfluvial slope and the upper valley slope is sharp and often marked by lateritic outcrops which usually form a steep perpendicular slope unit. The upper valley slope unit is composed of lateritic blocks and rubble derived from above, and the slope angle varies between 10° - 22° . The lower the slope angle, the longer the slope, but the slope segment generally

VALLEY CROSS PROFILES (LATERITISED PLAIN (PARTIALLY STRIPPED)
AIYETORO-MEKO AREA)

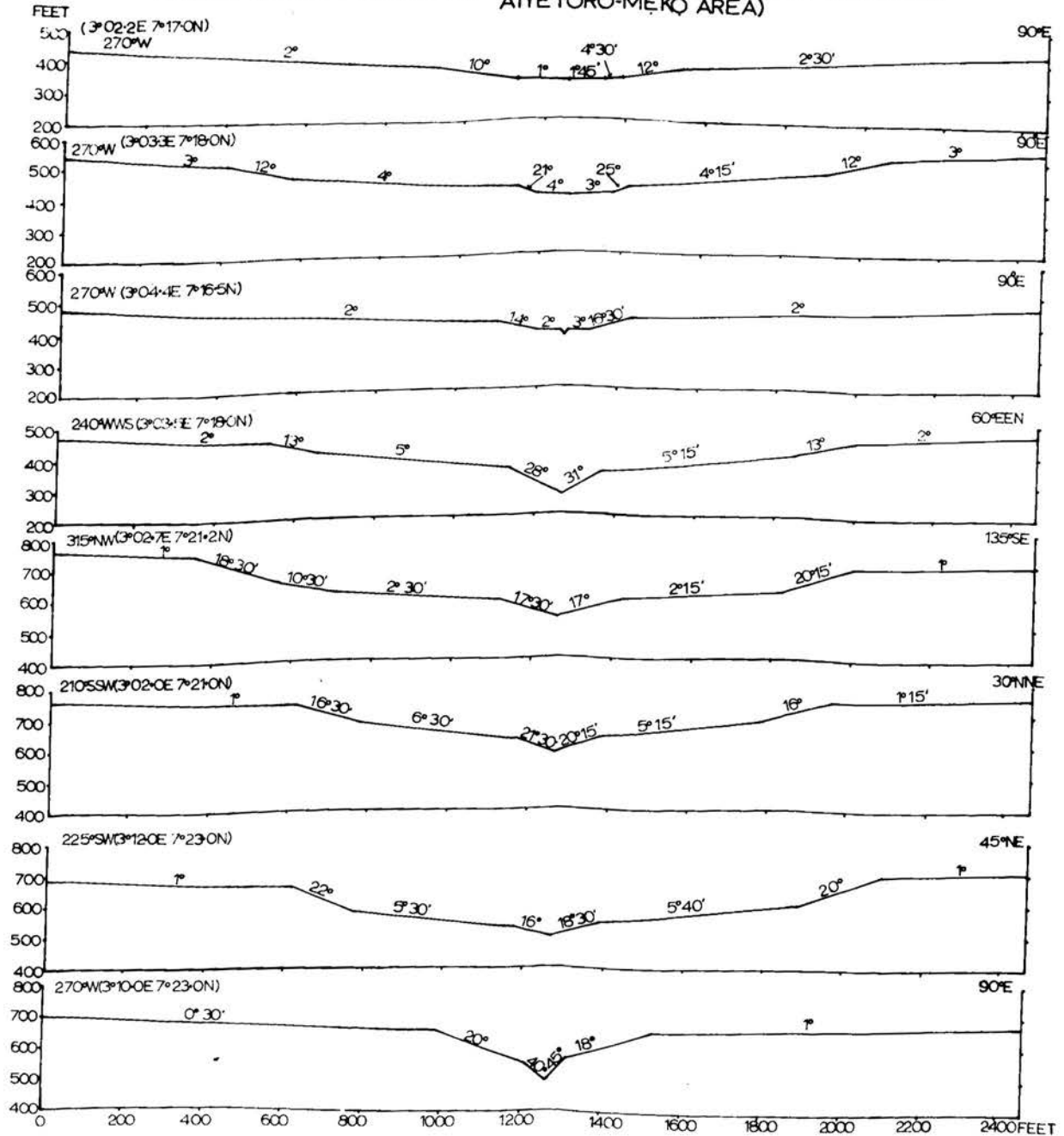


FIG. 59

varies from 120 - 250 ft in length. The lower slope below is separated from the upper by a small concave inflexion; this lower slope always occurs as broad terraces 400 - 700 ft wide with angles varying from 2° - 7° . The upper part of the terrace is often covered by laterite blocks and colluvial material, while the lower section is at times masked by detrital laterite or ferruginised material (Fig. 60). Succeeding the valley bench, is a short steep slope 16° - 45° and about 50 - 120 ft long, the upper part on which outcrop of laterite is frequent, while the lower part is developed on loosely cemented sandstone.

The surface of the upper slope unit is frequently scoured by small gullies and rills while the valley benches are eroded by surface wash. The steep lower slope unit may be dissected by widely spaced shallow gullies and rills. Soil creep is evident on the slope as the loose sand is often packed on the upslope side of the tree trunks while the trees themselves bend downslope. Valley floors are usually flat, 2° - 4° , and developed on alluvial and colluvial materials. The valley floor margin is well defined by a concave inflexion 5 - 15 ft wide. The whole valley slope appears to be undergoing parallel retreat. The upper steep slope is cut backward by a series of rills and gullies with the lower terrace-like slope as the local baselevel. The lower steep slope is also being cut back by rills with the stream as the local base level. The breaks of slopes along the valley profiles are associated with lateritic outcrops and these laterites serve in effecting parallel retreat of the slope profiles. The valley heads are deeper and steeper than those on the crystalline basement. Valley headward extension is by spring sapping and gullying (Plate 50).

The 'Bowl-shaped' Type: These are found south of Aiyetoro, eastward to the Ogun valley, and westward to Yewa valley on the dip slope of the Abeokuta formation. They are also present around Abeokuta in the zone of dissection especially east and south of the town. The valley types are also present south of Ilaro along

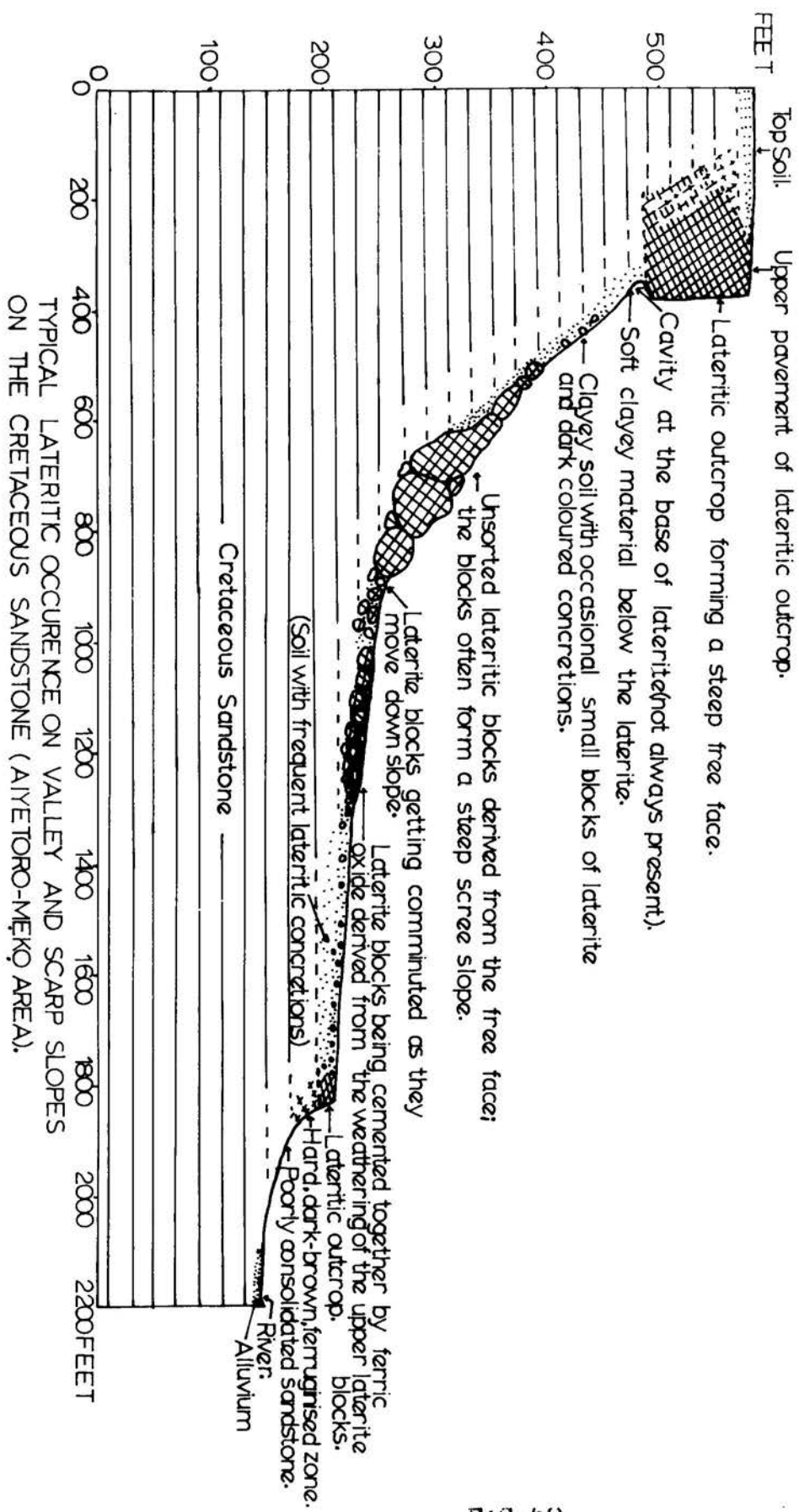


FIG. 60



Plate 49 - Deep amphitheatre head of a stream near Ibadan airport. Headward erosion by gullying and spring sapping.



Plate 50 - Deep, trough end of a stream on Cretaceous Sandstone near Obada. The spring is coming out at the junction between sandstone and weathered gneiss.

the Iju, Atuwara and Ore streams on the dip slope of the Ilaro formation.

Valley sides and interfluves south of Aiyetoro (a sample area) carry degenerated forest, but south of Ilaro (another sample area) valley sides and interfluves are heavily forested.

The valley profiles are symmetrical with three to four slope units (Fig. 61). Interfluves are narrow. On the Cretaceous sandstone these often carry massive vesicular laterites or remnants of such, while on the Eocene sandstone south of Ilaro, the interfluves carry ferruginised material. The upper slope crest is flat, but may reach a declivity of 4° , and is separated from the maximum slope segment below by a convex inflexion. The maximum slope segment is often long, varying from 400-1200 ft, but the shorter it is, the steeper its declivity. Long slope units are usually about 3° , while short slope units may be up to $13^{\circ}30'$; the mean is between 7° - 8° . The surface of the maximum slope segment, is sometimes littered with lateritic rubble and fragments of ferruginised material, and is frequently scoured by shallow widely spaced rills and by small gullies. Below the maximum slope segment, is a concave valley floor composed of alluvial material. The concave inflexion between the maximum slope segment and the valley floor is rather narrow, and the valley floor is well defined. The slope of the valley floor varies from $0^{\circ}15'$ to $3^{\circ}15'$, but where it is recently incised, the steep slope next to the river may vary from 8° - 15° .

These valley slope profiles are not unlike the 'saucer-shaped' type observed in the forested area around Ibadan except that the valley slope units are steeper. However, the valley head is not deep. Instead, it is usually shallow and ends as a broad convex-concave valley. As in the valley-in-valley profiles, the valley profiles here also appear to be undergoing parallel retreat, with the steep maximum slope being cut back by rills, shallow gullies and surface wash as the upper laterite disintegrates by block weathering. A noticeable point is

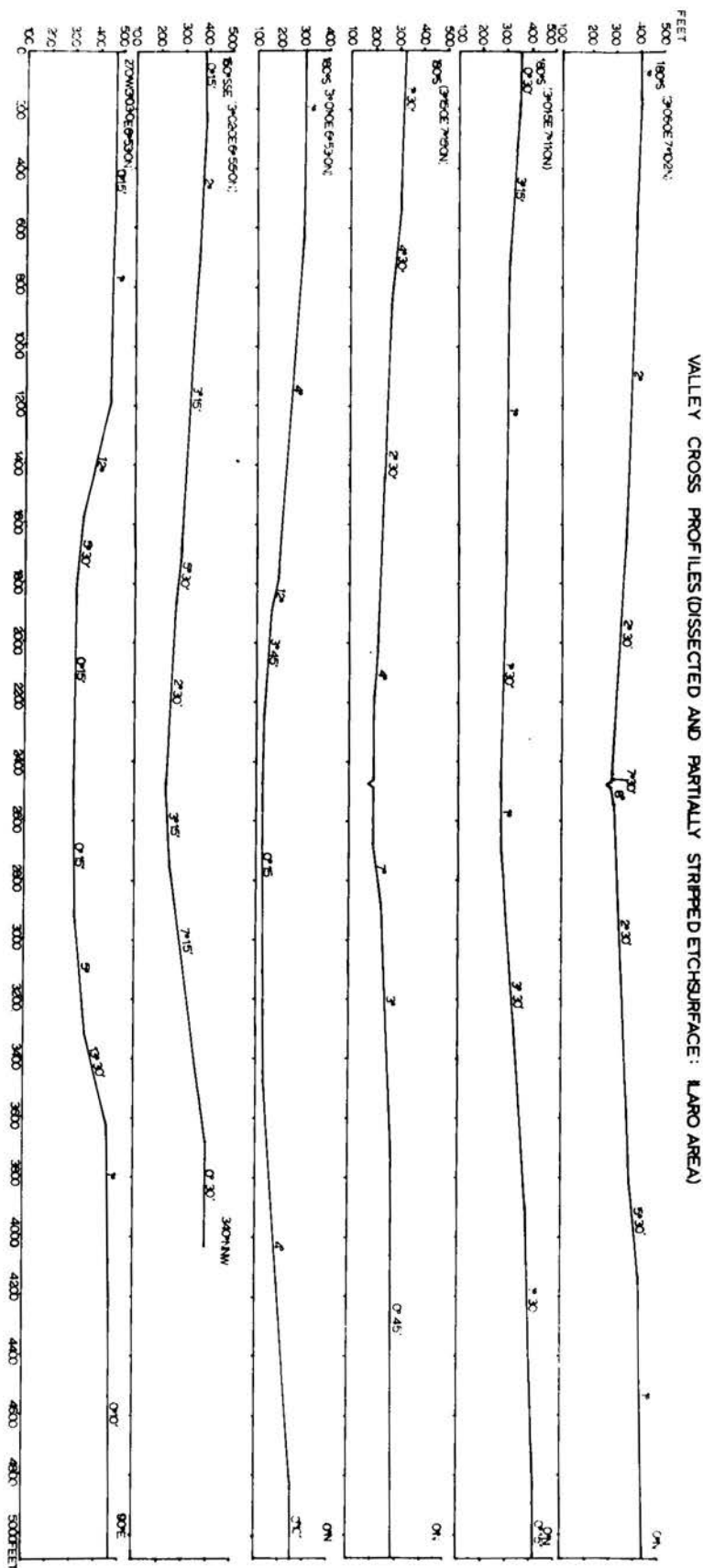


FIG. 61

that where the lateritic cap has been removed, the interfluves instead of being flat are rounded and the maximum slopes below them become considerably lower as a result of erosional lowering of the interfluves.

