THE SOILS OF THE CLOSED FOREST ZONE OF GHANA

by

A. J. CROSBIE

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The soil comes first. It is the basis, the foundation of farming. Without it, nothing ; with poor soil, poor farming, poor living ; with good soil, good farming and living. An understanding of good farming begins with an understanding of the soil.

Henry L. Ahlgren in Grass : Yearbook of Agriculture, 1948.
U. S. Department of Agriculture.

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Chapter 1

INTRODUCTION

This is a study of the edaphic factor in the ecology of the tropical rain forest. Within this environment, the processes of soil formation have been intense in operation and of long duration, and soils with distinct properties have developed. The factors of pedogenesis underlying the formation of the soils of the closed forest zone af Ghana are outlined according to the evidence of profile morphology, and the characteristic features of the great soil groups which occur are described. On the basis of their physical properties and nutrient status in relation to the tropical environment, principles of agricultural land use are indicated.

A geographical approach is maintained throughout. The spatial relations of soils as expanses forming integral parts of the landscape are emphasised and, in conclusion, the special contributions which the geographer can make to pedology are summarised.

Value of thesis.

Tropical rain forest is the climax vegetation of the equatorial climate which prevails over the moist, tropical lowlands. These lowlands extend in a belt round the globe through the Americas, Africa and Asia.

The soil is the most valuable, expendable, natural resource of this belt. In order to assess its value, it is necessary, first of all, to differentiate the major soils, to map their distribution, to determine their physical and chemical properties, to define their characteristic relief and drainage, and to study the association with their distinctive vegetation. Such information is only slowly becoming available but, by geographic correlation, it may be applied to extensive areas.

The fertility of tropical soils was assumed to be high by early recorders in view of the luxuriant forest which it supported. Later, there was a trend to regard all tropical soils as poverty stricken, e.g. Gourou (1953), until the post war development of soil surveys brought rapid re-appraisal, epitomised in the title of a paper by Vine (1954) : "Is the lack of fertility of tropical African soils exaggerated ?".

There were two reasons for the misconceptions on tropical soils. The criteria for assessment were based on temperate standards of nutrient status in relation to plant growth. These static criteria are inapplicable to tropical soils because of the difference in the rate of availability of plant food, and because of the tropical forest climate which is eminently suited to plant growth. The second reason is best stated in a quotation from Prescott and Pendleton (1952) writing on laterite :

" It is unfortunate that a number of often-quoted writers on laterite such as Bauer, Harrassowitz, Glinka and others were not themselves travellers in the tropics and had not seen, in the field, what they were writing about ".

The difficulties of soil appreciation aggravated the latter reason. At this period, soil was regarded as a vertical section rather than as an expanse, and many of the features of the soil were, and are, often concealed. The peculiarity of the data also distorted judgment. Most of the soil investigations were carried out in the densely populated areas of the tropics on soils with high bases status - e.g. limestone soils, young basic soils - and the recognised authorities were generally associated with such soils, e.g. Hardy in Trinidad, Mohr in the East Indies. Little attention was paid to the vast expanses of acid soils which supported no, or only specialised, crops.

The fundamental problem in the tropics is the practice of subsistence agriculture based on shifting cultivation. In the past, the forest lands have been thinly populated but the development of preventive medicine has eliminated many causes of disease and there has been increasing pressure of population. Food production in the forest zone has gradually changed to cater not only for inhabitants of the area, an increasing proportion of whom live in towns, but also for people in other areas. This factor, coupled with a growing demand for the products of the forest zone in world markets, has resulted in an unprecedented rate of destruction of the natural vegetation, and the underlying soils have been exposed to a new environment, often with disastrous results. It is essential, if these soils are not th be irretrievably lost, with consequent serious economic effects, that the genetic factors be appreciated and the morphological features comprehended and preserved.

A scientific appreciation of the environment is necessary as a first step in any plan for under-developed tropical countries. The United Kingdom has been responsible for a larger area of the tropics than any other nation and has spent large sums on the development of these lands. Unfortunately, the policy of agricultural development has been based on the introduction of temperate agriculture, with modifications where this proved unsatisfactory. It is on the physical conditions which prevail that policy should be based, particularly in areas where marked rainfall regimes dominate all formś of life, and where the severity of fall may be extreme. In these territories, if soil erosion and flooding are to be avoided, agriculture must fit into the pattern of the land, and agricultural schemes must form an integral part of the landscape and not be arbitrarily situated. The units of land utilisation are catchment areas within which soil patterns are often determined by relief and drainage conditions.

Finally, the basic data contained in the thesis have an intrinsic value. Most authorities on the tropics, e.g. Richards, (1957), have at some time commented on the vast amount of valuable information which exists unpublished in the minds of field officers, or remains buried in departmental files. There is a need for such information to be available outside the tropical zone.

<u>Definition of area of study.</u>

West Africa is particularly well suited to the study of ecological formations. Although it lies on the periphery of the great continental mass, there is a distinct and well defined zonation of vegetation from the Guinea coast to the interior. The gradient from the wet, short dry season, regime of the coast with a consistently high humidity, to the arid climate of the Sahara is reflected in the parallel zones of vegetation (Keay, 1959). The uniformity of this regression is interrupted by the Dahomey Gap where the drier climate of the interior extends southwards to the coast. This breach separates the large expanse of forest stretching from Sierra Leone to Ghana from the main equatorial mass. Possible reasons for the decrease in rainfall, which commences east of Takoradi and gives rise to the unique character of the Accra Plains, are outlined by Walker (1962). The zonation of vegetation is emphasised by the simple relief.

The closed forest or high forest includes all types of lowland forest in which the trees grow in closed canopy and the ground is not covered with grass. In Ghana, it extends from the coast in the southwest extremity northwards as far as latitude seven degrees forty-five minutes, from which point the northern boundary runs east north-eastwards for some fifty miles before trending south-east along the Ejura, Mampong, Kwahu and Koforidua scarps to Aburi. The southern boundary extends in a south-west direction from Aburi through Swedru to Takoradi where it reaches the coast. An outlier of the main zone covers the hill ranges of the Trans-Volta Region, but this is not included in the present account. The soils of the Togoland region were surveyed by the late A. W. S. Mould (1957a, 1957b) and are described in the annual reports of the Department of Soil and Land-Use Survey (S.L.U.S., 1957, 1958).

The high forest zone, including the outlier, covers an area of approximately 31,760 square miles (Lane, 1962).

Previous work.

There was no systematic work on soils in Ghana prior to the initiation of the soil survey of the cocoa areas by the West African Cocoa Research Institute in 1945. Subsequently, the organisation established for this purpose was transferred to the Department of Agriculture in 1948, and then became an autonomous Department of Soil and Land-Use Survey in June, 1951.

Previous work on soils in Ghana (at that time, the Gold Coast), consisted of three phases. Primafily, there were the comments of early explorers, travellers and missionaries who rarely described soils in any other terms than colour. Towards the end of this phase, the introduction of exotic plants to various colonies led to the establishment of Botanic Gardens. In the Gold Coast, these were located at Aburi, but no account of the soils by the Curator has been recorded.

The next phase was dominated by administrators and agriculturists employed on marketing and export of local forest products. There were a sprinkling of specialists, usually pure scientists, and soil was regarded as merely a rooting medium for plants. Such was the position when Marbut (Shantz and Marbut, 1923) review the contributions to the study of African soils.

From 1921-22 onwards, however, the emphasis in these territories was on the problems of local agriculture and the application of scientific methods to its improvement. Accordingly, there was an increase in the number of specialist workers. Unfortunately, most of the work on soils is of limited value due to the lack of good descriptions of soil profiles and a disproportionate emphasis on the results of chemical and physical analysis. This was supposed, by the doctrine of the day, to give direct guidance on agricultural possibilities, but they threw little light on essential features in soil morphology. Until recently, even localities and sampling sites have been inadequately described for plotting distribution patterns.

In West Africa, the work of Martin and Doyne (1927a, 1927b, 1930, 1932) in Sierra leone culminated in a soil survey in 1932. In Nigeria, Doyne, Hartley and Watson (1938) gave an account of some soil types, and, in the same year, Greenwood (1938) described some Gold Coast soils. A soil survey for the Gold Coast was proposed in 1935 (Dept. of Agric., 1935), and reviewed by the Colonial Advisory Council (1944).

For practical purposes therefore, the study of the soils of Ghana began with the appointment of C. F. Charter as Soil Scientist at the West African Cocoa Research Institute in 1944. An account of his work from then until his death in 1956 is given in the report on the Department of Soil and Land-Use Survey (1958).

<u>Basis of thesis.</u>

The thesis is based on work carried out in Ghana as a member of the Department of Soil and Land-Use Survey from 1953 to 1957. By 1953, Charter had devised methods of soil surveying for tropical forest lands (Charter, 1949a, 1949c), developed the organisation required for such projects (Charter 1950, S. L. U. S. 1957), and established the characteristics of the principal cocoa growing soils (Charter, 1949b). Just over 2,000 square miles of the forest zone had been surveyed. From 1953 to 1957, a further 14,000 square miles approximately of the forest zone were surveyed, of which the Kumasi Region (3,300 square miles) and the Birim Basin (1,500 square miles) were completed by the author.

Field work occupied some 30 months in total. It was during this period that the soil relationships with vegetation, geomorphology and parent material were observed and recorded, and these form the basis of the thesis. Although the forest surveys covered just over 50 per cent of the forest zone, they had been carefully selected so that the pattern of soils over the major geological formations under a representative range of vegetation and climatic conditions could be studied and comprehended. This was done in 1956 and 1957 when the author was responsible for forest zone surveys and for the correlation of data from all surveys throughout the country. During this period, various maps were produced of soils at different levels of classification for the country as a whole (S. L. U. S., 1958), the correlation of field characteristics and analytical data for the major forest soils was demonstrated (Crosbie and de Endredy, 1956), and the latter soils were also classified in terms of suitability for cocoa production (Crosbie, 1957a).

There has been no previous account of pedogenesis in Ghana. In the second part of the thesis however, the classification scheme of C. F. Charter is adopted as a framework for description because it is soundly based on genetic factors. A chapter entitled 'Lower Slope Soils' has been included in this section because of the areal extent of these soils in the aggregate and because they do not conform to any of the classification categories of Charter.

The principles of agricultural land-use outlined in the final section are evolved on the dominant environmental factors of climate and soil described in the main text.

Chapter 2

PEDOGENESIS IN THE TROPICS

The concept of soil is ill defined because of the range of interests in which it is included. To the geologist, it is over-burden with no particular relationship to the underlying, decomposing rock ; to the agriculturist, it is a media for plant growth ; to the zoologist, it is the home of micro-fauna ; to the chemist, it is an experiment in change. Yet soil deserves to be studied in its own right, for the pedological processes which have taken, and are taking place, for the characteristic features which result, and for the properties which it can possess.

What is soil ? Soil is the great bridge between the inanimate and the living (Kellogg, 1941). It is developed by the external agencies of climate as they affect plant growth, erosion and intensity of weathering operating on the surface features of parent material and topography. In time, the blending and fusion of the physical and biological processes gives rise to the formation of distinct soil profiles reflecting the total effect of all the factors in the environment and in the history of the soil. But it is more than merely a section of an era of weathering in a particular site ; it is an expanse or layer covering part of the earth and it develops surface features which are as characteristic as its profile. Soil is three dimensional and cannot be defined or classified as vertical sections, but must be viewed as part of the landscape with areal dimensions.

The first account of soils as natural bodies came from Glinka (1914). The significance of the concept was immediately grasped by C. F. Marbut, then in charge of the Soil Survey in the United States, and he applied it in his pioneering account of the soils of Africa (Shantz and Marbut, 1923). Marbut's emphasis was on rock weathering with zonation according to climate. For a period there after, the chemical weathering of rocks dominated tropical soil research, particularly in respect of the formation of laterite as exemplified by Harrassowitz (1930). The great change came with J. B. Harrison (1933) and C. S. Fox (1936) who regarded soils as the products of climatic processes. Gradually, there came the realisation that previous conceptions, particularly in respect of silica/alumina ratios, had limitations in application.

The overall picture of tropical soils was imperfect however, because of the lack of good descriptions of soil profiles. The principal problem lay, and still lies, in establishing the physiographic relationships of the soils. A paper on laterite by Morrow Campbell (1917) was neglected for many years, and general works such as Vageler (1933) contained only a sketch of soils in broad geographical terms. For this reason, the work of Geoffrey Milne (1935a, 1935b, 1936, 1940, 1947) is outstanding. Milne had a comprehensive outlook and viewed soils as part of the landscape in intimate relation with the vegetation. He also regarded them as something to be utilised for man's benefit in the best possible manner based on scientific principles and practices.

Soils are polygenetic in origin. They are formed as a function of climate, vegetation, relief and drainage, parent material and age. In the tropics however, the role of each factor in pedogenesis is modified due to the special conditions which prevail in these latitudes. Africa differs from the other continents, with the possible exception of Australia, in several important ways. The land mass is ancient, stable, and predominantly formed of granites with sediments derived from them. Warm dry periods in geological time, with prolonged sub-aerial erosion, have resulted in peneplaned landforms and low altitudes. Most African soils are therefore developed in relict peneplain drifts ; this contrasts with North American and Eurasian soils which are largely developed in glacial or fluvio-glacial drifts. In both cases, soils developed by weathering <u>in situ</u> of the underlying rock represent only a small proportion of the whole. Many of the soils are very old and have been subject to weathering for geological eras. The chemical processes in the humid tropics are intense and rapid and these old soils have been reduced to their unweatherable residues. Such soils are unique and irreplaceable.

Basic data on which to assess the effect of each factor is often lacking, particularly in the forest zone. Climate must be interpreted in terms of meteorological summaries. This is subject to two distortions, namely the location of the reporting stations and the presentation of the tabulated analyses. In the former, exposed sites give no indication of the micro-climate within the forest itself, although this is the environment which directly influences soil forming processes. In the latter, summaries are usually presented on a mean monthly basis. This is inadequate in dry season evaluation where the number of consecutive rainless days may be vital. In Ghana, mean pantad rainfall figures have been tabulated since 1952 and provide a more valid basis for assessment. The limited period of records consulted did not permit the calculation of means of any significance, however. Ecologically, other data are desirable but economically, the recording of such data is impracticable.

Biologically, the excellent work of the Forestry Department provides a sound base for the ecological investigations undertaken by various departments in the University of Ghana. The natural forest vegetation has attained a state of equilibrium with soil and climate, but much remains to be done on soil-vegetation relationships (Oliphant, 1940) and little has been done on the activity of micro fauna. Belfield (private communication) estimated that it would require ten years merely to record the fauna present in forest soils. The recording of data on vegetation also poses problems in an area of seasonal climate, as observations and sampling must be continuous throughout the annual cycle in order to obtain a representative cross-section.

Geomorphologically, the forest zone has been neglected, principally because the vegetation obscures both macro and micro scale features and renders surveying and measurement difficult. The data which are available are either related to geological surveys (Cooper, 1936, Junner, 1940, 1943) or to soil surveys (Crosbie, 1956b, Radwanski, 1956a), and only the accounts by Brash (1962) and Hunter (1959, 1961) deal specifically with aspects of erosional history.

The study of surface lithology has also received little attention. Most of the work of the Geological Survey Department has been concerned with the occurrence of economic minerals or on the problems of rural water supplies. The lack of fresh outcrops and the deep mantle of weathered material effectively masks the underlying rock. Yet most of the soils of the forest zone are upland soils in that they occur on the gently rolling undulations of the dissected peneplain. Differentiation within the major soil groups is largely based on variation in the physical composition of the parent material.

Time as an element in soil formation has not been of great concern to temperate zone pedologists in view of the relatively brief period since glaciation. The great age of tropical soils, and the rapid porcesses of chemical weathering, make it a significant factor in this study.

For methodological analysis, these factors are treated individually, but, in fact, they form a complex force in which all are inter-related and inter-dependent. Soils are dynamic and different factors may dominate at different stages of evolution. This feature makes analytical discussion difficult, particularly in a biological science where it is necessary to assess the importance of several contributory factors, some of which may be quantitative and others qualitative, and all of which unceasingly change form and degree.

Chapter 3

CLIMATE

The soils of the closed forest zone are predominantly climatophytic earths. It is the climate-vegetation complex, essentially a single ecological factor, which determines the characteristics and zonal distribution of the great soil groups. Within the concept of climatophytic earths, there is a simple division into hygropeds and xeropeds according to whether the profile is leached throughout or not (Brammer, 1956). These terms correspond to the pedalfers and pedocals respectively of earlier writers (Marbut, 1928, Robinson, 1951). The moist climate of the tropical rain forest gives rise to hygropeds, and these probably account for some 80 to 90 per cent of the upland soils. Other soils are only of local importance.

The characteristic hygroped of the tropics consists of red or yellow, friable, porous, thoroughly weathered, kaolinitic or gibbsitic soils which Kellogg (1948) termed latosols. They have also been described as tropical red earths, lateritic earths and ferrallitic soils. A significant distinction is made among latosols between soils where leaching is excessive, called oxysols, and those less thoroughly leached called ochrosols. This differentiation was noted in Nigeria by Vine (1953) and defined by Charter (1955). It is of critical importance in any discussion on the fertility of tropical forest soils (Crosbie, 1957a, Nye and Greenland, 1960).

In this chapter, the climatic gactors in the pedogenesis of tropical forest soils are outlined, with particular reference to the formation of the two great soil groups within the latosols.

The climate of Ghana.

The climate of Ghana has been described by Walker (1962). Because the southernmost part of the country lies within five degrees of the equator, and the northern boundary approximates mainly with the eleventh degree parallel, Ghana is in a transition zone between an equatorial regime with double rainfall maxima in the south and a tropical regime with a single maxima in the north. The closed forest lies within the area of two effective maxima (Taylor, 1952) although the transition from forest to savannah is not a climatic limit (Richards, 1957).

The elements of climate in pedogenesis.

Temperature is accorded primary consideration in view of its global distribution. Climatologically, the tropics are defined by the 20 degree Centigrade mean annual isotherm, and high and consistent temperatures throughout the year are characteristic features of the tropical rain forest (Richards, 1957, Evans, 1939). Variations are insignificant (Table 1) due to the small annual range in the length of day, the nature of the climate, the thermostatic effect of the soil and, to some extent, that of the surrounding oceans which comprise some two-thirds of the tropical zone.

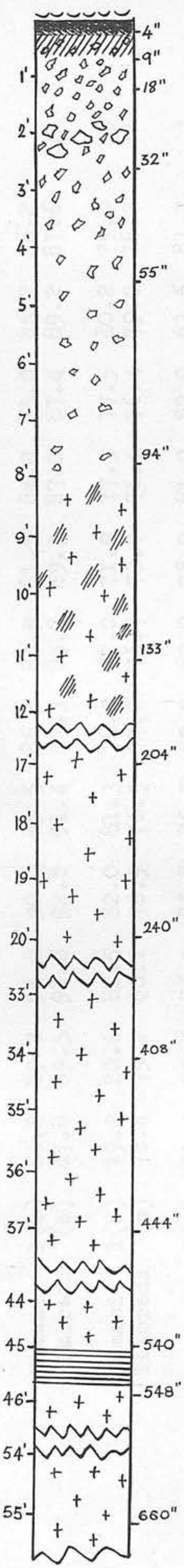
Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual Mean	Yrs. of Average
Kumasi	A.	87.7	90.3	90.2	88.9	87.5	84.6	81.4	79.9	82.9	85.4	87.3	87.1	86.1	10
Axim	A.	86.0	87.3	88.2	88.0	86.3	83.2	81.7	80.5	81.4	83.6	86.6	87.0	84.9	10
Kumasi	B.	66.6	69.0	70.9	71.2	71.3	70.6	69.7	68.7	69.7	69.9	69.5	68.4	69.6	10
Axim	B.	74.1	74.8	75.7	75.6	74.7	73.9	73.5	72.2	73.0	73.7	73.0	73.7	74.0	10
Kumasi	C.	98	99	100	97	95	91	88	86	89	91	92	92	100	18
Axim	C.	91	92	92	93	92	88	86	86	86	88	90	90	93	14
Kumasi	D.	77	81	77	79	77	77	74	74	75	73	78	76	73	11
Axim	D.	81	78	80	80	79	76	76	74	76	77	78	81	74	11
Kumasi	E.	74	76	77	76	75	74	73	71	73	73	75	75	77	11
Axim	E.	80	83	83	83	83	78	78	76	76	78	79	81	83	11
Kumasi	F.	53	54	64	65	65	65	62	60	65	60	57	51	51	18
Axim	F.	59	67	68	69	68	68	63	64	68	68	67	63	59	14
Kumasi	G.	65.6	68.3	70.2	70.4	70.7	70.2	69.1	68.2	69.4	69.6	68.8	67.3	69.0	10
Axim	GG.	71.4	72.6	73.1	73.3	72.9	72.3	71.3	69.9	71.2	72.0	71.2	71.4	71.9	6

Table 1. Temperature data for Kumasi and Axim (based on Walker, 1962). Degrees Fahrenheit.
A. Mean monthly maximum temperature.
B. Mean monthly minimum temperature.
C. Highest monthly maximum temperature.
D. Lowest monthly maximum temperature.
E. Highest monthly minimum temperature.
F. Lowest monthly minimum temperature.
G. Mean monthly grass temperature.

In the tropical lowlands, therefore, temperature is a consistent factor in pedogenesis. Altitudinal boundaries of vegetation, which are a reflection of temperature change, are outside the scope of this study.

While temperature has little direct role in soil formation, the effect is pronounced in view of persistent high values over prolonged periods. Chemical changes in the soil are rapid under these conditions, and, particularly, with an abundant water supply, hydrolysis is manifest. This is responsible for the great depth of chemical weathering. A profile pit excavated on the Central Agricultural Station, Kumasi, was still in the zone of thoroughly weathered granite at a depth of 55 feet (Fig. 1). Analytical data for the upper 14 feet of this profile have already been published (Brammer, 1962). At the Kumasi College of Technology (now the Kwame Nkrumah University), bore holes by the Geological Survey Department reached depths up to 100 feet before striking decomposing rock. Similar mantles of strongly weathered and leached sub-stratum extend over much of the humid tropics, and give weight to the oft-quoted remark by Robert L. Pendleton (1962) : " What much of the tropical areas need is a good case of erosion ".

Soil temperatures for Kumasi and Takoradi are given in Table 2. Variations are most significant in the surface 9 inches, but basic data is lacking. Below this layer there is slight variation and at depths below 4 feet there is a consistent temperature of 27 to 29 degrees Centigrade. Diurnal variations between surface and air temperatures are responsible for the formation of dew and mist at night, a feature well marked on exposed or cultivated ground but absent within the forest itself (Evans, 1939).



DARK GREY BROWN (10 YR 4/2) HUMOUS SANDY LOAM : 7·5

BROWN (10 YR 5/3) LOAMY SAND: FREQUENT FINE QUARTZ GRAVEL : 7·1

REDDISH YELLOW (5 YR 6/6) LIGHT CLAY: VERY GRAVELLY : 5·9

YELLOW RED (5 YR 5/8) GRITTY LIGHT CLAY: VERY GRAVELLY WITH FREQUENT SMALL SUB-ANGULAR QUARTZ STONES AND FE. CONCRETIONS : 5·7

PALE RED (2·5 YR 6/8) SLIGHTLY GRITTY LIGHT LOAM VERY GRAVELLY: 5·6

REDDISH YELLOW (5 YR 6/6) LIGHT LOAM: GRAVELLY: OCCASIONAL PATCHES OF RECOGNISABLE WEATHERED ROCK : 5·6

REDDISH BROWN (2·5 YR 5/4) MOTTLED WEAK RED (2·5 YR 5/2) LIGHT LOAM OF WEATHERED ROCK WITH FREQUENT VEINS OF FELDSPAR: 5·8

DARK RED (7·5 YR 4/6) MOTTLED PALE RED (2·5 YR 5/8) THOROUGHLY WEATHERED MEDIUM GRAINED BIOTITE GRANITE WITH VEINS OF FELDSPAR : 5·1

PALE REDDISH BROWN (2·5 YR 6/4): FREQUENT VEINS OF FELDSPAR : 5·7

AS ABOVE BUT VEINS OF FELDSPAR ABUNDANT AT BASE : 5·4

AS ABOVE BUT FEW VEINS OF FELDSPAR : 5·0

MASSIVE WEATHERED MEDIUM GRAINED BIOTITE GRANITE WITH VERY FREQUENT THICK VEINS OF FELDSPAR : 5·4

WATER TABLE

THOROUGHLY WEATHERED GRANITE : 5·7

FIG 1. PROFILE DIAGRAM OF KUMASI SERIES ON CENTRAL AGRICULTURAL STATION, KUMASI, ILLUSTRATING DEPTH OF WEATHERING

Station		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Years of Average
Kumasi	1(a)	83.0	85.4	85.2	85.7	84.6	81.6	79.4	78.1	79.8	80.7	82.5	83.1	5
Takoradi	(a)	83.6	84.9	86.2	86.5	84.3	81.2	80.1	79.8	80.7	82.3	83.9	83.8	11
Kumasi	1(b)	86.2	89.2	91.8	90.0	89.5	86.1	83.9	81.5	84.0	85.0	86.2	86.2	5
Takoradi	(b)	87.0	89.5	91.8	92.8	91.4	87.3	85.7	89.9	87.0	87.4	89.2	87.6	111
Kumasi	1(c)	79.2	80.6	81.5	82.0	81.3	78.0	77.0	71.9	77.5	77.5	80.2	79.0	5
Takoradi	(c)	78.4	79.2	80.2	78.9	76.5	77.8	76.7	70.7	76.4	76.4	79.0	78.2	11
Kumasi	2(a)	83.9	86.7	86.2	86.8	86.3	82.5	80.0	78.9	81.0	82.0	83.6	83.9	3
Takoradi	(a)	85.0	87.4	89.0	88.7	86.4	83.1	81.7	81.8	82.7	84.5	86.5	85.6	5
Kumasi	2(b)	88.0	90.8	90.8	91.0	91.0	87.0	83.9	83.0	86.3	86.8	86.5	90.0	3
Takoradi	(b)	87.8	91.5	93.6	92.5	92.0	88.6	87.0	87.0	87.0	89.5	90.6	90.5	5
Kumasi	2(c)	80.5	82.5	83.2	83.1	82.8	79.4	77.9	76.3	79.1	79.8	81.2	81.3	3
Takoradi	(c)	79.7	83.7	84.1	85.0	80.5	79.0	78.3	78.3	78.8	80.3	81.4	78.6	5
Kumasi	3(a)	83.1	84.6	85.3	85.7	85.5	83.8	81.9	80.5	80.7	81.5	82.5	83.4	5
Takoradi	(a)	83.9	84.8	86.1	86.1	85.2	83.2	81.8	81.3	81.7	82.8	84.2	84.5	9
Kumasi	3(b)	84.7	86.2	87.5	88.0	87.5	85.8	83.8	84.3	81.8	82.3	84.0	84.8	5
Takoradi	(b)	85.9	89.3	89.3	89.5	88.5	87.1	84.8	83.6	84.5	86.0	87.0	87.5	9
Kumasi	3(c)	80.0	83.0	83.5	82.6	84.0	82.1	80.3	76.2	77.9	80.5	81.2	82.2	5
Takoradi	(c)	82.0	81.4	82.7	82.7	76.0	80.4	79.6	79.1	79.1	80.1	80.9	82.1	9
Kumasi	4(a)	83.3	84.7	85.5	86.1	86.1	84.1	82.6	80.9	80.9	81.6	82.5	83.6	2
Takoradi	(a)	84.4	85.2	86.8	86.9	85.9	83.8	82.4	81.9	82.3	83.3	84.8	85.0	7
Kumasi	4(b)	85.0	88.0	88.0	88.5	89.8	86.0	85.0	82.0	82.0	83.0	83,8	85.0	2
Takoradi	(b)	86.2	88.4	89.6	91.5	89.2	87.3	84.7	83.7	84.8	86.0	87.7	88.8	7
Kumasi	4(c)	82.0	83.1	84.0	77.6	81.2	82.5	80.9	79.5	79.8	80.0	81.7	82.5	2
Takoradi	(c)	82.6	82.6	83.2	84.0	78.2	80.0	79.9	79.6	79.0	80.2	82.8	80.0	7

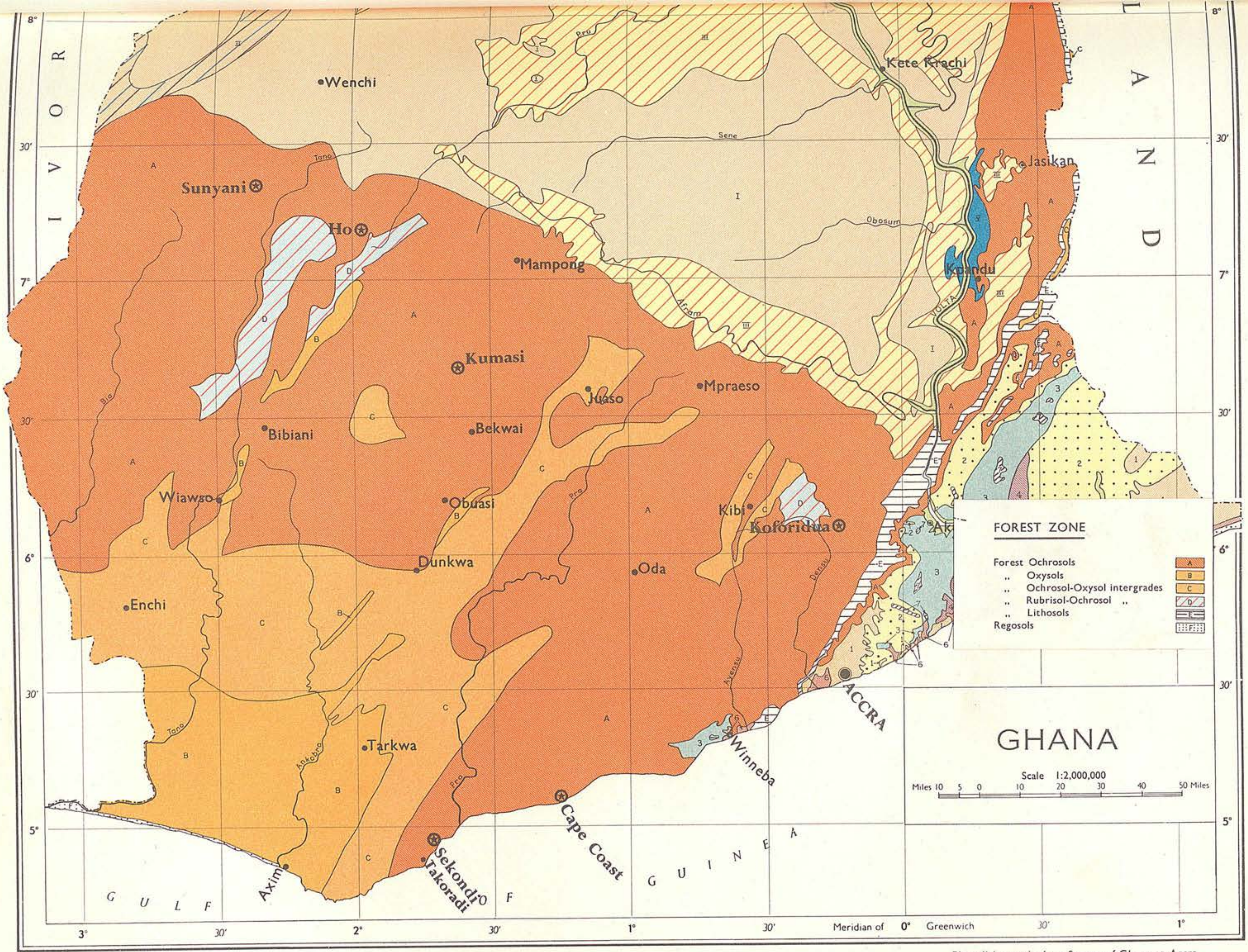
Table 2. Earth temperatures for Kumasi and Takoradi (based on Walker, 1962). Degrees Fahrenheit.
1. 1 foot ; 0900 hours. 3. 4 feet ; 0900 hours. (a) average temperature.
2. 1 foot ; 1500 hours. 4. 4 feet ; 1500 hours. (b) highest temperature.
(c) lowest temperature.

Biologically, the equable temperature conditions are favourable. Micro fauna and bacteria flourish in the topsoil and are responsible for the rapid transfer of organic matter into humus. Vegetative growth is stimulated, particularly in the seedling or early years. Adversely, it obviates the need for resistant strains adaptable to varied climatic conditions. Quality tends to be mediocre and individual plants lack stamina.

Rainfall.

Water is the fundamental agent in pedogenesis. It is the amount and distribution of rainfall which is primarily responsible for the formation of the two great soil groups - the oxysols and ochrosols - in the forest zone (Fig. 2a and 2c). Any assessment of rainfall efficiency is based on two considerations : initially, the source and quantity of water available is a function of the environmental climate ; secondly, the movement of water through the soil is a function of soil properties.

In examination of moisture regimes in relation to soil formation, the principal problem is whether, in free draining soils, precipitation is sufficient to connect with ground-water or not. This process may be achieved either by the total amount of rainfall or by the intensity of precipitation. Throughout the humid tropics, this operation is effective because, even in areas where precipitation is low, it occurs in the form of heavy showers which provide sufficient water for percolation to ground-water (Chamney, 1929, Walker, 1962). The principal earth is therefore the hygroped.



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GREAT SOIL GROUPS OF THE FOREST ZONE

Fig. 2a.

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Compiled, Drawn and Photolithographed by the Survey of Ghana at Accra, 1959.