The 'V' type: These valley profiles occur mainly on the dip slope of the Abeokuta formation between the Ogun and the Ibu river. The valleys, usually of 2nd or 3rd order streams are very deep (150 - 200 ft), and contain two slope units, i.e. the flat interfluve, and the steep valley slope below terminated by the stream line. Thick forest precluded field measurements along the valley slopes, but map measurements show the slopes to vary between 30° - 45° .

It appears that on both the crystalline and the sedimentary rocks, valley forms are related to rock types, erosional processes and landform types.

Rock Types and Valley Forms

The sedimentary rocks, especially the Abeokuta and the Ilaro formations are porous and pervious as they are mainly composed of high proportions of sandy material and low proportions of clay material. The rocks are deeply weathered and their porosity allows rapid passage of groundwater. The movements of iron enriched groundwater has led to the formation of laterites in the upper horizons of the sedimentary rocks. Due to the presence of laterites on the weathered sandstones, and the texture of the sandstones, streams developed have deep valleys, and the valleys are widened out by backward retreat of their slopes.

The basement complex rocks consist of granites, gneisses, quartzites and schists which when weathered gives a regolith with a high proportion of clay material, which is less pervious than the sandstone formations. Due to the absence of lateritic caps, and the texture of the weathered regolith, valley profiles are mainly convexo-concave.

It is difficult to relate valley form to specific rock types except in generalised terms. For instance on the basement complex north of Shaki, where

the rocks are deeply weathered, with the upper horizon of the weathering profile carrying massive laterite, the valley forms are similar to those in the Cretaceous and Eocene sandstones. It seems that valley forms are related to landform types rather than specific rock types.

Landforms and Valley Types

The lateritised (partially dissected) plain, and the partially stripped and dissected etch surface on the sedimentary rocks, and the different etchplains and surfaces on the crystalline basement, all have characteristic valley types (Table 35).

Table 35

Landforms and Valley Types

<u>Landforms</u>	<u>Valley Types</u>
Lateritised (partially dissected) plain	'Valley-in-valley' Type The 'V' type
Partially stripped and dissected etch-surface	'Bowl' shaped type
Dominantly stripped Etchplain	Broadly 'V' type
Dominantly stripped Etchsurface	"
Partially stripped Etchplain	'Saucer' shaped type

Each of these landforms represents different stages of weathering and erosion such as each valley type represents different stages of stream rejuvenation and incision, but it should be noted that each valley type is not strictly confined to each landform type.

The 'valley-in-valley' and the 'V' types of profiles are found in the lateritised (partially dissected) plain between Aiyetoro and Meko, and between Ogun river and Ijebu Ode. The former is an advanced development of the latter resulting from further rejuvenation and valley widening. The 'saucer'-shaped and the 'bowl'-shaped valley profiles found in the forested area on the crystalline basement, and on the sedimentary series can be associated with

advanced valley development in both areas. On the crystalline basement, these valleys are found in the partially stripped etchsurface, while on the sedimentary series, they are found on the dissected, partially stripped etchsurface. Both landforms represent advanced destruction of the lateritised (partially dissected) old plain described above, so that the 'bowl'-shaped and 'saucer'-shaped valley types represent advanced erosion. On the basement complex where these valley types with maximum slope segments varying from 4° - 9° are found, the footslopes occurring below the inselbergs are about 5° . This in essence shows that within the partially stripped etchsurface landform facets are uniform.

The broadly 'V' valley types are found mainly in the dominantly stripped etchplains and surfaces. These landforms exhibit from 6% - 30% of the basal surface of weathering which means that erosion is advanced. The landforms also occur mainly in the savanna area where the vegetation permits a greater amount of sheet erosion than elsewhere. The valleys have lost their steep maximum slope segments, and are flattened into low gentle slopes varying from $0^{\circ}30'$ - 5° , much the same as the footslopes below the local inselbergs which vary from 1° - 6° .

When an old lateritised and weathered surface on any rock type is dissected and eroded, the valley forms will assume different shapes following the different stages of dissection. Usually the valley profiles would be multi-faceted and concave at the initial stages of dissection, and with further incision and rejuvenation, the valley sides will open out. Where laterite serves as cap rock, the slopes have constant declivity, but where laterites are absent, the slopes will decline and become convexo-concave or broadly 'V' in shape. The relationship between laterites and slopes will be further examined in succeeding chapters.

As observed in Chapter 10, pediment slopes in the forest are steeper than in the savanna. Both on the 'bowl' -shaped and 'saucer' -shaped valley types developed in the forest, maximum valley slopes vary from 3° - 13° , and

4°-8° respectively, on the broadly 'V' shaped valleys in the savanna, maximum valley slopes vary from 10° 15' - 5°. This further confirms that erosion is more pronounced in the savanna than in the forest.

Chapter 12

Laterite and Landform Development

Laterite in relationship to erosion surfaces and to valley slopes has been discussed in Chapters 5 and 11. The physiographic location of laterite and its influence on the pattern of landform development are outlined in this chapter. Theories of laterite formation are not covered in detail nor is the chemical composition as these come within the realm of pedology rather than geomorphology. They are only discussed where relevant to the physiographic location of laterite.

The definition of laterite for the purpose of this study excludes chemical properties. The term 'laterite' was first applied by Buchanan in 1807 to the soft building material in Malabar which hardened on exposure and was used for construction purposes; the local people called it brickstone. Du Preez (1949) observed that the word 'laterite' as used by Buchanan is a misapplication and he contended that the word conveys a lithological rather than a genetic significance. Prescott and Pendleton (1955) however contested this view.

Since Buchanan there have been definitions of laterite by geomorphologists, geologists, and pedologists, and all are related to the special discipline of the writers. Holland (1903), MacLaren (1906), Fernor (1911), Simpson (1912), Campbell (1917) and Woolnough (1918) gave definitions generally similar to that of Buchanan. These definitions were later summarised by the Imperial Bureau of Soil Science (1932) which defined laterite as "a weathered rock product formed by the leaching of igneous, and metamorphic rocks whereby the bases and much of the silica are removed leaving a residue containing alumina combined". This genetic classification has little practical importance as it does not aid identification of laterite in the field. Further, apart from being misleading in

specifying the occurrence of laterite on igneous and metamorphic rocks only (it also occurs on sedimentary rocks), it expresses the residual theory of laterite formation on which there is no consensus of opinion among modern writers on the topic.

Kellogg (1949) confined the term 'laterite' to four principal forms of sesquioxide-rich material:

- a) soft mottled clays that change irreversibly to hardpans or crust when exposed;
- b) cellular and mottled hard pan crusts;
- c) concretions or nodules in a matrix of unconsolidated material;
- d) consolidated masses of such concretions.

Bruckner (1955) used the word in a general sense to include all the predominantly red soils of tropical countries, and several other writers have done likewise. Sivarajasingham et al (1962) proposed that 'laterite' be restricted to highly weathered material which is (i) rich in secondary forms of iron and aluminium or both, (ii) poor in humus, (iii) depleted of bases and combined silica, (iv) with or without non-diagnostic substances like quartz and (v) either hard or subject to hardening upon exposure to alternate wetting and drying. Moss (1963) defined laterite as essentially hard or compact or at least hardening, and on this basis, he recognised nine types of lateritic deposits in the Cretaceous and Eocene sandstone area in part of South Western Nigeria. While pedologists may be able to utilise these definitions to recognise laterite in the field, geomorphologists find them limited in application especially when 'laterite' is coined for some of the deeply weathered soils of the humid tropics.

The definitions by geomorphologists have always been descriptive. Gautier (1935) described laterite as a cuirasse de fer i.e. a very hard, dark, blackish rock which is essentially an iron ore. Du Preez (1949 p.2) defined laterite as

a "vesicular, concretionary, cellular, vermicular, slag-like, pisolitic or concrete-like mass, consisting chiefly of ferric oxides, with or without mechanically entangled quartz and minor quantities of alumina and manganese, it is of varying hardness, but it is usually easily shattered when struck with the hammer". Pullan (1967) accepted Du Preez's definition, and classified the lateritic ironstone and ferruginised rocks in Northern Nigeria into two types a) primary lateritic ironstones which are vermicular, vesicular, cellular, cellular-nodular, nodular, oolitic, and pisolitic, b) secondary lateritic ironstones which are recemented nodular, recemented conglomeratic, recemented breccia and platy.

This is a more practical description for identification in the field. Other forms over and above those described by Du Preez also occur. In areas of sandstone, there are extremely hard masses composed of fine quartz grains cemented together by ferric oxide. These often occur in the soil profile, also along road cuts. In the basement complex area, as seen in road cuts on slopes, laterite pisoliths are found in a matrix of indurated clay. In the present context, laterite will be regarded as a "ferruginous crust" which forms a convenient blanket term for all forms.

Laterite in South Western Nigeria

Observation of laterite is difficult in South Western Nigeria because of ^{its} the lack of continuity over a wide area. In the forest zone, laterites are frequently disintegrating where exposed, as a result of chemical weathering, and are only seen in rare instances. In the savanna, they occur as caprocks, terrace covers or as illuvial horizons. Mapping of lateritic outcrop on a regional scale is not practicable because of their mode of occurrence. Even on the Northern Upland where they are frequent, no exposure greater than 10 acres was seen. Mapping of laterite was based on airphotos, plotting the relative

frequency of occurrence from place to place (Fig. 62). Additional information for the map was extracted from the Soil Association/Land Type map of Western Nigeria.

Six types of laterite were recognised,

Massive - Vesicular - This is found on the Northern Upland, mainly north of Aiyetoro as far as Meko on a plateau-like surface 550-850 ft. a.s.l. It is associated with the erosion surface located here (see Chapter 7). Narrow interfluves south of Aiyetoro, and small erosional residuals around Abeokuta also carry this type of laterite. Vesicular laterite outcrops frequently as flat pavements of limited extent on the upland surface (Plates 51 and 52) and is usually covered by fine ^{powdery} ~~powery~~ soil whose depth varies from about 2 ins to 2 ft.

In several places, the laterite prevents rain water from seeping through. Water is retained at the laterite surface below the soil creating vast marshes and swamps e.g. between Obada and Adimo. As the water gradually seeps downward through the laterite, it becomes iron enriched, and the laterite grows thicker.

Vesicular laterite varies in colour, from brownish red to very dark brown. It is composed of pisoliths of various sizes ranging from 0.3 - 0.7 ins in diameter, tightly cemented together by iron. In some localities it may be slag-like with no vesicles seen, and its surface is polished and has a metallic sheen. Where it occurs on the surface as flat pavements, tiny connecting vesicles 0.2 - 0.5 ins wide, and frequently filled with ochreous and powdery substances are seen. The laterite is extremely hard, but breaks when repeatedly struck with the hammer.