VEGETATION ZONES

Fig. 2b

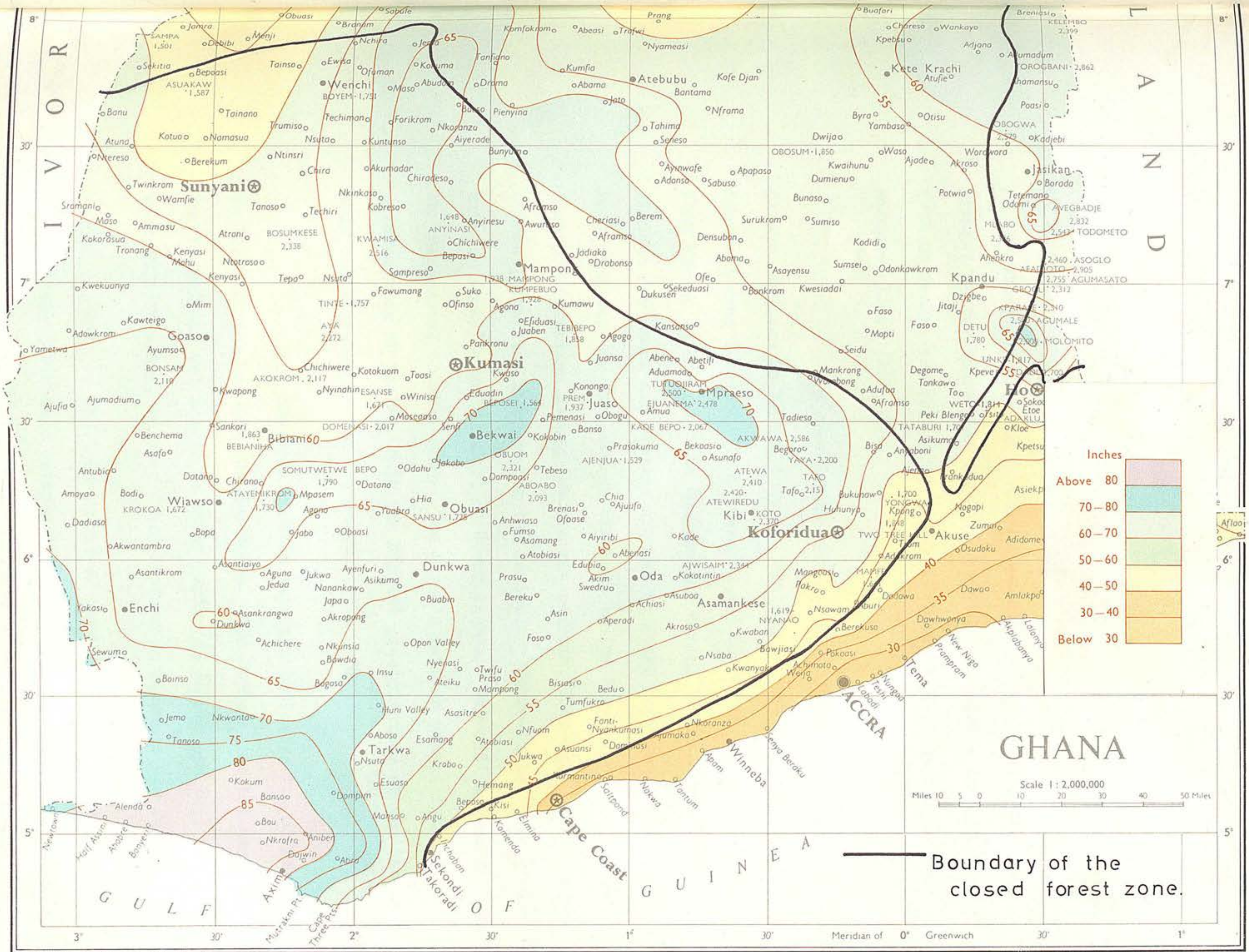

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Fig. 2c. AVERAGE ANNUAL RAINFALL

At the next stage of analysis, the problem concerns the degree of leaching and for this purpose a more detailed knowledge of rainfall distribution is necessary. The seasonal character of rainfall in the closed forest zone has already been noted. Because the rain is brought by the south-west monsoon, there is a decrease in annual rainfall from 85 inches or more on the coast at Axim to 45-50 inches at the northern limit (Fig. 2c).

A correlation between rainfall data and the great soil groups is given in Tables 3 to 5. The mean annual rainfall for the ochrosol zone (Table 3) is between 50 and 60 inches with a decrease from Wiawso in the south to Sunyani and Wenchi in the north. The higher figures fro Juaso and Nkawkaw are due to local factors of topography. Both stations are situated at the base of the Mampong scarp, and receive more precipitation during the two wet seasons, June-July and September - October, than the average for the latitude. Ochro-oxysol intergrades have an annual mean rainfall of 60-65 inches. Takoradi is transitional to the coastal thicket zone. The oxysols have an annual rainfall greater than 65 inches, with the highest precipitation at the two stations, Axim and Half-Assini, on the coast.

The mean monthly rainfall indicates the difference in distribution between the two zones. The oxysol zone has more rain in the primary wet season, a drier period in August and September, and most significantly, heavier precipitation in December and January.

The mean number of rain days per annum (Table 4) shows little difference between the ochrosol and oxysol zones. Stations in the north, Wenchi and Sunyani, have the fewest, and there is a

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann. Mean	No. of years
a. Ochrosols														
Bekwai	0.80	2.60	5.64	5.74	7.58	9.25	4.50	2.35	6.51	7.89	4.79	1.45	59.10	41
Bibiani	0.51	2.13	5.25	5.36	8.13	8.77	5.10	2.84	6.45	8.12	3.54	1.40	57.60	20
Goaso	0.64	1.90	4.68	5.37	7.72	8.64	4.39	2.61	6.28	8.52	3.72	0.83	55.30	35
Juaso	0.96	2.35	6.05	6.40	7.43	9.70	5.47	3.34	8.09	9.43	4.69	1.71	65.62	40
Koforidua	1.13	2.66	5.76	5.57	7.02	9.38	3.53	2.23	6.36	7.22	3.93	2.33	57.12	32
Kumasi	0.67	2.31	5.38	5.65	7.15	9.21	4.96	2.92	6.95	7.94	3.86	1.21	58.21	50
Nkawkaw	1.10	2.24	5.21	6.37	7.78	10.38	6.04	3.85	8.90	10.21	4.75	1.92	68.75	30
Sunyani	0.46	1.48	4.66	5.91	6.96	7.56	4.23	2.41	7.27	8.08	3.06	0.58	52.66	41
Wenchi	0.27	1.77	3.40	5.71	6.97	8.29	3.72	2.61	7.90	8.96	3.21	0.67	53.48	34
Wiawso	0.84	2.25	5.27	5.84	7.41	9.88	5.22	2.53	6.24	8.07	4.03	1.31	58.91	40
b. Transition														
Dunkwa	0.91	2.10	5.96	6.44	8.37	10.36	5.51	2.73	6.40	8.43	5.22	1.80	64.23	41
Manso	1.90	2.63	4.84	5.75	9.32	11.95	4.91	2.17	4.86	7.85	5.46	2.98	64.62	41
Oda	1.14	2.65	5.95	6.83	7.07	9.09	4.62	2.80	5.92	7.56	6.53	2.40	62.56	41
Tafo	1.28	3.40	6.08	5.90	7.14	9.72	5.36	2.97	6.76	8.91	4.64	2.39	64.55	30
Takoradi	1.29	1.47	3.13	3.74	9.66	11.04	3.52	1.41	1.98	4.71	3.26	1.48	46.69	27
c. Oxysol														
Axim	2.02	2.42	5.06	5.61	16.52	21.07	6.16	2.13	3.44	8.07	7.55	3.77	83.82	41
Bondaye	1.84	3.26	5.94	5.67	8.95	10.23	4.60	2.20	4.82	8.45	6.97	3.25	66.18	19
Esuaso	1.84	2.89	5.79	5.98	9.58	11.33	4.24	1.90	4.58	9.20	6.42	3.25	67.00	30
Half-Assini	1.36	2.32	5.05	5.91	15.07	22.95	5.36	1.42	2.68	8.27	7.48	4.78	82.65	34
Tarkwa	2.09	3.06	6.14	6.38	8.88	11.97	4.94	2.32	5.08	8.47	7.20	3.54	70.07	41

Table 3. Mean monthly rainfall in inches for stations in the ochrosol, oxysol and ochro-oxysol transition zone (based on Walker, 1962).

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	No. of years
a. <u>Ochrosol</u>														
Bekwai	2	4	10	10	13	15	11	9	13	16	11	3	117	41
Bibiani	2	5	10	11	15	18	16	16	20	19	10	3	145	20
Goaso	1	4	8	8	12	15	10	8	13	16	7	2	104	35
Juaso	2	4	10	11	13	16	12	11	17	17	11	4	128	40
Koforidua	3	6	10	9	12	15	10	10	14	15	10	5	119	32
Kumasi	2	5	10	10	13	17	13	11	17	28	11	3	140	50
Nkawkaw	2	4	10	11	13	16	12	10	16	17	11	4	126	30
Sunyani	1	3	7	9	11	13	8	7	14	15	6	1	95	41
Wenchi	1	3	6	9	10	13	8	6	14	18	7	1	96	34
Wiawso	2	4	9	10	13	17	13	10	15	15	9	3	120	40
b. <u>Transition</u>														
Dunkwa	2	5	11	12	14	18	13	10	16	16	12	4	133	41
Manso	3	5	7	7	11	15	8	7	13	14	8	5	103	41
Oda	3	5	11	13	14	17	12	11	15	17	15	6	139	41
Tafo	3	6	11	10	12	17	11	10	15	16	9	6	126	30
Takoradi	3	4	7	8	17	17	11	10	14	15	9	5	120	27
c. <u>Oxysol</u>														
Axim	4	5	9	11	18	19	11	9	12	14	13	8	133	41
Bondaye	4	7	12	12	17	18	12	12	17	19	15	8	153	19
Esuaso	3	5	9	8	12	15	7	5	11	13	12	6	106	30
Half-Assini	3	3	7	8	13	16	16	5	7	11	12	7	98	34
Tarkwa	5	7	13	12	18	21	14	12	18	20	17	9	166	41

Table 4. Mean number of raindays for stations in the ochrosol, oxysol and ochro-oxysol transition zone (based on Walker, 1962).

marked increase towards the southwest, though Half-Assini is an exception. The difference in intensity between the temperate and tropical zone is worth noting ; Axim, with 84 inches in 133 rain days can be contrasted with London, 24 inches in 167 rain days (Beckinsale, 1957).

More than any other factor, the seasonal periodicity of rainfall differentiates the soils at higher levels of classification. The significant difference between the two zones is in the period December to February (Table 5), summarised as follows :-

Zone	Rainfall	No. of Raindays
Oxysol	7.98 - 8.69	13 - 21
Transition	4.24 - 7.51	11 - 15
Ochrosol	2.52 - 6.19	5 - 14

The variability of the rainfall emphasises the difference. In the oxysol zone, the number of consecutive rainless days rarely exceeds 14, while in January the rainfall is seldom less than 2 inches, so that the soil may be permanently saturated with consequent impeded aeration. In the ochrosol zone, the mean number of rain days for January gives no indication of their distribution. Kumasi, for example, may have four weeks or more between rain days, or, alternatively, may have the rain days on consecutive occasions. Such precipitation is valuable to plant life, but ineffective in soil processes. Pedologically, this means that in the oxysol zone leaching is more intense and continuous with no accumulation of bases, while in the ochrosol zone there is a well defined dry season during which period many of the trees shed their leaves and there is an accumulation of bases in the humous layer. In the intergrade zone, the total rainfall results in a

Station	Rainfall in inches for selected periods Nov.	Dec.	Dec.-Jan.	Dec.-Feb.	No. of raindays for selected periods Nov.	Dec.	Dec.-Jan.	Dec.-Feb.
a. <u>Ochrosol</u>								
Bekwai	4.79	1.45	2.25	4.85	11	3	5	9
Bibiani	3.54	1.40	1.91	4.04	10	3	5	10
Goaso	3.72	0.83	1.47	3.37	7	2	3	7
Juaso	4.69	1.71	2.67	5.02	11	4	6	10
Koforidua	3.93	2.33	3.46	6.12	10	5	8	14
Kumasi	3.86	1.21	1.88	4.19	11	3	5	10
Nkawkaw	4.75	1.92	3.02	5.26	11	4	6	10
Sunyani	3.06	0.58	1.04	2.52	6	1	2	5
Wenchi	3.21	0.67	0.94	2.71	7	1	2	5
Wiawso	4.03	1.31	2.15	4.40	9	3	5	9
b. <u>Transition</u>								
Dunkwa	5.22	1.80	2.71	4.81	12	4	6	11
Manso	5.46	2.98	4.88	7.51	8	5	8	13
Oda	6.53	2.40	3.54	6.19	15	6	9	14
Tafo	4.64	2.39	3.67	7.07	9	6	9	15
Takoradi	3.26	1.48	2.77	4.24	9	5	8	12
c. <u>Oxysol</u>								
Axim	7.55	3.77	5.79	8.21	13	8	12	17
Bondaye	6.97	3.25	5.09	8.35	15	8	12	19
Esuaso	6.42	3.25	5.09	7.98	12	6	9	14
Half-Assini	7.48	4.78	6.14	8.46	12	7	10	13
Tarkwa	7.20	3.54	5.63	8.69	17	9	14	21

Table 5. Analysis of rainfall and number of raindays for period November to February, based on Tables 3 and 4.

high degree of leaching while the duration of the dry season varies considerably from year to year and locality to locality. These soils possess the trends and nutrient ratios of the ochrosols, but with a low total base status.

The consequences of these distinctions are reflected in the profiles (Fig. 3). The colour of the mineral soil is usually orange-brown to yellow-brown in the oxysols in contrast to the reddish brown of the ochrosols. Depth of profile is greater in the oxysols with a thicker weathered substratum, and there is also a greater degree of compaction in the subsoil. The reaction profile, however, is the most remarkable symptom of the degree of leaching. The intensity and duration of this process has left a residual clay mineral of kaolin and sesquioxides. Because of the low exchange capacity of the clay fraction, the content of cations is closely related to the pH and amount of organic matter. Oxysols, by current processes, remain permanently acid with pH values of 4.0 - 4.6. These values are close to the ultimate pH value of kaolinitic clays fully leached of their exchangeable cations (Prescott and Pendleton, 1952). Organic matter tends to be concentrated markedly in the surface few inches, with a high C/N ratio, usually over 14. Ochrosols have a slightly acid to neutral reaction in the topsoil and become increasingly acid with depth. Organic matter accumulates during the dry season and has a C/N ratio of 10-12. There is a general trend in nutrient content therefore, particularly marked in the case of Ca. and Mg., from very low in the oxysol zone of high rainfall and low pH rising to a maximum in the ochrosol zone with a marked dry season and relatively high pH and organic matter content (Nye and Greenland, 1960).

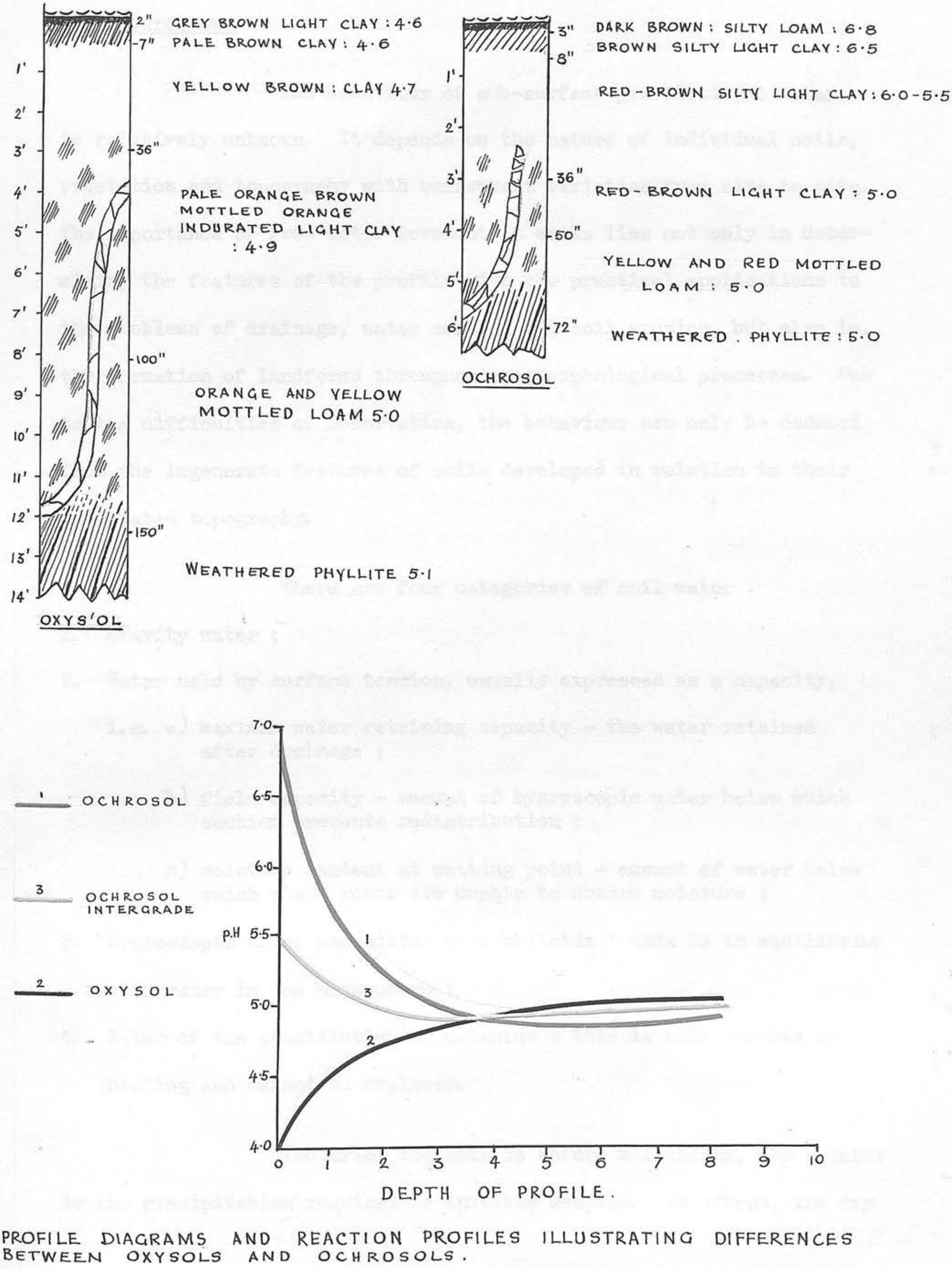

FIG 3 PROFILE DIAGRAMS AND REACTION PROFILES ILLUSTRATING DIFFERENCES BETWEEN OXYSOLS AND OCHROSOLS.

Soil hydrology.

The behaviour of sub-surface gravitational water is relatively unknown. It depends on the nature of individual soils, vegetation and topography with consequent variation from site to site. The importance of free water movement in soils lies not only in determining the features of the profile with the practical applications to the problems of drainage, water control and soil erosion, but also in the formation of landforms throughout geomorphological processes. Due to the difficulties of observation, the behaviour can only be deduced from the ingenerate features of soils developed in relation to their associated topography.

There are four categories of soil water :

1. Gravity water ;
2. Water held by surface tension, usually expressed as a capacity,
   i.e. a) maximum water retaining capacity - the water retained after drainage ;
   b) field capacity - amount of hygroscopic water below which suction prevents redistribution ;
   c) moisture content at wetting point - amount of water below which plant roots are unable to absorb moisture ;
3. Hygroscopic water associated with colloids : this is in equilibrium with water in the atmosphere ;
4. Water of the constitution of colloids : this is only removed by heating and cannot be replaced.

The drier the soil is before moistening, the greater is the precipitation required to initiate seepage. In effect, the dry season is intensified and prolonged for the ochrosols, and leaching of the profile is minimal during this period.

Surface absorption under closed forest is high. In Ghana, on the gently undulating topography of the dissected peneplain, the litter layer under forest remains intact and is not removed by run-off. Indeed, rain is only seen to collect along the surface of paths and exposed sites.

Underlying the litter layer, the upper topsoil usually consists of wormcasts and fermenting organic matter. Water flows easily through this, aided by vertical feeding rootlets. Just below the surface, the majority of tree roots travel laterally and provide a network of conduits for drainage together with channels left by decayed roots and faunal tunnels. These old channels are frequently lined with grey clay deposited during drainage, while coatings of hydrated ferric oxide may be present on the roots. Soil aggregates in the topsoil are to a large extent water stable. Beneath this, free drainage promoted by stable micro-aggregation is a characteristic of the latosols.

Downward percolation depends on textural differences in the soil. If the rate of percolation is lowered on passing from one layer to another, water will accumulate above the less pervious layer. Where the upper layer has lateral channels in which water can move freely, such as root and faunal channels, then the water will flow along them down to lower levels of topography. Impedance between layers need not imply that the lower layer is impervious. The difference in permeability may be incurred by biotic structure or by a significant change in pedological structure. Where there is a marked textural difference, e.g. sand over clay, then lateral flow will, in such cases, increase the textural difference by initiating lateral eluviation.

Field observations suggest that water entering the soil does not make its way to the ground-water by downward vertical percolation below the point of entry, but proceeds more or less horizontally through the soil to drainage grooves as described by Hotson (1956). The quantity of water which travels laterally, however, depends on the gross structure of the soil profile and the constitution and detailed structure of its component horizons.

A mature sedentary soil has a three horizon profile consisting of a topsoil, 7-8 inches thick, overlying 30-36 inches of subsoil which grades into weathered substratum. The subsoil generally has a higher clay content than the topsoil, but principally, it is a horizon of gravel accumulation. Mottling in the upper layers of the weathered substratum may indicate impedance. Similarly, profiles developed in transported parent material such as peneplain drifts, frequently have features, e.g. mottling or induration, as a result of impedance at the base of the parent material or in the upper part of the underlying weathered bedrock (Fig. 4).

Lateral eluviation is probably important in the transport of surface materials, and Marbut, (Shantz and Marbut, 1923), considered that it had an effect in producing the light textured surface layers in Africa. Charter (1949b) describing cocoa soils stated " the sandy upper layer owes its origin to rain-water draining laterally

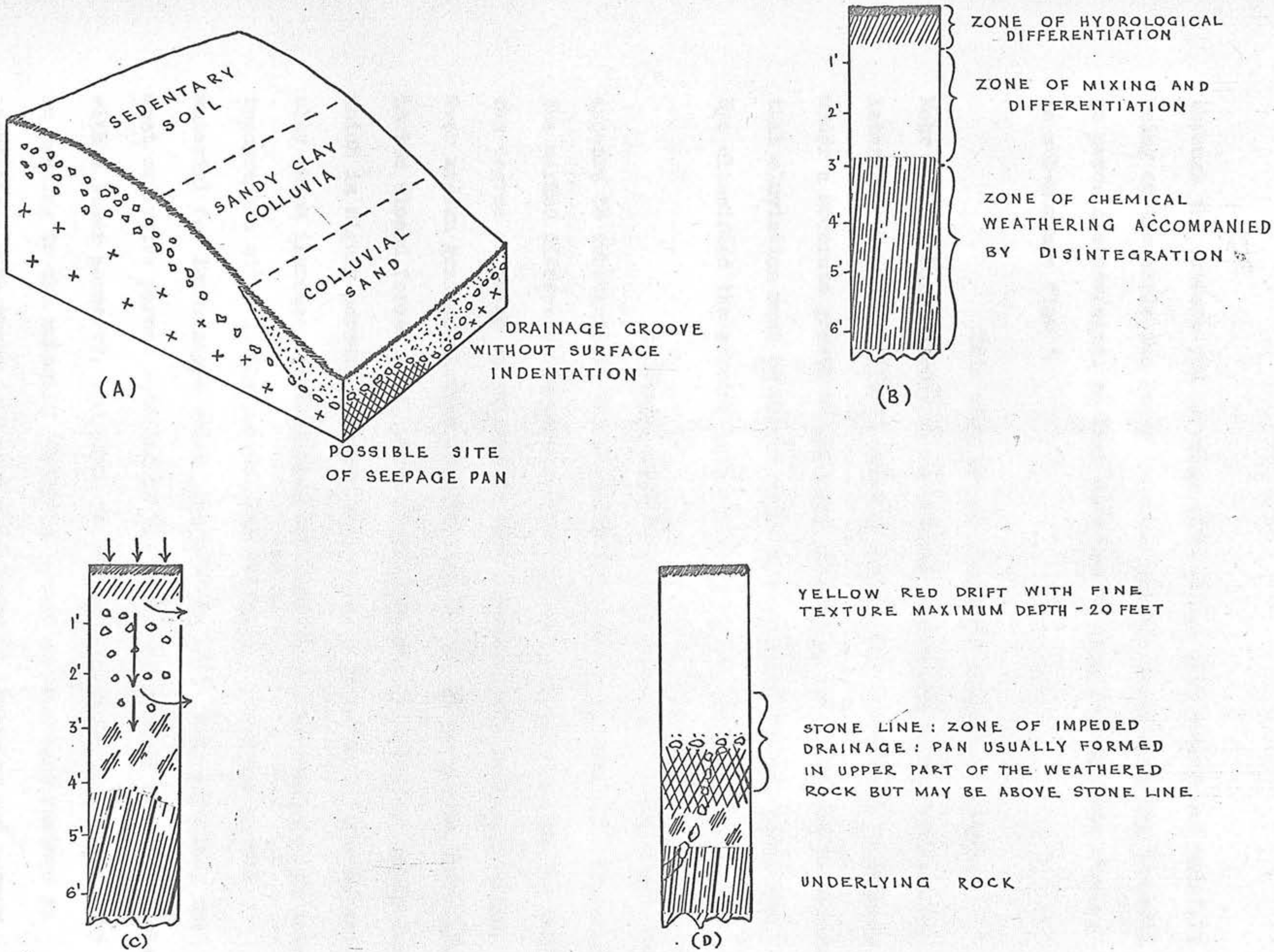

FIG 4. DRAINAGE FEATURES IN UPLAND SOILS : (A) DIAGRAMMATIC TOPOGRAPHIC SUCCESSION OF SOILS; (B) ZONATION OF PROCESSES IN SOILS; PROFILE DIAGRAMS ILLUSTRATING POSSIBLE INTERNAL DRAINAGE IN (C) SEDENTARY SOILS AND (D) DRIFT SOILS.

through the surface and carrying with it the clay - tropical rainfall being on the whole too heavy to allow all the water entering the soil to percolate downwards so that some has to find its way into streams as sub-surface flow ".

This view is not generally accepted, however. Mohr and van Baren (1954) do not attach importance to sub-surface lateral flow and Nye (1954) carried out a rough experiment in Nigeria under a moderate growth of Imperata cylindrica which led him to believe that eluviation must be almost entirely vertical. At the same time, Nye classified the subsoil as a horizon of soil creep.

In Ghana, profile morphology under forest vegetation appears to substantiate the argument for lateral eluviation. There is the marked difference in permeability between the topsoil and the subsoil, the degree of which is related to the texture of the parent material. Over medium grained biotite granite, one of the major parent materials in the closed forest zone, the topsoil consists of a gritty, sandy loam which is highly porous. Beneath this horizon there is a layer of sandy clay which increases in thickness and becomes coarser textured on lower topographic sites in the catena, and ultimately forms the parent material for lower slope soils (see chapter 13). Over phyllite, the most extensive parent material in the zone, the topsoil is a silty clay with a lower porosity, and there is little difference in permeability on passing to the subsoil. Colluvia is not an important feature in association with these soils and only forms an irregular and narrow expanse at the break of slope above the valley floor.

Lateral seepage within the subsoil results in a deterioration in drainage down slope. The well drained upper slopes have characteristic reddish hues in the subsoil, while the soils of the middle slopes have brown hues reflecting the moister conditions due to water percolating down from higher ground (Fig. 11).

The moisture retaining capacity of the weathered underlying rock will also vary with texture and structure. In the medium grained granite, there is relatively little coarse material and a low content of silt, while the phyllite is silty in texture and generally impregnated with numerous quartz veins. The quantity of gravitational water should therefore be less in the former than in the latter. If so, the pattern of drainage would be open in the granite areas with seasonal drying up of minor streams in the ochrosol zone, and dendritic with perennial streams in the phyllite areas. This, in fact, has been recorded (Crosbie, 1956a).

<u>Summary.</u>

The major soils of the closed forest zone owe their characteristics primarily to the climate under which they occur and the vegetation which they support. These soils are formed under the following conditions :

1. The average annual temperature is greater than 70 degrees Fahrenheit (22 degrees Centigrade) with consequent intense chemical and biological processes ;
2. Altitude is below 3,000 feet ;
3. Precipitation is sufficient, in total or intensity, to connect with ground-water in free draining soils ;

4. Seasonal periodicity of rainfall qualifies the degree of leaching and gives rise to the zonal distribution of the great soil groups.

Climate also affects soil formation through the vegetation which it allows and the landscape which it develops. The basic pattern of zonality established components of climate is modified by local conditions, notably those of parent material and time. These are discussed in the subsequent chapters of this section.

Chapter 4

VEGETATION

Vegetation introduces the biological factor into soil formation. It is the decomposition of plant residues and their incorporation into the soil as humus by a varied and multitudinous population of micro-fauna and micro-organisms which distinguishes a soil from a simple geological stratum. The correlation between soil and begetation is particularly close under hot, humid climates where a large proportion of the available plant nutrients is immobilised in the living organisms of the forest. In this environment, there is a closed cycle of nutrients between the soil and the vegetation.

The spatial relations of plant formations over wide areas are determined by the seasonal periodicity and annual total of the rainfall. Boundaries between formations are accordingly ill-defined, and transition zones occur. Since the zonal distribution of the great soil groups of Ghana is also largely determined by these same climatic factors, the inter-relationship between soil and vegetation in Fig. 2a and 2b is apparent.

The forest vegetation of Ghana.

The problem of defining the forest types in the closed forest zone was described by Foggie (1947). Principally, this is due to the heterogeneous composition of the vegetation. Early attempts were based on climate (Chipp, 1927, Marshall, 1945), and Kinloch and Miller (1949) used six arbitrary units of moistness to simplify their notes on the distribution of Gold Coast timbers. The foundation for ecological studies in the forest zone was laid by Taylor (1952) who divided the high forest floristically, and whose map delineating the vegetation zones was only slightly amended in the later account by Lane (1962).

The closed forest comprises the rain forest of approximately 2,905 square miles (Lane, 1962) situated in the south west, and the major expanse of moist semi-deciduous forest. Between them is an ecotone consisting of a narrow belt up to 30 miles wide, and covering an area of 3,245 square miles. In the north and east of the moist semi-deciduous forest there is an ecotone to the savannah woodland, while in the south east it grades into coastal thicket.

The area of rain forest is similar to the area of oxysols, 3,300 square miles (Crosbie, 1957a). The small difference is due to the occurrence of oxysols on high level peneplain remnants and over parent rocks which are high in iron minerals or which allow free oxidation. The ecotone between the rain forest and the moist semi-deciduous forest corresponds to the intergrade zone, but the latter is more diffuse and covers an area of some 7,100 square miles. The difference probably reflects the moisture retaining capacity of the soils modifying the degree of drought for, as Richards (1957) points out, the boundary between the rain forest and deciduous forest...... " is a true climatic limit. There is good evidence that this is mainly determined by seasonal drought and that temperature plays little direct part in it ".

The role of vegetation in soil formation.

Vegetation has a double role in soil formation. It stabilises and ameliorates the environmental climate as it affects the soil, and it directly influences profile development.

Within the forest, environmental conditions are settled (Evans, 1939). The physiognomy of the forest is similar throughout, consisting of an unevenly aged, heterogeneous collection of trees in which three layers may be more or less distinct. In the deciduous forest, the upper stories are less dense and the average height of the individual trees is lower, but this is offset by the fact that the periods of deciduousness are not coincident and that many of the species have wide crowns. Throughout the forest, moreover, the shrub and lower layer are evergreen.

The closed canopy gives protection from the direct impact of rain, the soil surface is kept cool by shade, and the upper horizon is freely pervious to water at all degrees of moistness. Losses due to non-penetration of intense precipitation and to the direct drying out of the top soil by sun and wind are likely to be small. It is doubtful whether light showers reach the surface of the soil at all ; conversely, the heaviest rains at the early part of the wet season are utilised by the deciduous trees.

The production of organic matter by forest vegetation for decomposition on the forest floor, and the reabsorption of the liberated nutrients throughout the soil by the flora and fauna, are the major factors in the formation of the characteristic topsoil of the closed forest soils. The quantity of plant residue suffices to ensure an overall superimposition of features irrespective of topography or the nature of the parent material. In Ghana, litter fall is of the order of 9,400 lbs./acre (Nye and Greenland, 1960) which compares with 7.500 to 9,000 lbs./acre in Colombia (Jenny, Gessel and Bingham, 1949). These figures provide a marked contrast with the unfounded estimates of 100 tons/acre (Vageler, 1933) which, unfortunately, are still quoted on occasion (Tempany and Grist, 1958).

The surface of the soil is covered by a thin litter layer of twigs and leaves, about ½ inch thick. At the base of the layer, the litter is partially decomposed and merges into a thin layer of highly decomposed debris with mineral matter brought up by the action of ants and termites as they digest the litter, together with worm casts. Fine rootlets are concentrated in this layer and fungal hyphae are abundant. This is tied directly to the underlying root mat which is very dense in the dark brown loam of upper topsoil, 2-3 inches thick. This horizon is porour, humous, and has a crumb structure. It is the layer of most active biological life. Beneath it, there is a gradation into the lower topsoil where the humous is less pronounced, the texture is heavier, and the major rooting system of the vegetation is found (Fig. 5). The thickness of this layer varies considerably with factors of soil and local micro-topography.

The composition of the organic matter varies according to the floristic divisions and according to individual species. The change in floristic composition from the rain forest to the moist semi-deciduous forest, with the increase in the proportion

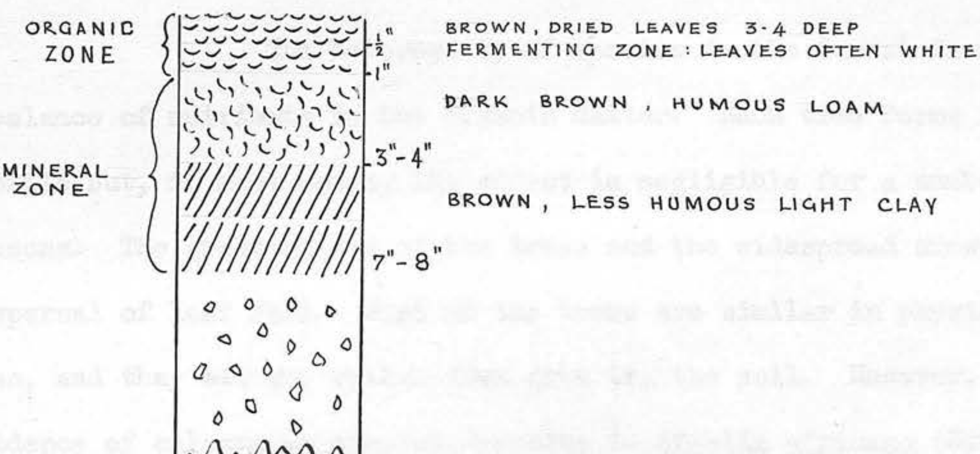

FIG. 5 FEATURES OF UPLAND SOIL PROFILE REFLECTING ROLE OF VEGETATION IN SOIL FORMATION.

of deciduous species, is partially reflected in the balance of carbon and nitrogen in the organic matter. In the rain forest, the C/N ratio is high and micro-biological populations are profoundly influenced by deforestation or burning (Dommergues, 1954a, 1954b), while in the deciduous forest, with a C/N ratio of 10-12, the micro-biological population is relatively stable (Nye and Greenland, 1960).

The heterogeity of species in the forest favours a balance of nutrients in the organic matter. Each tree forms its own profile but, in most cases, the effect is negligible for a number of reasons. The great height of the trees and the widespread crowns give a dispersal of leaf fall. Most of the trees are similar in physical habit also, and they sit on, rather than grow in, the soil. However, the evidence of calcareous mineral deposits in Afzelia africana (Crosbie and Hotson, 1958) and Chlorophera excelsa (Harris, 1933) indicate that a concentration of chemical elements may take place. Ferrous nodules have also been observed in some species, notably Nauclea diderrichii (Kinloch and Miller, 1949). The soil developed under the trunk of an Odum tree, Chlorophera excelsa, which had fallen and decayed on the forest floor, gave rise to a black, humous topsoil with a neutral or alkaline reaction. It was observed that such a soil, while appearing admirable for cultivation, is unsuitable for cocoa.

The concentration of plant nutrients in the upper 2-3 inches of the soil emphasises the importance of organic matter in the productivity of the forest soils (de Endredy and Montgomery, 1954). Leaching has reduced many of the soils to a residue of kaolinitic minerals and sesquioxides with a very low nutrient retaining capacity.

Consequently, the total storage capacity of the soils depends very largely on the organic matter content which makes the largest contribution to the exchange capacity of the surface horizons. In the sub-surface horizons, there is a sharp decrease in organic matter and the exchange capacity is low. The more acid humus of the oxysols possibly has a lower base exchange capacity than the ochrosols (de Endredy and Montgomery, 1956), and the fact that the upper topsoil of the latter is half an inch thicker than the former increases the differences between the total base content of the two great soil groups.

Effect of vegetation change.

The process of deforestation has attained a critical stage. It was estimated in 1957 (Lane, 1962) that about 10,610 square miles remained as high forest out of the total area. Of the area under forest, 5,850 square miles are forest reserves, while the remaining 4,760 square miles is mainly situated in the west and south west. Clearing was estimated at a rate of 350 square miles per annum (For. Dept., 1956), and it was inferred that 800 square miles would be put under cocoa in Western Ashanti alone between 1955 and 1960 (Tanburn, 1955). A large proportion of the unreserved forest occurs in the oxysol zone of the lower Tano basin which is unsuitable for cocoa cultivation and farmers show little interest in clearing (Ahn, 1959).

The immediate effect of deforestation is to alter the role of climate in soil formation. Soils are exposed to the considerable kinetic energy of precipitation. This results in the dispersal of the finer clay particles, leaving a residue of gritty quartz or sand on the surface. Crumb structure is rapidly destroyed, the colour of the surface is changed and the soil moisture capacity is reduced. On fine sandy soils, a skin of baked earth frequently forms. This cover is about ½ inch in thickness and may be coated with white circular patches which frequently coalesce to form a larger mass. Within the skin, soft concretions appear to originate. Such a skin is relatively impermeable and rain water flows off it.

The most important single characteristic of the tropical rain forest is its wealth of species. However, the semi-natural vegetation which regenerates after clearing is limited floristically and is growing in a different environment from undisturbed forest. Typically, secondary vegetation is composed of species which are light demanding and fast growing. The soil climate is also drier as a result of exposure. These factors may be partly responsible for the occurrence of species characteristic of drier (i.e. more seasonal) types of forest in clearings and secondary forest in the evergreen rain forest (Richards, 1957).

Regrowth which has developed in response to shifting cultivation varies considerably with age, form and distribution. Forb regrowth is dominant for two to four years and is gradually replaced by thicket. At approximately ten years after cultivation, young secondary forest begins to develop, usually dominated by Musanga smithii, until twenty years after cultivation when species characteristic of the broken forest become marked.

The species which occur in each of these units have been described by Ahn (1959). There is a conspicuous concentric progression around villages from forb regrowth outwards. Around towns a similar sequence occurs, but it is generally star shaped with extensions along the main routeways.

Forest fallow has two functions. One is the accumulation of plant nutrients in organic combinations and prevention of nutrient losses by virtue of plant immobilisation. The other is improvement of soil structure by stimulating biological activity. This complex biological and chemical process has been reviewed in its entirety by Nye and Greenland (1960), substantiated by the results of experiments in the University of Ghana Forest Farm at Kade.

In the course of mapping the forest soils, it was policy to site profile pits on individual soil series under as wide a range of vegetation as possible. On the major soils, this permitted tentative conclusions on changes under the fallow system which, generally, were in accordance with the work of Bartholomew, Meyer and Laudelout (1953) in the Belgian Congo. For this reason, their work is quoted in Tables 6 and 7.

Nutrient uptake is rapid in forb regrowth and the early stage of thicket, when immobilisation in the leaves is pronounced. As the vegetation becomes more woody, and leaf growth has approached a maximum, the rate of total immobilisation decreases.

	Length of forest fallow			
	18 years	8 years	5 years	2 years
a. <u>Nutrient uptake</u>				
Leaves	100	95	94	94
Wood	100	61	45	9
Roots	100	59	64	27
Litter	100	100	80	19
Mean	100	79	71	37
b. <u>Total nutrient immobilisation</u>				
Nitrogen	100	83	81	28
Phosphorus	100	32	30	21
Calcium + Magnesium	100	81	59	19
Mean	100	65	57	24

Table 6. Proportion of plant nutrients immobilised at various intervals compared to the 18 year forest fallow plot (Bartholomew, Meyer and Laudelout, 1953).

Fallow plots	N Kg/ha.	P Kg/ha.	S Kg/ha.	K Kg/ha,	Ca + Mg Kg/ha.
18–19 year forest	701	108	196	601	822
8 year forest	579	35	101	839	668
5 year forest	567	32	103	456	421
2 year forest	189	22	37	186	160
Grass fallow (3 years old)					
Panicum maximum	374	37	51	351	169
Setaria sphacelata	378	35	63	273	151
Cynodon dactylon	463	52	60	423	250

Table 7. A comparison of total nutrient immobilisation among forest and grass fallow plots (Bartholomew, Meyer and Laudelout, 1953).

By the beginning of young secondary forest, litter accumulation has reached equilibrium. Thereafter, there is a gradual increase in total nutrient immobilisation with a change in the relative proportions of the nutrient elements. Woody tissue is particularly important in the immobilisation of the cations and phosphorus. This possibly is one of the reasons why 18-20 year old secondary forest is regarded as suitable for further cultivation. Work by de Endredy and Quagraine (1956) established a correlation between the amount of total phosphorus and organic matter and provided a strong indication that phosphorus nutrition in the soils of the forest zone is mainly linked with organic phosphorus. The importance of forest fallow as opposed to grass fallow is illustrated in Table 7.

Reduction in the period of fallow is marked with the increasing demand for food, particularly in the vicinity of towns. Empirical observations suggest that with a decrease in the fallow period there is a degeneration in the fallow vegetation. Around Kumasi, there is an ever expanding area of forb regrowth where, even after a period of up to seven years, thicket has not established itself. This degeneration of vegetation reflects the impoverishment of the soils which, in many cases thereafter, will be restricted in use to the cultivation of cassava. This progression provides a marked contrast to towns in the temperate zone where the best soils occur in the

b / environs of the built-up area ; in regions of subsistence agriculture on a land rotation basis, the poorest soils surround the town.

Faunal activity.

As is customary in animal ecology, the zoological factor is included with vegetation. Mention has already been made of the role of fauna in forming the topsoil. Fauna are largely responsible for the mixing in of the parent material, for breaking it up and destroying the remnants of rock structure. Unfortunately, there is little information on their specific activities.

This is an age of abundant insects. 95 per cent of all insects spend part of their life in the soil (Waksman, 1932), and many probably originate there. Activity is related to climate and thereby to the formation of the soil profile. The depth of penetration is of particular importance, but until there is detailed research, the place of biological organisms in the complexities of the natural root environment must be assumed but cannot be estimated.

Summary.

The characteristics of the climatophytic earths are as follows :

1. A two horizon profile consisting of a topsoil overlying parent material ;
2. Rapid decomposition of organic matter by the intense activity of micro-organisms 1 accordingly
3. A closed cycle of nutrients between the vegetation and the soil ;
4. A concentration of organic matter in the topsoil, principally in the upper 2-3 inches ;

5. The exchange capacity is practically a function of organic matter ;
6. Leaching of bases leads to acidity, varying with the seasonal distribution of rainfall ;
7. The unweatherable residues of rock decay, mainly kaolin and sesquioxides, form the mineral basis ;
8. The mineral soil has reddish hues.

Chapter 5

RELIEF AND DRAINAGE

Landforms have two functions in soil formation. They establish the drainage relationships of soils, and they provide a key to the distribution of parent materials and their mode of origin. Because the climate and vegetation are constant throughout the zones of the great soil groups, the constituent soils are defined according to differences in relief and drainage over any particular parent material. For this reason, regional surveys in Ghana were conducted on the basis of drainage basins of major rivers. These formed natural geographic regions which comprised not only similar soils and parent materials, but usually, similar vegetation and agricultural practices.

Physiographic description of the closed forest zone.

The major physiographic feature of the closed forest zone is a low level dissected peneplain consisting of gentle undulations separated by relatively small drainage channels. Over the phyllites and schists of the Lower Birrimian formation (Fig. 6), the valleys are very wide, while over the acid igneous intrusions, the valleys are narrower and have a graded slope rising to gently rounded or flat summits.

Most of the drainage of the closed forest zone flows south to the sea from the major divide of the country which is formed by the escarpment between Koforidua and Wenchi. Within the zone,

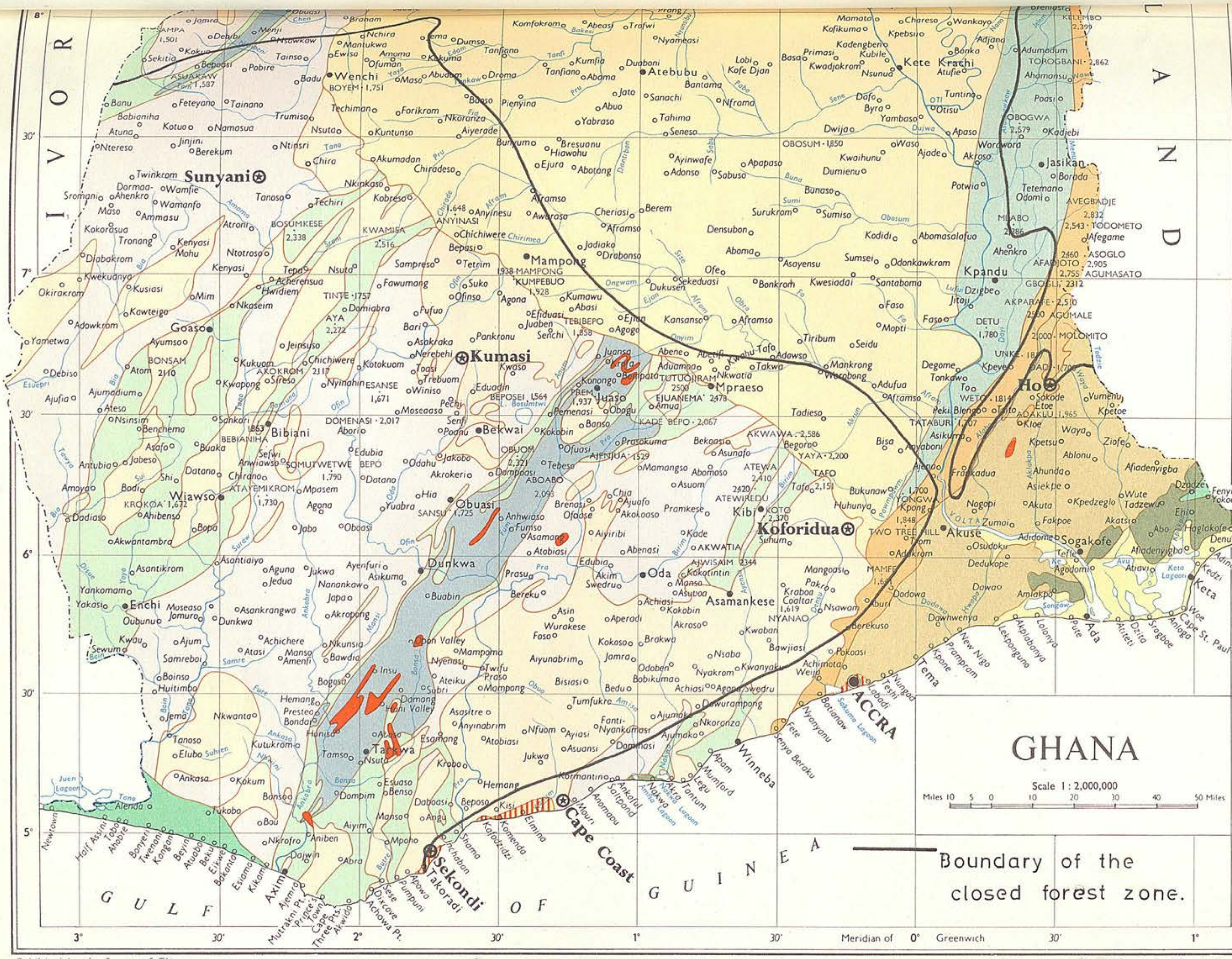

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Fig.6

GEOLOGY

TABLE OF FORMATIONS

Formation	Description	Formation	Description
RECENT	Unconsolidated Sand, Clay and Gravel.	TOGO SERIES	Quartzite, Shale, Phyllite.
TERTIARY	Red Continental Deposits, mainly Limonitic Sand, Sandy Clay and Gravel.	TARKWAIAN	Quartzite, Phyllite, Grit, Conglomerate.
EOCENE & CRETACEOUS	Marine Series of Shale, Sandstone, Limestone.	UPPER BIRRIMIAN	Metamorphosed Lava, and Pyroclastic Rock.
		LOWER BIRRIMIAN (Middle Pre-Cambrian)	Phyllite, Schist, Tuff and Greywacke.
SEKONDIAN & ACCRAIAN (Devonian)	Sandstone, Grit, Conglomerate, Shale and Mudstone.	DAHOMEYAN (Lower Pre-Cambrian)	Acidic and Basic Gneiss and Schists.
VOLTAIAN (Palaeozoic)	Quartzite, Shale, Arkose, Mudstone.	BASIC INTRUSIVES	Gabbro, Dolerite, Epidiorite.
BUEM FORMATION (Upper Pre-Cambrian)	Shale, Sandstone, Arkose, Lava.	GRANITES (Middle Pre-Cambrian)	Granite and Granodiorite.

the principal watersheds are formed by hill ranges which trend on a south-west to north-east axis (Fig. 7).

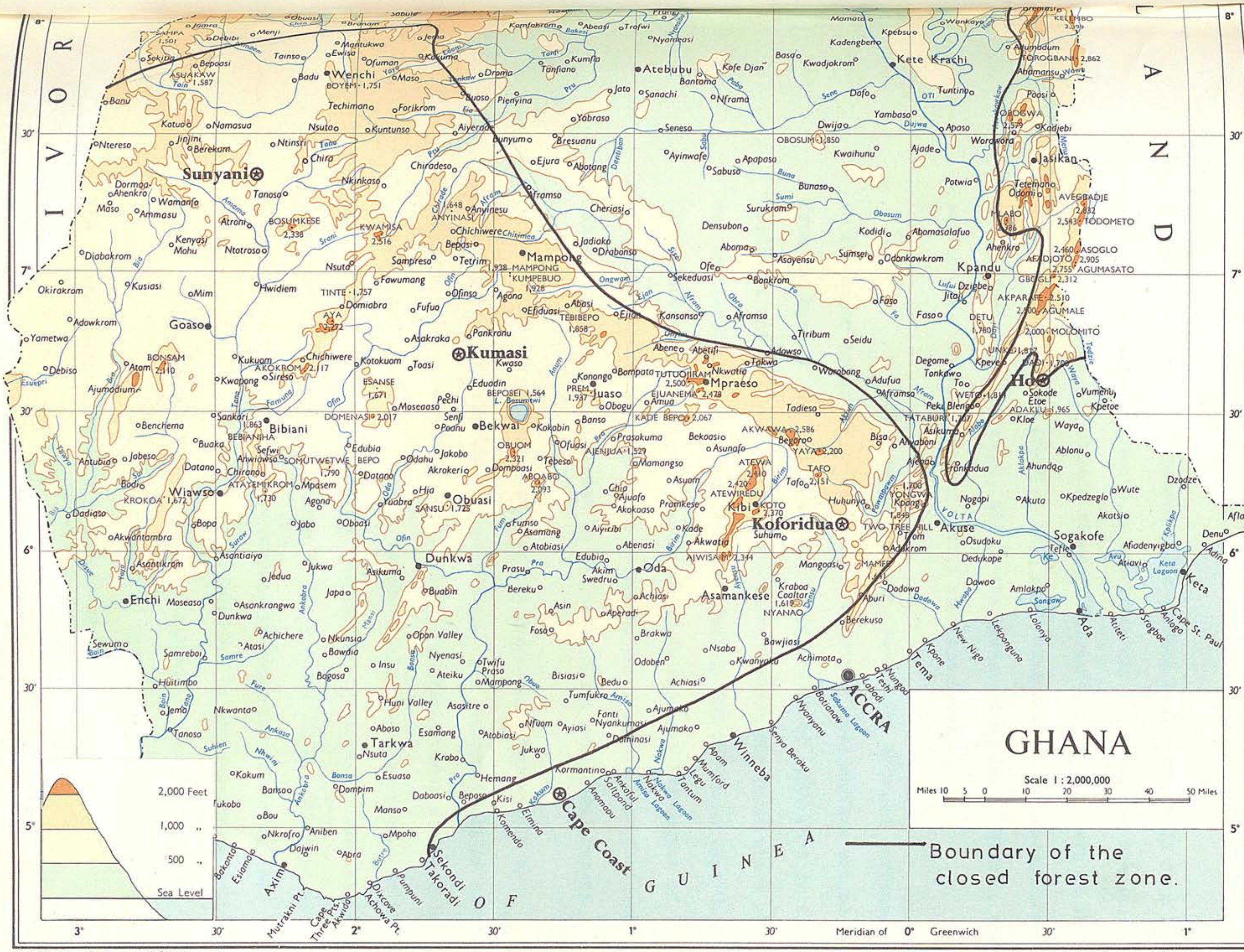
Terrace deposits are extensive in association with all the major rivers, and, notably in the Birim Basin, may constitute an important relief feature in themselves. They are well defined and occur at heights of 20-25 feet, 50-60 feet, 70-90 feet and 100-120 feet above the dry season level of the rivers.

Inselbergs are a regular feature in the ochrosol zone, but are absent in the oxysol zone. They are usually, but not always, composed of coarse grained granite or gneiss, and typically rise some 350 feet above the general level of the surrounding country.

The escarpment is in active retreat (Geol. Sur. Annual Rpt., 1934, Hunter, 1959) and alluvial fans form a minor relief feature along its base.

<u>Geomorphological history.</u>

There are remnants of at least two former erosion surfaces (Crosbie, 1956b, Radwanski, 1956a) and fluctuations in the present cycle are indicated by the terrace deposits. The oldest relics of a surface occur at altitudes of 2000 feet and over in the north of the zone ; this surface has been termed the Aya surface after Mount Aya in the Yinahin Range. Throughout the forest zone, it is mainly situated on the Birrimian hill ranges where its preservation has been aided by widespread flexing and faulting, probably connected with Alpine movements (Cooper, 1936) although it is also apparent on the



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RELIEF

Fig.7

Voltaian escarpment at Mpraeso. The surface slopes gradually from over 2,500 feet in the north to approximately 2,000 feet at the southern end of the Atewa and Yinahin ranges. Thereafter, it decreases at 12 feet per mile towards the coast at Axim where traces of it are recognisable at 600 feet. On the scarp, and to the southwest as far as Wiawso, the surface is frequently capped with a bauxitic crust.

The younger surface, termed the Akumadan surface, occurs on the major secondary interfluves. Relicts of this surface extend from the base of the Voltaian scarp at altitudes of 1,300 feet in the northwest and 700 feet in the Birim Basin towards the coast where it may be traced at an altitude of approximately 200 feet near Cape Coast. Cross sections of this surface are shown in Fig. 8. The degree of dissection increases from north to south, while within each drainage basin, there is a slight rise to the base of the peripheral ranges.

The Aya surface was dissected after uplift by consequent rivers flowing southwestwards. The younger cycle of erosion which followed had reached late maturity, probably under a more arid climate than exists at present, before it also was dissected. At the same time, the headwaters of the Ankobra were captured by the Ofin and the Tano, and those of the Nakwa by the Pra and Birim. The present courses of the main rivers are similar to those formed during the younger cycle of peneplanation, as indicated by the accordance between the highest terrace and the peneplain residuals. Rejuvenation, probably related to eustatic change, led to down cutting and further dissection. The terrace levels indicate fluctuations in the change.

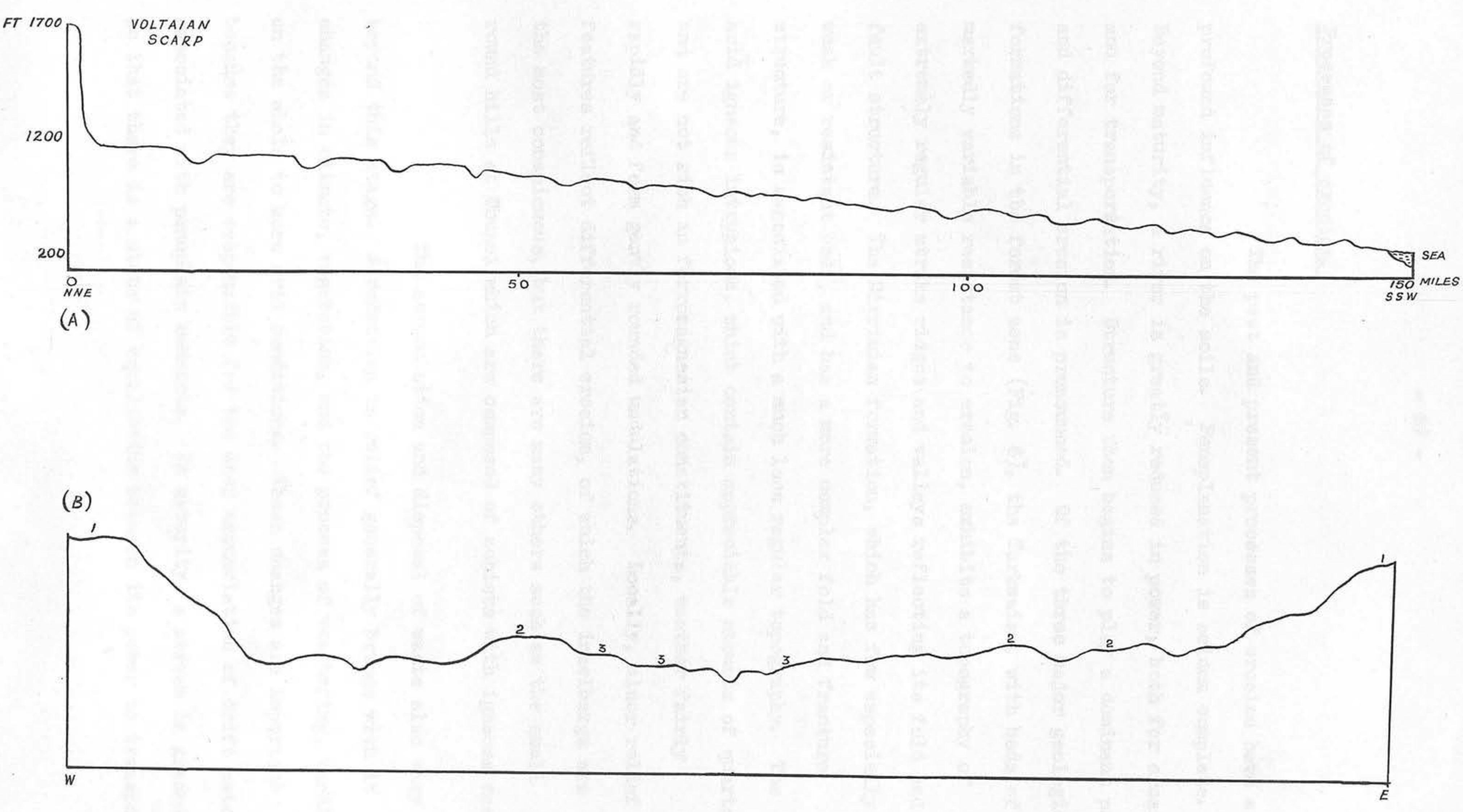

FIG 8 CROSS-SECTIONS OF AKUMADAN SURFACE (A) FROM NORTH TO SOUTH (B) WITHIN A MAJOR DRAINAGE BASIN IN THE OCHROSOL ZONE; (1) AYA SURFACE; (2) AKUMADAN SURFACE; (3) TERRACES

Processes of erosion.

The past and present processes of erosion have a profound influence on the soils. Peneplanation is seldom complete. Beyond maturity, a river is greatly reduced in power, both for erosion and for transportation. Structure then begins to play a dominant part and differential erosion is pronounced. Of the three major geological formations in the forest zone (Fig. 6), the Tarkwaian, with beds of markedly variable resistance to erosion, exhibits a topography of extremely regular strike ridges and valleys reflecting its fold and fault structure. The Birrimian formation, which has few especially weak or resistant beds, and has a more complex fold and fracture structure, is associated with a much less regular topography. The acid igneous intrusions, which contain appreciable amounts of quartz, and are not rich in ferromagnesian constituents, weather fairly rapidly and form gently rounded undulations. Locally, minor relief features reflect differential erosiom, of which the inselbergs are the most conspicuous, but there are many others such as the small round hills at Obuasi which are composed of schists with igneous cores.

The accumulation and disposal of waste also vary beyond this stage. A reduction in relief generally brings with it changes in climate, vegetation, and the process of weathering, tending on the whole to more arid conditions. These changes are important because they are responsible for the deep accumulation of drift material associated with peneplain remnants. In maturity, a stream is graded so that there is a state of equilibrium between its power to transport and the amount of material to be transported. Similarly, there is a graded conditioning of the waste on the slopes so that the supply of waste is equal to its removal by the available agents of transport. Consequently, in the late stages of peneplanation, when slopes are negligible and the agents of transportation are weak, the supply of waste must be small and of fine texture for removal. This is achieved by the waste accumulating to great depths in order to reduce the supply from the weathering of the underlying rocks, while, at the same time, there is a continual refinement of the drift by prolonged exposure. This deposition of drift materials commences on the lower slopes, but, in time, most of the topography is masked by it. In this way, the drift deposits, which form the parent materials of some of the soils of today, are closely related to the underlying rock although they may have been locally transported. Similarly, it is to be expected that there will be an accumulation of clay through the drift until it reaches a depth not subject to weathering.

The formation of drifts in this way was first postulated by Davis (1899) and certainly the distribution of soils on peneplain remnants (Crosbie, 1956b) and the accumulation of lower slope colluvium in areas underlain by granite (chapter 13) would appear to support this assumption. However, in areas underlain by phyllite and markedly so in those with the increased rainfall in the southwest, the main streams have meandering courses, steep valley sides, and flat swampy floors. These features are not due to alluvial aggradation for the layer of alluvium is usually thin and outcrops of rock commonly appear in the beds of streams or in the neighbouring flat ground or swamp. The valley profile has been cut by lateral planation of the deeply weathered clay, with some measure of parallel retreat of the inter-stream ridges and spurs which, under peneplain conditions, were protected by a ferruginous crust.

A feature of drift deposits in the tropics is the presence of termitaria. This feature has been interpreted as an indication that the drift is a sequel to biotic activity (Brammer, 1955), but it would appear more probable that it is the extremely favourable physical properties of the drift which attracts termites. Undoubtedly, the micro-fauna redistribute fine earth, as witness the redeposition of material over a stony garden path, but their action is limited. It has to be noted that other peneplain remnants throughout the world have drift deposits with no evidence of termitaria.

An indurated layer may form at the base of the drift or in the upper part of the underlying rock where the latter is relatively impermeable. This layer is "laterite", but this term has been so vaguely and widely applied that it has lost much of its value. On the Aya surface, the indurated layer has developed into a bauxitic crust, while on the Akumadan surface, a ferruginous crust is present over phyllites and schists.

Laterite and lateritic soils have been reviewed by Prescott and Pendleton (1952). It is not intended to discuss the origin or nature of laterite indetail here for two reasons. In the forest zone, laterite is of very minor importance and of local significance only. This compares favourably with the savannah zone where groundwater laterites are widespread. Secondly, the origin of laterite involves chemical processes but the aspects of formation and properties outlined below are based solely on field observations. In general, the evidence suggests that laterite is essentially a product of precipitation and is not a residual formation, that many of the formations are of ancient origin, and that process of formation are currently taking place. These implications concur with those of Campbell (1917) and Nye (1955).

The formation of ironpan begins at the zone of impeded drainage in the profile as a mere localised rusty staining or mottling somewhat akin to the gley mottling in swamp subsoils. This is due to the precipitation of iron and/or manganese salts brought intossolution by the acid leaching water. Further deposition occurs around the primary nucleii whereby pisoliths and tuberous pieces of concretionary gravel are formed. These coalesce to form ironpan, and this is thickened by repetition of the same processes.

There are three sites on which formation takes place : 1. The flat summits of erosion surfaces where these are underlain by fine textured rocks are characteristically capped by crusts. On the oldest (Aya) surface, this crust is massive, thick and extensive. On the younger Akumadan surface, the crust is located at the edge of the remnants or in sites where the overburden of drift is very thin (Fig. 9).

2. The middle to lower slopes of gentle topography where there is a marked break of slope due either to a pause in stream dissection or to sub-surface impedance, may be enriched by seepage water from

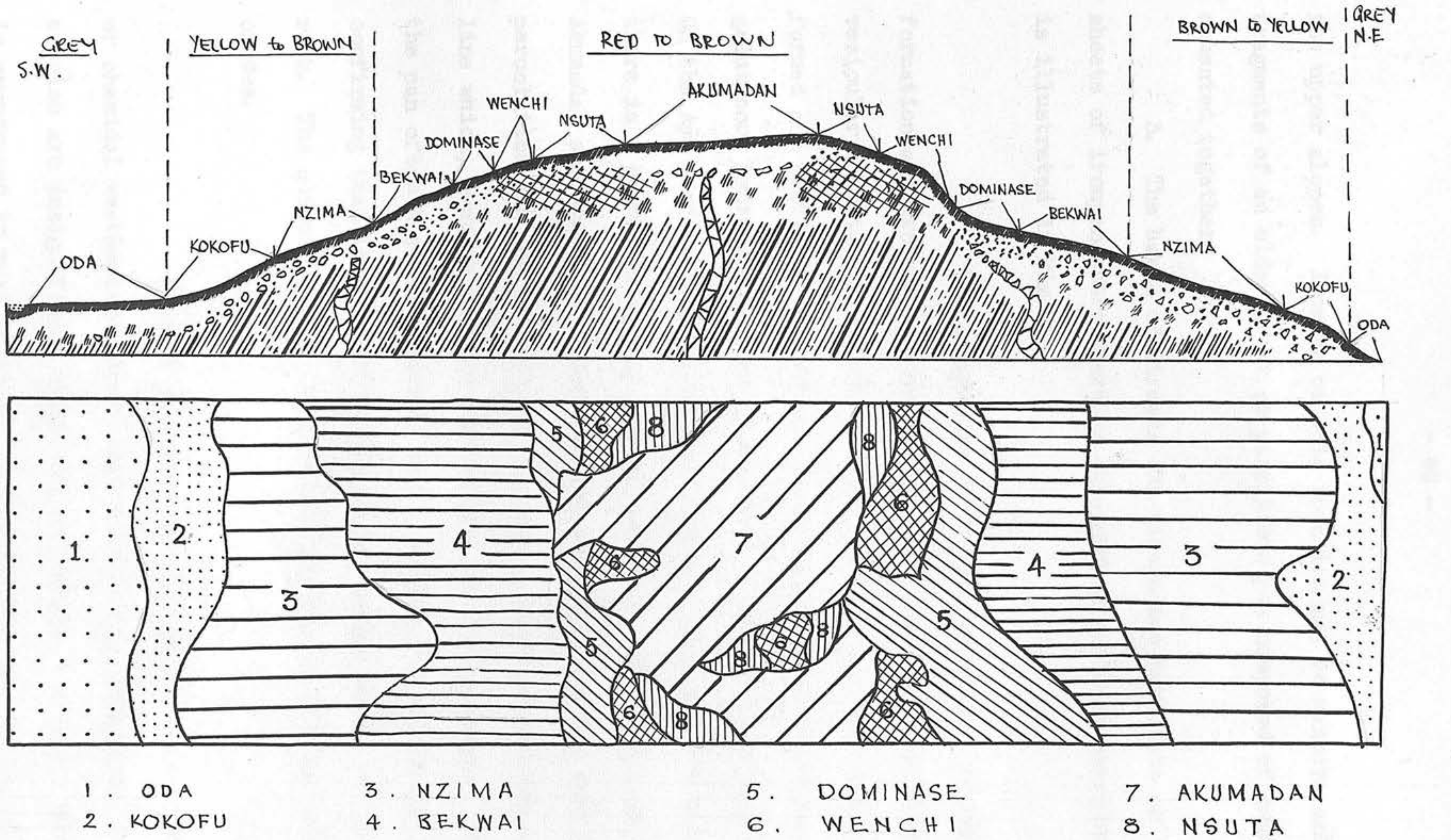

FIG 9 TOPOGRAPHIC SECTION AND SKETCH-MAP ILLUSTRATING THE DISTRIBUTION OF SOILS WITHIN A FOREST OCHROSOL ASSOCIATION OVER LOWER BIRRIMIAN PHYLLITE AND A PENEPLAIN RESIDENTIAL AREA (ROUGHLY BETWEEN AND PARALLEL TO CEDAR AND PATASI ROADS) (BRAMMER 1962)

the upper slopes. Ironpan on this location may be massive and include fragments of an older crust or pisolithic pan composed of concretions cemented together.

3. The banks of streams and rivers may have thin or thick sheets of ironpan where there is sub-surface drainage emerging. This is illustrated in Fig. 10.

The properties of ironpan which are related to soil formation are twofold. Principally, there tends to be a cellular or vesicular structure due partly to the presence of roots when it was formed and partly to changes in volume during the dehydration of gelutinous hydroxides. This means that it is not impervious to water. On the Aya surface, the bauxite cap forms a reservoir for moisture and there is a permanent spring line at its base. Similarly, on the lower Akumadan surface, the ferruginous capped remnants allow moisture percolation and, at the base of the slope, there is usually a spring line which, even in the dry season, has constant seepage. Secondly, the pan often has intact quartz veins running throughout it, thereby confirming that it has been formed in the upper layers of the underlying rock. The quartz is usually fractured and may be stained with ferrous oxides.