At scarp edges, vesicular laterite is underlain by a soft clay matrix in which occasional concretions occur. A laterite profile seen in a deep gully near Anigbado village north west of Aiyetoro shows

- a) 0-6 ins - brownish, silty, powdery soil,
- b) 6 ins - 15 ft 6 ins - reddish brown vesicular laterite,

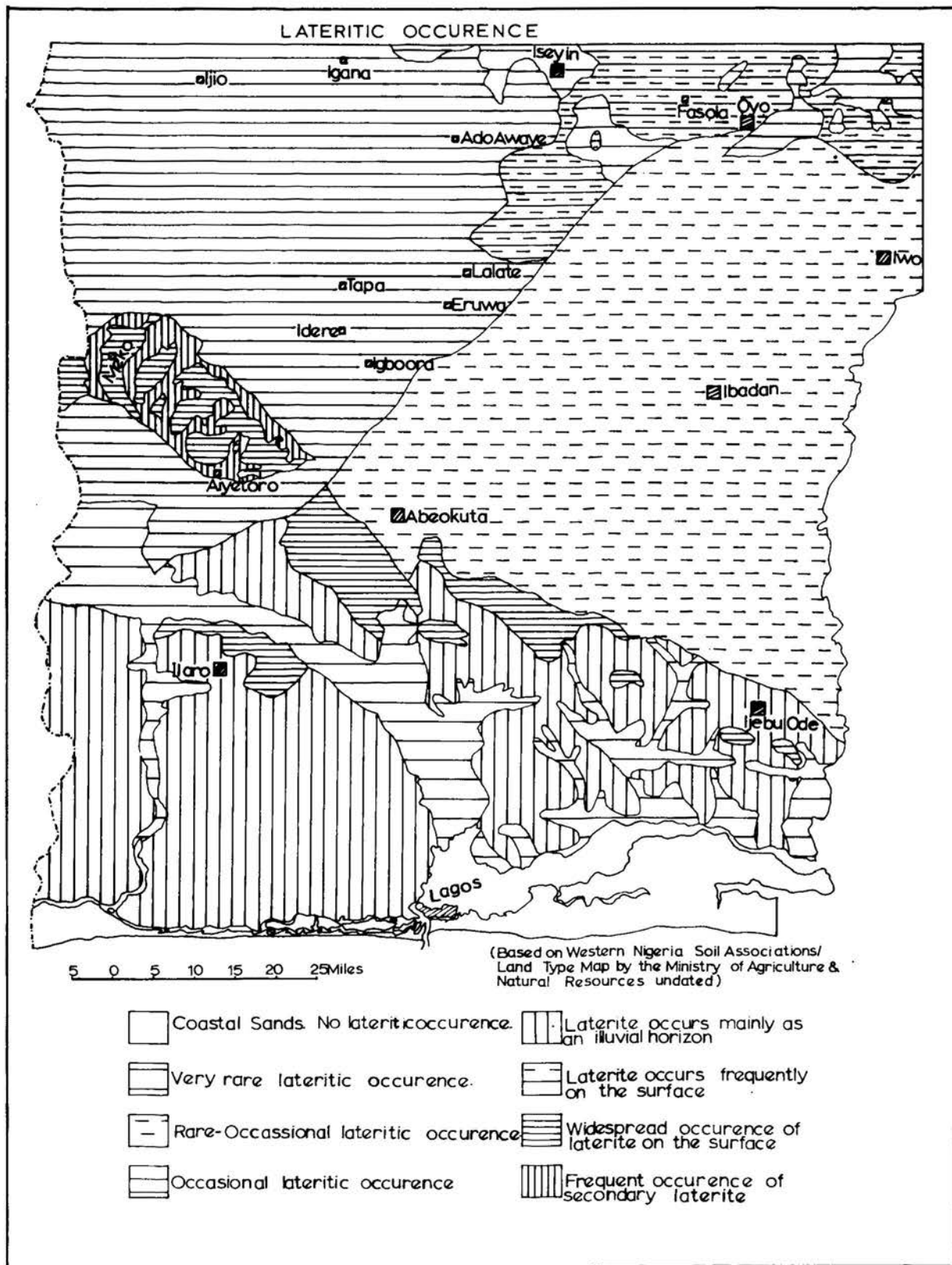


FIG.62



Plate 51 - Lateritic pavement on a sandstone residual west of Abeokuta. The surface is sparsely covered by grass, but the surrounding slopes are heavily forested.



Plate 52 - Lateritic pavement near Olorisa, north of Aiyetoro. Note the vesicles.

- c) 15 ft 6 ins - 21 ft 6 ins - clay matrix with few pisoliths in it,
- d) 21 ft 6 ins - 141 ft - mottled zone,
- e) 141 ft - pallid zone (the depth could not be determined).

The boundary between (b) and (c) is diffuse as they merge gradually one into the other. This gives the impression that the laterite was formed in situ.

Concretionary This is found mainly on the crystalline basement area. It is present around Ibadan on interfluves and valley slopes, but it occurs most frequently between Oyo and Fasola. Here it was observed on interfluves, on valley slopes 1°-3°, and close to the stream beds. Occasionally it marks breaks of slopes. It appears to be associated with migmatites and granites. Outcrops are very small (Plate 53) and up to 2 ft. thick.

The laterite is brownish and often has a metallic lustre. It is composed of laterite pisoliths of irregular size, 0.05ins - 0.5 ins in diameter, unsorted angular fragments of quartz and earthy material all cemented together by ferric oxide which itself may be dark or metallic, giving the laterite a variegated appearance. Another type is seen at Eruwa which is composed of fine quartz and fine concretions cemented together by ferric oxides. Small interconnecting, irregular vesicles are present, but are always filled with grey powdery material. The laterite may be extremely hard. Unlike the true vesicular laterite, the concretionary type has no gradual transition into its underlying material. On both interfluves and valley slopes, it has a sharp contact with the soil below and could often be seen resting directly on bare rock outcrop (Plate 54). This suggests that it is a secondary laterite formed by materials derived from a previously existing primary laterite. The implication of this feature is discussed later. Where it occurs under forest, it is undergoing physio-chemical weathering as the quartz pebbles could be easily detached by hand.



Plate 53 - A small outcrop of concretionary laterite near Egbeda, north of Fasola. Note the coarse quartz fragments; and the abrupt junction between the laterite and soil below.



Plate 54 - Concretionary laterite near a stream bed lying on bare granite; observed along Eruwa/New Eruwa road.

Pisolithic In both the crystalline basement area, and the Cretaceous sandstone, this occurs mainly on the lower valley slopes. On the former there is no conspicuous break of slope and the thickness rarely exceeds 2 ft; on the latter, it is closely associated with the terraces in areas of rejuvenation and occurs at the slope break overlooking the river. Here its thickness varies from 2 - 6 ft. It is dark brown and composed of irregularly sized pisoliths; in some parts vesicles are seen. The pisoliths are entirely composed of ferric material and show concentric growth. The surface of the laterite is dull grey and brown. It grades vertically downwards from hard laterite to firm indurated clay.

Detrital This is mainly found in the Cretaceous sandstone area in close association with the terraces below the upper surface in Aiyetoro-Meko area. It occurs on slopes varying from 2° - 6° . The composition and degree of cementation of this laterite varies from below the free face of the upper laterite, downslope to near the slope break. It is mainly composed of irregularly sized fragments of the upper vesicular laterite in various stages of cementation. Close to the free face, and on the constant slope, it is loosely cemented with ferric oxide (Fig. 60) and the laterite fragments of small blocks to larger fragments 5 ft across are unsorted. Downslope on the flatter segment, the fragments are increasingly comminuted and more tightly cemented together, but the surface of the laterite is highly irregular. The thickness cannot be determined as the base was not seen. The detrital character implies that it is of secondary origin.

Illuvial (as defined by Du Preez 1949). This occurs frequently on the basement complex. It is commonly seen on an interfluvium around Ibadan airport, especially along a railway cutting at Kongi, and is also found on slopes and interfluviums in the Oyo-Fasola area. The laterite is variegated in appearance and composed of dark, rounded or oval pisoliths 0.1 ins - 0.5 ins in diameter, together with angular unsorted quartz fragments embedded in a matrix of reddish brown hard clay.

The thickness of the exposure along the railway cutting varies from 2 - 7 ft and a quartz vein penetrates it. The laterite has a sharp contact with the soil above it, and often an irregular contact with the mottled clay horizon below it. This type has been quoted as evidence of an arid climate in the past in South Western Nigeria, (Burke et al 1966), but this is difficult to substantiate. The quartz vein cutting through it undistorted verifies an in situ formation.

Ferruginised Masses These are found mainly on the Eocene sandstone on top of the upland north of Ilaro. They occur in association with heavy slag-like masses. Occasionally they are found on the terraces on the cretaceous sandstone area. The colour in any single sample varies a great deal, but is often purplish brown. The quartz grains are often milky white, while the iron oxide varies from dark grey to purple. It is composed entirely of extremely fine quartz grains cemented together by iron oxide. There are no vesicles or pisoliths formed, and the ferruginised masses are compact. The thickness of the outcrops is unknown, and as the base was not seen, it is difficult to determine the ~~vertical~~ ^{vertical} variations, but the location on a flat upland would suggest a primary origin.

Lateritic concretions mainly in form of disaggregated iron oxide, 'pea-like' features, of diameter 0.2 in - 0.5 in. occur most commonly on the basement complex. They are found mainly on interfluves, valley slopes and in the upper soil profiles on some slopes in the savanna area. They are presumably derived from the disintegration of formerly existing laterites.

Physiographic location and laterite formation

The literature on laterite usually postulates a close association between the physiographic location of laterite and its origin. There is a consistent belief that laterite is formed mainly as an illuvial horizon on surfaces of low

relief with impeded drainage. Following a change of base level, the surface is dissected, and the water table moves slowly downward and in the process laterite is formed. With further dissection, the initial (primary) laterite will survive as caps on plateaux or mesas with younger detrital laterite formed on the slope below by recementation of laterite blocks derived from the break up of the primary laterite. In some cases, primary laterite could also form on the lower slope close to the rejuvenating stream.

By this argument, particular laterites tend to be associated with certain erosion surfaces e.g. the Peneplain (high level) laterite (or if further refined - bauxite) associated with older erosion surfaces, detrital or secondary laterite associated with the lower surface, and the terrace laterite associated with the slope adjacent to the stream. Thus they occur in step-like fashion over step-like series of surfaces - (Simpson 1912, Woolnough 1918, Campbell 1917, De Swardt 1962, Du Preez 1949, Pallister 1952, Varn 1963, Sivarajasingham et al 1962). Some writers further contend that the change of baselevel associated with the dissection of the old surface was caused by climatic changes so that lateritisation is a factor of alternation of periods of wet and dry climates (De Swardt 1962, Du Preez 1949 and Moss 1963).

There are many objections to this view. Prescott and Pendleton (1955) suggested that laterites found on mesas or on flat topped areas need not be remnants of dissection after uplift, and argued that they might have resulted from relief inversion. Trendall (1962) also mentioned that high surface implies no break up of a formerly existing high peneplain. He noted that around Buganda, the heights of the duricrust capped plateau remnants vary a great deal, but a continuous laterite patch, 30 ft. thick on each remnant may have a local relief of 500 ft. Trendall believes that such primary laterites on the plateau remnants were formed

on the individual hill tops, by the process of rock dissolution and surface lowering due to subsurface leaching.

The concept that the formation of laterites require an alternation of wet and dry periods is not widely accepted. Scrivenor (1909) observing lateritic development in the equatorial area of Malacca quoted figures of monthly rainfall for three consecutive years there to show that no alternation of wet and dry season is required for lateritic formation. Harrison (1933) wrote that "the primary process of formation of laterite is the same on high or in low levels on well drained mountain plateaux where the rainfall is high (> 150 ins) more or less continuous throughout the year, primary laterite appears to be permanent as such and where not exposed to washing, accumulates in considerable thickness."

There are varied opinions, then on the processes responsible for the physiographic location of a particular laterite.

From field observations in South Western Nigeria on the Cretaceous formations between Aiyetoro and Meko, the following lateritic sequences (Fig. 60) were noted. First, the massive-vesicular laterite occurs as free faces (Plates 55 and 56) on the upper scarp and valley slopes and also as pavements in the upland. Second, below the free face, a concave slope element occurs, and on the lower part of this slope, unsorted blocks of laterite are either embedded in a soil matrix or lie on the surface. The blocks are derived from the laterite above as they are similar in texture and structure. Third, below the concave slope element, a gentle slope segment occurs. On its upper part, it may be covered by detrital laterite in various stages of cementation; downslope the detrital laterite becomes more homogeneous and more firmly cemented. Towards the end of this slope, primary vesicular ^{or} pisolithic laterite or ferruginised masses may occur. Fourth, a steep slope segment may occur near the river, but this shows no lateritic cover.



Plate 55 - The lateritic outcrop here is about 35 ft. thick, and forms a *perpendicular* ~~perpendicular~~ slope. Below is a cave formed by basal scouring by ~~perpendicular~~ runoff on the free face. (Observed near Anigbado)



Plate 56 - The lateritic outcrop at the upper part of the plate forms a free face about 6 ft. In front of the free face is a pavement about 5 ft. wide formed by backward retreat of the free face (observed near Apata village).

The primary vesicular laterite occurs widely all over the upland and on sandstone residuals around Abeokuta. In all these places, it shows no altitudinal variations like those noted by Trendall in Buganda, and there is no evidence to support his suggestion that it could have been formed separately on the individual erosional residuals. The physiographic relationship between the primary vesicular laterite and the detrital type on the lower terraces lends support to views expressed by Simpson (1912), Woolnough (1918), Campbell (1917), Moss (1963), De Stardt (1962), Du Preez (1949) and Varn (1963). The massive-vesicular laterite on the upland plateau-like surface appears to have been formed under peneplain conditions. On the basement complex, the concretionary type of laterite appears to be of secondary origin, but as no vesicular primary laterite could be seen, its origin is difficult to establish, but essentially it implies that there was a cover above it now removed.

De Swardt (1946, 1964) opined that the association of upper and lower laterites in Nigeria indicated the presence of two or more erosional levels all over the country. This association was noted on the Cretaceous and Eocene formations (see Chapter 7) and was used to establish the presence of two erosional surfaces. This association between laterites and erosion surfaces could not be confirmed on the basement complex area where the laterites noted are mainly the concretionary secondary types formed by materials derived from a previously existing primary laterite, presumably at a greater altitude than at present. Except between Oyo and Fasola where they occur frequently, lateritic occurrence is so rare that any correlation in terms of altitudes is invalid over a large area. Further, the laterites observed on the interfluves are small and disintegrating rapidly, making the amount of differential interfluve lowering difficult to calculate.