Present processes of erosion are mainly sub-aerial or chemical weathering. Mechanical weathering, sheet wash and soil erosion are insignificant under the protective vegetative cover. Creep is pronounced in most soils due to the lateral eluviation of gravitational water. Drainage consists of a close network of streams and

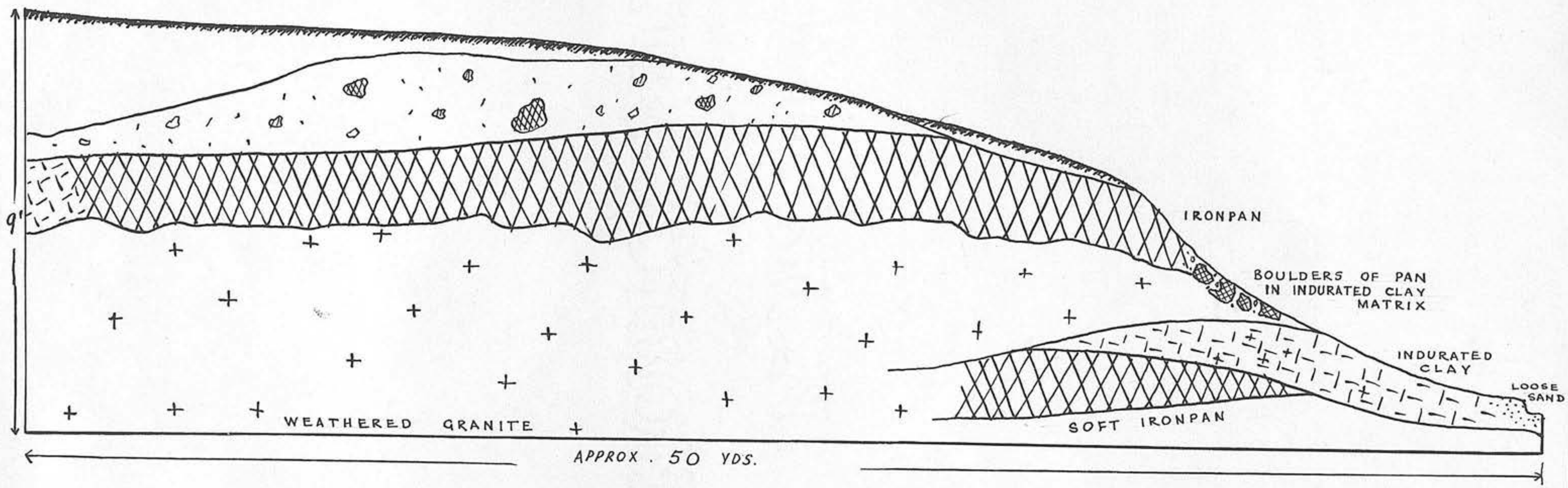

FIG. 10 IRONPAN OVER GRANITE ON CENTRAL AGRICULTURAL STATION, KUMASI

rivers, most of which are perennial. The relatively uniform vegetation and slopes of the dissected peneplain trend to an even disposal of run-off throughout the zone, and variations are related to soil, geology, and time and pattern of rainfall. The minor streams have little erosive power and flow in wide, misfit valleys. Their channels are shallow and consequently, when there is a seasonal rise in flood waters, widespread flooding results. This is responsible for the ill-assorted alluvial deposits, and swamp vegetation of these valleys. On these deposits, the great soil group of Gleisols are formed. Within the group, subdivisions are based on colour and reaction. The major rivers are still cutting down to base level, and they can absorb the flood waters without overflowing their banks.

The catena concept.

The physiographic relationships of soils provide the basis for pedological mapping in tropical regions. In these areas, the characteristic soil-topographic sequence associated with old erosion surfaces are dominant. The residual soils associated with these surfaces have been altered by weathering during the course of time, rejuvenation has taken place, and there has been a re-distribution of materials.

The catena forms the unit of mapping. This concept was established by Milne (1936) in East Africa and provides a means of grouping soils into associations based on topographical sequences. Such a grouping is particularly valuable in the tropics where patterns of soils are often repeated over wide areas, and where the heterogeneity of soils would make individual mapping too complicated.

The application of the concept was extended by Bushnell (1942) to cover all the various possible topographic- denudational-hydrologic situations on a given parent material. Whereas Milne had a simple catena made up of soil series homologous in all features except those due to drainage variations, Bushnell used multiple catenas composed of groups of catenas homologous in all features except those due to one soil forming factor in respect of which there is a gradation of characteristics. Logically, therefore, since climate, vegetation, parent material and time are the principal factors in formation in addition to drainage, there are four possible kinds of multiple catenas, as follows :

	Homologous factors	Variable factor
1.	Climate - vegetation - material	time
2.	Climate - vegetation - time	material
3.	Climate - material - time	vegetation
4.	Material - vegetation - time	climate

There are difficulties in the practical application of the multiple catena concept. It is implied that the formative effects of the pedogenic factors will be reflected in the characteristics of the soil profile. The recognition of the salient features would thus require an understanding of the processes involved and their consequences, with the added complication that the products of different combinations of factors may be so diverse that relationships are obscure. Further, the characteristics may not always be apparent on visual inspection or may be liable to misinterpretation. Colour, for example, usually indicates hydrological variation but it may also be imposed by the parent material.

The basic principle of equilibrium between soil profiles and environment remains valid, however, and supplies the basis for unity in pedology. The geography of soils is as significant a factor as those involved in soil formation. Each landform has its own distinctive mantle of unconsolidated material, either of transported or residual origin, and each mantle has its own distinctive morphology. This morphological character may directly affect plant growth and land utilisation.

A typical topographic sequence of soils is shown in Fig. 11. On the summits and upper slopes, drainage is free and the soils are reddish in colour, while on the middle to lower slopes, the soils are brown in colour. On the lower slopes there is an accumulation of colluvial material derived from the soils above, and this is yellow brown in colour. In the valleys, the alluvium is grey to white depending on the texture, site and season of the year.

Landforms and soils.

The role of landform in soil formation in the tropics is principally evident in the drainage and depth of profile. There is relatively little direct effect on the operation of the climatic factors of temperature and rainfall, although there is a

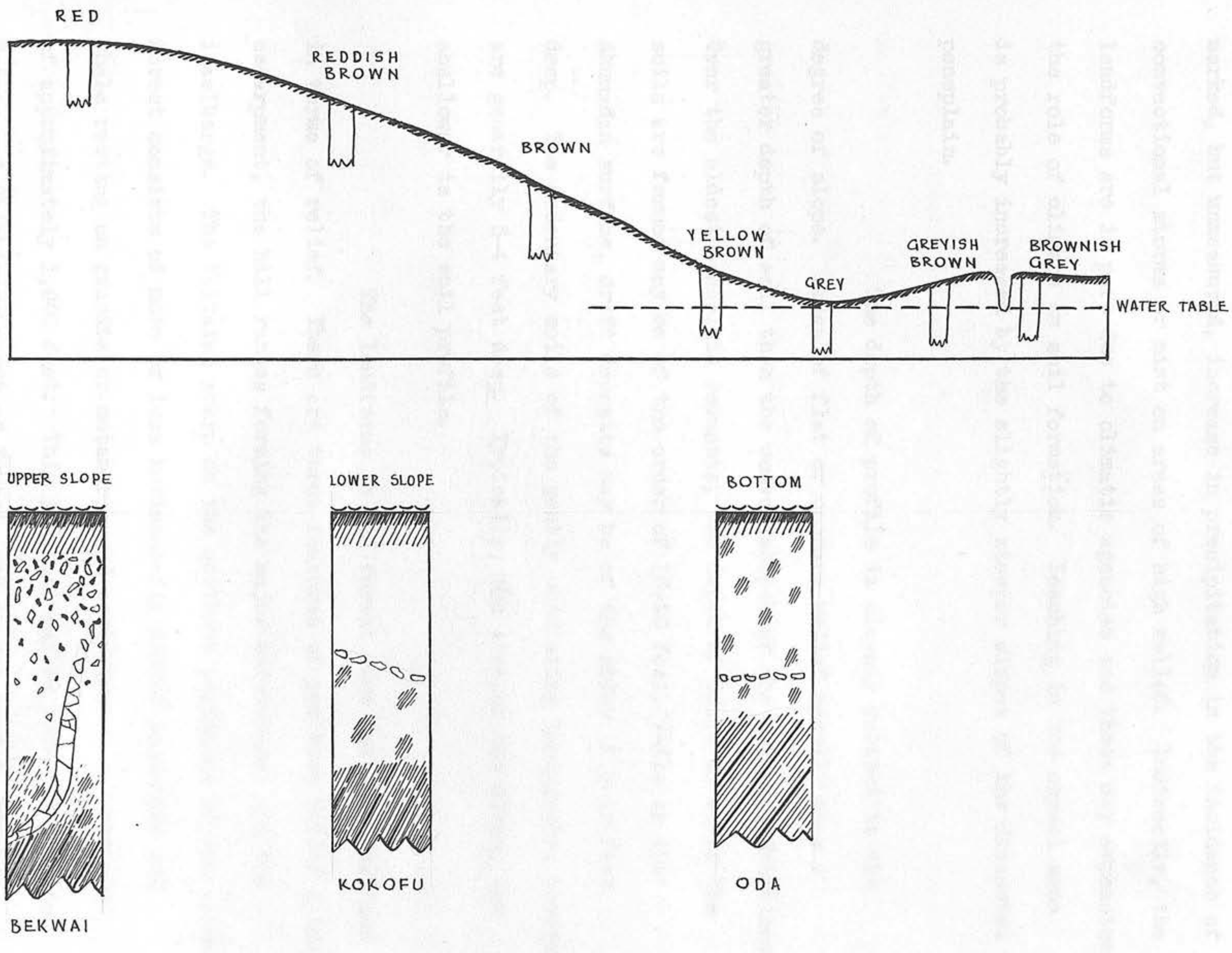

FIG. 11 TOPOGRAPHIC SEQUENCE OF SOILS ILLUSTRATING COLOUR CHANGE WITH PROFILE DIAGRAMS OF SOILS IN SEQUENCE OVER PHYLLITE.

marked, but unmeasured, increase in precipitation in the incidence of convectional storms or mist on areas of high relief. Indirectly, the landforms are in part due to climatic agencies and these may emphasise the role of climate on soil formation. Leaching in the oxysol zone is probably increased by the slightly steeper slopes of the dissected peneplain.

The depth of profile is closely related to the degree of slope. Areas of flat or concave relief usually have a greater depth of soil than the convex slopes of the gentle undulations. Over the oldest peneplain remnants, the depth of drift in which the soils are formed may be of the order of 15-20 feet, while on the Akumadan surface, drift deposits may be of the order of 8-10 feet deep. The sedentary soils of the gently undulating topography, however, are generally 3-4 feet deep. Typically, the steeper the slope, the shallower is the soil profile.

The landforms in the forest zone may be classified in terms of relief. There are three features of positive relief ; the escarpment, the hill ranges forming the major watersheds, and the inselbergs. The Voltaian scarp on the northern perimeter of the closed forest consists of more or less horizontally bedded sandstone and shale resting on granite or metamorphosed sediments at an altitude of approximately 1,000 feet. This junction may be observed between Tetrim and Chichiwere north of Kumasi, and on the road to Begoro.

The scarp presents an impressive face to the south. Skeletal soils are predominant on the summit, but on the northeast dip slope, the majority of the soils contain a colluvial element and comprise a moderate to deep layer of red sand or sandy loam overlying weathered sandstone. Where streams have cut back through the scarp face, the drift has been redeposited in cols and saddles. These retransported drifts are generally of considerable depth. In one exposure near Mile 30 on the Kumasi-Mampong road, they are 30 feet or more, and on occasion, one or more stonelines may be observed. The simplicity of the lithology has led to wide expanses of fairly uniform soils.

The hill ranges extend as parallel digits from the scarp in a southwest direction. They are steep sided, remarkably straight, and there is frequently a marked break of slope at approximately 1,000 feet (S.L.U.S. 1958, Hunter, 1959). The form is asymmetrical with a steeper face to the east, and a piedmont drift of transported material on the west. Soils are closely tied to the parent rocks and are immature in development. On the steep topography, they usually consist of a single layered topsoil, 2-3 inches thick, overlying thoroughly weathered rock. Where they are composed of quartzite, the slopes are bare of soil, the summits are narrow, and very often there is an accumulation of talus at the base. Where remnants of the Aya surface are preserved on the flat summits of these hills, the soils are developed in old, deep drifts.

In Western Ashanti, the isolated hill mass of Bosumkese, (2,338 feet), is largely composed of basic rocks and gives rise to the <u>basisol</u> great soil group. This is a climatophytic earth developed over parent materials from which bases are released sufficiently rapidly to replace those lost by leaching. In association with Bosumkese, which lies between the Tano and Srani rivers, there is an expanse of piedmont drift which retains some of the nutrients derived from the basic rocks (Radwanski, 1956b, 1957).

Inselbergs are insignificant areally, but they are none the less important to the development of forest soils and are described in detail in chapter 12.

Over the major physiographic feature of the dissected peneplain, variation in slope is a factor of geomorphology or lithology. Flat topped remnants of the peneplain are frequent in the north of the zone, but become less frequent and less extensive towards the coast. Where these are underlain by phyllite, drift deposits of red clay up to 5 feet thick are found, together with ferruginous crusts. Where granite underlies the remnants, the drift is somewhat thicker, being of the order of 8-10 feet, reddish brown in colour, and sandy loam in texture.

The undulating topography of the phyllite areas consists of wide valleys with a fairly abrupt break of slope at the base of the interfluve ridges. More gentle, rolling topography is formed over granite and there is a greater accumulation of colluvial drift. Towards the oxysol zone, slopes become steeper over both lithological units. Further east, where the forest zone grades into the drier environment of the coastal thicket, the granite has much gentler topography and the uplands may be completely masked by colluvial drift.

In the extreme southwest of the forest zone, an area of some 200 square miles of Tertiary sands is located just behind the coast (Ahn, 1961). Originally, the topography was flat, but it is now dissected by deep, steep sided gullies and young valleys. This area is remarkable in that it is almost entirely covered by a single soil series and the catena concept is inapplicable. The soils are uniform not only in expanse but also in the profile.

Chapter 6

PARENT MATERIALS

The importance of surface geology as a factor in soil formation has long been the subject of controversy among pedologists. In the early days of classification, the emphasis on geology as a dominating factor was pronounced, particularly in Britain where climatic variation is limited and the range of soils is closely related to parent materials. The Russian concept, in contrast, was based on the domination of climate because of the zonal pattern of soils which developed over diverse rocks. Both of these views required further modification with the study of the soils of the United States where neither factor could be described as dominant in any area (Crowther, 1930). In the tropics where rock decomposition may occur to great depths and where the process of sub-aerial erosion has been of long duration, the influence of lithology in soil formation has been subdued. There few dominant or distinct rocks in Ghana which characterise profile development. Instead, the major proportion of the upland soils have climatophytic features, irrespective of the parent material from which they are derived.

The geology of the forest zone.

Africa is an ancient land mass with a simple form. It consists of a plateau of marked geological stability whose foundation of Archaean rocks has mainly stood above sea level since

Pre-Cambrian times, with only intermittent submergence since Devonian times. The primitive rocks of the Archaean base are exposed at the surface over a large area of the continent. They contain a high proportion of quartz and comprise granites and gneisses over large areas which have been worn down to a dissected peneplain with occasional inselbergs.

The basement complex provides the geological base of West Africa with igneous and metamorphic rocks outcropping. In Ghana, the boundaries of the closed forest zone almost coincide with the southern portion of the Pre-Cambrian rocks (Fig. 6) with the exception of the outlier in Togoland. Bates (1962) has described the two principal formations : the Birrimian system and associated granites, and the Tarkwaian system. Small areas of Devonian rocks occur on the coast, but they are mainly obscured by Upper Tertiary sands and peneplain residuals. In the east of the forest zone, the Togo series form the Akwapim and Togo hill ranges, while the Buem formation underlies an area on the western side of these uplands.

<u>The lithology of the forest zone.</u>

The surface lithology of the geological formations forms the parent materials of the soils. Broad divisions may be distinguished according to whether the material is consolidated or non-consolidated, The former comprises bare primary or secondary rock, while the latter includes residual earthy accumulations derived from the weathering of rocks and transported material accumulated by various agencies.

The Birrimian system is differentiated into a Lower and Upper category. Rocks of the Lower Birrimian age extend over the greater part of the forest zone. According to Montgomery (1952) they consist of 50 per cent phyllites, 40 per cent greywackes, and 10 per cent tuff. Over the greater part of the region, however, phyllite has usually been evident on almost every occasion in rock exposures and soil profile pits. The phyllites show wide ranges of colour, but are predominantly black to dark brown, grey to green, with many red to dark brown types. The texture is a fine grained clayey rock with some fine sand which stains the fingers and has a greasy feel. Towards the hill ranges, the phyllites usually lose their structure and become more typical schists. Bands of tuff, which show very little signs of bedding, are intercalated with the phyllites. These beds are pale pink, yellow, buff or even white in colour, and possess a talc like texture. Greywackes do not occur as extensive expanses, but where they are intercalated with the phyllite to any degree, there are conspicuous increases in the degree of slope. Quartz veins are very common in the Lower Birrimian and may be locally abundant.

The dominant soil forming rock is phyllite which overshadows the greywackes and tuffs. Being composed of materials which are themselves the products of long continued weathering, the phyllites are but little affected by decomposition. The fine cleavage allows the rock to disintegrate into thin, flat plates but these, in turn, do not decompose rapidly and are present in the soil at depths of 3-4 feet. Phyllite yields fine textured soils, generally silty or clay loams, but the stringers of quartz may persist through the soil in considerable quantities.

The Upper Birrimian forms the principal watersheds in the forest zone. The rocks of this formation consist, in the main, of the same rocks as the Lower Birrimian although there is a change in the quantitative distribution together with a larger proportion of basic intrusions. Greenstones or hornblende schists may be locally significant and are often in geographical association with the Dixcove granite consisting of biotite-hornblends granite, granodiorite or diorite. These rocks are rich in ferromagnesium minerals, and give rise to soils with peculiar properties, the basisols.

The importance of this formation as a parent material of soils varies considerably. The lithological composition is usually exceedingly complex, and there is a mosaic of individual soils in any locality. However, the best soils of the forest zone are derived from the basic intrusions which characterise this formation. The basisols are well supplied with nutrients, contain little or no coarse material, and have a high retaining capacity for bases and moisture. They are inextensive and occur in pockets, 10-100 acres in size. The steep topography of the Upper Birrimian also permits erosion to keep pace with weathering, and thereby permits plant roots to exploit decomposing rock.

The Tarkwaian system has hill ranges composed of quartzites and grits, white and pale grey in colour, often containing false bedded lines of haematite. These are markedly poor soil makers. They are extremely hard and resistant to erosion, weathering is slow and shallow, stony soils, lithosols, are formed.

The sediments of the Voltaian formation on the northern boundary of the forest zone are mainly composed of coarse sandstone and grits with well rounded quartz grains (Junner and Hirst, 1946), which are the products of long continued weathering. In turn, they weather by disintegration and break into angular fragments, or the cement matrix is lost in solution. There are considerable portions of silt and clay in the sandstones, however, and the soils which develop in them are correspondingly heavier textured than expected.

Acid igneous intrusions are frequent in the Birrimian system. They occur as large batholiths of granite and granodiorite together with their associated aplites and pegmatites. These are very extensive and cover an area equal to that of the Lower Birrimian phyllites. The major rock is the typically foliated, black and white, medium grained biotite granite of the Cape Coast suite (Junner, 1940) but roof pendants, stringers and patches of schist and gneiss also occur. Near the margin of the intrusions, biotite-muscovite granite and muscovite granite are not uncommon. Locally extensive areas of pegmatite with a high quartz content may occur. When the granite intrudes comparatively little metamorphosed Birrimian sediments, there is always a clearly marked aureole, usually of biotite schist spotted by staurolite, andalusite and kyanite.

The composite character of the intrusions is reflected in the variable texture, mineralogical and chemical composition of the component rocks. In turn, this affects the resistance to weathering and the soil forming properties. Generally, the granites are deeply weathered, and give rise to gritty, sandy loams. If the parent material is coarse grained, e.g. pegmatites, then the subsoil may be exceedingly gravelly with consequent poor moisture and nutrient retaining capacity, but, more often, they give rise to clayey earths. Although most of the feldspars are soluble and lost by leaching, yet some remain in their original form and decompose very slowly yielding plant nutrients. It is this slow rate of decomposition, together with the satisfactory moisture relationships, which make the granitic soils suitable for continued cultivation.

Superficial deposits are distinguished according to their mode of origin. There are four categories, viz. erosion surface, colluvial, alluvial and coastal deposits.

The oldest erosion surface (Aya) has parent materials for soil in the form of drift deposits or bauxite crust with combinations of both on certain aspects of the slopes. On the summits, the depth of the drift material varies with minor undulations of the surface, while on the slopes the redeposited drift may be of considerable depth, and, in one excavation, the base had not been reached at 27 feet. The drift consists of a red, uniform clay with distinctive tinges typically associated with soils containing manganese. The soils developed in the drift are unusual in that they are red to the surface, despite the fact that they possess a very high organic matter content (Crosbie, 1957b). They also demonstrate the refinements associated with peneplain conditions (see chapter 5) in that they have an accumulation of clay throughout the profile (Table 8), and contain little other than kaolin and sesquioxides of aluminium and iron. Soils belong to the oxysol great soil group, but unlike the normal oxysols which are associated with high rainfall areas of 70 inches or more, the character of the peneplain soils is determined to a large extent by age.

The Akumadan surface has a greater variety of parent materials. Over the phyllites, red clays and ferruginous crusts are present with considerable variations in proportion dependent on the degree of dissection. Normal zonal soils are formed over the drift, and lithosols are present over the crust (chapter 12). Over the granite, the drifts are very deep, coarse sandy and paler in colour. Unlike many drifts, there is seldom a stone line at the base because of the paucity of coarse material in the underlying rock. Instead, there is usually a partially indurated layer, 18-24 inches thick , in which a few scattered granite core stones may be present.

Colluvial deposits are particularly important in association with the granite intrusions. In the aggregate, they form one of the major parent materials in the forest zone and are discussed in detail in chapter 13.

Alluvial deposits include terraces of the major river valleys, and recent alluvium in the minor stream valleys. All

Survey : Kumasi Region	Locality : Tr. 5E/390	Rainfall : 60-65 inches
Profile No. : PKR 40	Site : Summit - Yinahin Range	Altitude : 2000 feet
Lab. No. : B 283	Series : Aya	Vegetation : Broken forest

Lower depth of horizon in inches	Colour air-dry Notation	Colour air-dry Description	Colour wet (Plastic limit) Notation	Colour wet (Plastic limit) Description	Organic matter per cent C	N	C/N	O.M.
1. 2	5YR 3/4	Dk. reddish brown	5YR 4/3	Dk. reddish brown	7.34	0.479	15.32	12.62
2. 9	5YR 4/4	Reddish brown	2.5YR 3/6	Dark red	3.35	0.239	14.02	5.76
3. 21	2.5YR 4/6	Red	"	" "	1.33	0.116	11.47	2.29
4. 39	"	"	"	" "	0.99	0.079	12.53	1.70
5. 60	"	"	"	" "	0.54	0.051	10.59	0.93
6. 80	"	"	"	" "	0.52	0.051	10.20	0.89

Lower depth of horizon in inches	pH	Gross mechanical analysis % air-dry (Particle size in mm.) Stones >20	Coarse Gravel 20-6.25	Fine Gravel 6.25-2.00	Fine Earth <2.00	In Fine Earth per cent oven dry Silt .02-.002	Clay <.002	Moisture air-dry per cent
1. 2	4.0	Nil	Nil	Nil	100.0	6.18	71.75	6.16
2. 9	4.4	Nil	Nil	Nil	100.0	6.37	79.15	5.42
3. 21	4.6	Nil	Nil	Nil	100.0	5.90	84.61	5.04
4. 39	4.8	Nil	Nil	0.5	99.5	5.86	84.03	4.80
5. 60	5.0	2.7	0.1	0.1	96.2	5.59	85.59	4.62
6. 80	5.2	Nil	0.1	0.1	99.2	5.49	87.10	4.42

Table 8. Analytical data for a representative profile of an oxysol (Aya series) developed on drift deposits of the Aya surface (Crobbie, 1957b).

the terraces are covered with pebble layers of varying thicknesses. These layers consist of well rounded, closely packed quartz gravel in which some degree of sorting may be evident. A superficial cover of silty loam varying in depth from 1 to 8-10 feet may be present, and it is the presence of this layer which makes the terraces useful for agriculture. The highest terrace is always covered by 4-5 feet of coarse pebbles indicating the active power of the rivers in downcutting at this time. The lowest terrace is the deepest, the most extensive and the most important, particularly in the oxysol zone. In it, lenses of pebbles, stratification of layers, sorted and unconsolidated gravel, and deep layers of silt are all to be found. Generally, it is masked by silt and is suitable for cultivation. The other terraces have more frequent deep, alluvial silt deposits. This is because they have been formed on the slip-off slopes of wide meanders. Such terraces are seldom matched and usually occur in progression on alternate banks.

Parent material in soil formation.

It is the topsoil which exhibits the full effects of weathering, biotic agencies, and relief and drainage, while the influence of parent material is reduced to a minimum. This permits synthesis into classification units. As deeper horizons are included in the system of classification, the soils become more and more diverse until, in effect, they would become indefinable. The difference in the parent material is the basis therefore for the distinction of soils into individual series within the great soil group classification.

The inherent quality of the parent material may be sufficient in certain instances to distinguish great soil groups. In Ghana, the following may be recognised :

Basisols are soils developed over parent materials from which bases are released sufficiently rapidly to replace those lost be leaching ;

Lithosols are soils in which profile development is restricted by the resistant nature of the parent rock ;

Regosols are soils in which profile development is restricted by the inert nature of the parent material, usually loose sands ;

Alluviosols are soils in which profile development is restricted by the extreme youth of the parent material.

The lithological sequence of soils is of equal importance with topographical and hydrological sequences. The erodability of rocks is significant in the production of relief leading to this sequence. The development of soil from fresh rock represents the first stage in the manufacture of material for transport to lower slopes.

Soil properties in relation to parent material.

In the tropics, normal parent material consists of a mixture of clays, usually kaolinitic, and sands of various grades, with hydrous oxides. If one or the other of these constituents predominate, then the profile is affected and an abnormal profile results.

Moisture relationships of soils are determined by soil texture which is wholly controlled by the nature of the parent material. These relationships are of prime importance to agricultural land use. Water supply in the critical period of the dry season determines the ability of a soil to support vegetation. The correlation between the physical soil conditions and the distribution of species has been noted by Beard (1946) in Trinidad, Crosbie (1956a) in Ghana, and Smith (1949) in the Sudan. Drainage is perhaps even more important on a long term basis in that nutrients released in the topsoil will be subject to loss by downward percolation, the rate of loss varying, other things being equal, with the texture of the subsoil.

Phyllite and granite are the major parent materials of the forest zone soils. Soils derived from the former are silty in texture and generally contain high proportions of coarse material from the numerous veins which impregnate the rock. In consequence, the moisture retaining capacity is low and they are liable to drought, aggravated by the relatively impervious nature of the weathered rock. Drainage may also be excessive and bases are rapidly leached if the soil is exposed.

The apparent inferiority of the phyllite to the granite earths is principally due to differences in the coarse material and fine earth fractions. In the granite soils there is relatively little coarse material and a low content of silt (Table 9), while in the phyllite soils the fine earth fraction may be as low as 20 per cent in the subsoil (Table 10).

Lower depth of horizon in inches		Gross mechanical analysis % air-dry (Particle size in mm.)				Fine earth % oven dry (Particle size in mm.)					Corrected % of total	
		Stones	Coarse Gravel	Fine Gravel	Fine Earth	V. Coarse Sand	Coarse Sand	Fine Sand	Silt	Clay	Silt	Clay
		>20.0	20.0-6.25	6.25-2.0	<2.0	2.0-.65	.65-.2	.2-.02	.02-.002	<.002		
1.	4	Nil	1.0	1.6	97.4	21.69	19.80	21.35	8.51	20.59	8.08	19.54
2.	9	Nil	0.4	12.8	86.8	45.03	19.80	14.07	5.46	13.21	4.69	11.35
3.	18	1.1	0.8	16.9	81.2	29.79	14.64	12.30	5.39	36.39	4.30	29.05
4.	32	0.9	5.0	0.7	93.4	30.84	13.01	8.96	4.44	41.34	4.07	37.94
5.	55	Nil	1.6	5.6	92.8	24.86	11.34	8.61	6.24	47.87	5.68	43.59
6.	94	Nil	1.6	1.9	96.5	17.02	9.21	21.21	10.76	40.22	10.17	38.02

Table 9. Particle size distribution in Kumasi series developed over granite, profile no. B 590 (Crosbie, 1957a).

Lower depth of horizon in inches		Gross mechanical analysis % air-dry (Particle size in mm.) Stones >20.0	Coarse Gravel 20.0–6.25	Fine Gravel 6.25–2.0	Fine Earth <2.0		Fine earth % oven dry (Particle size in mm.) V. Coarse Sand 2.0–.65	Coarse Sand .65–.2	Fine Sand .2–.02	Silt .02–.002	Clay <.002		Corrected % of total Silt	Clay
1.	$2\frac{1}{2}$	Nil	Nil	Nil	100.0	:	1.66	5.08	20.33	22.56	40.09	:	21.76	38.66
2.	7	Nil	Nil	Nil	100.0	:	1.33	7.26	22.39	22.82	41.87	:	22.32	40.96
3.	15	23.9	33.9	16.6	25.6	:	20.56	4.44	15.82	17.35	39.54	:	4.35	9.92
4.	31	12.7	31.1	31.6	24.6	:	21.92	3.43	9.84	12.12	51.08	:	2.91	12.27
5.	41	Nil	1.0	9.8	89.2	:	7.39	2.24	11.45	19.89	57.11	:	17.34	49.80
6.	52	Nil	0.5	0.7	98.8	:	2.57	1.85	12.32	25.98	56.26	:	25.01	54.16
7.	72	Nil	0.4	0.3	99.3	:	0.97	1.63	15.44	39.66	41.39	:	38.64	40.33
8.	95	Nil	Nil	Nil	100.0	:	1.09	3.29	18.02	49.60	27.43	:	49.00	27.10

Table 10. Particle size in Bekwai series developed over phyllite, profile no. B 231 (Crosbie, 1957a).

The permanent productivity of an earth is governed by the mineralogical composition of the material which gives rise to it. The inherent nutrient status of soils depends primarily on the presence of minerals which on weathering release readily available plant food. Primary rocks such as granites and granodiorites, and base rich rocks such as greenstone, are satisfactory in producing nutrients, but secondary rocks such as phyllite and sandstone are low in minerals. Again, the availability of nutrients is related to the quantity of fine earth in the profile. Calculated on a lbs. per acre basis, the phyllite soils, under comparable environmental conditions, contain, on the average, only 50-60 per cent of the available nutrients present in the granitic earths. (Table 11).

Mantle earths on peneplain remnants are limited in value. In general, these consist of old, thoroughly weathered material in which there are no minerals which on decomposition could yield plant foods. Unless roots can penetrate below the mantle into the underlying weathering bedrock, then leaf-fall will not enrich the surface soil. However, even if the fertility of the mantle soil itself is maintained by deeply penetrating roots of the natural vegetation, under continuous cultivation this will soon be depleted.

<u>The changing importance of parent material.</u>

Up to the present, agricultural land utilisation of the forest soils has been based on the exploitation of the accumulated fertility under primary forest. Prior to cultivation, the surface layer was similar on upland soils throughout the ochrosol

Lower depth of horizon in inches		Exchangeable bases Ca	Mg	K	Mn	Total P	Lower depth of horizon in inches		Exchangeable bases Ca	Mg	K	Mn	Total P
1.	4	2994	492	534	47	337	1.	$2\frac{1}{2}$	2537	281	69	43	290
2.	9	992	159	185	21	195	2.	7	1036	220	49	26	439
3.	18	850	335	100	35	321	3.	15	266	16	25	4	177
4.	32	1237	577	36	38	575	4.	31	466	65	11	7	367
Total for 32 inches		6073	1563	855	141	1428	Total for 31 inches		4305	582	154	80	1273
Kumasi series (B 590)							Bekwai series (B 231)						

Table 11. Comparison of exchangeable bases and phosphorus in lbs. per acre between a granitic earth (Kumasi series) and a phyllite earth (Bekwai series). (Crosbie, 1957a).

zone irrespective of the wide range of underlying soils. Under clearing and cultivation however, the degree to which nutrients are lost varies according to the texture of the soil. Consequently, soil conditions, which under forest are uniform for all soils, become specific under continuous cultivation for each individual soil. In other words, under natural vegetation, the individual soil is unimportant, but in areas which have been cultivated, the soil series becomes a factor of major importance.

Chapter 7

TIME

Time is not a causal factor in soil formation. Soil is dynamic with soil forming processes in continuous operation and a constant interaction of each factor in a complex force. The difficulty of using time as a factor is apparent, but, in the tropics, some attempt is necessary in view of the fact that much of the zone has been subject to sub-aerial erosion since Gondwana times, and that pedogenic processes operate rapidly.

The rate of soil formation may be assessed in terms of the soil profile. Mature soils are in equilibrium with the environment. Sufficient time has elapsed for the development of a red earth with a profile 3 feet deep by prolonged decomposition of the parent rock, accompanied by leaching under a humid climate and a vegetation cover dense enough to ensure that losses by erosion at the surface are slower than the progress of soil formation at depth. These soils occur on gently undulating topography and cover the greater area of the forest zone. In the oxysol zone, the balance is maintained by a deeper profile, usually of the order of 5 feet, compensating for the steeper topography.

Young soils are those in which there has been insufficient time for profile development, principally due to the mode of occurrence of the parent material. They occur on alluvia and on rocks which are resistant to current forms of weathering. Alluvial soils consist of a shallow topsoil underlain by sand, silt or clay in undifferentiated deposits, located mainly in minor stream valleys. Seasonal flooding prohibits soil formation. Lithosols, due to the nature of the bedrock, occur on the steep slopes of hill ranges or inselbergs where erosion is equal to, or greater than, the process of rock weathering. They also occur on duricrusts capping remnants of former erosion surfaces.

Senile soils are found on the oldest peneplain remnants where erosion is negligible and soil forming factors have been operative for so long that little remains except unweatherable residue. Age has reduced these soils to oxysols composed almost entirely of kaolinitic clay with a very low exchange capacity and moisture retaining capacity. Their colour, however, is red in contrast to the yellow brown leached profile of the evergreen forest. This is probably due to the soil material having undergone irreversible dehydration during a previous climatic regime.

The practical significance of the soil profile lies in the replacement of soil after erosion. The mature, sedentary profiles have distinct pedological horizons in the topsoil and subsoil. If the former is lost, then the other cannot immediately take its place as its reactive mechanisms are still undeveloped. This problem is emphasised when the parent material is composed of drift. Such material is at least secondary in origin and possibly tertiary, and there are simply no unweathered minerals in it for decomposition and the liberation of nutrients for plant growth.

A variable time scale is provided by the intensity of each pedogenic process. In the climatophytic earths, climate is dominant and creates an environment which is conducive to rapid chemical and biological activity. Leaching can take place with each individual thunderstorm, while the marked rainfall regime is reflected in a cycle of chemical change. The accumulation of bases during the dry season in the ochrosols has been noted, but there may also be a seasonal reversal of process. Greenland (1956) suggested that denitrification occurs in tropical soils as well as nitrification, and fertiliser trials by Stephens (1956) substantiate this view.

Modifications of the climatic processes are imposed by local factors. Parent material alters the rate of soil formation markedly ; coarse textured, acid parent materials form soils more rapidly than fine textured, basic materials. This is responsible for differences in landscape mantles and soil distributions. In general, also, the older the landform, the poorer the soil because where the climatic elements have been effective over long, continued periods, weathering is deep and nearly complete.

The rapid rate of pedogenic development in the tropics led Milne (1947) to suggest that it might be possible to foster the synthetic process of soil formation in areas where fresh rock is available. In Ghana, however, the depth of weathered mantle masking fresh rock is generally great because of the duration in which the processes have been active. It is difficult to postulate earlier phases in the history of the soils, and the suggestion by Carter and Pendleton (1956) that podzolisation and laterisation are related

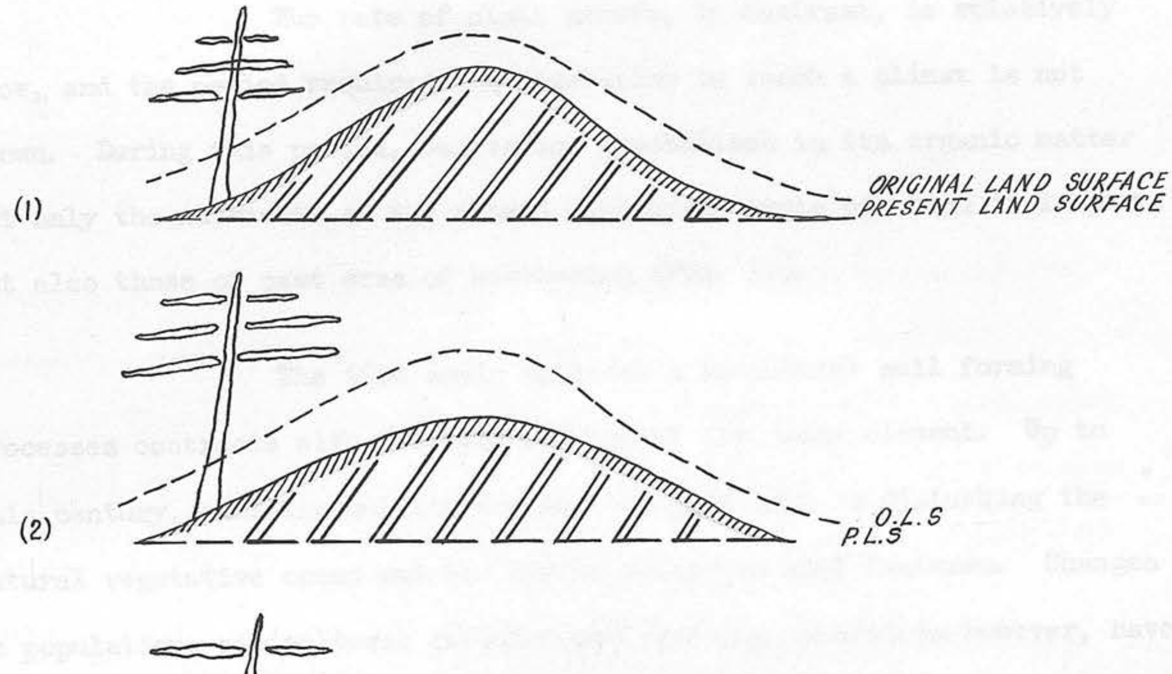

FIG. 12. DIAGRAM ILLUSTRATING THE EVOLUTION OF HUMOUS TOPSOIL OF A TROPICAL RED EARTH FROM ROCKS NOW NON-EXISTENT

climatic processes differentiated only by age may well be valid.

The rate of plant growth, in contrast, is relatively slow, and the period required for vegetation to reach a climax is not known. During this period, vegetation immobilised in its organic matter not only the nutrients of the closed ecological cycle of which it is part, but also those of past eras of weathering (Fig. 12).

The time scale applicable to natural soil forming processes contracts with the introduction of the human element. Up to this century, shifting cultivation was insignificant in disturbing the natural vegetative cover and had little effect on soil features. Changes in population, agricultural practice and economic conditions however, have replaced the dispersed mosaic of small clearings with large scale deforestation. The reservoir of nutrients gradually accumulated in the vegetation and the organic horizon of the soil has been exploited and depleted. Environmental conditions have been altered and the soil exposed to the climatic elements in greater intensity, with pronounced changes in moisture relationships. On the periphery of the forest zone, particularly in the older cocoa growing areas in the south-east and the Afram Basin, the semi-deciduous rainforest has been replaced by drier forms of vegetation as a result of widespread clearing and a consequent decrease in the moisture retaining capacity of the soil.

In conclusion, the role of time in soil formation under natural vegetation in the tropics may best be comprehended by regarding the landscape as a palimpsest on which the history of the soils is recorded. With agricultural land-use however, there is a halt or regression in soil formation with modifications in the characteristics and properties of the individual soils.

Chapter 8

CLASSIFICATION OF SOILS

Soils result from the action of living organisms upon the products of rock weathering ; both living organisms and rock weathering are dependent on temperature and moisture. In order to organise information about soils, and to demonstrate their relationship to each other, a system of classification is necessary. This provides the only method whereby existing knowledge of soils may be interpreted for any region.

A really satisfactory system of classification may not be possible due to the nature of the subject. Soils are neither complete nor precise ; they grade into each other both in space and depth. Changes in climate and vegetation are rapidly reflected in the soil, and geographic understanding of their distribution is required. Knowledge about some soils is as yet extremely scarce, and there is the undoubted fact that others are simply not worth classifying. Any system will, at best, be transient, and require modification and revision as further information and knowledge is accumulated.

There are three methods of classification, viz. morphological, genetical and applied. The morphological approach, based on profile characteristics determined either by field or laboratory examination, is used in Australia (Leeper, 1954). This method has several weaknesses, however. It ignores the basic fact that soils are the products of environmental factors and are therefore mappable ; it ignores the fact that soils are expanses ; it ignores facts which are not readily applicable, e.g. colour ; and it assumes that soils are static. Soils are dynamic and possess properties which can change : it is necessary to predict the range of expression of these properties.

Genetic systems of classification are based on the definition of critical horizons which are a key to development. These horizons tend to have a geogrpphic distribution and give rise to zonal soils. This approach is followed by the United States Soil Survey in their classification schemes.

Applied systems are based on the differentiation and interpretation of the soil material for a specific purpose. There are many systems of this nature, notably those of agriculture and engineering. Relatively little attention is paid to the natural soil, but the soil qualities are given concentrated attention. This is an ad hoc approach in that it requires constant revision with fresh knowledge and new practices and techniques.

In pedology, systems of classification are primarily concerned with soil genesis. The aim is to derive general principles of soil genesis and to assess the effect of each genetic factor. In the tropics, the diversity of soils presents problems of classification which are not encountered elsewhere. C. F. Charter, shortly before his death, had prepared an interim scheme of classification (Brammer, 1956) which has been used in this study. Soil classification is an extremely complex philosophy which requires disciplined thought, sound knowledge of the basic principles, wide experience and mature vision. Charter had these qualities and, as far as his scheme is outlined, it is soundly based on genetic principles.

These principles are based on the soil and not on the soil parent material. By the soil, Charter meant the organic and organo-mineral surface complex which developed as a result of growth of vegetation at the surface of the parent material. He emphasised the relationship of the vegetation and the structure of the soil layers, an association which had not previously received due consideration. His principal sub-divisions are based on the dominance of climate and vegetation, relief and climate, relief and drainage, and rock and time. The advantage of his classification is that it concurs with vegetation and land use associations. The weaknesses are that climates merge, and that soils with closely similar morphology may occur in more than one climatic zone. These features complicate the common problem of all natural sciences, namely the recognition and definition of the intergrades between categories.

<u>The classification scheme of C. F. Charter.</u>

The classification scheme of Charter is applicable becuase it treats mainly of West African conditions. It was incomplete at the time of his death, and the following outline was compiled by Brammer (1956).

The classification is based on Neustrev's formula Soil = f climate, vegetation, relief and drainage, parent material and age. At the highest level of classification, soils are grouped as soil orders according to the predominating action of the factors already mentioned. Table 12, (Brammer, 1962), summarises the scheme as it applies to Ghana.

1. Climatophytic earths have characteristics predominantly determined by climate and vegetation. This order is equivalent to that formerly termed zonal. Suborders are distinguished simply according to whether the profile is leached through or not, viz.

   Hygropeds in which precipitation connects with a ground water table ; this is the major unit in West Africa.

   Xeropeds in which precipitation does not connect with a ground water table. These soils do not occur in the forest zone.

2. Topoclimatic earths have characteristics predominantly determined by relief and climate. This order is intended to include the soils of tropical mountain regions, and, as these do not occur in Ghana, the order will not be further discussed.

3. Topohydric earths have characteristics predominantly determined by relief and drainage. Suborders are differentiated mainly according to the relief form with which the soils are associated :

   Planopeds are developed on peneplain topography or on marine or river terraces. Such soils may occupy entire landforms and are of widespread occurrence in the older tropical land masses. Charter regarded these soils as poorly drained, but the soils on

Table 12. PROVISIONAL CLASSIFICATION OF SOILS SO FAR DISCOVERED IN GHANA[1]

Order	*Suborder*	*(Soil Group Family)*	*Great Soil Group*	*Great Soil Subgroup*
CLIMATOPHYTIC EARTHS	HYGROPEDS	Latosol	Forest Ochrosol	Red Forest Ochrosol
				Yellow Forest Ochrosol
			Savanna Ochrosol	Red Savanna Ochrosol
				Yellow Savanna Ochrosol
			Forest Oxysol	Red Forest Oxysol
				Yellow Forest Oxysol
		?Basisol	Forest Rubrisol	Red Forest Rubrisol
				Yellow Forest Rubrisol
			Savanna Rubrisol	Red Savanna Rubrisol
				Yellow Savanna Rubrisol
			Forest Brunosol	
			Savanna Brunosol	
	XEROPEDS		(Reddish Prairie ?)	
TOPOHYDRIC EARTHS	PLANOPEDS	Very Acid Planosol ?	Groundwater Podsol	
		Acid Planosol ?	Groundwater Laterite	
		Calcium Planosol	Tropical Black Earth	
			Tropical Brown Earth	
		Sodium Planosol ?	(Tropical Grey Earth)	
	DEPRESSIOPEDS	Very Acid Gleisol	(Savanna Grey Very Acid Gleisol)	
		Acid Gleisol	(Savanna Black Acid Gleisol)	
			(Savanna Brown Acid Gleisol)	
			(Forest Grey Acid Gleisol)	
			(Savanna Grey Acid Gleisol)	
		Neutral Gleisol	(Forest Black Neutral Gleisol)	
			(Savanna Brown Neutral Gleisol)	
			(Forest Grey Neutral Gleisol)	
			(Savanna Grey Neutral Gleisol)	
		Calcium Vleisol	(Black Vleisol)	
			(Brown Vleisol)	
			(Grey Vleisol)	
		Sodium Vleisol	Solonetz ?	
			Solonchak	
	CUMULOPEDS	Cumulosol	Very Acid Bog ?	
			Acid Bog ?	
			Saline Bog ?	
	HYDROPEDS	Hydrosol	Neutral Hydrosol ?	
			Saline Hydrosol	
LITHOCHRONIC EARTHS	LITHOPEDS	Basimorphic Lithosol	(Black Basimorphic Lithosol)	
			(Brown Basimorphic Lithosol)	(Yellow Basimorphic Lithosol)
			(Red Basimorphic Lithosol)	
		(Non-Basimorphic Lithosol)	(Non-Basimorphic Lithosol)	
	REGOPEDS	Regosol	(Dune-sand Regosol—with calcareous pan)	
			(Dune-sand Regosol—without calcareous pan)	
			(Other Regosols)	
	ALLUVIOPEDS	Alluviosol	(Black Alluviosol)	
			(Brown Alluviosol)	
			(Grey Alluviosol)	

N.B. (i) The use of brackets round a term indicates that the nomenclature is still provisional.
(ii) ? before a term indicates that there is some doubt as to the exact place of the soil group or group family in the classification.
(iii) ? after a term indicates that there is some doubt as to the classification of the soils examined within the group indicated or of the soil group in the group family indicated.

[1] This classification table, together with the account of the major soils of Ghana which follows and the soil map included at the end of the book, are based on information available at the end of 1956.

these topographic sites in the forest zone possess characteristics with closer affinities to the climatophytic earths.

<u>Clinopeds</u> are developed on slopes where seepage occurs and various substances are precipitated from solution. Such soils are of restricted importance.

<u>Depressiopeds</u> are developed in poorly drained depressions. Such soils are frequently of economic importance, but seldom of any extent.

<u>Hydropeds</u> are developed under water in lagoons or permanent rice paddies. Such soils are of limited extent under natural conditions, but may develop from depressiopeds under cultivation or disturbance.

<u>Cumulopeds</u> are developed in depressions where peat has accumulated. Such soils are only locally important in the tropics.

4. <u>Lithochronic earths</u> have characteristics predominantly determined by parent material and/or age. This order incorporates the former azonal order, as well as certain former intrazonal soils. Suborders are differentiated according to the particular factor retarding profile development, viz.

<u>Lithopeds</u> are soils in which profile development is restricted by the resistant nature of the parent rock or the rapid erosion of products of rock weathering on steep slopes.

<u>Regopeds</u> are soils in which profile development is restricted by the inert nature of the parent material, namely loose sands.

<u>Alluviopeds</u> are soils in which profile development is restricted by the extreme youth of the parent materials, namely volcanic ash or river alluvium.

Great soil groups of the forest zone.

Suborders are divided into great soil groups. These comprise soils with common profile characteristics developed in response to similar environmental conditions. Within some suborders there are large numbers of great soil groups. For convenience, Brammer arranged the latter into great soil group families according to distinguishing criteria, usually colour or the reaction of the profile. Such criteria are manifestations of more fundamental differences in soil properties between various groups.

Under humid tropical conditions, the hygroped suborder of the climatophytic earths is subdivided according to the ability of the parent material to supply mineral bases at a sufficient rate to counteract those lost by leaching. Latosols are developed over highly weathered parent materials in which the clay fraction consists mainly of kaolinite and iron and aluminium sesquioxides ; basisols are developed over incompletely weathered parent materials in which the clay fraction contains montmorillonite together with the kaolonite and sesquioxides.

The suborders of the topohydric earths are categorised according to the nature and reaction of the groundwater influencing the soils. Only the depressiopeds are present in any importance in the forest zone, and the great soil group family is termed Gleisols, subdivided into very acid, acid and neutral groups with further distinctions according to colour.

The major great soil groups of the forest zone belong to the climatophytic earths. Latosols cover the greatest expanse and are subdivided into ochrosols and oxysols by the processes described in chapters 3 and 4. Basisols are subdivided into rubrisols and brunosols according to the colour of the solum. Such soils are, unfortunately, of minor extent. Other great soil groups belonging to the topohydric order, i.e. the various gleisols, and to the lithochronic order, i.e. the lithosols, regosols and alluviosols, also occur but in lesser degree.

In summary, the following great soil groups are present in the forest zone :-

Forest Ochrosols
Forest Oxysols
Forest Rubrisols
Forest Brunosols
Lithosols
Regosols
Alluvisols
Gleisols

Soil series, which are the individual soils comprising the great soil groups, are differentiated mainly on the nature of the parent material and relief. They are subject, under natural conditions, to similar drainage, possess similar profiles and support similar vegetation. Each series exhibits a range of variation of values of the constituents of each horizon, but the number and succession of horizons will be the same throughout the series. A soil series is not a section of the soil at specific points, but is an expanse. The series form a particular part of a landscape and as such, will have similar relief and external drainage throughout.

In the description of the soils in this section of the thesis, representative soil series of the major great soil groups are taken to illustrate the basic characteristics. More than 600 soil series had been established in Ghana by 1957 (S.L.U.S. 1958), and only the more important of those in the forest zone are included here.

Characteristics of tropical forest soils.

The upland soils of the low level dissected peneplain are red, brown and yellow-brown, relatively well drained soils. They are developed in parent materials derived from the weathering of intermediate or moderately acidic rocks, from peneplain drifts of the younger (Akumadan) erosion surface, and from terrace alluvia.

The typical profile of the climatophytic earth in the forest zone consists of an A and a C horizon, i.e. a horizon of accumulation of organic materials overlying parent materials. In a sedentary soil derived from the weathered rock and occurring on sloping topography, the subsoil is well defined although, in fact, it is really a zone of rearrangement, largely as a result of biotic activity, intermediate between the topsoil and the weathered sub-stratum. In a drift soil developed in transported material, there may be no weathered substratum in the profile.

The characteristics of the profile layers are distinctive. The topsoil is a zone of mechanical eluviation, mainly lateral, as well as a zone of organic matter accumulation. The subsoil is a zone free from mechanical eluviation, but subject to chemical eluviation in which ferruginous and manganese concretions could form. There is also a marked accumulation of mineral materials, such as quartzy gravel, ferruginous concretions, etc., and possibly clay. The underlying weathered substratum is a zone free from mechanical eluvia eluviation but subject to chemical eluviation in some degree. There may be some accumulation of carbonates or sulphates, but, primarily, this is a zone of sterile weathering. Below 6-8 feet, the parent material has no effect on soil fertility.

Differences between the great soil groups of the ochrosols and oxysols were outlined in chapter 3, exemplifying the effect of climate on soil formation. The major differences are in the environment and in the soil properties and characteristics. The amount and distribution of the rainfall is reflected in the different growth forms of the vegetation and the composition of the surface and soil fauna. The morphology of the topsoils differ, possibly because these may be faunal contributed structures, and the ochrosols have a slightly deeper upper layer and a thicker horizon in total. The reaction is markedly different in the topsoil with the ochrosols being slightly acid to neutral and the oxysols being highly acid. The residual mass of weathered material in the profile is similar in both great soil groups. Organic matter is higher in the ochrosols, stable, and concentrated in the topsoil. In the oxysols, the organic matter is more diffuse through the profile, although the topsoil is still the zone of maximum accumulation. Base exchange capacity is largely a function of the organic matter and base saturation is related to the reaction. With pH values below 5.5, base saturation decreases rapidly (de Endredy and Montgomery, 1956). Carbon and nitrogen are similar in both great soil groups, but calcium decreases very rapidly with increasing acidity. Magnesium also decreases with acidity, but in a lesser degree than calcium. The Ca/Mg ratio alters therefore from 3.78 in the upper topsoil of the average ochrosol to 2.22 in the same layer of the average oxysol (Ahn, 1961). In both groups, the ratio falls rapidly below the topsoil with absolute amounts of the bases becoming very small and ratios being barely above unity. Exchangeable potash also decreases with acidity, but at a lesser rate than calcium or magnesium. Accordingly, the proportion of potash in the total exchangeable bases increases in the more acid soils, even though the absolute amount has decreased.

The amount of readily available phosphorus appears to decrease with high acidity, but no definite data may be quoted. Laboratory techniques for the measurement of available phosphorus are difficult and not of great accuracy, and certainly much of the phosphorus is locked in compounds of iron, aluminium and calcium. It has already been noted that the most important source of phosphorus is organic phosphorus (de Endredy and Quagraine, 1956).

The most obvious differences between the two groups are the colour and the depth of weathering. Colour is related to drainage and degree of hydration. The yellow hues of the oxysols are due to greater hydration under the higher annual rainfall, and the same factor is responsible for the much greater depth of weathering of the bedrock.

Under the present conditions of soil formation, soil development in the tropics is towards the formation of clay. While the forest vegetation is maintained, however, the rate of formation is slow.

Chapter 9

OCHROSOLS

The ochrosols are a great soil group of the climatophytic order developed over a variety of parent materials under semi-deciduous rain forest vegetation on the well drained uplands of the dissected peneplain. The annual rainfall is 45-65 inches but seasonally distributed with a well defined dry season. During the dry season, many of the trees shed their leaves and there is an accumulation of bases in the humous layer. Throughout the year, the reaction of the surface horizons remains slightly acid to neutral and the soils are consequently well supplied with nutrients.

These soils are the most extensive and the most important in the forest zone. For this reason they are given priority in description, although froma pedogenetic view, they represent a modification of the oxysols formed under a wetter climate. Their characteristics and properties have been well described in Ghana by Charter (1955b), Crosbie (1957a) and Brammer (1962). For practical purposes, however, it is the morpho-geomorphological features which are most important, and these form the basis of this account.

The topographic sequence from summits to lower slopes with consequent changes in drainage is reflected in the colour of the soil. Generally, the soils are red or reddish brown on the summits and upper slopes, become orange brown to brown on the middle slopes, and grade into yellow brown on the lower slopes. These colour changes to yellowish hues are caused by the increasing hydration of the iron in the profile as the drainage consitions deteriorate downslope. Textural differences, due to the nature of the parent material or to the topographical site, influence the colour of the soil also.

A typical profile has a porous, loamy topsoil, 7-9 inches thick, which is dark grey-brown in the upper 2-3 inches, and becomes paler coloured in the lower layer. Under natural vegetation, the litter layer has a blanketing effect and practically all the ochrosols have a concentration of organic matter in the surface layer with a decrease in the lower part of the topsoil. The reaction varies from moderately acid to mildly alkaline in the upper topsoil, and the lower horizons become increasingly acid. Soils on the middle to lower slopes are usually moderately acid in reaction in the surface layer, and become very acid with depth. Below the humous layer there is a sharp decrease in plant nutrient status although the lower horizons generally have a higher clay content than the topsoil. The parent material is underlain by a thick, mottled red or white loam of thoroughly decomposed rock in which the structure of the rock may be recognised and which is firm in situ but friable in the hand.

Ochrosols associated with Lower Birrimian topography.

In the north of the forest zone remnants of the Akumadan erosion surface over Lower Birrimian metamorphosed sediments are characterised by drift soils on the flat topped summits with sheet ironpan occurring locally but more typically as a peripheral ring. The soil distribution pattern is complex with redistribution of the drift deposits on the dissected slopes and sedentary soils incorporating varying proportions of material derived from the disintegration of the ironpan collar (Fig. 9).

Further south, where dissection has been more advanced, sedentary soils predominate and all that remains of the former peneplain mantle are accumulations of ironstone concretions, sometimes with relict ironpan boulders, in the summit soils. The major soil is Bekwai series which, with its less well drained associate Nzima series, is developed in parent material derived from phyllite. In the catenary sequence, Nzima series occupies 40-45 per cent of the association and is actually the more extensive of the two sedentary soils. Areally, Nzima series is the most important soil in the forest zone.

The drift soils over phyllite have a dark brown loamy topsoil (10YR 4/3 dry, 10YR 3/3 wet) overlying a reddish yellow (5YR 6/8 dry, 2.5YR 4/8 wet) uniform light clay below 6-8 inches. The depth of the drift varies from 2-3 feet to 6-8 feet according to the subsurface topography of the ferruginous crust, with a well marked stone-line of subangular quartz stones at the base. The reaction in the topsoil is slightly acid to neutral, pH 6.6 - 7.0, falling in the lower layers to very acid values, pH 5.0 - 5.4. Clay content in the topsoil is of the order of 50-60 per cent, increasing below 6-8 inches to 70-80 per cent (Crosbie, 1956b).

The ferruginous crust becomes increasingly indurated towards its outer edge and, generally, the degree of induration is inversely related to the depth of the overburden. In all cases observed, it appears to have formed in the uppermost layer of the weathered rock and included quartz veins are frequent. Occasionally, where the crust is exposed, the stone-line of subangular quartz stones has been cemented into the surface. Erosion is restricted on the summit because of the protective crust, but, on the flanks of the residuals, parallel retreat of the slopes has allowed soils to develop in place from the underlying rock.

Bekwai series : profile description

Bekwai series is a red, well drained, clay loam with a three horizon profile developed over phyllite on the summits and upper slopes of the dissected peneplain. It is one of the major soils of the forest zone and is widespread in occurrence in the west and north.

The natural vegetation has usually been destroyed over these soils and the thin leaf litter layer may be absent. Below this layer lies 2-3 inches of dark brown (7.5YR 4/3) loose and crumbly humous clay loam containing abundant fine roots. It grades fairly sharply into 5-6 inches of brown (7.5YR 5/4) friable light clay, humous stained but with much fewer rootlets. Very small amounts of quartz gravel and small, round, polished ironstone concretions which have been brought up by the plant roots are incorporated in the fine earth.

The transition from the topsoil to the subsoil is irregular and diffuse at times with occasional humous root channels passing down through the subsoil. The reddish brown to yellowish red (5YR 5/5) light clay subsoil is, on the whole, exceptionally low in organic matter. Structureless and firm, there is an accumulation of quartz gravel and angular quartz stones in the upper 12 inches, but this decreases with depth. Occasional to frequent small ironstone concretions are also concentrated in the upper layer and decrease down through the subsoil. Drainage is impeded in the lower layers and orange and red mottles occur in the indurated soil.

Thoroughly weathered rock, ranging in colour from red to blue, underlies the subsoil at depths of 45-50 inches with mottles of red, yellow and orange. Firm and generally structureless, the rock has a silty clay texture and is greasy to the tough. Close examination may reveal very fine foliation and local impregnation by quartz veins is very common.

The fine earth in the topsoil is of the order of 95 per cent. In the concretionary horizon, the average content falls to 65-70 per cent, and frequently, in individual profiles, it may be less than 30 per cent (Table 10). In the weathered rock, the fine earth fraction increases to 90-100 per cent. Coarse material is predominantly angular quartz stones and approximately equal proportions of fine and coarse gravel, the latter consisting essentially of ironstone concretions.

The proportion of clay, kaolin being the dominant mineral, increases gradually with depth until the weathered rock is reached, although there may be a deficiency in the upper layer of the subsoil. Conversely, the silt fraction decreases from 20 per cent in the topsoil to 10-15 per cent in the concretionary horizon, but increases rapidly in the weathered rock to 50 per cent.

Where the phullite is intercalated with tuff, graphite or schist, subseries of the soil are differentiated with topsoil textures ranging from sandy clay loam to light clay. Local quartz stringers may give rise to a stony subseries.

Nzima series : profile description

A comparison of some of the features between Bekwai and Nzima series is given in Table 13. Nzima series has a more acid reaction profile than Bekwai series with a consequent slight decrease in nutrient status (Crosbie and de Endredy, 1956). Colour differences reflect the drainage conditions, and the texture of the subsoil is slightly heavier.

Beneath the leaf litter layer, there is 2-3 inches of dark grey brown (10YR 4/2) humous loam which is crumbly and loose. This grades into a yellow brown to brown (10YR 5/4) slightly humous light clay, 5-6 inches thick. Rare quartz gravel and rare subangular quartz stones with rare to occasional ironstone concretions may be present. There is a slightly cloddy structure and the layer is slightly compact.

Horizon	Depth		Thickness		Reaction		Colour		Texture	
	Bekwai	Nzima	Bekwai	Nzima	Bekwai	Nzima	Bekwai	Nzima	Bekwai	Nzima
Topsoil 1	2.375	2.359	2.375	2.359	6.285	5.831	7.5YR 4/3	10YR 4/2	Heavy loam	Loam
Topsoil 2	7.312	7.234	4.937	4.875	5.825	5.469	7.5YR 5/4	10YR 5/4	Lt. clay	Lt. clay
Subsoil 1	17.937	16.890	10.625	9.656	5.496	5.387	5YR 5/5	7.5 YR 5/5	" "	" "
Subsoil 2	33.124	30.827	18.187	13.937	5.306	5.306	5YR 5/6	7.5YR 5/5	Heavy loam	" "
Subsoil 3	49.209	47.202	16.085	16.375	5.200	5.213	5YR 5/6	5YR 5/5	" "	Heavy loam
Weathered substratum	68.257	66.105	19.048	18.903	5.109	5.000	5YR 5/5	5YR 6/5	Loam	Loam

Table 13. Differences in profile morphology between Bekwai and Nzima series (Crosbie and de Endredy, 1956).

The subsoil is sharply differentiated by an accumulation of coarse material in the upper layers. A brown (7.5YR 5/5) light clay matrix contains occasional quartz stones and gravel, with frequent ironstone concretions which decrease in quantity with depth. Although there is some aggregation round quartz stones, the layer is structureless and firm. At 30-36 inches, it grades into a reddish brown to yellowish red (5YR 5/5) clay loam with only rare quartz gravel and occasional ironstone concretions which is structureless and slightly firm.

The weathered substratum is usually at about 4 feet. The upper 2 feet is typically light reddish brown to reddish yellow (5YR 6/5) with conspicuous orange, yellow and brown mottles. With a loam texture, this horizon is structureless and firm but slightly plastic to the touch and stains the fingers. Rare ironstone concretions, washed down into it, may be seen. Below this is the zone of decomposing rock which breaks into small, bedded plates of various colours which are greasy to the touch.

Gross mechanical analysis reveals a similar distribution of coarse material and fine earth to that of Bekwai series. A slight variation in acidity of the topsoil was noted between the series in the Kumasi Region and the series in the Upper Tano Basin. The soil in the former was slightly more acid, partly because of higher rainfall and partly as a response to cultivation. In the latter region, most of the samples were under forest and the remainder under fairly young cocoa. On the other hand in the Kumasi Region, only 20 per cent of the samples were from forest and 60 per cent from cocoa, most of which was twenty years or more of age.

Combinations of drift, ironpan, disintegrated ironpan and parent material derived from the underlying rock occur in varying proportions on specific sites in the topography. It should be noted that the presence of polished ironstone concretions in the two sedentary profiles indicates local transportation of coarse material derived from the break up of the ironpan, and does not indicate chemical processes within the soil.

Ochrosols associated with acid igneous intrusions.

Remnants of the Akumadan surface over the acid igneous intrusions have a much simpler soil pattern than those over the phyllite. Dissection is less pronounced, ironpan is absent, and the drift deposits are much deeper and extend over most of the flat topped interfluves. The distribution in relation to the topography is shown in Fig. 13.

Towards the south, sedentary soils developed from biotite granite occur in regular, simple sequence with colluvial deposits forming the parent materials of soils on the lower slopes. In the extreme south of the zone, where dissection has reached a mature stage, these colluvial deposits have increased to the stage where they extend over the whole topographic sequence. These deposits, and the soils on them, are described in chapter 13.

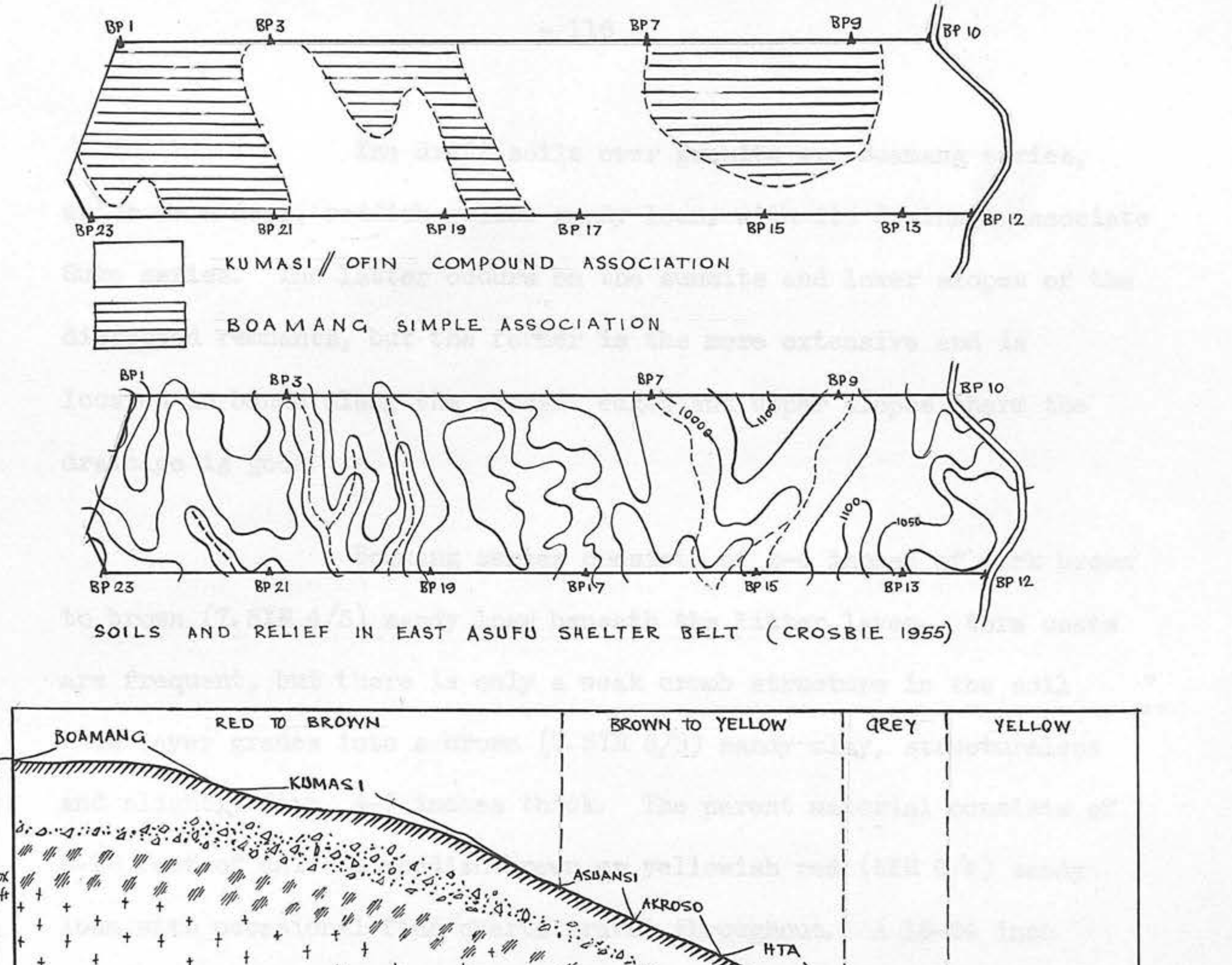

FIG 13 TOPOGRAPHIC SEQUENCE OF SOILS OVER PENEPLAIN RESIDUALS OF AKUMADAN SURFACE OVER GRANITE IN OCHROSOL ZONE.

The drift soils over granite are Boamang series, which is a deep, reddish yellow sandy loam, with its drainage associate Suko series. The latter occurs on the summits and lower slopes of the dissected remnants, but the former is the more extensive and is located in bands along the remnant edges and upper slopes where the drainage ig good.