In the dissection zone around Abeokuta township where there are laterite capped mesas, there is a big difference in the heights of erosional residuals

capped with laterite, and erosional residuals without caps. This suggests that erosional residuals with no lateritic caps are lowered faster than those with lateric caps. If differential lowering of interfluves occur over a small area of uniform material, then it will be amplified on the basement complex with its heterogenous rocks. Thus the amount of differential lowering caused by the absence of, or disintegrating laterites on the basement complex interfluves cannot be calculated and erosion surfaces cannot be established.

Pattern of laterite formation and landscape evolution

There is no doubt that the massive-vesicular laterite found on the upper Cretaceous sandstone was formed on a gently sloping surface. The pattern of formation of the lower laterites is similar to that outlined by Moss (1961, 1963 and 1965) but may not necessarily involve drastic changes from arid to humid conditions for which there is no evidence. Experiments in Guinea, cited by Sivarajasingham et al (1962), have shown that at least laterites could form not from pronounced temperature or rainfall changes, but as a result of wetting and drying from rain to rain in cycles of several days or weeks.

It must be emphasised that the formation of laterite is recognised by several authors (Campbell 1917, Woolnough 1918, Varn 1963) to depend on:

- i) the texture and lithology of the regolith
- ii) the amount of iron and aluminium present in the regolith
- iii) the pattern of subsurface movement of water, especially its rate of flow and its direction of flow
- iv) the nature of the ground surface.

Laterites and ferruginised masses can form on gently sloping ground surface composed of relatively permeable material with a water retaining capacity. As the groundwater moves vertically downward under gravity or as it moves laterally towards lower slopes, it dissolves the iron and aluminium content of the regolith;

wherever the movement of the groundwater is impeded by a more impermeable stratum, the dissolved ferric and alumina oxides in the groundwater are deposited. Where aluminium forms the largest part of the deposit, bauxite will be formed. Deposition can occur either close to the ground surface on a slope, or the laterite can be formed at a break of slope be it caused by a quartz vein projecting through the weathered material or by rejuvenation and stream incision. The formation of laterite in association with downward moving ground water, has led to the occurrence of primary laterite directly over little weathered quartzite in Entebbe peninsula as observed by Dubois and Jeffrey (1955). Upward movement of groundwater by capillarity can also lead to the formation of laterite near the ground surface. What is important in all these is that primary laterites are most likely to form where the subsurface drainage is impeded. Essentially it appears that primary laterite is formed as an illuvial horizon, and is not initially hard. Hardening and induration occurs when the illuvial horizon is exposed either by surface wash or by linear dissection. Lateritic exposures are further hardened with fine veneer of iron carapace deposited on them when iron rich water flows over them. As the gently sloping surface on which laterite is formed is dissected, the laterite becomes harder and can survive as high level laterite. Alternation of wet and dry periods may cause downward and upward movements of ground water, but strictly speaking this is not the direct cause of lateritic formation because the formation of primary laterite depends mainly on the moisture retaining capacity of the soil.

On the Northern upland where primary laterites are found, the cause of base level change that led to the dissection of the upland was uplift (see Chapter 5). The thick lateritic deposits at the upper parts of scarp and valley slopes could have been caused by the lateral movement of iron bearing water seeping towards the valley and scarp slopes. Away from the scarp and valley slopes, the thickness of

the laterite is unknown.

There is no doubt that backwearing and parallel slope retreat following stream incision were, and are, still important landform processes in the area where these massive laterites occur. The upper laterite is broken up as a result of basal scouring and by runoff from the surface above down the free face of the laterite (Plate 57). The slope below the free face is rilled and gullied and this, with lateral erosion at the base of the scree slope, leads to the backwearing of the whole slope profile. Laterite blocks breaking from the upper surface move down slope in the form of debris creep and slump, getting comminuted as they move to the flatter part of the lower slope. In favourable locations, the blocks are recemented either by iron dissolved from them by water seeping through or by iron bearing solution seeping out below the upper laterite. Following another change of base level, another rejuvenation and stream incision, the lower slopes get incised. At the break of slope overlooking the stream, lateral movement of groundwater towards the stream line could lead to the formation of vesicular or pisolithic laterite. Thus the sequences from the valley bottom to the valley top are terrace primary laterite, detrital laterite, then primary vesicular laterite. This is the typical lateritic sequences on valley slopes on the Northern Upland, but may vary where terrace development is inhibited or where dissection is pronounced. The primary vesicular laterite on the upper surface appears to be Tertiary. Although there is no organic material to facilitate accurate dating, it may be presumed to have been formed following the uplift of South Western Nigeria in the Pliocene period. The detrital laterite on the lower slopes and the terrace primary laterites are considerably younger.

The formation of laterite on the basement complex is difficult to explain because no primary laterite is found and the secondary laterites are on interfluves, on valley slopes, and even on bare granite or gneiss. The concretionary laterites



Plate 57 - To the right of the plate is the free face, to the left are the large blocks broken off from the free face.

show no genetic relationship with their underlying material. It appears therefore that these laterites are derived from previously existing laterites, and this would involve a great amount of erosion. The presence of secondary laterites on interfluves need not indicate a landscape inversion, as no old stream channels could be traced on the interfluves.

The following explanation may possibly be applicable. With the deep weathering of the basement complex rocks, rocks producing water retentive regoliths e.g. schists, amphibolites and gneisses would have primary laterite formed on them. This type of deep weathering and primary laterites are still present on the primary watershed further to the north. With a change of base level, rejuvenation and incision, the landsurface would be dissected, and where primary laterites have developed the valley slopes would retreat parallel to themselves in the manner described above for the sandstone areas. As the valley slopes retreated, the upper laterite would break up gradually, leading to the formation of secondary laterite on the lower slopes. Where opposing slopes meet, the upper primary laterite will be destroyed, disintegrating into rubble. These rubble may be transported downslope to form detrital laterite and lateritic concretions, or may be recemented on the interfluves to form a reconstituted laterite.

This pattern of lateritic occurrence and slope development could be interrupted where the basal surface of weathering is exhumed, and inselbergs and tors will then project above the local ground surface. With the destruction of the primary laterite, slope wash will become more important, and valley slopes would be flattened. The reconstituted laterite on the upper slopes would continue to be destroyed. This then may lead to the situation whereby secondary laterite is found close to the interfluves and on valley slopes, and lateritic concretions also present on the slope. Thus the patchy distribution of laterites on the basement complex can be explained.

The physiographic location of primary and secondary laterites shows that backwearing and parallel slope retreat could, to a great extent have been an important landform processes in South Western Nigeria. These are still important where there are suitable lithological arrangement especially in the sandstone area, but on the basement complex, the destruction of the primary laterite, means that backwearing is no longer an important landform process. The laterites of the basement complex are Tertiary or pre-Tertiary and have been much more involved in landform development than those on the sandstones to the south.

Laterites are thus very important in landscape evolution and this will be further illustrated in the next chapters.

Chapter 13LANDFORM DEVELOPMENT AT THE BOUNDARY OF CRYSTALLINE AND SEDIMENTARY
ROCKS.

In the contact zone between the Cretaceous sandstone and the basement complex rocks, the sandstone overlies the granites and gneisses. The erosional processes in this zone have produced a contrasting pattern of landforms in which bare and partially covered igneous rocks occur close to sandstone residuals. The convex, domed form of the low inselbergs contrast sharply with the faceted slope forms of the sandstone residuals. The inselbergs form part of the dominantly stripped etch surface while the sandstone residuals form part of the zone of dissection and partial stripping discussed in Chapter 6. Savigear (1960) hinted that the removal of the sediments from over the crystalline basement rock can lead to the evolution of low inselbergs. In this respect Falconer (1911, p. 247) observed in Northern Nigeria that "where the pre Cretaceous sediments have been removed, the land surface is marked with domes and inselbergs". He further noted that in Kabba province, the Cretaceous and Tertiary sediments rest on a "hummocky granite floor". This type of relationship between the Cretaceous sediments and the crystalline rocks appears to exist also in this contact zone, specifically in Abeokuta area, but there has been no detailed study of the link between the low inselbergs and the sandstone residuals around the town. In this chapter an attempt is made to elucidate the following points:-

- i. the former extent of the upper Cretaceous sandstone over the crystalline rocks
- ii. the pattern of erosion and the slope types on the sandstone both on the scarp face and in the dissected area around Abeokuta

- iii. The mode of inselberg formation in relationship to the erosion of sandstone.

The contact zone was studied around Abeokuta and also north-west of Abeokuta where the Cretaceous scarp is well defined between Imala and Obada. The scarp face and the sandstone residuals are densely forested. Along the twenty mile stretch from Imala to Obada (Fig. 2), 21 slope profiles were measured, especially at stream re-entrants and where the streams flow at some distance to the scarp foot (Fig. 65). Measurements were taken from the top of the scarp to the stream lines along cut traverses on farmlands, and, in some cases along minor foot paths traversing the scarp face.

The sandstone residuals around Abeokuta were mapped from 1:40,000 air photos. By this means it was relatively easy to determine the presence or absence of lateritic caps on the residuals, and the area of the residuals were calculated. The heights and maximum slopes were computed from the 1:50,000 maps. These residuals were confirmed in the field, but the thick forest cover precluded the investigation of most of them. The morphometric data is shown in Appendix 5., and the residuals in Fig. 64.

Pattern of stream flow near the boundary of the sandstone and the former extent of the Cretaceous Sandstone

The 1:125,000 Geological map of this area shows outliers of the Cretaceous sandstone on the basement rocks, especially east of Abeokuta and north of Ijebu Ode, which indicate the former extent of the sandstone. This is not seen west of Abeokuta where the sandstone has a sharp boundary with the crystalline rocks and there are no outliers. In order to trace the former extent of the sandstone over the crystalline area, the pattern of stream flow over the crystalline rocks at the northern boundary of the

Abeokuta formation was examined.

To the West, the Oha and Oyan rivers have their sources on the crystalline rocks far to the north, ^{flowing N-S} but near the Cretaceous escarpment, the rivers change direction and flow in a NW - SE direction until the Oyan joins the Ogun (Fig. 15). They flow in the same direction as the strike of the sandstone. The Ogun river, however, flows in a N - S direction and is ^{consequent} ~~superimposed~~ on the sandstone in the Abeokuta area.

To the east of Abeokuta, the Ibu river rises on the crystalline basement a few miles to the north of the Abeokuta formation, and flows in a NNW - SSE direction over the crystalline basement. Near the Upper Cretaceous sandstone, it changes to a NW - SE direction, much as Oha and Oyan do to the east. The Ona river originates near Ibadan and flows in a N - S direction over the crystalline rocks, but near Ipara, close to the sandstone area, it starts to flow in a NW - SE direction until it joins the Omi. The Omi river maintains a N-S flow for most of its course on the crystalline rocks as it flows between N-S trending quartzite bands, but close to the sandstone it flows in a NE-SW direction through schists and migmatites until it joins the Ona river near Ijebu Ode.

With the exception of the Omi, all the other rivers flow in a NW-SE direction near the upper Cretaceous sandstone (Fig. 15). This pattern of stream flow in relationship to the northern boundary of the Cretaceous sandstone suggests either that these streams were ^{consequent} ~~superimposed~~ on the sandstone as the Ogun or that they developed as scarp foot streams. The NW-SE direction of flow of most of these streams is consistent with the NW-SE strike and the direction of the scarp of the sandstone. From this, it may be inferred that these streams developed in the vicinity of the sandstone as scarp foot streams. However, this view is difficult to substantiate if the

implications are examined.

Where streams develop as scarp foot streams, the insequent streams developed on the scarp face will be shorter than the tributaries developed on the crystalline rocks. Moreover, as the scarp retreats, as a result of erosion by the insequent streams, residuals of the scarp will be present on one side of the scarp foot stream, and absent on the other. Where streams are superimposed, they are developed on the basement complex and the sandstone when the level of the surfaces of both rocks were uniform. The streams are superimposed into the basement rock below by cutting through the sandstone. The streams will develop tributaries equally on both sides, and residuals of the sandstone will be present on either side. The former consideration applies to the Oha - Oyan rivers, while the latter applies to the rivers east of Abeokuta.

Near the Cretaceous sandstone, the Oha - Oyan rivers developed as scarp foot rivers. They developed insequent tributaries on the scarp slope and these tributaries are shorter than the northern tributaries developed on the basement complex. The amount of lateral shift towards the scarp face by the Oha-Oyan rivers cannot now be calculated, but their insequent streams have effected the retreat of the scarp for 5-8 miles from their parent stream lines. Between the scarp and the main streams, some low outliers of the Cretaceous sandstone resting on the basement complex are seen, but none is seen on the northern sides of these rivers. Thus it can be tentatively concluded that west of Abeokuta, the courses of the Oha-Oyan rivers indicate the former extent of the Cretaceous sandstone.