Boamang series consists of 2-4 inches of dark brown to brown (7.5YR 4/3) sandy loam beneath the litter layer. Worm casts are frequent, but there is only a weak crumb structure in the soil This layer grades into a brown (7.5YR 5/3) sandy clay, structureless and slightly firm, 4-5 inches thick. The parent material consists of 8-20 feet of uniform reddish brown or yellowish red (5YR 6/4) sandy loam with occasional fine quartz gravel throughout. A 18-24 inch mottled, indurated zone may occur at the base of the drift. The fine earth fraction is 100 per cent throughout the profile, with sand the dominant constituent. This soil is prone to erosion when exposed, and in these circumstances, a thin crust is formed over the surface of the soil.

The sedentary soils developed in the medium grained biotite granite form one of the most extensive soil associations in the forest zone. The major soil in the association is Kumasi series which is a red, well drained, light textured soil on the summits and upper to middle slopes of gentle undulations with an average slope of 5 per cent. The drainage associate on the middle slopes is Asuansi series but this is relatively inextensive with the development of colluvial soils from the middle slopes to the valley bottoms.

<u>Kumasi series : profile description</u>

Beneath the normal forest litter layer, there is nearly always an accumulation of worm casts on the surface overlying 2-3 inches of dark grey brown to dark brown (10YR - 7.5YR 4/2) humous loam which is crumbly and loose. Below this is 5-6 inches of brown (7.5YR 5/4) slightly humous, gritty heavy loam with occasional to frequent fine quartz gravel, which is porous and slightly crumbly. The gritty nature of this layer is a distinguishing characteristic for the series.

The transition into the subsoil is normally abrupt, but occasionally there may be a 4-6 inch brown (7.5YR 5/4) sandy layer. The upper layer of the subsoil is reddish brown to yellowish red (5YR 5/5) gritty light clay with frequent to abundant fine quartz gravel and rare subangular quartz stones. Firm and structureless, this layer merges at 18 inches into a reddish brown to red (2.5YR 4/5) heavy loam with frequent fine quartz gravel and occasional subangular quartz stones which remains firm and structureless. At 36 inches, there is a 2 foot layer of reddish brown to yellowish red (5YR 5/5) loam with yellow mottles. Fine quartz gravel is occasional to frequent and small mica flakes are also present.

The subsoil grades into the weathered substratum at 55-60 inches. The upper 24 inches of the latter is yellowish red

(5YR 5/6) with yellow mottles, loam in texture, and with only rare to occasional fine quartz gravel. The structure of the weathered rock may be distinguished in situ and though it is slightly firm in excavations, it is friable in the hand. The depth of the weathered granite was illustrated in Fig. 1. Within the orange brown mass, the feldspar patches are white.

The fine earth fraction is high throughout the profile (Table 9). It is least, 80-85 per cent, in the lower topsoil and upper layer of the subsoil, but otherwise is greater than 90 per cent. Sand is the dominant constituent, although the clay content is high, 40-50 per cent in the subsoil. In the weathered rock, the clay decreases slightly ; silt is low in the solum, less than 10 per cent, but increases to 15-20 per cent in the weathered rock.

Asuansi series is similar in profile to Kumasi series with the exception of the distribution of coarse material. In the subsoil, the fine earth decreases to 60-65 per cent at approximately 30 inches where the maximum quantity of quartz stones occur. This is in contrast to Kumasi or Bekwai series where the greatest accumulation of coarse material occurs in the upper 18 inches of the profile. In Asuansi series, the heavier coarse material descends down the profile with successively lower topographic situation.

Ochrosols associated with terrace deposits.

Terrace deposits are a characteristic feature along the major rivers of the forest zone. Although they are usually mapped as a zone along the rivers, they are located on alternate banks in close correlation with the meanders of the river (chapter 5). The exception to this distribution is in the Birim Basin. The parent material of the soils consist of water sorted deposits laid down during intervals in the uplift of the Akumadan surface. The higher terraces are composed of deep, gravel layers with abundant quartz pebbles, while the lower terraces consist of sandy clay of varying thickness. Many of the gravel beds are most irregular with lenses of pebbles and a general undulating sub-surface topography. Variations in association with micro-relief and derived parent material are common. The topography is level or very gently sloping on the terraces, with a marked break of slope between each level. Small streams in narrow, steep sided valleys breach and dissect the terraces (Fig. 14).

The terrace soils are differentiated on the presence or absence of pebble beds. Variations are therefore considerable as fluctuations in the river levels during rejuvenation are indicated by laminations of fine earth and pebbles and irregular discontinuities which are especially frequent on the lower terraces. There are two major soils on the terraces, viz. Awaham series which consists of a topsoil overlying a bed of pebbles, and Birim series, which consists of a topsoil overlying a variable depth of silty clay. These soils are described only briefly because local variation is the rule rather than the exception.

Awaham series may be found on any of the terrace levels, and is the most extensive soil on this feature. It has a 2-3 inch layer of light brownish grey (10YR 6/2) coarse sandy loam under

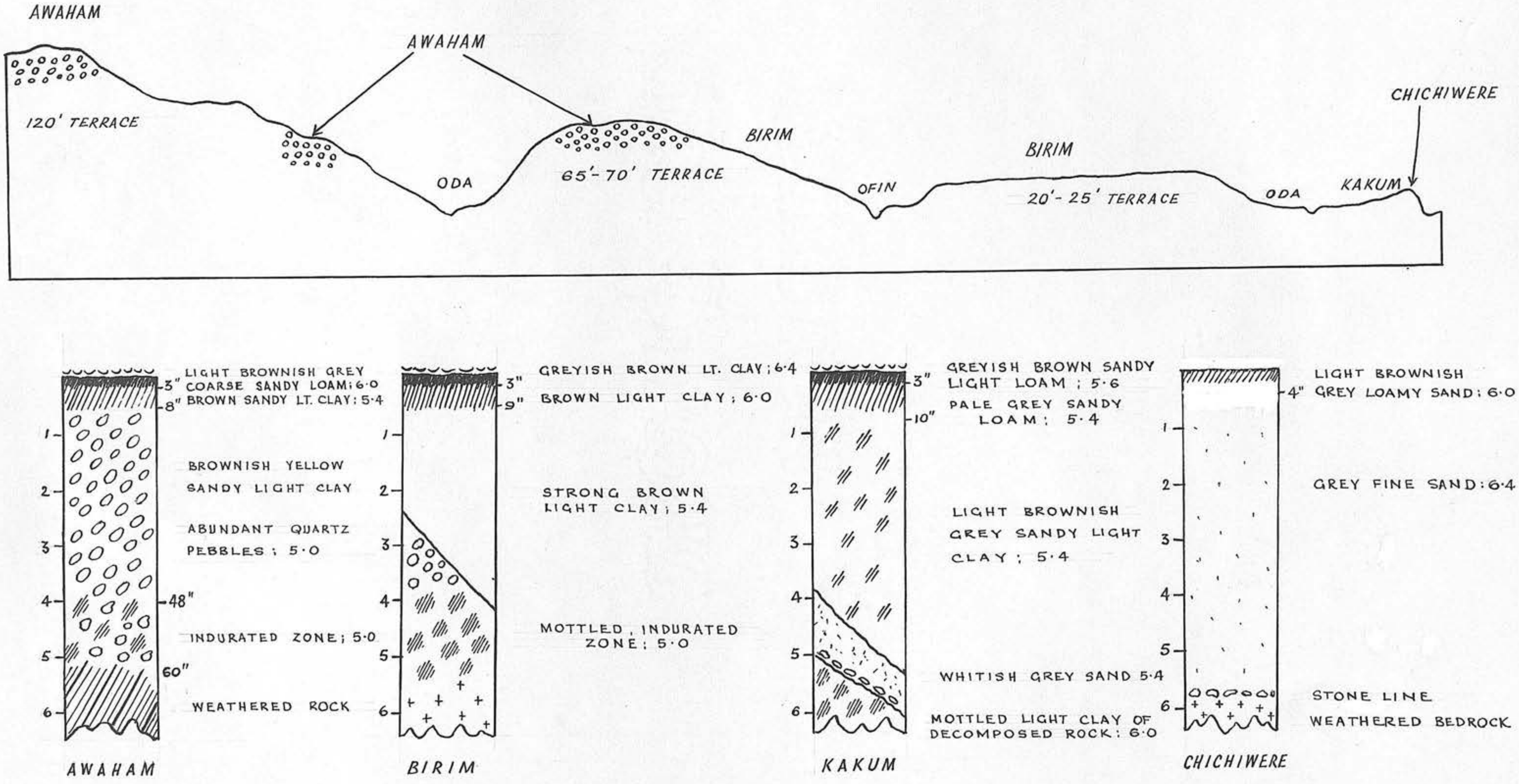

FIG 14. IDEALISED SECTION ILLUSTRATING TERRACE AND LEVEL SOILS.

the litter layer. Under natural vegetation, this layer is well defined but where the soil has been cultivated, the soil texture is heavier, usually sandy light clay, and pebbles may have been brought to the surface. Frequently, the surface of the soil may be covered with pebbles from native gold pits which may be a local feature. The upper topsoil is crumbly and loose, and these features persist into the lower topsoil, 4-6 inches thick, which is brown (10YR 6/3) sandy light clay.

The transition into the pebble layer is abrupt. Abrownish yellow (10YR 6/6) sandy light clay matrix encloses a high percentage of round, quartz pebbles. Soil features are masked by the abundant coarse material, but the horizon is firm. The thickness of this horizon may be of the order of 4-20 feet, and occasionally, some degree of sorting of the pebbles may be observed. On the 100-120 foot terrace, the soil is, on the average, 4 feet thick and frequently is underlain by ironpan with included quartz pebbles. On the lower terraces, the pebble beds may be of great thickness and thin bands of ironpan, about 1 inch thick, may occur where there is relative impedance in the layer. At the base of the soil on the middle terraces, there is a zone of mottling. On the lowest 20 foot terrace, the pebble beds rest directly on weathered rock.

Organic matter is concentrated in the surface 2 inches of the soil, and would easily be lost by cultivation. The parent material, predominantly quartz pebbles, can only be regarded as sterile. Gradations to Birim series are frequent and differentiations may be made on the depth of the silty clay over the pebble beds.

Birim series has the characteristic topsoil of the ochrosols. 2-3 inches of greyish brown (10YR 5/2) light clay with frequent fibrous roots is underlain by some 7 inches of brown (7.5YR 5/4) light clay. Beneath the topsoil, there is a variable depth of strong brown (7.5YR 5/6) light clay, slightly cloddy and compact with a mottled, indurated layer at the base.

Value of the ochrosols.

In assessing the value of the ochrosols for agricultural production, certain factors and qualifications must be borne in mind. The fact that the soils are upland soils on a dissected peneplain means that they do not form a continuous expanse but occur in limited areas on ridges and interfluves. The complex distribution pattern due to geomorphological and geological factors is conspicuous in that the average peasant farm of 2-3 acres is usually situated on two or more soils. Under natural vegetation, the ochrosols are reasonably fertile because of the formation of the humous topsoil in pedogenesis. This horizon is principally affected by heavy cultivat ion, and the status of the soil is basically altered. Lastly, in Ghana, the economic organisation of agriculture has become exploitive in that manuring is not practiced and husbandry is kept to a minimum so that long term production depends entirely on the properties of the individual soils. Cocoa is the only crop which can be used as a standard for assessment.

The criteria of inherent fertility, moisture relationships and depth of profile were defined by Charter (1948) in classifying the soils of the forest zone for cocoa production, and these were later reviewed in the light of more extensive evidence (Crosbie, 1957a). In this revision, some indication of the area covered by each category in the classification was given.

Soils suitable for continuous cultivation due to the high inherent fertility of the parent material do not occur in the ochrosols. Such conditions, by their nature, would affect soil formation and give rise to basisols. The best soils are therefore those in which the percentage of coarse material is relatively small, which give rise to clay earths, and which are able to conserve moisture throughout the dry season. The great proportion of these soils are developed over medium or fine grained biotite granites or schists, and occupy less than 8 per cent of the forest zone, mainly in the east and central areas.

The most extensive and widely distributed category comprises soils which have low nutrient reserves, or are subject to drought during the dry season, or are situated on poor topographic sites. These soils would give good yields for 20-25 years before markedly declining. They are developed over phyllites, some colluvia with imperfect drainage, and over all parent materials in the marginal climatic conditions towards the north of the forest zone. Approximately half of the zone has soils of this category, and local environmental conditions are responsible for the divergent assessments of their productivity, particularly over the major parent material of phyllite (Adams and McKelvie, 1955).

The remainder must be regarded as unsuitable, by prevailing methods of agriculture, for continuous cultivation. They comprise soils which are drought, low in nutrients, shallow or poorly drained. Included in this category are the soils developed over coarse grained granites and pegmatites which are extensive throughout the zone, but are particularly widespread in the southern part of the former Eastern and Central Province, and the soils developed over the deep, peneplain drifts to the north of Kumasi and in Western Ashanti. Approximately, 20 per cent of the zone is occupied by these soils.

<u>World distribution of ochrosols.</u>

The ochrosols have been described in Nigeria (Doyne, Hartley and Watson, 1938, Vine, 1956a), the Congo where they are termed as Red Latosols under forest (Kellogg and Davol, 1949) and in Uganda (Tothill, 1940). They have also been described in Trinidad (Hardy, Duthie and Rodriguez, 1936) and in Puerto Rico (Roberts, 1942).

Chapter 10

OXYSOLS

The oxysols are a great soil group of the climatophytic order developed over similar parent materials and on similar topography to the ochrosols, but, in addition, are developed over unconsolidated Tertiary deposits near the coast at Axim. They occur in the southwest corner of the country under a rainfall exceeding 70 inches without a pronounced dry season. Reaction trends are inverse to those of the ochrosols, with the surface horizon being extremely or highly acid, and the lower horizons becoming gradually less acid ; pH values increase from 4.0 - 4.8 at the surface to 4.5 - 5.4 at depths between 3-6 feet.

In the previous chapter, it was noted that the ochrosols are, pedogenetically, a modification of the oxysols due to climatic variations Other modifications, but of minor extent and importance, occur under lower rainfalls where constituents of the parent material favour oxysol formation, notably over highly siliceous rocks of the Tarkwaian formation and pyritiferous phyllites of the Lower Birrimian formation. Oxysols also occur in the peneplain drifts on the oldest (Aya) erosion surface where the extreme age of the deposits is the dominant pedogenic factor.

The topographic sequence in the oxysol zone is shown in Fig. 15. The most extensive soil is Boi series which is

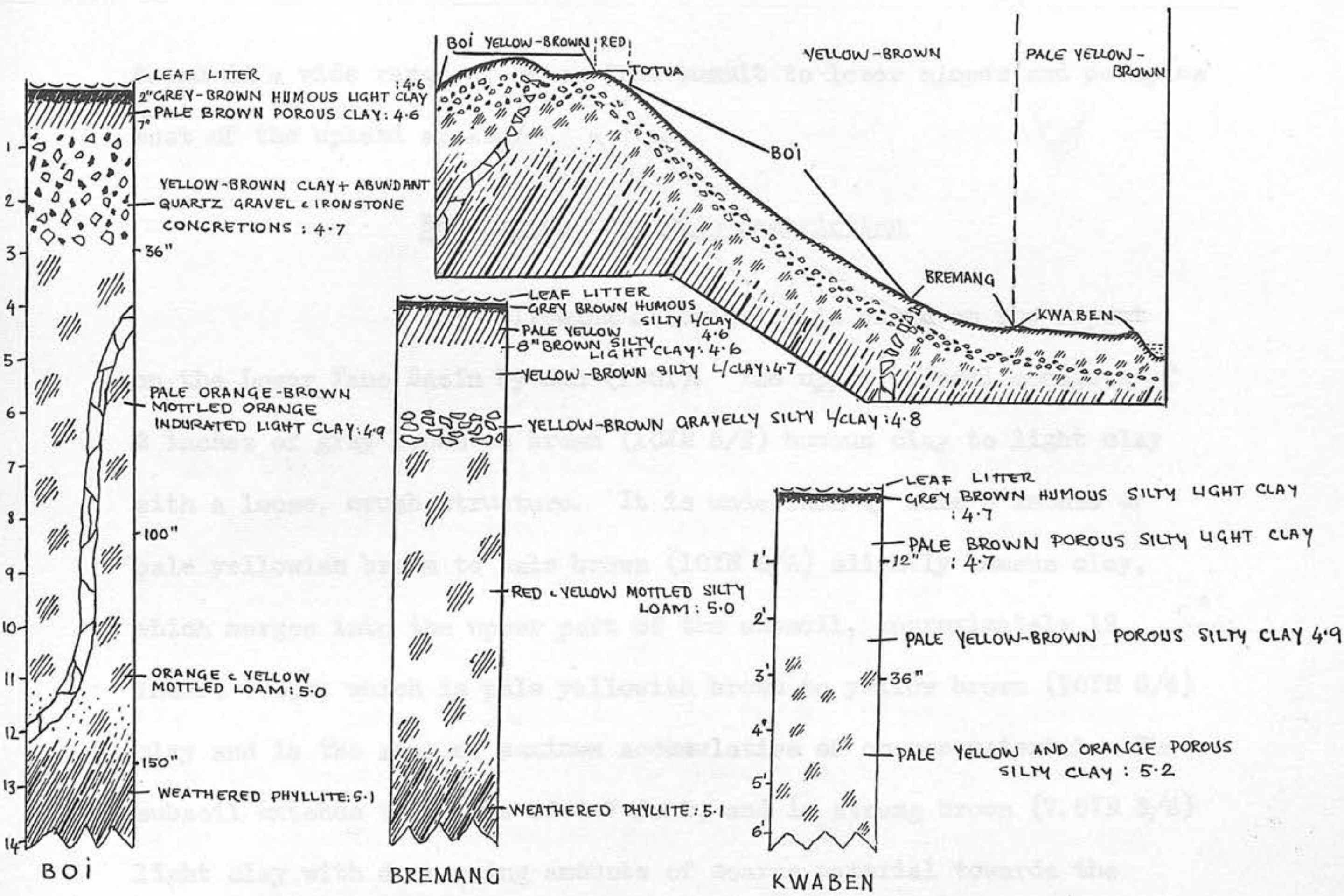

FIG.15 IDEALIZED SECTION ILLUSTRATING A FOREST OXYSOL ASSOCIATION OVER LOWER BIRRIMIAN PHYLLITE. (BRAMMER, 1962)

found in a wide range of sites from summit to lower slopes and occupies most of the upland areas.

Boi series : profile description

The following description is based on the report on the Lower Tano Basin by Ahn (1961). The upper topsoil consists of 2 inches of grey brown to brown (10YR 5/2) humous clay to light clay with a loose, crumb structure. It is underlain by some 5 inches of pale yellowish brown to pale brown (10YR 6/4) slightly humous clay, which merges into the upper part of the subsoil, approximately 12 inches thick, which is pale yellowish brown to yellow brown (10YR 6/4) clay and is the zone of maximum accumulation of coarse material. The subsoil extends to depths of 4-7 feet, and is strong brown (7.5YR 5/6) light clay with decreasing amounts of coarse material towards the weathered substratum. At the base of the subsoil, mottling, and occasionally some degree of induration, are evident and this becomes stronger with depth. The weathered substratum is usually 7-8 feet of heavy loam with increasing traces of decomposing phyllite.

The reaction of the surface layer is about pH 4.6 on the average, rising to values of pH 5.2 in the weathered substratum. Organic matter appears to be generally lower in amount than in the ochrosols, although it is diffused more deeply down the profile. Visible humous staining may be confined however, to the surface 1-2 inches. Brammer (1962) suggests that the organic matter in the oxysols may have a much lower capacity to retain nutrients than that in the ochrosols. The nutrient status is low compared to the ochrosols, and Ahn believes that the total exchangeable bases in a typical Boi series is probably of the order of 10 per cent of a typical ochrosol. In relation to oxysols developed over Tertiary sands or granite in the lower Tano Basin, however, the nutrient status is higher.

The Tertiary sands are 25-50 feet thick over an area of some 200 square miles in the extreme southwest of the forest zone. The soils are almost exclusively Tikobo series. This consists of a thin, pale greyish brown (10YR 5/2) humous sandy loam topsoil, some 6 inches thick, overlying a considerable depth of uniform, yellow brown (10YR 5/4) sandy light clay which becomes lighter in texture below 5-6 feet. Coarse material is absent from the profile. The annual rainfall of 85 + inches is rapidly absorbed through the soil with consequent excessive leaching. The reaction is highly acid throughout with pH values of 4.6 - 5.0.

With the possible exception of the soils on the gentle topography of the Tertiary deposits, the oxysols are not suitable for cultivation without extreme precautions against erosion. The slopes are somewhat steeper than in the ochrosol zone, and clearing has often led to topsoil removal with the result that gravel is present at or near the surface. In turn, the process accelerates with increased run-off and still further loss of topsoil, and consequent deterioration both in nturient status and moisture relationships. Continuous cultivation may result, even with the rainfall totals of the area, in the invasion of gras species into the fallow system, possibly including Imperata cylindrica as a dominant form, as has happened in parts of Sierra Leone (Waldock, Capstick and Browning, 1951).

Oxysols of the Aya erosion surface.

These soils are located principally on the summit of the Yinahin and Atewa Ranges. They are minor in extent, and, because of their altitude and location, are included within protective forest reserves on the watersheds. They consist of deep drift underlain by bauxitic pan. Locally, on the pan there are edaphic climaxes, and these are described in chapter 12.

The soils are Aya series, a red, uniform clay, and its drainage associate, Atewiredu series. The former soil is dominant on the Yinahin Range, while the latter occurs on the Atewa Range. This is probably because of the greater precipitation on the latter hill range with annual totals in excess of 70 inches. Observations by J. Coldwells (personal communication) showed a change from semi-deciduous to evergreen rain forest species on the summit, and lareg areas of swamp vegetation were observed during the Birim Basin survey (S. L. U. S., 1958).

Aya series : profile description

The leaf litter layer is thin and is underlain by a dark reddish brown (5YR 3/4 dry, 5YR 4/3 wet) light clay topsoil. Humous staining is very weak, although the organic matter content is of the order of 12-15 per cent (Table 8), and there are few roots.

There is a slight crumb structure in the surface inch or two, but this becomes less evident in the lower topsoil where the colour is still reddish brown but of a redder hue (5YR 4/4 dry, 2.5YR 3/6 wet).

The topsoil gradually merges into the parent material at 6-8 inches. Below this, there is a red (2.5YR 4/6 dry, 2.5YR 3/6 wet) clay, structureless and firm, but becoming more friable with depth, which may be 18 inches to 15 feet thick. The dominating feature of the soil is uniformity. It is composed entirely of fine earth with clay increasing throughout the profile. Characteristically, the organic matter content is fairly high and penetrates well down the profile, but it is not of a form which retains bases. The extremely acid reaction in the topsoil gives way to less acid reactions towards the base of the drift.

Oxysols over other parent materials.

It is doubtful if the soils developed in parent materials derived from the weathering products of highly siliceous rocks are true oxysols, while the pyritiferous phyllites found in the northwest quadrant of the Birim Basin develop soils whose characteristics are probably climatic in origin, although the possibility that the parent materials set free sulphuric acid during decomposition may be cofrect. The former soils are the more extensive and have been examined in the Jimi valley near Obuasi where they are heavily cultivated. The dominant soil is Atasi series which is a yellow brown loam developed on very gentle toppgraphy over coarse grained Tarkwaian quartzite.

Atasi series : profile description

Over the greater part of the area, the forest has been destroyed. Thicket is the dominant vegetation, and beneath it is 3 inches of grey brown (10YR 5/2) fine sandy light loam which is slightly crumbly and loose. This grades into 7-8 inches of light brown (10YR 6/3) fine sandy loam which is a transition layer into the parent material.

The parent material varies considerably in depth from 3 feet to 10 feet or more. It consists of a uniform, yellow brown (10YR 5/4) to brownish yellow (10YR 6/5) heavy loam or sandy light clay in the upper layers but becomes lighter textured with depth. There is little or no coarse material, structure is absent, and the horizon is firm but friable in the hand.

The soil is not wholly sedentary. Evidence of movement is provided by an irregular stoneline which occurs at the base of the parent material on the middle to lower slopes. However, without observing the stoneline, it is impossible to distinguish between sedentary and transported soil. The composition of the stoneline varies with the locality ; over pure quartzites, it consists of an occasional subangular quartz stone ; near the bands of phyllite which run parallel to the quartzite, and which have been capped with ironpan in the past, it may include ironstone concretions, pieces of ironpan and abundant quartz stones. Beneath it, there is always a mottled, slightly indurated zone of varying thickness overlying the decomposing quartzite in which the individual quartz grains are very conspicuous.

The fine earth is predominantly sand with the clay fraction increasing from 10-12 per cent in the topsoil to 40-45 per cent in the indurated zone.

The reaction profile is not typical of the oxysols, however. While the topsoil has very acid to highly acid reactions, with pH values of 4.6 - 5.0, the acidity increases with depth and, at the base of the profile, pH values of 4.0 - 4.4 are characteristic. In one excavation, the reaction was extremely acid and a pH value of 3.3 was recorded. Such a trend is contradictory to the oxysols and raises doubts as to the mode of origin of the soil.

Organic matter is concentrated in the surface layer and devreases abruptly below 3 inches. Bases are also largely confined to this layer, but even so are very low in total. The underlying rock, being mainly composed of quartz grains, is extremely low in plant foods, and no reserves are available to replenish the soil. Once exhausted, there would be great difficulty in rejuvenating the land. Simce the immediate vicinity of Obuasi has been cleared of vegetation throughout this century (Moore and Guggisberg, 1909), this soil may be an example of a degraded ochrosol.

Value of the oxysols.

These soils are pre-eminently suited to tree crops, not because of any properties which they possess, but because of the climatic conditions under which they occur. They are unsuitable for cocoa, but oil palm and rubber could be grown. The broken topography necessitates great care in utilising these soils, however, even for perennial tree crops.

Fortunately, in Ghana, the oxysols are not extensive but elsewhere in the very humid forest regions of the tropics they are extremely widespread. They predominate in Liberia (Reed, 1951), and Sierra Leone (Martin and Doyne, 1932), and are also found in areas with 80 inches or more of rainfall in Nigeria (Vine, 1956b), in the Congo (Kellogg and Davol, 1949) and in Madagascar (Pernet, 1954). In Central America they were recorded by Charter (1940) in British Honduras, and in Puerto Rico by Roberts (1942). They occur in Malaya (Owen, 1951) and in Indonesia (van der Voort, 1950).

Chapter 11

BASISOLS

Basisols are developed from non-quartzose rocks of basic affinity in the moist semi-deciduous rain forest. In the evergreen forest, leaching is sufficiently intense and continuous to form oxysols over all parent materials, but elsewhere in the forest zone, basic rocks with high calcium and magnesium content give rise to soils with illitic or montmorillonitic clays. These soils are differentiated into Forest Rubrisols when they are dark red in colour, and Forest Brunosols when they are dark brown in colour (Brammer, 1956).

It would be misleading to generalise about these soils from evidence in Ghana. At most, they occupy in total an area of 300 square miles (Crosbie, 1957a) or less than 1 per cent of the area of the closed forest zone. There is a concentration around Tafo, and a mappable expanse near Goaso in Western Ashanti. An area of some 24 square miles occurs on Bosumkese in the Upper Tano Basin (Radwanski, 1957), but generally, the basisols are located as small pockets, 10 - 100 acres in size, on the Upper Birrimian hill ranges. These pockets are frequent near Lake Bosumtwi, between Osino and Bunsu, and on the northern extremity of the Yinahin Range.

Similar soils have been examined from the Cameroons, but otherwise no geographic correlation has been established with other tropical countries.

Parent rocks of basisols are amphibolite, epidiorite, hornblende schist and greenstone, all of which are found in Upper Birrimian formations. Near Tafo, there are expanses of soils intermediate between the ochrosols and rubrisols and these are developed over hornblende and biotite granodiorites.

The reasons for the development of Rubrisols distinct from Brunosols are not understood, but there is a suspicion that the former soils may be associated with rocks inherently richer in iron. Brunosols are the more frequent in occurrence and accordingly have received greater attention. On the hill ranges, the series which occurs most is Anum series. This soil is remarkable in the consistency of its profile characteristics.

<u>Anum series : profile description</u>

Unless situated within a forest reserve, this soil is always under cocoa cultivation. The leaf litter layer overlies 2-3 inches of dark grey brown (10YR 4/2 dry, 10YR 3/2 wet) humous light clay with frequent root hairs. Crumbly, loose and porous, the upper topsoil grades into 5-6 inches of dark brown (10YR 5/6 dry, 10YR 4/3 wet) clay which is slightly cloddy and compact. Occasional root hairs are present and rare to occasional soft manganese concretions are a feature.

The transition into subsoil is not well defined. There is a brown (10YR 5/6 dry, 10YR 4/3 wet) layer, 10-12 inches thick of light clay with occasional manganese comcretions. This is slightly cloddy and slightly compact. It overlies a yellowish brown (10YR 5/8 dry, 10YR 5/4 wet) light clay which varies in thickness according to the degree of slope. Compact and structure less when wet, there is incipient structure when dry. Manganese concretions are frequent together with rare, small boulders of greenstone. At the base of the layerm there are orange, grey, yellow and brown mottles in a matrix, together with an increase in rock stones and frequent minute manganese concretions. Decomposing rock is present at depths below 40 inches. The greenstone weathers into spheroidal boulders with a characteristic dull yellow patina, and these may form a layer at the base of the profile (Fig. 16).

The nutrient status is very good. Throughout the profile, the reaction is only slightly acid with pH values of 6.4 to 7.0. Organic matter and nitrogen content are medium high in the topsoil, and are well dispersed down the profile. C/N ratios are of the order of 9-10 in the topsoil, and 7-8 in the subsoil. The exchange capacity is high with a very high base saturation. Calcium is very high and may be free in the profile. Magnesium is also high, and the Ca/Mg ratio decreases with depth. Potassium is medium high and decreases with depth.

The rainfall of 60-65 inches is readily absorbed by the soil. External drainage is good on the steep slopes, but internal drainage is rather slow although groundwater is generally absent except during the wet season when there is a marked seepage zone above the decomposing rock.

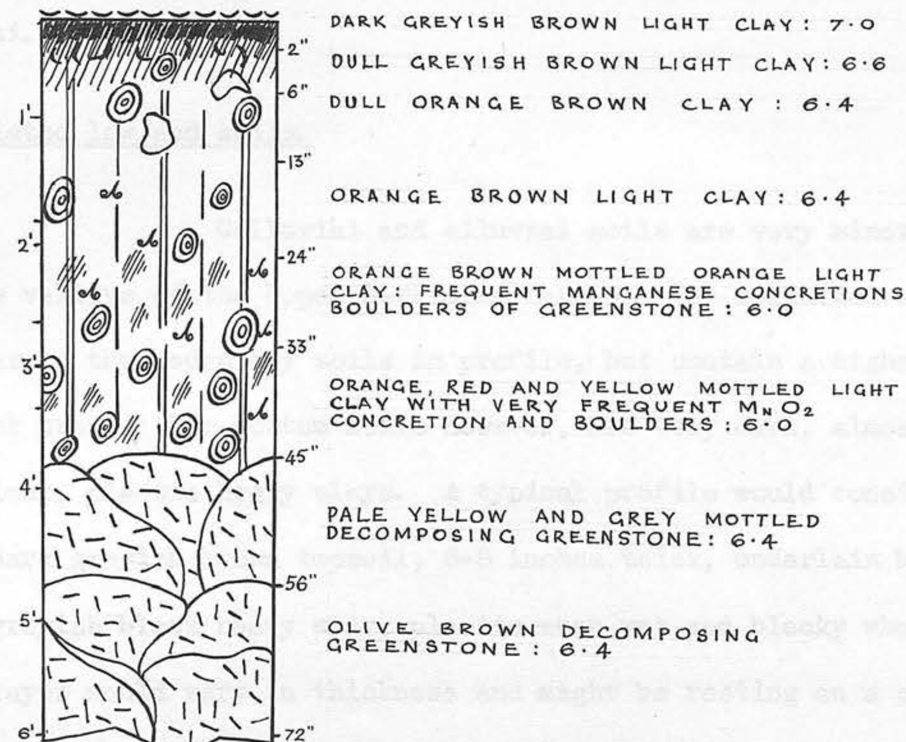

FIG 16 PROFILE DIAGRAM OF ANUM SERIES

On more gentle topography, these drainage features give rise to an indurated layer which is black in colour and highly manganiferous, at depths of 2-4 feet on the lower slopes. This is a recurrent morphological feature in the soils near Goaso in Western Ashanti.

Associated lowland soils.

Colluvial and alluvial soils are very minor in the narrow valleys of the Upper Birrimian ranges. The colluvial soils are similar to the sedentary soils in profile, but contain a higher proportion of rock brash. The bottom soils however, are very dark, almost black in colour, plastic heavy clays. A typical profile would consist of a very dark greyish brown topsoil, 6-8 inches thick, underlain by a very dark greyish black heavy clay, plastic when wet and blocky when dry. This layer would vary in thickness and might be resting on a stone-line, but, generally, it would be 30-50 inches deep. The reaction would be neutral throughout the profile, with pH values of 6.6 - 7.4. During the wet season, the soil would be waterlogged for considerable periods due to the heavy texture.

Such soils would be classified as forest brown neutral gleisols on the basis of present information, but it is possible that their confined situation restricts their development. In some profiles, calcium carbonate concretions have been observed. This would suggest a re-assessment, and possibly these soils will ultimately be classified either as tropical brown earths or as forest vleisols.

Chapter 12

LITHOSOLS

A lithosol is a shallow soil with little or no profile development. Soils in this category are azonal and owe their characteristics to the nature of the parent materials rather than to any soil forming process. They occur over igneous, metamorphic and sedimentary formations where the lithology is resistant to current forms of weathering, and also over duricrusts. Differential erosion ensures that these rocks persist as hill ranges, while duricrusts occupy topographic sites marking former erosion surfaces. In the oxysol zone, lithosols are virtually absent.

Skeletal soils usually consist of a humous horizon, characteristically lacking any differentiation into an upper and lower topsoil, overlying rock fragments or solid rock. There is no well developed parent material since this is wholly absorbed in soil formation in the humous horizon. The depth of soil may vary from two to sixteen inches, but solid rock is usually present within a foot of the surface. Generally, the soil comprises a dark grey brown loam, nearly black when wet, of a mixture of rock brash, leaf mould and roots, with a variable proportion of true earth matter.

Lithosols occur most frequently on steep slopes, but also develop over more or less flat bedded sediments and over duricrusts on gently sloping land.

Drainage is free to excessive externally. Within the profile, drainage is also free down to the parent rock, the composition of which determines the degree of impedance. On flat or very gently sloping sites, however, there may be seasonal waterlogging. Seepage is a feature at the periphery of these soils, and may affect vegetation forms. With the exception of a few, irregular and patchy expanses of lithosols derived from basic rocks, these soils lack any means of conserving moisture and all suffer from drought during the dry season.