To the east of Abeokuta, the streams appear to be superimposed on the ^{in their upper courses} sandstone _{of the crystalline rocks.} The Ibu river has its source some twenty miles north of the present boundary of the Cretaceous sandstone. There is no way of actually

determining whether it developed on sandstone in its upper course, but its predominant NW-SE direction of flow on both the basement complex rocks and on the sandstone strongly suggests that it was initially developed on a uniform material possibly the Cretaceous sandstone. This observation does not apply to the Ona and the Omi which flow mainly in a N-S direction until near the Cretaceous sandstone where they change their direction of flow. It seems that these streams were ^{consequent} ~~superimposed~~ ^{from the crystalline rocks} on the sandstone with their change of direction of flow near the sandstone effected by the strike of the rock. The Omi does not flow in a NW-SE direction near the sandstone as its flow is strongly influenced by the schists and migmatites which it flows across. In the sandstone, the streams developed wide valleys and tributaries of uniform length with the result that sandstone residuals are present on either sides of these streams. These outliers are found 7-10 miles from the main sandstone on the basement complex. From this evidence, it seems that the Cretaceous sandstone used to extend up to 10 miles further north of its boundary with the basement complex rocks, which, in effect, meant that it covered the whole of the present landscape around Abeokuta.

The Cretaceous scarp at Imala-Obada

The scarp has two features of interest: as a watershed between north and south flowing streams; its mode of erosion. It forms the watershed between the dip streams flowing to the Ogun and the Yewa, and the insequent streams flowing to the Oha-Oyan system to the north. For the most part, this watershed is broad and flat-topped, but in some places, it is less than half a mile between the north and south flowing streams (as at Olorunredo). West of Idiami, the scarp has been completely cut through by the headwaters of Yewa, and the watershed is continued on the basement rocks as far as Dahomey boundary.

The pattern of watershed recession east and west of Idiami was investigated to determine whether the south flowing streams are eroding headward more strongly than the north flowing streams i.e. is there a northward recession of the watershed, or vice versa? The Cretaceous sandstone dips southwards at 1° and is composed of ferruginised sand bedded with silt and pebbles. It is highly porous and pervious, supporting fewer streams than the watershed basement rocks to the north. The scarp slope of the sandstone is very steep. In this dip and scarp area, with uniform rainfall on both sides, it would be expected that the scarp streams, which are shorter and with steeper gradients would effect more watershed recession than the longer streams on the dip slope. On this premise, the gradients of the north and south flowing streams were examined in the two watershed section described above (Fig. 63).

The gradients of the headstreams of Yewa, Ireri, and Oyo flowing to the south are less steep than the gradients of the streams flowing opposite them in a northward direction to Oha river. The gradients of the Afon, Obete, Igboori and Ireri flowing to the south, however, are equally as steep as the gradients of the streams flowing to the north. In the former, it appears that watershed recession is southwards while in the latter, it appears the watershed is stable. It is possible that in the first case, the watershed between the south and north flowing streams was equally eroded by the stream systems, but since the sandstone scarp has disappeared, the north flowing streams are moving headward at the expense of the south flowing streams. Here the watershed will retreat southward. In the second case, most of the north flowing streams appear graded, while the south flowing streams are still ungraded and capable of more erosion than the north flowing streams. The watershed stability is maintained because it is mantled by laterite equally

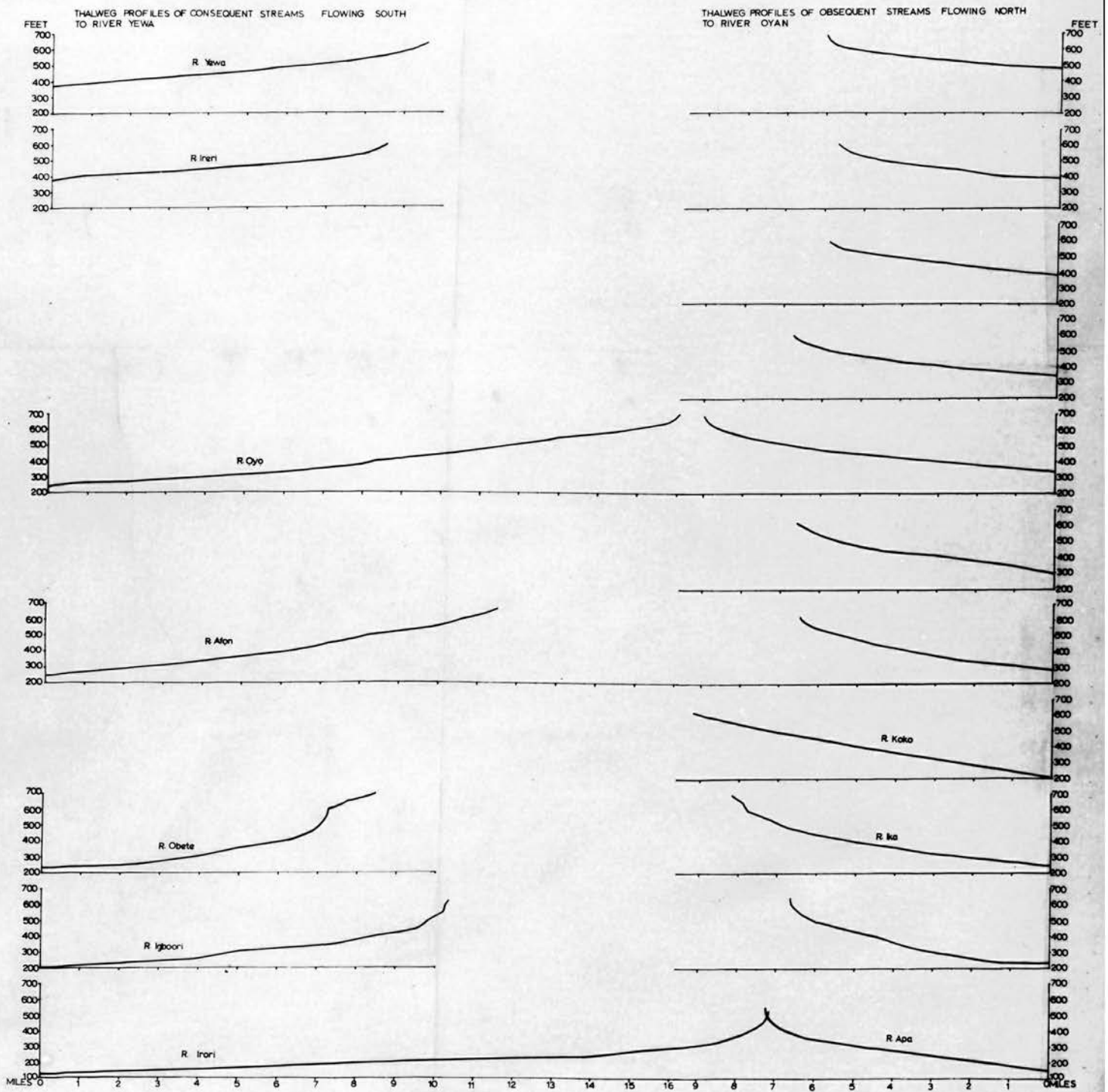


FIG.63

resistant to both the north and south flowing streams.

Scarp Erosion

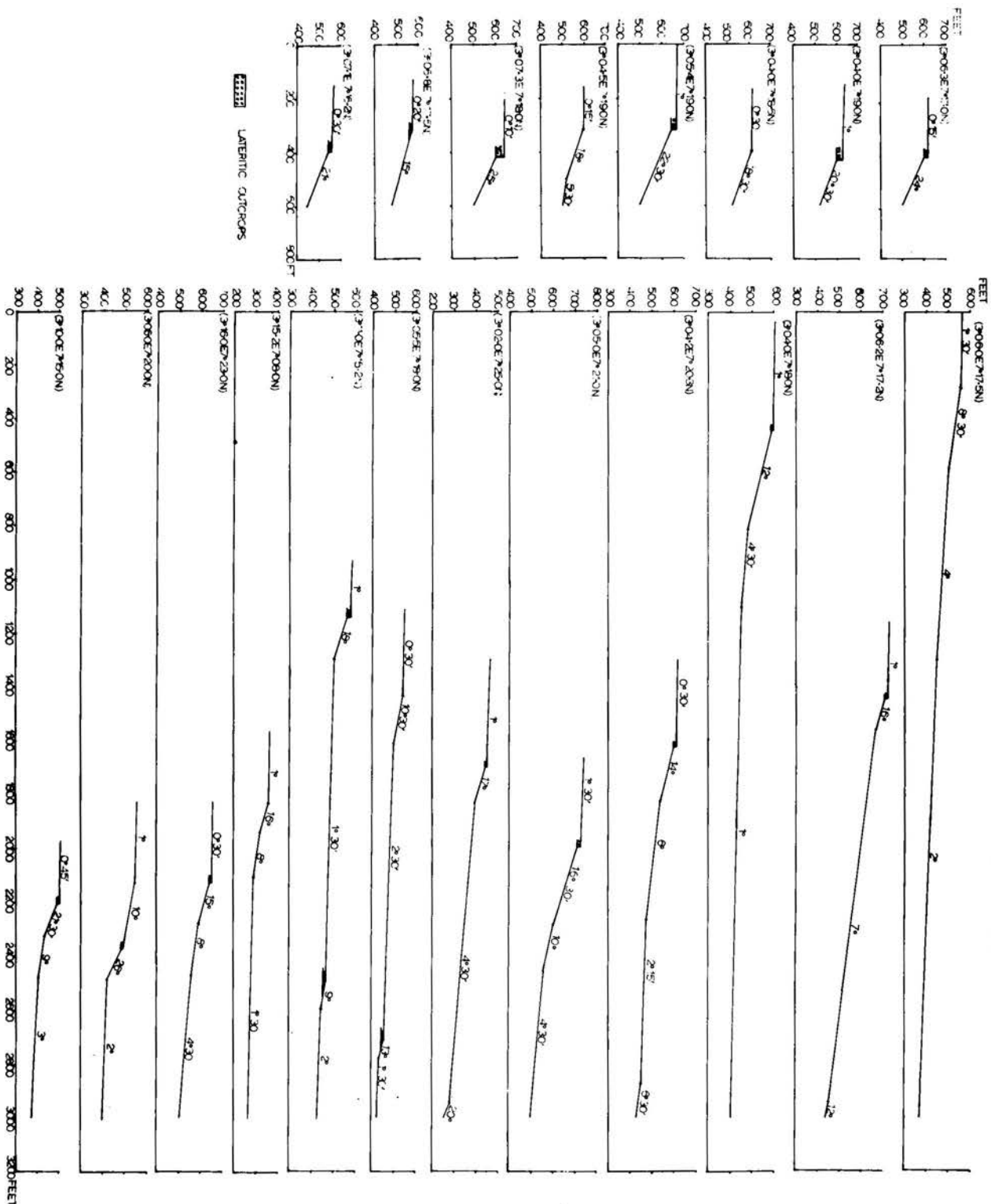
The scarp has been preserved because it is a compound scarp composed of an upper resistant laterite cap rock 6-35 ft. thick, which is underlain by weaker rocks. This lithological arrangement in effect means that the scarp cannot be lowered unless the resistant cap rock is destroyed.

There are from 2-5 slope segments from the top of the scarp to adjacent stream lines (Fig. 65). The slope on the top of the scarp is usually flat or may be up to 1° , while below perpendicular slopes formed by lateritic outcrops are common. The constant slope composed of lateritic blocks is often steep, varying from 8° - 25° in all the samples below the constant slope is a gentle slope unit that can be described as the footslope; it is longer than all the other slope units, and has a declivity of 1° - 7° . In some cases, the footslope is followed by a steep rejuvenation slope, 25-120 ft. long, and angled between $6\frac{1}{2}^{\circ}$ - 20° . Following the rejuvenation slope is a rather flat slope unit at 2° - 4° . Nearly all these slope units are separated by sharp breaks of slope.

The scarp profile varies from a simple concave form, to multi-concave forms where there have been multi-phased stream incision and rejuvenation, or, in rare cases, it may be concavo-convex. This last type was seen in one instance (Fig. 65; 3^o06,0E7^o20.ON; 2nd lowest profile). The upper most slope is flat, and is followed by a convex inflexion. The slope below the inflexion is 10° , and following this slope is a lateritic outcrop. The slope below the laterite is 26° , and the footslope is 2° . The reason for this may be basal sapping of the marginal laterite. In this simple concave and multi-concave types of profiles, the breaks of slopes are usually very sharp and often associated with ferruginised crusts.

Wherever the lateritic cap is thin or absent on the upper scarp slope,

SCARP SLOPES ON THE UPPER CRETACEOUS SANDSTONE MALA-OBADA AREA.



the value of the constant slope is low and varies between 8.5° - 18.5° with a mean of 14.75° and standard deviation of 2.9° for 12 samples. Where lateritic cap is especially thick on the upper scarp slope, the value of the constant slope is high, being of the order of 18° - 26° with a mean of 22.3° and standard deviation of 2.4° for 9 samples. A student *t* test is employed to show whether the difference noted between the means of the samples is significant. The *t* value is 5.44 and the degree of freedom is 19, which is significant even at 0.1% level as seen from Table 3 of Cambridge Elementary Statistical Tables by D.V. Lindley and J.C.P. Miller. This shows that the steepness of the constant slope depends entirely on the presence of the lateritic cap rock.

The scarp face is covered by thick forest (Plate 58) making observations of processes under the natural vegetation cover difficult. Most of the field work was carried out where the slope has been cultivated for cocoa, kola nuts and plantains. To a great extent these crops shield the slope from the effects of deforestation hence the processes observed could be taken as indicative of those under natural vegetation.

The scarp is undergoing parallel retreat. In some places it is dissected by large U shaped valleys whose headward extensions often end in gullies and steep re-entrant slopes. These deep gullies carry very small amount of water during the dry season and their floors are often littered with blocks of laterite. Since the formation of these valleys and their associated gullies, rejuvenation has led to the development of smaller and narrower gullies into the old ones with breaks of slopes seen on the gully sides. Most of these gullies are not active now as their sides have been colonised by trees (Plate 59). In some cases, the gully heads are also filled up with laterite debris on which plants have established themselves



Plate 58 The upper Cretaceous scarp as seen between Abeokuta and Aiyetoro. To the left is the scarp, and to the right is the footslope.