The vegetation of these soils is characteristically woody, even in savannah areas, and consists of forest scrub unless artificially cleared. Because of their frequent location on watersheds, they are often protected as forest reserves. The shallow soil body, together with the drainage features, may create edaphic climaxes, particularly over duricrusts. Root room is sharply limited and species may develop stilt roots for support. Wind throw is common, particularly where trees are exposed to the north-east squalls.

Soil fauna are also limited by the shallow profile, particularly in the dry season when they are unable to seek refuge from the drought by retreating to the subsoil.

Erosion is generally active on these soils and the products of weathering are removed almost as fast as they are produced. There is a constant lossof soil and water from the lithosols <u>in situ</u> and a proportionate gain in the deposits situated topographically below them. Lithosols must be preserved by maintaining the original vegetation cover. If exposed, they would be rapidly lost by erosion.

Because of their direct relationship with the underlying strata, lithosols could be differentiated according to the varied compositiom and character of each geological formation. Pedologically, however, their limited development, together with their restricted role in land use, make such distinctions unnecessary. In Ghana, where the immaturity of soils is largely a reflection of unweatherable minerals or topographic conditions, and where young volcanic material is lacking, it is sufficient to distinguish lithosols according to marked textural differences in the parent material.

Quartzose rocks.

Lithosols are most extensive over these geological formations whose rocks have a high quartz content. Such rosks are quartzites, sandstones, and quartz impregnated phyllites.

Quartzites are associated with steep hill ranges, occasionally with bare rock faces, forest vegetation, and major watersheds. The rock ranges from the coarse grained quartzites of the Tarkwaian hills to the finer grained rock in the Togo formation of the Akwapim and Togo ranges. Lithosols are confined to the steep slopes but may extend for a considerable distance along the hill ranges. The soil consists of a dark brown sandy light loam with bedrock within a foot of the surface. Occasionally, with variation in site, the unweathered quartzite may be found at depths of 25-35 inches. On the middle slopes of the steep ranges, the topsoil is usually underlain by a strata of rock brash to some depth.

Variation between the two geological formations is principally a function of climate. The Tarkwaian range has a greater rainfall, probably of the order of 65-70 inches, and the vegetation is semi-deciduous rain forest. On the Togo and Akwapim ranges, the rainfall is of the order of 35-50 inches and the vegetation is of a drier type. Both formations are usually shrouded in mist and this ameliorates the droughty nature of the soil.

At the base of the steep slopes, there are usually talus soils. These comprise a pale brown, humous sandy light loam topsoil overlying 2-3 feet of yellow brown sandy light clay containing abundant rock brash, quartz gravel and occasional quartz stones. The colour of this layer is slightly paler inthe upper 12 inches. Below 30-36 inches, reddish yellow loam of decomposed quartzite grades into decomposing rock at about 5 feet. The rock is capable of absorbing moisture but becomes less permeable with depth, and the natural grey colour is highly mottled. The soil is developed on 12-25 per cent slopes with a high rainfall, and, accordingly, the profile is leached with a highly acid reaction throughout.

Sandstones give rise to lithosols on the Voltaian escarpment and in Togoland. These have been described by Mould (1957a, 1957b). The site characteristics are better defined on these formations and a greater variation may occur. On the horizontally bedded sandstones of the Voltaian, the lithosols are shallow, sandy loams. In Togoland, the sandstone is associated with scarp topography, and there is a difference, mainly marked in drainage and vegetation, between the dip and scarp slope.

Talus derived from the sandstone accumulates in a narrow band at the base of the steep slopes and ridges. The soil consists of a thin topsoil overlying angular and subangular pieces of sandstone in a sandy matrix which becomes heavier in texture with depth until decomposing rock is reached at 3-4 feet.

Located on the northern periphery of the forest zone in the ecotone to the savannah, the soil moisture relationships aggravet the intensity of the dry season and the effect of the harmattan. On the horizontally bedded sandstone, the lithosols have usually been farmed and are now associated with derived savannah. Frequently, there is also a slightly deeper and darker topsoil due to the inclusion of charcoal from burnt vegetation.

Quartz impregnated phyllites are of local importance only. Lithosols associated with them occur in sequence with sedentary soils and are not mappable as individuals.

Metamorphosed sediments.

Metamorphosed sediments occur in irregular distribution with other rocks on the steep sides of Upper Birrimian hill ranges. Lithosols are minor soils of small expanses as the complex bedding and gradation of rocks in these ranges give continual changes and mixtures of parent materials. They consist of a silty clay, single layered topsoil, usually greyish brown (10YR 5/2) overlying a slightly mottled silty loam with increasing proportions of rock brash grading into weathered rock at a shallow depth. The schistose or tuffaceous nature of the bedrock is easily crumbled in the hand. By their location, these soils are preserved under forest reserves. If exposed, they would be rapidly eroded.

Inselbergs.

Inselbergs are described in this chapter since the greater area of this phenomena is covered with skeletal soils. They forma regular relief feature in the ochrosol zone, but are conspicuously absent in the higher rainfall areas. Typically, they occur near the contact zone of the acid igneous intrusions and the Lower Birrimian metamorphosed sediments, generally in the igneous rock. Similar genetic relations are implied by the similar features which each exhibits.

Coarse grained granites comprise the inselbergs in contrast to the country rock of medium grained granite, granodiorite or biotite schist common in the contact zone. The granite is jointed and fissures in the rock are visible on inspection. Bands of biotite, feldspar and quartz giving a gneiss like structure run through the granite, while small phenoliths of schist frequently occut. Superficial deposits, 6-8 feet deep, derived from the decomposing gramite, form an apron drift at the base and extend for some 3-400 yards.

The height differential is similar throughout the forest zone, averaging some 350 feet above the surrounding plain. Table 14 records the elevation of five inselbergs in the vicinity of Kumasi, together with Epamso which is some eight miles east of Achiasi in the Birim Basin.

Inselberg	Altitude	Altitude of surrounding plain	Height differential
Nkabin	1275	950	325
Mile 14, Kumasi-Mampong Road	1300 +	950	350
Bari-Boaw	1275	900	375
Kintaboaw	1203	900	303
Mile 13, Kumasi-Sunyani Road	1100 +	750	350
Epamso	950 +	600	350

Table 14. Height differentials for inselbergs in the forest zone.

The form of the inselbergs, Fig. 17, was determined by abney levelling. Each inselberg is circumscribed by a stream which only leaves a narrow neck unbroken. From this stream, which is slightly incised, there is a well defined, but relatively narrow, piedmont with a marked break of slope at the base of the inselberg. Above this, there are steep rocky slopes to the dome shaped summit. Bare rock faces are conspicuous in some cases, while in others the rock is only masked by a very thin layer of soil.

Analysis of the slope usually reveals several consistent facets. The whaleback form of the apron drifts gives way by a break of slope to the piedmont with slopes of 1-2 per cent ; where the anular stream flows at the base of the piedmont, the break of slope is exaggerated. At the inward edge of the piedmont, there is a steep slope to a step composed of very large boulders forming a girdle round the hill. Behind these boulders, smaller boulders have usually accumulated and a few of these may have broken through to lie on the piedmont. Above this there is a gentler slope with a few relatively small boulders, rising to a collar of large boulders on the upper slope of the hill. This is surmounted by a convex slope, frequently with very large rock exposures, leading to the summit which is covered with large, sub-angular boulders. One aspect of the inselberg usually presents a steep or vertical rock face from the girdle to the summit.

Weathering has had little effect on the inselbergs. The very large rectangular granite boulders have resulted from

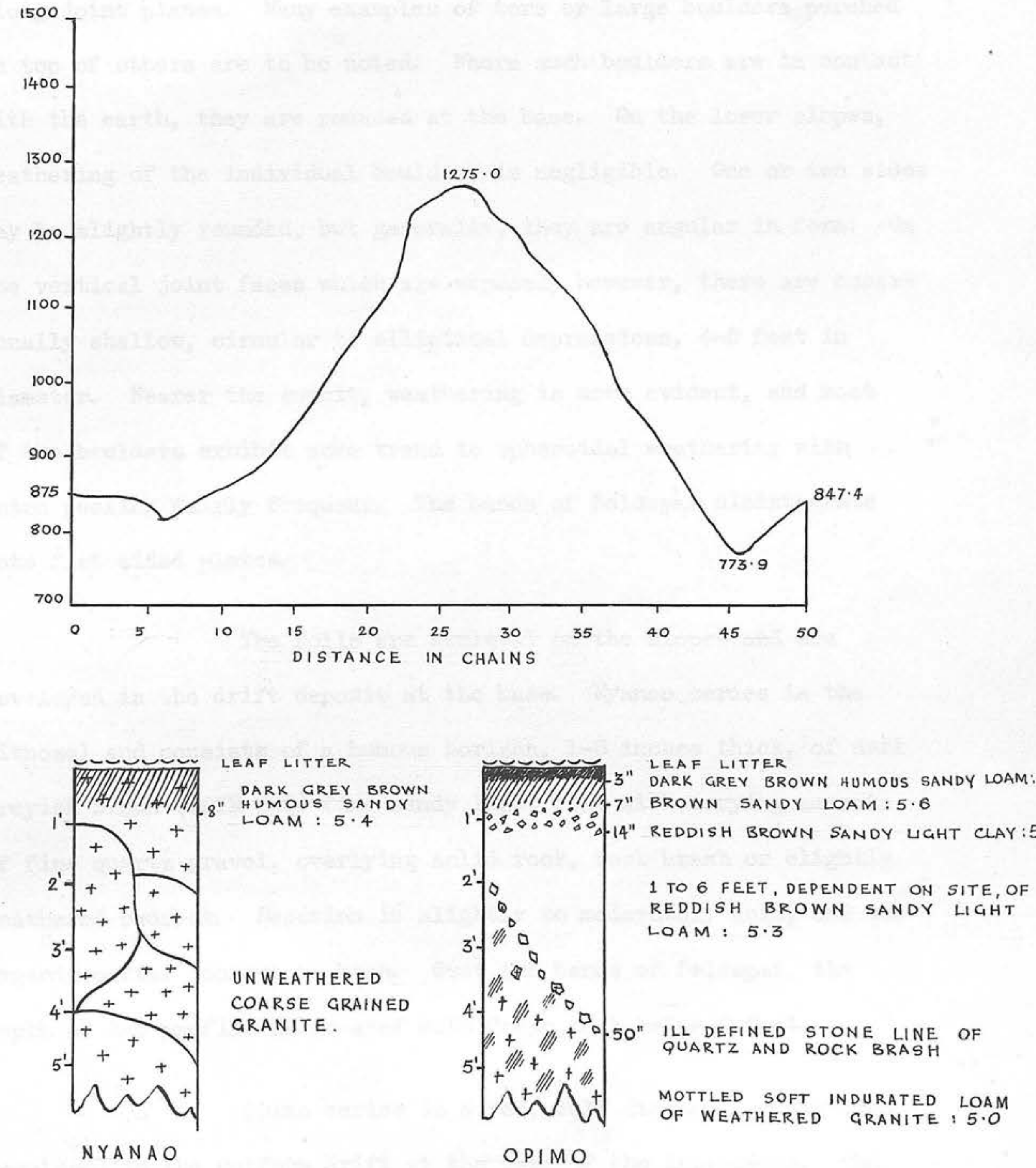

FIG. 17 CROSS-SECTION OF NKABIN INSELBERG NEAR KUMASI WITH PROFILE DIAGRAMS ILLUSTRATING THE ASSOCIATED SOILS.

fracturing of the joints, and, in turn, are themselves disintegrating along joint planes. Many examples of tors or large boulders perched on top of others are to be noted. Where such boulders are in contact with the earth, they are rounded at the base. On the lower slopes, weathering of the individual boulders is negligible. One or two sides may be slightly rounded, but generally, they are angular in form. On the vertical joint faces which are exposed, however, there are occasionally shallow, circular to elliptical depressions, 4-5 feet in diameter. Nearer the summit, weathering is more evident, and most of the boulders exhibit some trend to spheroidal weathering with onion peeling fairly frequent. The bands of feldspar disintegrate into flat sided plates.

The soils are skeletal on the slopes and are developed in the drift deposit at the base. Nyanao series is the lithosol and consists of a humous horizon, 1-8 inches thick, of dark greyish brown (10YR 3/2) fine sandy light loam with varying amounts of fine quartz gravel, overlying solid rock, rock brash or slightly weathered bedrock. Reaction is slightly to moderately acid, and the organic matter content is high. Over the bands of feldspar, the depth of the profile is greater with fresh rock below 2 feet.

Opimo series is a red, well drained, gritty loam developed in the uniform drift at the base of the inselbergs. The drift varies in depth from 1-6 feet in relation to position on the slope.

Opimo series : profile description

Opimo series is ubiquitously utilised for cocoa cultivation and a layer of cocoa leaves covers the soil. This is underlain by a very thin layer of decomposed leaf litter whuch grades into 2-3 inches of very dark greyish brown (10YR 3/2) fine sandy loam. There is a good crumb structure but this is absent in the lower 4-5 inches of the topsoil. In this layer, the soil is brown (7.5YR 4/3) sandy loam with occasional fine quartz gravel and frequent coarse quartz gravel.

A transition layer, 5-7 inches thick, of reddish brown (5YR 4/4) sandy light clay merges into reddish brown drift. The drift deposits are a sandy light loam, 1-6 feet thick, which may be separated from the underlying weathered rock by an ill defined stone-line of small sub-angular quartz and granite stones. The upper layer of the weathered rock is usually a soft, indurated loam mottled yellow, grey, red and brown, with occasional patches of thoroughly decomposed rock. Where the slope is very gentle, the degree of induration is greater and there may be an accumulation of manganese at the base of the drift.

The fine earth fraction is high throughout the profile, being of the order of 85 per cent in the topsoil, 60-65 per cent in the parent material, and increasing rapidly to 80 per cent in the weathered rock. The reaction is neutral in the surface 2-3 inches, but becomes moderately to very acid, pH values 5.0 - 5.6, below this layer.

The soils of the inselbergs, though discontinuous and inextensive, are of considerable pedological significance. They are the first product of the soil forming processes transforming weathered rock and organic residue into soil, and they represent the uppermost components of the soil catena.

Duricrusts.

Duricrusts are the massive or concretionary cappings of ironstone which overlie areas of low relief. The term was invoked by Woolnough (1927) who suggested the existence of duricrust surfaces to be a valuable criterion of peneplanation. This is generally accepted, together with the conclusion, expressed by Milne (1940), that such plateau ironstones can survive weathering as a surface formation long after the land surface on which it was developed has been thoroughly dissected by geological weathering. Lithosols associated with duricrusts are geographically determined by topographic site.

The parent material of these soils is laterite. The term here is restricted to massive vesicular or concretionary ironstone formationm following the conclusions of Prescott and Pendleton (1952) who state :

"... that laterite is essentially the exposed illuvial horizon of an ancient soil. The principal differences from a soil in current process of formation in that the scale is materially greater in the case of the laterite profile, some examples being forty feet or more from the surface capping to the parent rock. Originally there must have been surface eluvial horizons and in some cases there is a suggestion that these have survived. On the whole, however, the cycle of erosion initiated by the uplift has resulted in the removal of the surface horizons, and the laterite itself, by nature of its chemical character and hardness, has acted as a protective capping, resistant to erosion and providing in itself a valuable criterion of peneplanation".

There is now an implied recognition, particularly in Australia, that the term be restricted to its original geological meaning and thereby as a parent material giving rise to an association of soil series with characteristic mutual relationships.

The Aya surface.

Although the Aya surface is characteristically capped by bauxite, the areas where the crust is exposed are not of great extent. Small expanses occur on the Yinahin Range, the Obuom Range, the Atewa Range and the Mpraeso Scarp. The lithosol which is developed over the bauxite, Yinahin series, is a shallow soil merely consisting of a humous horizon. This horizon is 5-10 inches thick, very dark brown (10YR 2/2) when dry and black (10YR 2/1) when wet. During the wet season, the drainage is impeded and for several consecutive months, the soil is completely waterlogged and may form the source of numerous streams.

Interesting edaphic conditions give rise to peculiar vegetation on the Yinahin and Atewa Ranges which can only be fully comprehended in terms of geomorphological history. Numerous inextensive patches of Yinahin series occur on the periphery of the ranges, but the s soil may cover 4-5 acres in saddles and cols on the summit. Fig. 18b, based on Cooper (1936), illustrates diagrammatically how denudation has carved a bauxite cap from an aluminous laterite crust. The fact that prolonged mechanical erosion leaves the hill in this form, implies that the centre is approximately flat, and that water lies longer here

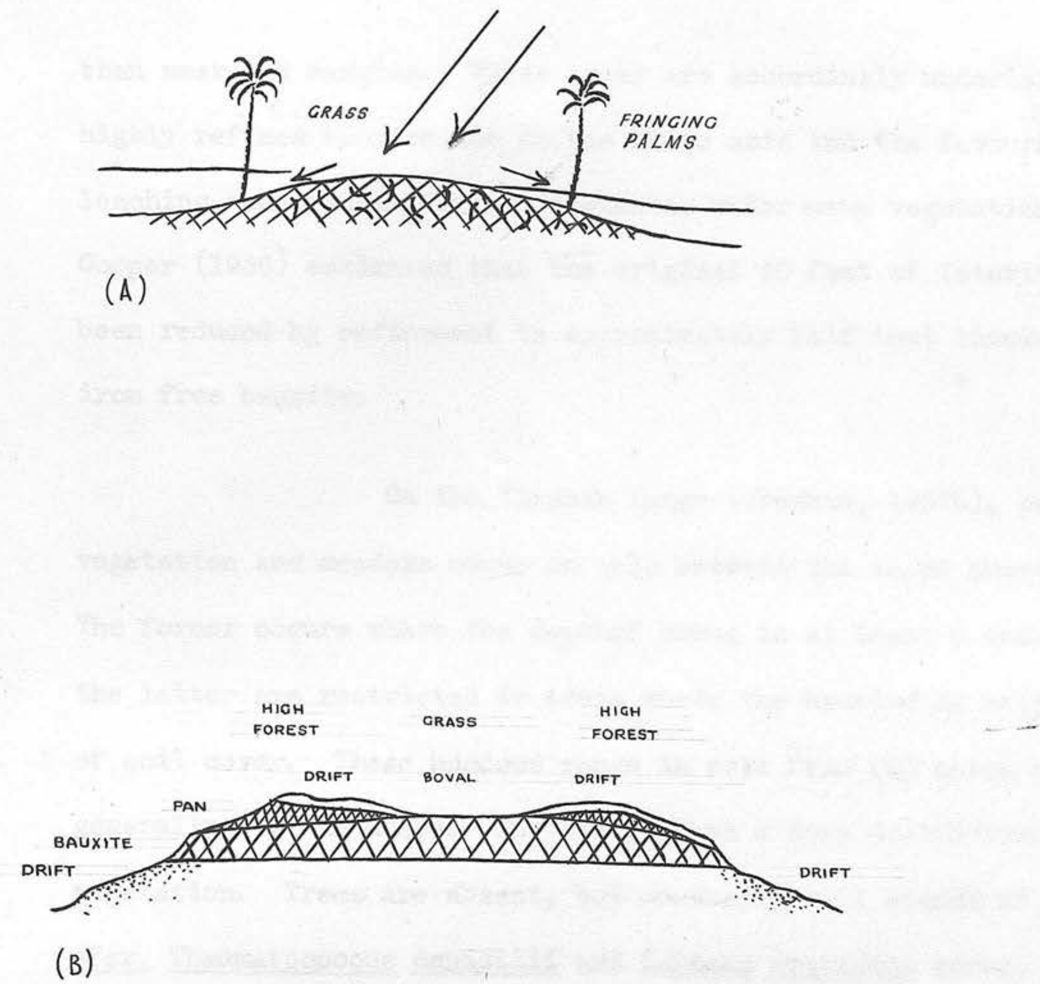

FIG. 18. LITHOSOLS ON DURICRUSTS : (A) AKUMADAN SURFACE WITH DRAINAGE FLOWING TO FRINGE; (B) SITUATION OF BOVAL ON AYA SURFACE (COOPER, 1936)

than near the margins. These areas are accordingly underlain by highly refined bauxite due to the humic acid and the favourable leaching conditions. In one instance, under swamp vegetation, Cooper (1936) estimated that the original 40 feet of laterite had been reduced by refinement to approximately half that thickness of iron free bauxite.

On the Yinahin Range (Crosbie, 1957b), swamp vegetation and meadows occur on cols between the major summits. The former occurs where the depth of humus is at least 6 inches, while the latter are restricted to areas where the bauxite is nearly devoid of soil cover. These meadows range in soze from 103 acres and are generally oval in shape. The swamps have a very distihctive vegetation. Trees are absent, but unusually tall stands of Costus afer, Thaumatococcus daniellii and Calamus deerratus occur, mixed with herbs and grases. The seasonal change in the moisture regime of the lithosols introduces a seasonal aspect to the flora. In May-June, the meadows are composed of Loudetia spp., with Andropogon tectorum and Setaria chevalieri on the periphery, and sedges of Fimbristylis ferruginea and Scleria barteri mixed with herbs of Wedelia africana, Tristemma hirtum and Dissotis rotundifolia. Towards the end of the wet season in November, however, the dominant grass appeared to be Andropogon canaliculatus, while the Loudetia spp., and Wedelia africana were less evident.

A fringe of savannah trees surrounds the meadows. The species present include abundant Dichrostachys glomerata, Allophyllus africanus, Stereospermum kunthianum and Elaeophorbia drupifera.

On the Atewa Range meadows were not located, but large areas of swamp vegetation occur. Again, the growth is unusually rank and high. Occasional ponds on the summit were surrounded by pure stands of "screw pine", Pandanus candellebrum.

The Akumadan surface.

Ferruginous crusts occur where the peneplain remnants of the Akumadan surface overlie Lower Birrimian metamorphosed sediments. These are located along watersheds, at the base of hill ranges, and occur in large, unbroken expanses in Western Ashanti in the extreme north of the Tano Basin.

Lithosols on the crust consist of up to 12 inches of dark brown (5YR 4/2) humous loam to light clay, with frequent ironstone concretions. In Western Ashanti, these soils occasionally give rise to an edaphic climax of grass. Such climaxes correspond to the bovals of Aubreville (1947) and Hamilton (1954) and are most frequent near Sunyani. Further north, drainage from the bovals is utilised by a fringe of Borassus palms (Fig. 18a).

Regosols.

Along the coast in the extreme southwest, there is a belt of varying width of coastal sands covering in total area some 90 square miles. On the upper 12 inches of the sands of the coastal dunes and raised beaches, there is humous staining, but structure is completely lacking. The organic matter is slightly more acid than the marine sands, and the reaction profile appears to be similar to the oxysols.

Within the sands, on old infilled lagoons, savannah patches are found, but in total, these are less than four square miles in extent. They have been described by Ahn (1959) who drew attention to the presence of hard, organic pan within the profile.

These soils are lithochronic earths although Ahn (1961) and Brammer (1962) consider that they should be classified as dilute oxysols. The nature of the parent material precludes the possibility of any profile development on these beaches, and the soils are accordingly grouped with the other lithochronic soils in this study.

Chapter 13

LOWER SLOPE SOILS

The soils of the lower slopes of the catenary sequence in the forest zone have received little attention from pedologists in the past. Yet these soils, with their relatively small range of variation, cover a very large area in the aggregate, and pose problems in utilisation which are basic to the zone as a whole. They are secondary soils, derived from the weathering products of the upper slope soils, and possess no inherent nutrients. The moisture retaining capacity is low and, under present forms of agriculture, they form a poor media for plant growth.

The characteristic soils consist of two horizons : a humous layer 7-9 inches thick overlies 2-3 feet of lower slope colluvium, frequently underlain by an irregular stoneline of subangular quartz. Below this, there is weathered country rock.

There are, virtually, only three distinguishable soil series although they may be derived from soils whose parent materials differ widely in lithological character. The essential division is based on the texture of the parent material of the upland soils : coarse grained parent materials predominate in forming colluvia, fine textured parent materials give rise to limited amounts.

Colluvia from coarse grained parent materials.

Lower slope soils are derived from the red earths of the higher slopes by the lateral transport of slowly eroded material. The redistributed fragments of red earth are differentiated during erosion with the clay content decreasing markedly downslope. Ultimately, the clay is gradually lost to the valleys, or lost in flood waters, while compact sand remains. The soils lose body, crumb structure and mineral reserves in proportion to the degree of transport and sorting.

The soil developed in the coarse sandy clay of the middle to lower slopes is Akroso series. On inferior topographic sites, the accumulation of coarse sand gives rise to Nta series. These two soils frequently occur in association but one or other component may be a absent dependent on site, location and texture of the upland sedentary soil.

Akroso series : profile description

Beneath the leaf litter layer, there are 2-3 inches of greyish brown (10YR 5/2) sandy light loam. Humus is present and there is crumb structure. This layer is loose and porous, and under cultivation, may lose all structure. The lower topsoil is 5-6 inches thick, light yellow brown (10YR 6/4) with slight humus staining. The texture is heavy loam and there are traces of crumb structure and slightly loose consistency.

The topsoil grades into 4 feet of coarse sandy light clay. In the upper foot, the colour is light yellow brown (10YR 6/4) but it grades to strong brown (7.5YR 5/6) at the base. Cloddy and firm, the fine earth presents a uniform appearance. Between the creep deposits and the indurated layer on the top of the weathered country rock, there is frequently a stoneline composed of quartz gravel and subangular quartz stones in a light brown (7.5YR 6/4) light clay matrix. The indurated loam of weathered rock is yellow brown with red and yellow mottles.

The fine earth fraction is high throughout the profile except in the stoneline. Sand is the dominant fraction, but silt and clay increase down the profile. Coarse material is of the order of 20 per cent in the stoneline.

The reaction in the upper topsoil is moderately acid with pH values of 6.0. With depth, the acidity increases to pH values of 5.0 - 5.2 in the stoneline, but it may decrease slightly in the weathered rock.

Akroso series is a major soil in the closed forest zone. It is found in association with all soils developed over the Cape Coast granite complex, and generally, the coarser the texture of the country rock, the greater the expanse of this soil. It has been recorded in every major survey in the zone.

Nta series : profile description

The topsoil beneath the litter layer generally consists of 3-4 inches of grey (5YR 6/1) humous sand with occasional root fibres. It is structureless and loose. There is an abrupt transition into 3-4 feet of light brownish grey (2.5YR 6/2) loamy coarse sand, structureless and loose. Under cultivation, the upper 6-9 inches of this horizon may be leached to a pale grey colour. Below 40-50 inches grey, yellow and orange mottles appear and these increase with depth. In the loamy sand matrix, quartz gravel and stones may be frequent. With depth, the earth becomes firm and there may be some degree of induration where it grades into weatherdd rock.

The fine earth fraction, predominantly sand, is high throughout the profile. In the stoneline, the coarse material is composed of fine and coarse quartz gravel and small quartz stones, and may be of the order of 30 per cent or more.

The reaction of the topsoil is neutral or slightly acid. Below 3-4 inches however, the acidity increases abruptly and very acid or highly acid reactions are obtained. With cultivation there is disturbance of the upper layers of the soil and organic matter is more widely dispersed. This frequently results in higher pH values being recorded to a depth of 15-18 inches. Nutrients are confined almost entirely to the topsoil. The parent material has few reserves being composed mainly of inert sterile quartz sand.

Subseries occur with variation in the texture of the country rock. Around Kumasi, Nta series is derived from coarse grained granites and pegmatites. The soil has a very high content of quartz gravel and, in consequence, it is excessively drained with a high degree of leaching reflected in the highly acid reaction throughout the profile. Apart from the topsoil, this subseries is more or less sterile and very limited in use.

A very minor subseries consists of normal profile features to a depth of 18 inches underlain by ferruginous pan. This was first recorded by C. F. Charter in the Densu Basin in 1946 and subsequently mapped as Suhien series (WACRI, 1946). It is found in the north of the closed forest zone near the base of the Mampong Scarp, and also occurs close to major watersheds. The ferruginous pan marks the level of former drainage grooves which have since been dissected in the course of rejuvenation. On numerous gravel roads north of Kumasi, exposures of pan outcrop some 8-10 feet above stream level and form an abrupt break of slope.

Nta series is classified as a regosol at great soil group level. Regosols should be classified according to their affinity with the other great soil groups characteristic of the region in which they occur. However, the close association of this soil with the other members of the topographic sequence justifies its inclusion with the description of these components. Like Akroso series, Nta series has been recorded in all the regional surveys in the forest zone, but it is particularly widespread and extensive in the Auensu and Densu Basins.

Variation in mode of occurrence.

There is a significant relationship between the extent and quantitative proportions of these soils and the stage of the current cycle of erosion. The upper courses of the rivers on the dissected peneplain are associated with rolling topography on which the lower slope soils occur in a zone parallel to the contour, but are of minor extent in comparison to the area of the sedentary upland soils. Near the coast the topography is very subdued, and the colluvial soils are the dominant, if not the sole, component on the slopes of the undulations (Hotson, 1956).

The angle of slope also affects the differential gradation of fine fractions in the colluvium. On gentle slopes, there is a decrease in the movement of the clay and a consequent limitation in the development of Nta series. The absence of this series in the southwest of the forest zone has been noted by Hotson (1956) and Ahn (1961). There is therefore, an oxysol equivalent of Akroso series only, termed Ankasa series. In profile it is almost identical to Akroso with the exception that it remains light yellow brown throughout. The reaction of the topsoil varies from pH 3.8 - 4.8, and it is one of the most acid soils in the Lower Tano Basin where it has been fully described (Ahn, 1961).

Colluvia from fine textured parent materials.

Lower slope colluvia of silty clay is derived from all soils formed in the metamorphosed sediments of the Lower Birrimian rocks. The parent material of the soils is nearly always devoid of bases. Kokofu is a regular component of the catenary sequence, but it is inextensive and locally unimportant.

Kokofu series : profile description

The surface 3 inches beneath the litter layer is greyish brown (10YR 5/2) humous light loam which becomes dark brown (10YR 3/3) when wet. There is a good crumb structure and the layer is loose and porous. It grades into 4 inches of pale brown (10YR 6/3 dry, 10YR 5/3 wet) light clay or clay loam in which the crumb structure is less pronounced and the consistency is slightly firm.

The parent material consists of 4-5 feet of colluvia. In the upper 12-15 inches, it is yellow to yellow brown (10YR 6/6) becoming greyish yellow with grey, orange, yellow and red mottles at depth. The texture is light clay but becomes more friable with depth. An irregular stoneline occurs at the base of the horizon, and consists of a thin line of ferruginous concretions or a 2 foot zone of quartz stones and concretions. Where the stoneline is thick, there may be some degree of induration.

Weathered rock directly underlying the deposit is mottled and indurated, but becomes less mottled and softer with depth. Generally, in the upper 6 inches there are a few, small, subangular quartz stones present, together with soft ironstone concretions.

Fine earth is dominant throughout the profile except in the stoneline where coarse material may be 50 per cent or more. The fine earth is composed of silty clay with a little sand. Coarse material is mainly ironstone concretions where the stoneline is thin, but where thicker, the bulk of the material is subangular quartz stones. Occasionally, limonite coated iron pyrites are present.

The reaction is moderately acid in the topsoil with p^H values around 5.6. The acidity increases with depth and highly acid reactions of less than 5.0 may occur.

Kokofu series was established by Charter on the Central Agricultural Station at Kumasi in 1946. It has been found in every major survey, albeit in minor extent, in the forest zone with the exception of the Ayensu and Densy Basins (Charter, 1955).

The oxysol equivalent of Kokofu series is a very minor soil termed Bremang series. This was discovered in the Kumasi Region and an unusual relationship between Kokofu and Bremang series was established. Ferruginous capped peneplain remnants over phyllite are aligned with north and south facing slopes (Fig. 9) ; the southward facing slope is gentler and Kokofu series occurs on the lower slope site. The northward slope is more irregular and Bremang series occurs in a narrow strip parallel to the contour on a 12 per cent slope just above the valley floor. Bremang series is also found on the lower slopes of steep hills and, undoubtedly, there is a correlation between degree of slope, drainage and leaching.

Geomorphological significance of lower slope soils.

The cycle of erosion in the tropical forest zone has profound effects on the distribution and areal extent of soils. The red earths are in the process of elimination by slow or accelerated erosion in accordance with the tendencies inherent in the topographic and climatic conditions. The soil is travelling downhill and changing its fundamental character as it occupies successively lower positions.

It has been noted how, as dissection becomes greater towards the coast, the topography is reduced and the areal extent of alluvial and colluvial soils increases at the expense of the sedentary upland soils. In places, these soils cover the subdued topography to the exclusion of the red, upland soils.

It is inevitable therefore, that these soils will extend, either by natural processes or due to accelerated erosion caused by soil exhaustion or deforestation, to become in time the major soils of the forest zone. It is essential that an understanding of the geomorphological processes is obtained in order that these soils may be utilised to the best advantage. Fortunately, by the very processes which creat them, the individual soils are few in number and the principles evolved may be adapted to extensive areas.

Utilisation.

The utilisation of these soils must be based on their physical characteristics. While they are inherently poor in nutrients and severely limited in their water retaining capacity, they still provide a fair medium for plant growth in that they are light, easily worked, and generally stoneless. On the other hand, it is of little avail endeavouring to exploit these soils for they will not respond, and are liable to erosion by wash if cleared and cultivated by ordinary, non-intensive methods in large blocks. They cannot, in fact, be regarded as independent agricultural units ; thay are only cultivable to a reasonably productive standard if the resources of the other members of the topographic sequence are brought to their aid. In other words, they must form part of a utilisation catena.

The difference from the upland soils to the African farmer is that these soils cannot give the introductory period of soil exploitation commonly desired. The soil conditions are too austere for this, and they cannot support a more intensive cropping system than is normally required for food production. Yet these soils could be utilised by manuring and kept in good heart. This implies, however, the adoption of advanced methods of husbandry prior to planting, such as the return of nutrients to the soil, the lavish use of compost, and the adoption more or less of a market garden technique.

These soils do, therefore, illuminate one of the fundamental problems of the tropics. The establishment of new crops on such soils is not an impossible task, but the raising of agricultural standards from subsistence level to commercial level, in advance of the introduction of new crops, is more difficult. Time and education are required, but it is essential, particularly in areas of poor soil, if standards are to be improved. There has to be an improvement in agricultural methods to the point where prudence and forethought begin to compensate for low natural productivity.

Chapter 14

GLEISOLS

Gleisols are the depression soils associated with the upland soils of both great soil groups, the ochrosols and the oxysols. They occur mostly under swamp forest, are poorly drained, and may be waterlogged or flooded during the wet season. Subdivisions of this great soil group family, based on colour and reaction, include the following in the forest zone :

Grey very acid gleisol
Grey acid gleisol
Grey neutral gleisol

Extensive areas of alluvium do not occur in the forest zone of Ghana. Individual soil series are irregular and inextensive in occurrence, and are confined, in the main, to minor valleys. It has been estimated however, (Crosbie, 1957a) that lowland soils, comprising lower slope soils and bottom soils, occupy approximately 20 per cent of the total area of the forest zone.