Plate 59 A gully in the scarp is colonised by plants and cultivated cocoa. Note the narrower gully below the old one.

(Plate 60), and this also shows that these gullies are no longer active. Where the gullies are still active, large amphitheatre like heads with springs which effect basal sapping and slumping of the laterite blocks into the gully channels are characteristic. The rate of headward sapping is slow and in few instances the springs are choked with lateritic debris. Headward erosion is fast in some localities however, as near Araromi village.

On the scarp slope profiles, slope erosion follows a simple pattern. Runoff on the slope above the laterite cap is never channelled, but on the free face of the lateritic outcrop, runoff becomes channelled. The free fall of water leads to eddy action in the softer material below the laterite, eroding the material. The effect of the basal scouring by runoff is to undermine the laterite sheet which in turn slumps and break up into large blocks which move downslope. In some cases a small flat pavement may be found just below the free face.

On the constant slope, runoff may be in three forms. First, in some cases, gullies up to 10 feet deep and 6 feet wide have developed but these rarely continue to the footslope below. They form where the channelled runoff across the free face continues into the constant slope. The development of these gullies is intermittent, most of those observed have their upper slopes overgrown with vegetation, and their lower slopes bare. The gullies effect further basal sapping of the lateritic cap.

Second, in most places, runoff on the constant slope is in form of rills which are often parallel and constantly regrading their sides. These rills are a few inches to about a foot in depth and often disappear on the footslopes where they may or may not deposit small fans. The rills are powerful erosional agents cutting back the constant slope as the laterite breaks up.



Plate 60 Laterite blocks on which trees have established themselves.
Note the block firmly entwined by tree roots



Plate 61 An outcrop of iron pan at Abeokuta.

Third, unchannelled sheetwash especially on farmlands, is effective in removing materials from the constant slope. Soilcreep is another agent of erosion on the constant slope.

The footslope is mainly eroded by sheetflow as the small gullies and rills do not often continue over it. Spring sapping is also active. Near Anigbado village on a $4\frac{1}{2}^{\circ}$ slope, a spring with typical amphitheatre-like head has developed and is moving headward rapidly on to the constant slope.

A comparison between the weathered profile of the scarp and of the footslope further illustrates this backward retreat of the scarp face. Near Anigbado village, a deep gully in the scarp shows a complete and matured weathering profile consisting vertically of the upper soil horizon, the lateritic outcrop, the clayey layer below the laterite, the mottled and the pallid zones (the thicknesses are given in Chapter 12 under lateritic profile). On the footslopes, about 300 yards away from the scarp face, the weathering profile shows an upper clayey layer in which lateritic pisoliths are common, about a foot thick, and this is followed by the pallid zone about six feet deep, of the same material as on the scarp face. This weathering profile is clearly truncated, and the interpretation that can be given is that the backward retreat of the scarp has led to the truncation of the weathering profile, and the whole weathering profile from the top soil to the pallid zone is involved in the backward retreat. This is much the same as the truncation of weathering profile and backward retreat noted in Uganda by Ollier (1959a).

From the evidence cited so far, it may be inferred that it is the lithological pattern whereby laterite caps the sandstone that has allowed the backward retreat and the essential preservation of the scarp. In some cases, sandstone residuals are seen a few hundred yards from the main scarp

with the laterite cap still intact; here the constant slopes are as steep as on the scarp face. Where such residuals have lost their lateritic caps (being replaced by lateritic blocks) the constant slope has become flatter. Near Apata village (Aiyetoro-Imala road) the constant slope of the scarp is 24° , but the slope of the residual nearby with no caprock is 16° .

The scarp slope profiles show distinct breaks of slopes, and it is possible to determine the levels of slope breaks and compare these with what were observed in the valleys on the dip slope (chapter 7). The upper surface on the scarp varies between 550 ft. around Apata to about 750 ft. near Idiemi. Between Apata and Anigbado village the break of slope appears to delimit two surfaces; an upper surface above 550 ft., and a lower one at 375-475 ft. These correlate with the surfaces noted around Aiyetoro at 400-600 ft. and 275-380 ft. (chapter 7). Between Anigbado and Idiemi, the break of slope delimits two surfaces at above 700 ft. and at 450-650 ft. respectively. These are much the same as the surfaces noticed around Meko at 500-800 ft. and 475-650 ft. It seems that the erosional phases operating on the dip slope have also possibly operated on the scarp slope.

Erosion of the Sandstone around Abeokuta

In the vicinity of Abeokuta, the Cretaceous sandstone slopes to the Ogun river and to the south. In this area, it is covered with massive vesicular laterite which outcrops in several places. The pattern of erosion and landform development is dependent on whether or not this lateritic cap is present. The sandstone here is being dissected by the tributaries of the Ogun - the Anikanga, Shokori and Oya. The Ogun itself has cut through the sandstone to the basement rocks.

The sandstone was initially dissected into large blocks by streams.

LANDFORMS AT THE BOUNDARY OF THE BASEMENT COMPLEX ROCKS AND THE ABEOKUTA FORMATION

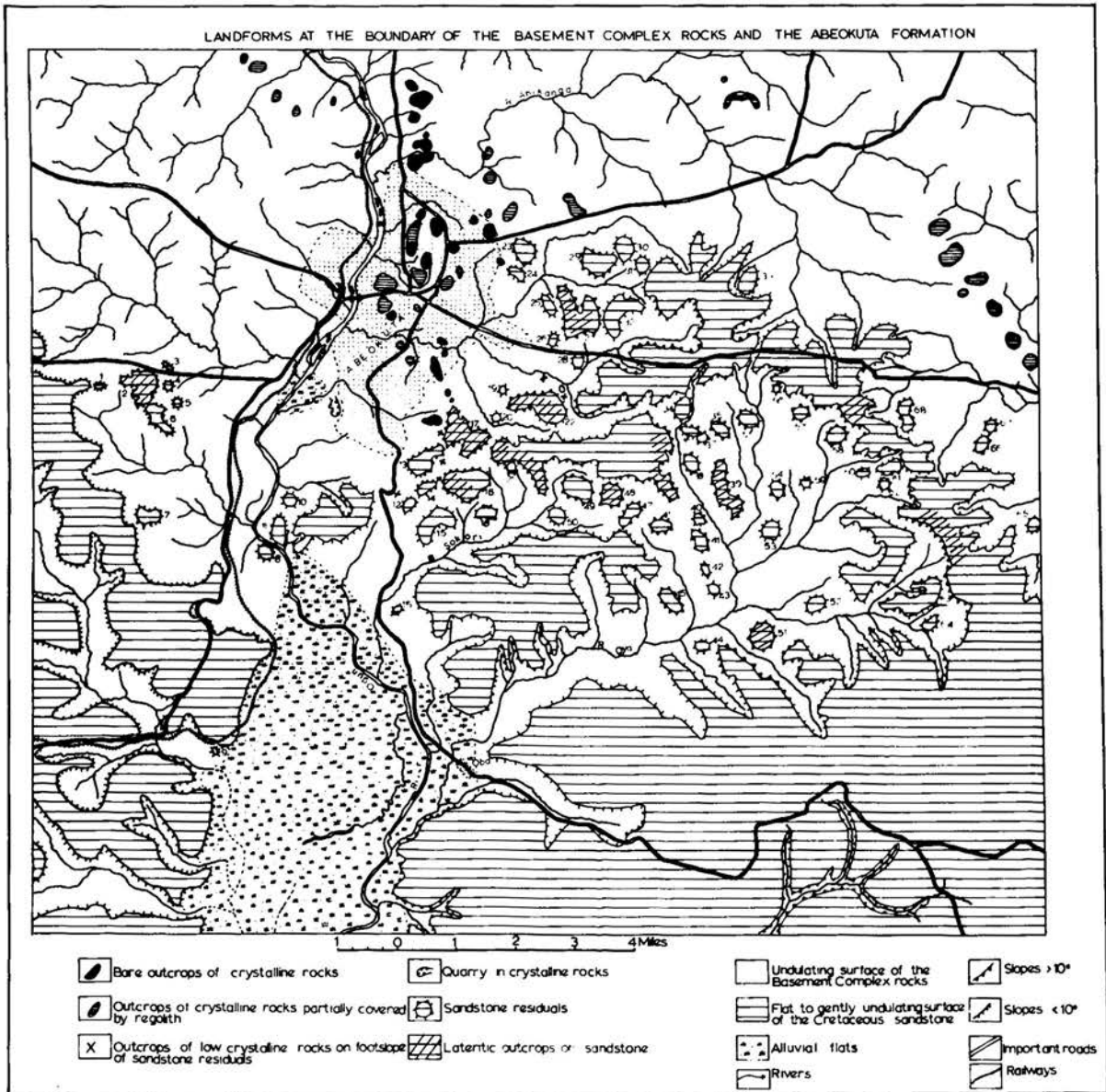


FIG. 64

As the streams developed more tributaries, the blocks were further subdivided into smaller blocks. The headstreams of the rivers are now incised into deep narrow valleys and are still actively engaged in headward erosion, but due to laterite cover and thick forest on the slopes, spectacular gully erosion is not prominent. In cleared areas, sheet erosion is not pronounced probably because of the porosity of the soil. Between the Oya river south of Abeokuta and the headstreams of the Anikanga, the characteristic landforms are:

- a) the residual hills
- b) the deep valleys
- c) the undulating area with crystalline rock outcrops near and between the residual hills (Fig. 64)

The Residual Hills: These are the remnants of the once continued Cretaceous sandstone. They may be categorised according to whether they are tabular (mesas), conical, domical or elongated ridges. There are also very large types in the form of small plateaux. The tabular types almost invariably have a thick laterite cap and are at the same elevation as the main sandstone; the domed types may or may not have laterite caps; the conical types have no laterite cover; the elongated types, when they are flat topped have laterite caps, but when narrow and knife-like have no laterite cap; the large plateau-like residuals almost invariably have laterite caps exposed at their edges.

It was not possible to carry out more than a few slope profile survey, but where this was done it was observed that most of the slope elements noted on the scarp face in the Imala-Obada area, are also present on the slopes of the residuals. The only difference is that the free faces of the laterite caps are infrequently seen, being obliterated by the debris on the constant slope. The effects of peripheral slumping of laterite due to sub-

surface sapping is well exhibited on the residuals. There are altitudinal differences of up to 20 feet from the laterite at the peripheral slope to the top centre of the residuals. The debris slope of the surveyed tabular residuals vary from 19° - $21\frac{1}{2}^{\circ}$ and the footslopes vary from 2° - 7° ; the constant slopes of the surveyed conical residuals near by vary from $5\frac{1}{2}^{\circ}$ - $10\frac{1}{2}^{\circ}$, their footslopes are the same as for the tabular residuals. The maximum slopes of the residuals were calculated using Strahler's (1956) method, and the table below shows the frequency of occurrence of the maximum slopes of the different residuals. The complete data is given in Appendix 5.

Table 36. Maximum slopes of the Sandstone Residuals

Types of Residuals	0° - 3° %	3° - 6° %	6° - 9° %	9° - 12° %	12° - 15° %	15° - 18° %	18° - 21° %	21° - 24° %
Tabular with laterite cap	-	-	7.7	7.7	23.07	7.7	46.14	7.7
Domical with or without laterite cap	3.125	6.25	34.375	12.5	18.75	9.375	15.625	-
Elongated with or without laterite cap	-	-	33.3	-	33.3	-	16.7	16.7
Conical without laterite cap	6.25	6.25	18.75	37.5	25.0	-	6.25	-

The mode of maximum slopes for the tabular types of residuals is 18° - 21° , and for the domical type it is 6° - 9° , while the elongated type is bimodal at 6° - 9° and 12° - 15° , the conical type is 9° - 12° . This shows that residuals with laterite caps have the steepest slopes. This is also verified from the large residuals with laterite exposed at their upper slopes; their constant slopes are always very steep.

It is difficult to postulate a genetic link between the different residuals. Although the tabular types may be observed in airphotos, there is

less certainty about the domical and the conical types, and field verification is rendered difficult by the forest cover. The tabular types however are often closer to the main sandstone and invariably larger than the others - Appendix 5. It may be tentatively concluded therefore that the tabular and the elongated types with lateritic cover represent the stage of youth, while the domical and the conical types represent the maturity stage in the evolution of the sandstone residuals.

Stream Valleys in the Dissected Sandstone Most of the valleys have wide floors filled with alluvial material, especially in their middle and lower courses. In their upper courses, they are deep, steep sided and often end in gullies incised either into the large residuals or into the main sandstone. The most interesting aspect is that some of the valleys are dry. Like the dry valleys in chalk or limestone, they carry very small amount of surface water in the wet season. Some of the dry valleys constitute tributaries of the Oya river and can be seen in Fig. 64. These dry valleys are wide bottomed and often look exactly like those valleys carrying water, but the basic difference between the two types is in their upper reaches. The dry valley heads are not in form ^{of} deep gullies. Instead they flatten out against the residuals ^{or} ~~at~~ the main sandstone, and are at higher levels than those of the water-carrying valleys.

The presence of these dry valleys can be interpreted in two ways. They might have been formed in a relatively wetter period than the present, and thereby constitute useful evidence of climatic fluctuations. However, if this were so, most of the valleys in this area would be expected to be dry since they were formed under the same conditions and in the same rock type. The alternative explanation is ^{to} ~~the~~ assign the formation of these valleys to

the uplift and erosional dissection that led to the formation of the whole landform. With uplift and increased dissection, the water table below the sandstone would migrate downwards, and the rivers would have to deepen their valleys. Rivers deficient of erosional material cannot effect linear erosion as those rivers with erosional material especially laterite debris and quartz fragments, hence would be relatively shallower than the others. At the cessation of uplift, the watertable would have migrated far below the level of the shallow valleys hence such valleys would be dry in their upper reaches, carrying water at their lower reaches which are at the level of the local watertable.

The Inselberg Terrain ^{AROUND} Abeokuta

The sedimentary rock overlying the crystalline rock is composed of materials previously weathered and recemented. As it is pervious, weathering has advanced far into the crystalline rocks below the sandstone. At the headstreams of rivers Irori and Igbori, the point of contact between the sandstone and the crystalline rocks was seen. Here the gneissic rock is weathered in a whitish clayey substance, but the quartz constituents are still present and the structure of the rock is still preserved. In no instance was the sandstone seen to lie on fresh crystalline rock, but on the footslopes of the sandstone residuals south of Abeokuta and near the Cretaceous scarp, small convex rock outcrops, up to 30 ft. high with small corestones littering their surfaces were seen. As the sandstone is of marine deposition, it appears that the crystalline rocks have been weathered since the sandstone was deposited on them in the late Cretaceous.

The pattern of weathering in the sandstone is not difficult to envisage. As it is composed of clastic material of uniform porosity and perviousity, the weathering front will be fairly regular; the weathering front on the

underlying crystalline rocks is not easy to determine. Evidences of weathering beneath the sandstone near the basement complex are derived from records of boreholes of the Nigerian Geological Department, Ibadan. The boreholes are confined to four localities all of them lying on interfluves on the sandstone,

- i. At Meko weathering into the crystalline rocks below the sandstone is 10 - 29 feet.
- ii. At Aiyetoro, it is 47 - 57 feet.
- iii. At Maroko, it is 190 feet.
- iv. At Ijebu Ife/Ijebu Ode area, it varies between 13 - 47 feet.
- v. At Isaga it is 34 - 85 feet.

This is insufficient to warrant any serious conclusion ~~and fortuitous~~ ~~in distribution~~, but it still suggests that the depth of weathering in the crystalline rocks may be deep and the weathering front appears to be highly irregular. With the erosion of the overlying sandstone and the regolith incumbent on the unweathered crystalline rocks, the irregular basal surface was revealed as low rock pavements, corestones, tors and low inselbergs. The inselbergs are mainly composed of porphyritic granite and porphyroblastic gneiss, rocks which form many of the inselbergs on the basement complex further to the north.

The heights of the inselbergs in Abeokuta vary between 200-569 feet above the sea level, the sandstone residuals east and south of the town vary between 500-625 feet. This height differential between the two types of residuals meant that the sandstone could have once covered the sites of these inselbergs. Except for unloading sheets on these inselbergs, their vertical joints are still relatively unopened, and this means that the inselbergs are relatively young. Their age can be tentatively estimated as

late Tertiary to Quaternary.

The depth of weathering in between the inselbergs is extremely shallow and many runnels within Abeokuta have bare rock outcrops in their channels. The present weathering profile is immature consisting of:

- a) 0 - 9 ins. an upper soil horizon, reddish grey and composed of sand and clay,
- b) 9 ins. - 2 ft. 3 ins. an iron pan composed of fine sand cemented together by ferric material, and outcrops quite often (Plate 61),
- c) 2 ft. 3 ins. - 4 ft. 6 ins. a whitish grey horizon composed of hydrated felspar and quartz fragments with the texture of the parent rock still recognisable; in gneiss, this horizon is pinkish red.
- d) over 4 ft. 6 ins. the unweathered parent rock.

In several places in between the inselbergs, no weathering has taken place, the bare rock surface is exposed as wide irregular pavements carrying small corestones on their surfaces.

It appears that the observations of Falconer (1911) that weathering below the sedimentary rocks into the crystalline rocks can lead to the evolution of low inselbergs is confirmed by the pattern of landform development in Abeokuta area. The occurrence of the low inselbergs, tors, corestones and rock pavements close to the Cretaceous sandstone, leads to the conclusion that they were produced as a result of deep weathering of the basement complex below the sandstone and revealed when the overlying sandstone and regolith were removed.

APPENDIX 5

MORPHOMETRIC PROPERTIES OF THE CRETACEOUS SANDSTONE
RESIDUALS AROUND ABEOKUTA

Tabular Type (with Lateritic Cover)

Domical Type (with or without
lateritic cover)

No.	Height ft.	Max. Slope	Area (sq. mls)
2	480	21° 30'	0.2304
7	370	10° 3'	0.0896
13	460	13° 18'	0.1600
16	480	19° 24'	0.3200
17	520	19° 24'	0.3200
22	520	19° 24'	0.3072
27	610	19° 24'	0.3520
29	615	13° 18'	0.1792
48	510	19° 24'	0.1024
49	515	16° 24'	0.1600
51	515	20° 48'	0.1600
61	560	13° 18'	0.0704
63	460	6° 42'	0.3200

No.	Height ft.	Max. Slope	Area (sq. mls)
3	275	3° 18'	0.0192
8	170	9° 20'	0.0512
10	125	6° 42'	0.0256
11	170	14° 33'	0.1024
12	260	3° 18'	0.0256
14	320	8° 6'	0.0448
18	370	9° 42'	0.0512
23	560	10° 24'	0.1152
24	510	16° 24'	0.0448
30	510	2° 42'	0.1024
31	590	8° 6'	0.0512
34	510	13° 18'	0.0832
35	620	19° 24'	0.0576
38	460	13° 18'	0.0640
40	360	7° 24'	0.0320
41	530	20° 40'	0.0640
43	310	6° 42'	0.0320
44	320	6° 42'	0.0320
45	460	14° 33'	0.0896
46	515	16° 24'	0.0640
50	515	6° 42'	0.0640
52	390	10° 3'	0.0640
53	415	13° 18'	0.0768
54	410	11° 21'	0.0576
55	515	13° 18'	0.0768
57	600	19° 24'	0.0448
58	615	19° 24'	0.0832
59	415	8° 6'	0.0256
60	455	6° 42'	0.0320
62	510	16° 24'	0.0320
64	375	6° 42'	0.0256
65	500	8° 6'	0.0384

CONICAL TYPE (with no Laterite Cover)

No.	Height ft.	Max. Slope	Area (sq. mls)
1	450	10° 54'	0.0192
4	320	9° 20'	0.0160
5	270	2° 42'	0.0160
9	120	10° 3'	0.0096
19	330	3° 18'	0.0128
20	360	9° 42'	0.0192
21	460	14° 33'	0.0160
25	460	6° 42'	0.0448
26	460	8° 6'	0.0192
28	410	9° 42'	0.0384
36	570	13° 18'	0.0256
37	620	19° 24'	0.0192
42	370	10° 3'	0.0256
56	500	8° 6'	0.0096
66	610	13° 18'	0.0512
67	610	13° 18'	0.0320

ELONGATED TYPE (With or without lateritic
cover)

* 6	410	13° 18'	0.1152
15	325	6° 42'	0.1920
32	570	6° 42'	0.2560
* 39	560	22° 24'	0.2240
47	520	19° 24'	0.0832
68	670	14° 33'	0.1124

* indicates lateritic cover.

Chapter 14Conclusion

This thesis is in two parts. The first is devoted to an examination of the physical background, the geomorphological processes, and the broad landform pattern of South Western Nigeria; the second is a discussion of some important landform elements on the crystalline and sedimentary rocks.

Landform development in South Western Nigeria depends on the factors of geology, geological history, climate especially rainfall and temperature, chemical weathering, erosion and vegetation. Based on surficial configuration, the following physiographic regions were recognised:

Coastal Sands, Creeks and Lagoons

Coastal Plains

Alluvial Flats

Dissected Southern Upland

Ewekoro Depression

Southern Meko Plain

Northern Upland - Area of deep incision

Area of mature dissection

Dissected Margin

Dissected Terrain - With low ridges and hills

With high ridges and hills

Gently Undulating Terrain with Occasional Hills

Hilly Terrain.

Geomorphological regions were delineated on the basis of area of basal surface of weathering exhibited, the amount of laterite present and the intensity of erosion in the different drainage basins as signified by certain drainage properties. These landforms do not consist of widespread erosion surfaces, but

are etchplains and etchsurgaces developed across the weathered profile of the initially sloping surface whose remnants are still preserved on the primary watershed further to the north. The landforms are:

Sedimentary Area - (Partially Dissected) Lateritized Plain

Dissected and partially stripped Etchsurgace

Zone of Dissection and Partial Stripping

Aggraded Plain

Partially Dissected Coastal Plain

Crystalline Basement Area - Partially Stripped Etchsurgace

Dominantly Stripped Etchplain

Dominantly Stripped Etchsurgace.

The sedimentary landforms are related mainly to the geology and the drainage pattern of South Western Nigeria. On the crystalline rocks, the dominantly stripped landforms are developed on granites; quartzites and schists, while the others are developed on gneisses and schists. Vegetation also affects landform development for the dominantly stripped types are mainly in the savanna.

The physiographic regions and the landform types correspond closely. The Coastal Plain forms an individual unit, while the Ewekoro Depression; Southern Meko Plain, and the Alluvial Flats correspond to the Aggraded Plains. The dissected parts of the Southern and Northern Uplands are identical with the Dissected and Partially Stripped Etchsurgace on the sedimentary rocks while the incised part of the Northern Upland covers the same area as the (Partially Dissected) Lateritized Plain. The Dissected Margir is the same as the Zone of Dissection and Partial Stripping.

On the crystalline rocks, the Dissected Terrain with Low Hills and Ridges nearly corresponds with the Partially Stripped Etchsurgace except for some areas

south of Ibadan and west of Ijio. The Gently Undulating Terrain covers the same area as the Dominantly Stripped Etchsurface except for the area west of Ijio, while the Hilly Terrain covers nearly the same area as the Dominantly Stripped Etchsurface except for areas north of Iwo, around Iseyin and around Iwere.

The most important geomorphological process in South Western Nigeria is chemical weathering. It affects all the rocks, but the degree to which it is effective depends on the structure, the texture and the lithology of the rocks. Jointed and foliated schistose rocks can absorb water and are relatively more quickly weathered than rocks with few joints. The basal surface of weathering is highly irregular in the crystalline rocks, with depth of weathering shallow below river channels, but deeper under interfluves. In the sedimentary rocks, the weathering front is regular. The effect of weathering over a long geological period is to produce a thick layer of regolith. Where the regolith is developed on schists, amphibolites and other ferro magnesian rocks, such regolith is relatively impermeable and can lead to the formation of laterite.

After weathering or concurrently with weathering base level changes may lead to erosional stripping of the regolith. In South Western Nigeria, erosion is in form of gullying, rilling, surface wash, eluviation and mass movement. Where the lithology is suitable for the formation of laterite caps over the regolith, backwearing may occur; otherwise slope flattening is normal. The effects of differential erosion under multi cyclic phases is to produce the various etchplains and surfaces and also inselbergs. On the sedimentary rocks, local erosion surfaces are produced.

The characteristics of individual inselbergs will depend on the nature of the parent rock; they are large and occur close together in granites, and they are of various sizes and occur further apart in gneisses. Inselbergs disintegrate

* At the boundary between the crystalline rocks and the sedimentary rocks, the pattern of stream flow to some extent reveals the former extent of the Abeokuta formation over the crystalline rocks. Close to the Upper Cretaceous scarp east of Abeokuta, the Oha-Oyan rivers flow parallel to the scarp in a NW - SE direction following the strike of the sandstone, and there are few, low sandstone residuals between the scarp and the river. East of Abeokuta the Ibu river appears to be superimposed in its upper course. Other rivers like Ona and Ibu though they flow in a NW - SE direction close to the scarp, they appear to be extended consequent rivers on the sedimentary rocks. It can be concluded tentatively that west of Abeokuta, the former extent of the sandstone is marked by the Oha-Oyan rivers, and east of the town, the sandstone outliers show that the Abeokuta formation extended about 10 miles further to the north of its present boundary with the crystalline rocks.

as a result of physico-chemical weathering and superficial erosion by runoff. Pediments are formed at their base, and are at present being eroded by surface wash and eluviation. Pediment angles vary under different vegetation cover, but are steepest under forest. Valley cross profiles vary from one landform type to the other, and they are mainly related to the stages of erosion within the landforms.

* Laterites by their presence or absence play important roles in landform development both in the form and development of slopes. They also preserve the local erosion surfaces on the sedimentary rocks.

Discussion and Problems

The study of geomorphology in the humid tropics most especially in Western Nigeria is inhibited by the lack of sufficient data about the physical environments, about the geomorphological processes and about the geomorphological features. Temperature and rainfall data are scanty and the collection is haphazard. Evapotranspiration processes are largely unknown, but ^{it} ^{is} ^{essential} ^{to} ^{obtain} ^{data} ^{concerning} ^{its} ^{amount} in order to determine the amount of water available for chemical weathering. The geology is still not definitive as the boundaries of the various rocks on the geological maps are uncertain. It is difficult to explain how the 100 foot generalized contour line (Fig. 7) is approximately the same as the boundary of the Alluvial deposits along the rivers (Fig. 3). Data on erosion and sedimentation are sparse and collected by untrained operators; hence they are of limited value in assessing the processes and amount of erosion.

A major difficulty in quantifying landform properties, which plagues even government surveys, is the absence of large scale maps. Most of the survey work carried out by government agencies are based on the 1:50,000 maps, and landform properties cannot be accurately determined from these sheets. This emphasises the importance of detailed field survey ^{based on airphoto and interpretation}. Collection of field data on landform

properties has its own inherent problems. When landform properties e.g. slopes, are to be measured, the recommended approach is to decide the area of sampling, the number of samples, and the sampling points (either by random, linear, or stratified method) on the maps. Quite often in the forest and the derived savanna area such sample points are difficult to locate and may be inaccessible. The effect is, that data on landform characteristics ^{are} is always too few.

It is admitted by most authors that chemical weathering is the most important geomorphological process in the humid tropics. What happens however, when minerals are undergoing changes, the pattern of ion changes and development into secondary minerals are still largely matters of conjecture. Thin sections of partially weathered rocks can yield an invaluable information about this, but both the chemical and the physical changes still require detailed studies. In areas of low to moderate relief as in South Western Nigeria, the depth of weathering is seen (Figs. 17 - 20) to be shallow along the stream lines becoming deeper under the adjacent interfluves. This was confirmed by Ruddock (1967) in Kumasi district in Ghana, but Mabbutt (1961a) observed the opposite in Australia. In Western Nigeria, all the data on this pattern of weathering is derived from sites specially selected for dam building, where the outcrops of fresh rocks along the streams favour seismic investigations. Thus the data may not be representative of the weathering pattern. It is necessary to collect more data in order to be able to confirm or reject that this pattern of weathering is the norm in areas of low to moderate relief in the humid tropics. The cause of deep weathering beneath interfluves has been ascribed to the vertical movement of groundwater beneath the interfluves, but this explanation by no means answers all the problems.

The landforms of South Western Nigeria have resulted from chemical weathering baselevel changes and erosion, but the pattern is not clear, ^{nor} likewise, so is the

effect of climatic changes on this weathering and erosion. It is uncertain whether chemical weathering and erosional stripping occurred pari-passu or whether deep weathering occurred first before uplift, rejuvenation and erosional stripping. The first situation can arise if the land is being uplifted gradually over a long period, and this is the situation envisaged by Wayland (1933) to explain the etchplains he recognised in Uganda. The second situation can arise if a period of tectonic stability is followed by an uplift, with both alternating at regular or irregular intervals. The two processes would essentially give rise to widespread stripping of the weathered regolith to reveal a large proportion of the basal surface of weathering as seen in the crystalline basement of South Western Nigeria. Evidence of distinct breaks of slopes on valley cross profiles, development of wide valley benches and terraces associated with detrital laterite on the sedimentary rocks, knickpoints on the long profiles of the important rivers and local levels of erosion in the granitic terrain at Eruwa-Lalate and Idere-Tapa, lead to a tentative conclusion that uplifts of the land in South Western Nigeria was intermittent. The number and the relative amount of uplifts are still largely unknown and further studies are required to elaborate on the pattern of tectonic movements.

So far, it has not been possible to identify the influence of past climatic changes on the pattern of landform development. The evidence submitted is not convincing and is capable of various interpretations. Tricart (1956), Moss (1961) and De Swardt (1953) state that vesicular laterites associated with high erosion surfaces were formed in the dry phases, and in the following wet periods, the surfaces were dissected, and lower surfaces with detrital laterites developed below them. The formation of laterite may require phases of wetting and drying either over long geological periods or over relatively shorter periods, but the most important factors in lateritic formation are

the topography, and the water retaining capacity of the parent regolith i.e. whether or not it contains an impervious stratum. Climatic changes in the forested area appear to be slight as it has not inhibited deep chemical weathering which requires water. The pattern of climatic changes and the effect on landform development has yet to be determined.

The effect of vegetation, especially thick forest on landform development is still not clearly understood. The micro climate at the floor of the forest is relatively unknown, but it is important because here the humidity is higher and temperature lower than outside the forest. Humid tropical rain forest produces large amounts of organic debris and these encourage deep weathering through the supply of organic complexing agents, and by assisting infiltration of rain water into the soil. There ^{are} ~~is~~ virtually no data on runoff, but from observations, it is clear that runoff in the forest is small; consequently erosion is inhibited. The important geomorphological processes are thus leaching and eluviation. The soils are relatively deep and there are few exposures of parent rocks. In the savanna area, more of the soil surface is exposed and this leads to oxidation, while runoff is large; consequently degradation by surface wash, rilling and linear erosion is important. It is necessary to collect data on the bed loads and solutes of rivers in order to assess the degree of erosion in the different vegetation zones.

South Western Nigeria in Tropical Geomorphology: The humid tropics of which South Western Nigeria is a part, appears to be a distinct morphogenetic region. Here, over a long geological period, the geomorphic processes have operated essentially continuously; the intensity of these processes are governed by a set of factors peculiar to the humid tropics - high temperature, high relative humidity and large amount of rainfall. The distinct morphogenetic

elements are rock weathering and transportation of the products. Chemical and to some extent physical weathering account for the major part of material available for transportation. Because the dominant process is chemical, the structure and lithological variations are of major significance in the evolution of the landscape. This is compounded by the vegetation cover, and the effectiveness of the climatic factors is enhanced or diminished accordingly. The presence of absence of rock exposures and the depth of residual soils in any locality is determined therefore by the combination of these factors.

Chemical weathering depends on the volume of water penetrating into the soil, and this in turn depends on the total rainfall and the pattern of precipitation. The total amount of rainfall in South Western Nigeria is everywhere above 45 ins., but the amount available for weathering depends on several factors especially vegetation. In the forest, the volume of rain water reaching the ground is reduced by interception in the canopy; on the other hand the leaf litter helps water to infiltrate into the soil. High temperature also encourage rapid chemical reactions, such as organic decay, leaching and weathering which break down the parent rocks. As nutrients are provided, these are incorporated in the closed cycle of vegetation which in turn, prevents surface erosion. Thus there is an ecosystem involving the vegetation and the geomorphological processes in the forest. With no sudden change in the system, the tendency is for the depth of weathering to increase, hence the spectacular depths of weathering peculiar to the humid tropics alone. Where there is a disruption in the system either by removal of vegetation or by change of base level, depth of weathering will become reduced as a result of accelerated erosion; the lithological variations within the different rocks will be manifest in the different types of landforms that result. Thus in South Western Nigeria, although chemical weathering is pronounced, the effect of the tectonic movements and vegetation differences has led to the

formation of different landforms in which the rock structure is the most important factor. These different types of landforms are shown in Chapters 4 and 6.

The most important erosional agents are rilling, gullying basal sapping, surface wash and mass movement. Due to the absence of coarse bed load, linear erosion is weak in most of the stream channels. The development of rills and gullies depend on the vegetation cover and the soil structure. Where the vegetation is removed as illustrated in Chapter 5, rills develop very rapidly and such rills often grow into large gullies. The development of gullies is intermittent, and except at favourable locations like scarp faces, gullies are relatively unimportant erosional agents. Basal sapping operates in areas of steep slopes on the regolith under the different vegetation. Surface wash is particularly important in the savanna area where the land surface is exposed for some part of the year. Mass movement like slumping and sliding are important in areas of steep slopes, otherwise they are not of much importance, but soil creep is particularly important as it operates everywhere in South Western Nigeria. Relatively little is known of these various processes and further studies are required in order to fully assess the pattern of erosion in the humid tropics.

Application

Most theories on landform development in the humid tropics are based on inadequate data and mostly on visual evidences. Instrumental data has been used in this study to substantiate or disprove some of the existing theories. Important landform elements have been measured and described e.g. inselbergs, pediments, valley slopes and scarp slopes, and these are observed to vary; the data further provides an insight into the nature of the processes affecting these landform elements.

Geomorphology is becoming an applied science. This is particularly relevant where economic development is connected with the efficient exploitation of the land. In this context, it is valuable in identifying the broad geomorphological characteristics and the processes operating in the different areas. Thus where soil, vegetation and geomorphological factors are in a delicate balance, it is necessary to preserve this balance. For instance, on the sandstones of Eastern Nigeria, the removal of the forest, coupled with the weakness of soils' texture and the torrential thunderstorms led to serious sheet and gully erosion that destroyed about 500 sq. miles. Similar effects could occur in South Western Nigeria as deforestation at Shasha on the Eocene Sandstone has led to spectacular gully erosion. Gully development on the steep scarp slope of the Upper Cretaceous sandstone is kept in check by the forest cover, if the forest is removed, gully development would be a serious problem. The solution to this problem lies in understanding the soil structure and the local hydrology. Road making requires some knowledge of the local geomorphology. Areas liable to slumping and mass movement were not properly identified before the road making programme started in Nigeria, with the result that in Udi area, on the sandstones, the roads are frequently blocked by large masses that fall on them. In this area, drainage from the road also leads to gullying. This problem is also encountered in the sandstone area between Obada and Meko where the road is built on the steep valley of the Yewa with large masses occasionally slumping on it. Where sedimentation is an important process, such places may be especially valuable for rice cultivation. This is clearly illustrated in the fadama land of Sokoto Province where rice cultivation has become important in recent years. The same may be possible in South Western Nigeria on the Alluvial Flats along the important rivers.

On a wider scale, the land capability of the whole state can be assessed based on the knowledge of the geomorphology. For instance, soil mapping is intimately related to the evaluation of surficial configuration especially slopes, and the nature and amount of rock outcrops. In following this principle, the F.A.O. (1962) carried out a landtype and land classification survey of part of Western Nigeria. The survey was based on topography and soils. The area was described as gently rolling, rolling, steeply rolling and rugged broken country. Moss (1963) also carried out a land use survey of part of Western Nigeria based on slope characteristics, but most of the slopes were measured from maps. This type of topographic classification although detailed, is inadequate in two respects, it only conveys vague impressions about the nature of the landforms and secondly it makes no mention of the dominant processes that will likely affect any development scheme. The dominantly stripped landform with several rock outcrops around Oyo is described by the F.A.O. as gently rolling. This gives the impression of a deeply weathered landform, whereas the particular landform with its several outcrops has shallow depths of weathering and shallow soils unsuitable for large scale cultivation.

In this instance, the role of the geomorphologist is to produce a map showing the geomorphological characteristics of the landforms. Detailed morphological mapping as suggested by Savigear (1965) is desirable, but is time consuming and expensive as large scale maps are necessary. A quicker approach would be to identify the general surface form and the materials constituting the ground surface, the slopes of the ground surface, and the relative amount of rock and lateritic outcrops from airphotos. These factors are most likely to affect the soil sequences and the soil catena on the different landforms. Deeply weathered landforms with few rock or lateritic outcrops and with uniformly gentle slopes, will have all

developed soils, even though each soil type will be related to the parent material and to the slope of the land. Landforms with several rock outcrops will have shallow depths of weathering, and will give rise to stony and immature soils. Landforms with widespread occurrence of laterite and with steep slopes as between Meko and Aiyetoro will carry poor thin soils. Using the criteria mentioned above, the various landforms can be delimited from airphotos as carried out in Chapter 6. Examinations of the drainage basins within the different landforms will provide additional information especially about the dominant processes. Detailed information about each landform type can be obtained in the field by cutting traverses and mapping the angles and extents of the different slope facets, and flats, rock outcrops, laterites etc; and observing the important processes operating on the land facets. Using this data, the landform can be further subdivided into smaller units. For each unit, it is necessary to give accurate descriptions of the land facets, to identify the genetic processes and to indicate the trend of further evolution. Such maps and the accompanying descriptions can give preliminary knowledge about the land and soils to pedologists by enabling them to situate soils in their proper perspective, and also to rid them of the initial problems of soil mapping. The maps will further supply a body of data which are of aid in establishing improvement schemes. By specifying the direction of the evolution of the land facets it will be possible to avoid areas of potential erosion, make it easier to adopt methods to check such erosion, and help to locate agricultural schemes in suitable areas. The maps have the merit that they can be rapidly compiled and are inexpensive. The preliminary mapping done in Chapter 6, and the details on landform facets in subsequent chapters can be extended to cover the whole of Western Nigeria.

This thesis is a contribution to knowledge of the geomorphology of South Western Nigeria, and further gives an insight into the geomorphology of the

humid tropics. Its practical significance is that it can be of help in solving some of the problems of land development in South Western Nigeria.

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GLOSSARY

Landform - Can be defined simply as "the form of the land" or as "a feature of the earth's surface with distinctive form characteristics which can be attributed to the dominance of particular processes or particular structures in the course of its development and to which the feature can be clearly related." The second definition is implied in this thesis.

Landform element - This is a component of a major landform. For instance an eroded landform may be composed of valleys, interfluves, streams, rock outcrops and laterites. Each of these constitute an element within the major landform, but each of them by itself is still a minor landform unit.

Landform facet - Is used in the same sense as landform element.

Physiography - The word is used in this thesis to mean the physical features of the terrain, their causes and their relation to one another.

Youth, Maturity and Advanced Maturity - These are words used to describe the various chronological stages of landform dissection. Davies (1902) is of the opinion that a dissected landform is youthful till valley widening has consumed the initial surface, mature when the interfluve is being lowered and old when it is a peneplain. King (1951) believes that the landform is youthful when the initial surface covers about 40-50% of the whole area, and mature when the adjacent valley sides converge. The Davisian definition poses the problem of recognition. How can an interfluve be recognised as part of the initial surface? The same applies to King's definition. There is little doubt that in the humid tropics, valley widening and

interfluvial lowering occur simultaneously, hence it is difficult to recognise any initial surface. Thus to describe the various stages of landform dissection in the humid tropics, it is necessary to establish what areal percentage of the landform occur as valley slopes ($>2^{\circ}$) and valley bottoms, and what percentage of it is on the interfluvial. This has been done in this thesis - Pages 47-48 and Page 51. The calculation is especially valuable in showing the intensity of dissection in an area.