Alluvial soils range in texture from clays to coarse sands according to the source of origin of the parent material and the mode of deposition. In general, the distribution of the various soils is haphazard on the valley bottoms reflecting the changes in stream channels. Ideally, the sands occupy the better drained sites, while the clays are located in the depressions ; in practice, the complex history of drainage channels results in a diverse pattern of sands and clays in three dimensions.

A considerable range of clays, sandy clays and sands is to be expected due to the mixed parentage, the influence of fluctuating drainage conditions with annual flooding, and the redistribution of surface materials by surface waters. However, like the lower slope soils, the mixed parentage gives rise to a few soils only, of which three series are dominant. These are Ofin series which is developed in coarse sand, Oda series which is developed in silty clay, and Kakum series which is developed in better drained silty clay on the landward banks of levees.

Ofin series : profile description

Ofin series consists of an undifferentiated topsoil overlying coarse sand. There may be a slight accumulation of litter during the dry season in the ochrosol zone, but this is rapidly assimilated when the wet season commences. The topsoil sonsists of 3-5 inches of grey to greyish brown (10YR 5/1) humous sand which is structureless and loose. There is an abrupt transition into parent material of coarse sand, some 3-5 feet thick, which is structureless and loose. In the upper layers of the grey to whitish grey (10YR 7/1) sand, red rusty root channels are frequent, while slight yellow mottles may be seen at depth. A stoneline, 6-8 inches thick, of small, subangular quartz stones occurs at the base of the alluvia, and indicates the location of a perched water table. Decomposing rock directly underlies the stone-line.

The fine earth fraction is high and consists almost exclusively of fine and coarse sand. The percentage of coarse material in the stoneline varies from 1-40 per cent.

The reaction is very acid to highly acid in the topsoil with pH values between 4.6 and 5.6. There is a decrease in acidity with depth, and neutral reactions with pH values of 7.0 may be obtained. Nutrients are concentrated entirely in the organic matter fraction in the humous horizon. The organic status is low, however ; 1-2 per cent being average value. The parent material, composed of coarse sand, is inherently infertile.

Close to the contact zone of the granite intrusions and the metamorphosed sediments, the parent material is slightly heavier in texture, being loamy sand. This variation is termed Temang series, and it is distinguished from Ofin series in the field by a characteristic bluish tinge. Ofin series, like Nta series on the lower slopes, should be classified as a regosol associated, in this instance, with forest grey acid gleisols.

<u>Oda series : profile description</u>

Oda series is a grey, silty clay soil. The topsoil, which is usually undifferentiated, is similar in depth and colour to Ofin series, but the texture is silty clay. The transition to the parent material is less marked however, and traces of humous staining may be observed to 12-16 inches. Orange, yellow, grey and brown mottles are prominent in the 3-4 feet of light grey (10YR 7/2) matrix of light clay. The stoneline may not be as well defined as that of Ofin series.

The fine earth fraction is of the order of 95-100 percent above the stoneline, with silt and clay being the dominant constituents. Variations in texture due to differential deposition are common, and the stoneline may be absent from the profile.

Topsoil reactions are moderately acid with pH values of 5.6 to 6.0. Acidity increases in the lower layers to pH values of 5.0 to 5.4. Again, some variation may be noted dependent on the derivation of the alluvial parent material.

This series belongs to the grey acid gleisols. In the permanently wet conditions of the typical vegetation of swamp forest, oxidation of iron is reduced to a minimum and the predominant colour below the horizon of vegetable residues is grey. As long as an outflow of drainage is maintained, and the principal country rock is acid, then the swamp floor deposits will be acid also.

Grey neutral gleisols are extremely rare. They consist of a grey, plastic heavy clay with poor drainage features. The clay is fairly impermeable and the soil is usually permanently waterlogged on the flat valley bottoms ; on the rare occasions that it does dry out, the clay forms into a hard cake. It is probable that this soil develops when montmorillonite is present in the clay fraction.

<u>Soils of the levees.</u>

The presence of levees is a normal feature in association with rivers subject to pronounced variations in seasonal flow. In Ghana, this feature is well developed along the banks of contemporary streams and small rivers, and also fringing old river courses. It is most marked in the topography of areas underlain by granite ; in the broad valleys of the metamorphosed sedimentary areas, it may be absent. By their mode of origin, levees occur as narrow, discontinuous strips which are relatively inextensive ; where they occur in association with the terrace deposits along the principal rivers, the total areal expanse may be significant. This is due to the recurrent impedance of the large number of streams and minor rivers entering the major drainage channels when the latter are in flood. Consequently, these streams are continually overflowing their banks and depositing levee alluvium.

The levees are composed of fine sand in which Chichiwere series is developed. On the inner slope away from the river, Kakum series is a more extensive, and agriculturally more important, soil.

<u>Chichiwere series : profile description</u>

The topsoil is undifferentiated and consists of 4-5 inches of light brownish grey (10YR 6/2) loamy sand grading to fine loam. Humus and root fibres are present, but the horizon is structureless and loose like the 5-6 feet of grey or pale brown (10YR 6/3) fine sand which it overlies, although there is slight compaction with depth. Faint grey, brown or orange stains may be visible. Where the soil occurs in association with granite topography, minute mica flakes are present in the parent material. At the base, there is a stoneline of quartz gravel in a coarse sand matrix, overlying weathered bedrock.

The surface reaction ranges between pH 5.5 and 6.0, but is usually slightly acid. In the parent material, pH values of 6.0 to 7.0 are characteristic. Organic matter and nitrogen are concentrated in the topsoil but even here are relatively low : 2-3 per cent carbon in proportion to 0.1 - 0.2 per cent nitrogen. Below the topsoil, both carbon and nitrogen are negligible with values below 0.2.

Chichiwere series is classified as an alluviosol since the constant addition of fresh material at the surface prevents the development of a true soil profile.

<u>Kakum series : profile description</u>

As well as occurring on the inner banks of levees, Kakum series is also developed on the flat, narrow, scattered alluvial deposits of the flood plain which are situated 8-10 feet above the dry season level of the major rivers and their larger tributaries.

Beneath the leaf litter layer characteristic of the forest environment, there is 2-3 inches of greyish brown (10YR 5/2) humous, sandy light loam. Root hairs and decaying organic matter may be abundant in this layer, although there is no structure and the soil is loose and porous. This grades into 4-8 inches of humous stained, sandy loam which is dominantly pale grey or greyish brown (10YR 6/2) with distinct brown and yellow stains. Under cultivation, when the humous layer is disturbed, there is staining to be observed at the surface. Although the lower topsoil is structureless and loose, and roots extend down into it, the porosity is less than the surface layer.

The topsoil merges into 3-5 feet of light brownish grey (2.5YR 6/2) sandy light clay with grey, yellow and orange mottles. These are, of course, more conspicuous in the wet season and are fainter in the dry season. No structure is to be observed, and the soil is mainly loose and porous ; in the terrace areas, however, the consistency is slightly heavier.

At the base of the levee deposits, there is characteristically 18-24 inches of grey or whitish grey sand with yellow and orange mottles. A stoneline of quartz gravel and, occasionally, subangular quartz stones, is frequently present in this layer which is structureless and loose. In turn, it directly overlies mottled light clay, slightly plastic, of decomposed bedrock. Since the levees are mainly associated with minor drainage channels, the depth of the deposits are not great and seldom exceeds 5 feet. At the base of the levee slope, the clay overlies sand deposited prior to the building of the levee formation.

The fine earth fraction in the topsoil is composed of approximately equal proportions of sand, silt and clay. There is an accumulation of clay, up to 50 per cent, in the upper 18 inches of the subsoil, but below this, the clay fraction decreases steadily to negligible quantities in the sand layer. Silt, apart from the topsoil, is low throughout ; fine sand increases down the profile in inverse ratio to the clay content. At the base of the profile, coarse sand is dominant and comprises 70 per cent or more of the fine earth fraction. In areas associated with Birrimian sediments, particularly in the Lower Tano Basi, the texture of the soil is heavier with a higher proportion of silt and a corresponding decrease in sand.

Coarse material is restricted, on the whole, to the sand layer at the base. Rare quartz gravel may occur in the clay horizon, but is atypical. In the granite areas, minute mica flakes may be present throughout. The stoneline is composed predominantly of fine and coarse quartz gravel, possibly totalling 10-15 per cent of the soil. Quartz stones, when present, are usually small and partially rounded.

The reaction is moderately to very acid throughout the profile with pH values between 5.0 and 5.6. Towards the base, the reaction becomes less acid and pH values increase until slightly acid reactions, pH 6.4 - 6.6, are obtained in the underlying bedrock.

Kakum series is a grey acid gleisol. In the north of the zone it is relatively unimportant, areally and in contrast to the ochrosols of the uplands. As dissection of the landscape and rainfall increase towards the southwest, however, the soil becomes an important member of the catena and forms a better cocoa soil than the sedentary soils of the uplands. Eventually, with increasing acidity, the soil is termed Kwaben series and classified as a grey very acid gleisol in the Lower Tano Basin. In this region, it becomes the most valuable and productive soil in the topographic sequence. This is because the base exchange capacity is similar between the upland and the valley bottom soils, but the latter has a higher fine earth fraction with greater total base reserves. It is the only soil which supports cocoa in the oxysol zone. Full analytical data and detailed descriptions for this area have been given by Ahn (1961).

Chapter 15

SOIL MAP OF THE CLOSED FOREST ZONE

Prior to the establishment of the formal soil survey in Ghana, very little systematic soil surveying had been carried out in the tropics and practically none at all in territories where shifting cultivation was practiced. It was necessary for Charter (1949a,1949c) to devise methods of soil survey whereby the soils of the country could be differentiated and mapped within a reasonable period.

It was not possible to adopt the systems of temperate latitudes because of the differences in environment and economic organisation. In the tropics, the nature of the terrain, the form of the vegetation, particularly forest and secondary regrowth, and the lack of permanent fields are formidable obstacles to routine survey. Soil patterns are more complex and with finer gradations over small expanses in the forest zone, while forms of cultivation with mixed cropping and shifting cultivation deprives the surveyor of any assistance in assessing the merits of a particular soil.

The purpose of a soil map is three fold : primarily it records the distribution of the differentiated soils, secondly, it permits correlation with other environmental factors, and thirdly, policies of land use may be defined on varying scales according to the properties and potentialities of the soils.

A soil map is not a final document. It merely records a stage in the accumulation of data of the environment based on the information available at the time. The essential requirement is to define mapping units which are based on inherent properties of the soil, and not on potentialities as these change with increased knowledge and improved techniques.

Soil mapping units.

The individual soil is the soil series. At lower levels of classification, a subseries may be defined based on some unalterable characteristic of the profile such as depth, content of coarse material, etc. ; a soil phase may be defined where the profile has been modified, usually in the topsoil, by some external influence, such as cultivation or erosion, and which, granted no further disturbance, would ultimately have the normal profile restored by the operation of environment factors.

It is impracticable, however, to map the individual soils of the forest zone, except where the detail required is sufficient to warrant the expense and effort involved. The heterogeneous pattern of soils, the relative shortage of good communications, the methods of agriculture and the inability to utilise the techniques of aerial photography within the forest zone render individual differentiation on a large scale impossible.

But soils cannot be considered independently of the topography and vegetation that characterise them, and each landform has a characteristic pattern of soils. Therefore, over any particular rock, under constant climatic and vegetation conditions, the pattern of soils are determined by differences in relief and drainage. These patterns are grouped into geographical assemblages, termed soil associations, which form natural and integral parts of the landscape. Four mapping units were defined (S.L.U.S., 1957) :-

1. A soil association comprises a group of soils formed from similar parent materials and possessing similar profile morphology, but differentiated by relief and drainage.
2. A compound soil association comprises soils developed in parent materials derived from a common source, but with different profile features according to topographic site. This is the most useful mapping unit in the forest zone. It includes the sedentary soils of the uplands grouped with the yellow, seasonally poorly drained colluvial soils and the grey, perennially ill-drained, alluvial soils. Such a grouping corresponds to the catena concept of Milne.
3. A complex soil association comprises a group of topographically related but diverse soils which due to the limitations of the scale of mapping cannot be mapped separately.
4. A soil complex comprises a group of diverse soils which are unrelated topographically.

Soil map of the closed forest zone.

There are two soil maps in this study : in Fig. 2a, the soils are classified genetically into great soil groups ; in Map 1 (end paper), the soils are classified in more detail by parent materials within the great soil groups. Fig. 2a is a relatively simple map which was prepared for inclusion in the Ghana atlas. It is a revised edition of Charter's preliminary map of the great soil groups (S.L.U.S., 1957) and delineates the boundaries of the oxysols, ochrosols, ochro-oxysol intergrades, rubrisol-ochrosol intergrades and lithosols ; the regosols are represented by a strip of conventional width along the southwest coast. There are two printin/ errors on it : Ho is situated in Trans-Volta Togoland and not in Western Ashanti, and there should be a strip of coastal thicket soils delineated from Takoradi to Accra.

The most recent published map of the soils of the forest zone classified them in terms of their suitability for cocoa production on the basis of their physiaal and chemical properties (Crosbie, 1957a). This map has been amended, within the limitations of scale, and the major topographical associations of parent materials within the great soil groups have been distinguished.

Chapter 16

ENVIRONMENTAL FACTORS IN AGRICULTURAL LAND UTILISATION

Climate and soil are the dominant environmental factors in defining the principles of agricultural land utilisation in the closed forest zone. Under the present economic and social organisation of agricultural production, and in the forseeable future, the physical factors are of prime importance in the continuous cultivation of the land either for subsistence crops or for perennial tree crops. The operation of these factors, both in distribution and influence, is complex within the forest zone.

The equatorial monsoon climate provides perpetually warm and moist conditions. These are eminently suited to the growth of crops and it is this factor, rather than soil fertility, which is the great asset of the forest zone (Charter, 1955). In chapter 3, it was noted, however, that such conditions are not conducive to high quality crops which would be heavy yielding or resistant to disease, but are favourable to pests, weeds and disease.

Pedologically, the climate leads to deep weathering of parent rocks to a degree whereby fresh plant nutrients are released at a depth beyond the reach of plant roots. The intensity of weathering is marked, particularly in the upper part of the solum, and only the unweatherable residues of quartz, kaolinitic clays and sesquioxides, which have a low capacity for retaining moisture or nutrients are left. Leaching of bases leads to acidity in the soil and a common low level of fertility, but the degree of leaching varies according to the rainfall regime and the two zones of the ochrosols and oxysols are distinguished. In the former, there is an accumulation of bases during the dry season and the soil profile is consequently less acid. In the latter, leaching is continuous with permanent acidification of the soil. The effectiveness of the rainfall is proportional to the moisture retaining capacity of the soil which, in turn, is related to the texture and slope. The intensity of the rainfall on exposed soil would result in widespread erosion and the disappearance of the topsoil.

The organic matter content of the soils is also relatively low as the climate favours intense activity of micro-organisms with a consequent rapid decomposition of animal and plant residues, so that there is no accumulation. The humous topsoil and the leaf litter layer are correspondingly thin.

Soil factors in agriculture.

Within the zonal distribution imposed by climate, the characteristics of the upland soils are common irrespective of the site or parent material. Unweatherable residues of rock decay form the basis of tropical red earths. These climatophytic soils tend to become puddled under direct impact of heavy rainfall and to become indurated when exposed to direct insolation, unless a friable structure is preserved by the maintenance of a satisfactory vegetative cover.

The profile consists of a humous, loamy topsoil overlying a subsoil of locally transported mineral matter grading into weathered parent material. The topsoil is the horizon in which the vegetation grows, the biological activity is concentrated, and the nutrients are stored.

Organic matter is the key to productivity. It is concentrated in the topsoil, principally in the upper 2-3 inches, and in such well drained, well aerated soils, it is rapidly oxidised. The exchange capacity, together with the phosphorus and nitrogen content, is practically a function of the organic matter because of the relative incapacity of the fine earth fraction to hold mineral bases. Inherent fertility is a function of the parent material. Soils derived from base rich rocks are well supplied with nutrients, but other sedentary soils have limited resources, and transported materials are usually almost devoid of plant foods.

Physical, rather than chemical, properties differentiate the forms of land use. The proportion of coarse material is directly related to the availability of nutrients, drainage and aeration status of the soils. These properties are not easily modified, particularly on the undulating topography of the forest zone.

Chemical properties are related to the zonal distribution of the great soil groups. Little is known of the availability of plant nutrients in the oxysols, although it must be low, but there is an excess of aluminium which may be present in amounts sufficient to be toxic to some plants (Ahn, 1961). Plant growth, which is the key to any form of agricultural production, is markedly affected by soil acidity, although the mechanism is not comprehended as yet. Until there is data on the major plant requirements, trace elements are relatively unimportant, although they have been observed and studied, e.g. zonc deficiency has been noted where dumps of decomposing cocoa pods have upset the nutrient balance in the soil (Greenwood and Hayfron, 1951).

Lastly, the diversity of the distribution of individual soils demands general applications of principles rather than the practice of specific policies. This diversity is partly due to topographic sequences and partly due to the mosaic pattern of the parent materials. Micro relief is also irregular with tree stumps, surface indentations of uprooted trees, and termite mounds being characteristic. Much of the earth of the termite mounds consists of mineral matter from the subsoil, and care must be taken to prevent distributing this sterile material.

Principles of agriculture.

Any system of farming on upland soils must be primarily concerned with the conservation and provision of organic matter. Artificial fertilisers, while probably essential for the development and consistent yields of crops grown, cannot by themselves maintain productivity permanently.

Two policies of maintaining soil fertility are required : one for food farming, the other for perennial tree crops. Organic matter can be conserved in the soil in four ways under a subsistenwe agricultural economy. Initially, the soils should be disturbed as little as possible in order to avoid aeration. When land is cleared, stumps should not be killed off, but should be left to sprout and rot, so that the network of roots will retain the soil in place. The impostance of this factor is fundamental to any scheme for mechanisation on these soils. Secondly, the balance of nutrients may be maintained by growing mixed cultures, rather than pure stands of crops. This practice necessitates hand cropping if food crops only are grown. Legumes could be interplanted with food crops for fallow however, and these could be mechanically cropped. Thirdly, the land should be kept shaded for protection against insolation and erosion. Finally, there should be a successional rotation of crops to aid the return to bush fallow : generally, annuals in the first year giving way to semi-perennials in the second or third year, with the last crop being harvested after the farm has returned to bush.

Traditional methods are ideally suited for this purpose. Some mineralisation of humus is inevitable on cropping, and large quantities of nutrients are leached out of the topsoil during this period, but whether these are lost from the profile is not known. A single cropping period of 1-3 years will not decrease the exchangeable cations in the soil (Nye and Greenland, 1960).

The replacement of organic matter may be affected by animal manure or vegetative fallows. At present, environmental conditions preclude the widespread use of animal manures. Even if this were feasible, however, it implies the importation of artificial fertilisers for improving pastures and concentrated foodstuffs for animal nutrition. Little benefit will be derived from manure locally available, since it merely consists of feeding one area of land at the expense of another.

Vegetative fallows are therefore the prime means of renewing organic matter. These fallows help to provide nutrients, see chapter 4, to restore tilth, to crowd out obnoxious weeds, and to prevent erosion. The potentialities of bush fallowing are not thoroughly understood, but the following aspects are vital. The composition of bush fallow in natural regeneration requires further study for it appears that the quality of the fallow is more important than the quantity. A short elephant grass fallow will give the same amount of organic matter as bush fallow over a longer period, yet it may be less beneficial, for it is probable that the success of the fallow system depends not only on the total amount of nutrients replaced in the soil, but also on the proportion of each.

Improvement of the natural fallow is often suggested, but there is no evidence that a planted fallow will restore fertility any faster than the natural woody vegetation. The species which could be useful probably include the Legu minosae, some of which make available nitrogen and phosphorus to other plants, but, at present, they are insignificant and unimportant both in bush fallow and cocoa farms. It is desirable that a species should also provide an economic product, such as firewood or charcoal wood. Although the natural succession may be aided by the introduction of indigenous species, experience in Sierra Leone has shown that, especially in areas which have been heavily cultivated, botanical successions must proceed naturally and cannot be telescoped (Macgregor, 1940).

The period of fallow varies greatly throughout the tropics and assessment must be made for each region of the time required for the restoration of a reasonable degree of fertility in relation to the pressure of population, In Ghana, seven years is generally taken as the minimum period, but the Forestry Department regard this as inadequate and recommend fifteen to twenty years. This coincides with the formation of layered forest, and the evidence in chapter 4 would support this recommendation. Nye and Greenland (1960) have established that as the period of fallow declines, so does the amount of phosphorus and potassium added in the ash, the level of humus, and the amount of nitrogen and phosphorus mineralised from it. Ultimately, a stage is reached whereby the fertility is so low that the decrease in yield would offset the extra time available for cropping.

Organic matter in farms with perennial tree crops may best be maintained by preserving a canopy to shelter the soil and stabilise the environment, by spacing the trees according to crop and yield, and by planting the trees in lines parallel to the contour in order to minimise loss by erosion and to conserve moisture. Mulches may be applied between rows of trees, and careful husbandry can keep weeds at a minimum. Perennial tree crops are particularly suitable in the oxysol zone as they minimise the risk of erosion.

The long term effects of subsistence agriculture on the fertility of the soil depends partly on the inherent qualities due to pedogenic factors of climate, vegetation and parent material, and partly on the history of land utilisation. Under the present system of land utilisation, with a trend towards shorter fallows and increasing monoculture or mere crop rotation for specialised food production, the capabilities and potentialities of the forest soils are decreasing each year. The continual degradation of the natural vegetation is reflected in the consequent deterioration of the soil.

Chapter 17

PEDOLOGY AS A BRANCH OF GEOGRAPHY

Recognition of the fact that a prosperous and permanent agriculture depends on the conversion of the present, mainly exploitative systems of farming to systems that conserve or augment the productivity of the land, is fundamental to any policy for the development of the economy of Ghana. The closed forest zone possesses environmental conditions favourable to the production of certain commodities, e.g. cocoa, for which there is a world market, and these resources should be utilised to the best advantage. At present, the production per man is extremely low and based on a primitive form of land tenure and fragmented holdings. Systems of organisation must be devised which will utilise economically the fragmented cultivation pattern, with modifications for their operation on different landform units.

The most valuable resource of the zone is the soil. In this study, the principles of soil formation have been outlined and the consequent characteristic features of the great soil groups described. The dominating influence of vegetation in the formation of the soil profile, the development of a reserve of plant nutrients and their gradual release with decomposition of the organic matter in surface layers, can hardly be over-emphasised, and methods of maintaining these conditions within the indigenous agricultural systems have been suggested. Over much of the forest zone, and particularly in the oldest cocoa growing areas in the east, the soils are degraded. Unless the deterioration of the soils is to continue, the factors of pedogenesis must be comprehended and methods of crop husbandry adapted to preserve the features of the soil. Unfortunately, in a peasant subsistence economy, the dissemination of the concept of conservation of resources is extremely difficult and there is little doubt that future generations will inherit soils whose productivity has been impaired, in some cases permanently.

Pedology in the field of geography.

Soils are part of the physical environment and as such come within the field of the geographer. Ecological balances and the utilisation of soils by man are aspects of study for the geographer, and indeed, present a wide and largely untouched subject for clarification, classification and correlation. Yet there is another basic factor which brings pedology within the geographical discipline.

Soils are expanses. They form part of the landscape and are three dimensional. In morphological analysis, soils achieve unity through geographical relationships or through local environmental conditions such as moisture regimes. Zonality and intrazonality are geographic features, and the soils of the various continents develop special characters and may be unique. Any system of classification must place as much emphasis on geographical relationships as on other factors.

There is also a more practical and urgent reason for geographical study. Comprehension of the soils is essential for development, particularly in tropical lands. Agricultural policy and development should be based on the physical environment which prevails in any region. Other things being equal, the soil comes first.

A geographer, by his discipline and technical skill, has a distinct advantage in the field of pedology. In the first place, he is able to comprehend soils as natural bodies with areal extent, and not as vertical sections for study and description. In the second place, he is able to communicate knowledge and description of soils through the techniques which he normally employs. Maps, quantitative treatment, and descriptions are his tools for distributing the facts to the people who require them, and these people are not specialist pedologists. In the majority of cases, they are people engaged on agriculture either as farmers or agricultural advisers. Foresters, engineers and hydrologists require facets of soil information, and the geographer is well qualified to present these data.

The distribution of soils is a physical fact of the greatest importance. Once again, the geographer is working within his discipline. In undeveloped areas, mapping soils is very largely a problem of mapping landscape units in terms which provide an accurate description, a genetic identification and an evolution curve for the current erosional processes. This requires an expert knowledge of landforms, an expert knowledge of soils, especially of profile and hydrological properties, and training in areal surveying, particularly of levelling in small areas for detailed study.

The use of natural regions for development projects is gradually being recognised. Such a region is the normal unit of study to the geographer, and one which he accepts with its limitations and advantages. Again, in undeveloped countries, this is an essential requirement where rainfall regimes are pronounced.

In surveys of natural resources in thinly populated or undeveloped territories, it has become the practice to employ teams of specialists in many related aspects to collaborate in field work. Yet the synthesis of their individual reports must be done by one man : for this task, the geographer as a correlator is unsurpassed.

By so doing, the geographer can make a practical contribution to world agricultural problems, a contribution based on his knowledge of environments. In assisting the understanding, and demonstrations, of the limitations and potentials of the environment, a task which constantly changes in relation to technological skill, and cultural level of society, the geographer fulfils an essential duty.

REFERENCES

ADAMS, S. N. and McKELVIE, A. D. 1955. Environmental requirements of cocoa in the Gold Coast. Rpt. Cocoa Conference, London.

AGRICULTURE DEPARTMENT, GOLD COAST. 1935. Proposed soil survey. Chemical Division. (Mimeo.)

AHN, P. M. 1958. Regrowth and swamp vegetation in the western forest areas of Ghana. J. West Afr. Sci. Ass., 4, No. 2.

AHN, P. M. 1959. The principal areas of remaining original forest in western Ghana and their agricultural potential. Kumasi. Div. of Agriculture, Soil and Land-Use Branch. (cyclostyled) ; copy of paper to 7e Conf. Int. des Africanistes de l'Ouest, Accra.

AHN, P. M. 1961. Soils of the lower Tano basin, southwestern Ghana. Accra. Div. of Agriculture, Soil and Land-Use Branch. Memoir No. 2.

AUBREVILLE, A. 1947. Erosion et bovalisation dans l'Afrique francais noir. L'Agronomie Tropicale, No. 7-8.

BARTHOLOMEW, W. V., MEYER, J., and LAUDELOUT, H. 1953. Mineral nutrient immobilisation under forest and grass fallow in the Yangambi (Belgian Congo) region with some preliminary results on the decomposition of plant material on the forest floor. Brussels. I.N.E.A.C. Ser. Sci. No. 57.

BATES, D. A. 1962. Geology. in Wills, J. B. (Ed.) Agriculture and land use in Ghana. London.

BEARD, J. S. 1946. The natural vegetation of Trinidad. Oxford For. Mem. No 20.

BECKINSALE, R. P. 1957. The nature of tropical rainfall. Trop. Agric., 34.

BELFIELD, W. Private communication.

BRAMMER, H. 1955. Detailed soil survey of the Kpong pilot irrigation area. Kumasi. Dept. of Soil and Land-Use Survey. Memoir No. 1.

BRAMMER, H. 1956. C. F. Charter's interim scheme for the classification of tropical soils. Kumasi. Dept. of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. of Soil Sci.

BRAMMER, H. 1962. Soils. in Wills, J. B. (Ed.) Agriculture and land use in Ghana. London.

BRASH, H. T. 1962. Geomorphology. in Wills, J. B. (Ed.) Agriculture and land use in Ghana. London.

BUSHNELL, T. M. 1942. Some aspects of the soil catena concept. Proc. Soil Sci. Soc. of Amer., 7.

CAMPBELL, J. M. 1917. Laterite : its origin, structure and minerals. Mining Mag., 17.

CARTER, G. F. and PENDLETON, R. L. 1956. The humid soil : process and time. Geog. Review, XLVI.

CHAMNEY, N. P. 1929. The hourly distribution of rainfall in the Gold Coast. Dept. of Agriculture Yearbook, Paper XLIII. Accra.

CHARTER, C. F. 1940. A reconnaissance survey of the soils of British Honduras. Belize.

CHARTER, C. F. 1948. Cocoa soils - good and bad. West African Cocoa Research Institute. (cyclostyled).

CHARTER, C. F. 1949a. The detailed reconnaissance soil survey of the cocoa country of the Gold Coast. Rpt. Cocoa Conference, London.

CHARTER, C. F. 1949b. The characteristics of the principal cocoa soils. Rpt. Cocoa Conference, London.

CHARTER, C. F. 1949c. Methods of soil survey in use in the Gold Coast. Bull. Agric. Congo Belge, XL.

CHARTER, C. F. 1950. The organisation of soil surveys in British West Africa. Proc. Afr. Regional Sci. Conf., 1949, Vol. II.

CHARTER, C. F. 1955a. Expanded legend to the provisional soil association and soil complex map of the Ayensu and Densu basins. Kumasi. Dept. of Soil and Land-Use Survey. Tech. Rpt. 8.

CHARTER, C. F. 1955b. The nutrient status of Gold Coast forest soils with special reference to the manuring of cocoa. Rpt. Cocoa Conference, London.

CHIPP, T. F. 1927. The Gold Coast forest : a study in synecology. Oxford For. Mem. No. 7.

COLDWELLS, J. Private communication.

COLONIAL ADVISORY COUNCIL. 1944. Report of the soils sub-committee. London. C.A.C. 708 (mimeo.).

COOPER, W. G. G. 1936. The bauxite deposits of the Gold Coast. Accra. Geological Survey Bull. No. 7.

CROSBIE, A. J. 1955. Soils of the East Asufu Shelterbelt forest reserve. Kumasi. Dept. of Soil and Land-Use Survey. Tech. Rpt. 14.

CROSBIE, A. J. 1956a. Soils of the Asenanyo forest reserve. Kumasi. Dept. of Soil and Land-Use Survey. Tech. Rpt. 19.

CROSBIE, A. J. 1956b. Peneplain remnants in the Kumasi Region, Gold Coast. Kumasi. Dept. of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. Soil Sci.

CROSBIE, A. J. 1957a. The suitability of the forest soils of Ghana for cocoa production. Rpt. Cocoa Conference, London.

CROSBIE, A. J. 1957b. The Yinahin Range. Kumasi. Dept. of Agric., Division of Soil and Land-Use Survey. (cyclostyled) ; issued to members of West Afr. Sci Ass., Nov. 1957.

CROSBIE, A. J. and de ENDREDY, A. S. 1956. Correlation of field characteristics and analytical data. Kumasi. Dept. of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. Soil Sci.

CROSBIE, A. J. and HOTSON, J. McG. 1958. Mineral deposits in Afzelia africana, Sm. Emp. For. Review, 37, No. 92.

CROWTHER, E. M. 1930. The relationship of climate and geological factors to the composition of soil clay and the distribution of soil types. Proc. Royal Soc., Series B. Biological Sciences, 107.

DAVIS, W. M. 1899. The geographical cycle. Geog. Jour., XIV.

DOMMERGUES, Y. 1954a. Biology of forest soils of central and eastern Madagascar. Trans. Vth. Int. Congr. Soil Sci., III.

DOMMERGUES, Y. 1954b. Modification de l'equilibre biologique des sols forestiers. Mem. Inst. Sci. Mad., D. 6.

DOYNE, H. C., HARTLEY, K. T. and WATSON, W. A. 1938. Soil types and manurial experiments in Nigeria. Proc. 3rd. W. Afr. Agric. Conference.

de ENDREDY, A. S. and MONTGOMERY, C. W. 1954. Some nutrient aspects of the Gold Coast forest soils. Trans. Vth. Int. Congr. Soil Sci., III.

de ENDREDY, A. S. and MONTGOMERY, C. W. 1956. Some aspects of cation exchange in Gold Coast forest soils. Kumasi. Dept. of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. Soil Sci.

de ENDREDY, A. S. and QUAGRAINE, K. A. 1956. Total phosphorus in Gold Coast soils. Kumasi. Dept. of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. Soil Sci.

EVANS, G. C. 1939. Ecological studies on the rain forest of Southern Nigeria. II. The atmospheric environmental conditions. J. Ecol., 27.

FOGGIE, A. 1947. On the definition of forest types in the closed forest zone of the Gold Coast. Farm and Forest, 8, No. 2.

FORESTRY DEPARTMENT. 1956. Annual Report. Accra.

FOX, C. S. 1936. Buchanan's laterite of Malabar and Kanara. Records of the Geol. Survey of India, 69.

GEOLOGICAL SURVEY. 1934. Annual Report. Accra.

GLINKA, K. D. 1914. Die Typen der Bodenbildung, ihre Klassification und geographische Verbreitung. Berlin.

GOUROU, P. 1953. The tropical world. Trans. by Laborde, E. D. London.

GREENLAND, D. J. 1956. Is aerobic denitrification important in trppical soils ? Trans. VIth. Int. Congr. Soil Sci.

GREENWOOD, M. 1938. Some Gold Coast soils. Proc. 3rd. W. Afr. Agric. Conference.

GREENWOOD, M. and HAYFRON, R. J. 1951. Iron and zinc deficiences in cacao in the Gold Coast. Emp. J. Exp. Agric., 19.

HAMILTON, R. 1954. Bowals in the Gold Coast. Tijdschr. econ. soc. Geogr., 45.

HARDY, F., DUTHIE, D. W. and RODRIGUEZ, G. 1936. Studies in West Indian soils (x) - the cocoa and forest soils of Trinidad. Port of Spain.

HARRASSOWITZ, H. 1930. Boden der Troposchen Region (y) Laterit und allitischer (lateritischer) Rotlehm. in Blanck, E. Handbuch der Bodenlehre. Vol. III. Berlin.

HARRIS, C. M. 1933. Stone in Chlorophera excelsa. Emp. For. Jour., 12, No. 2.

HARRISON, J. B. 1933. The katamorphism of igneous rocks under humid tropical conditions. Ed. by F. Hardy. Imp. Bur. Soil Sci.

HOTSON, J. McG. 1956. Some little known soils of the closed forest zone of the Gold Coast. Kumasi. Dept. of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. Soil Sci.

HUNTER, J. M. 1959. Aspects of the erosional history of the upper Birim Basin, Ghana. J. West Afr. Sci. Ass., 5, No. 2.

HUNTER, J. M. 1961. Morphology of a bauxite summit in Ghana. Geog. Jour., 127, Pt. 4.

JENNY, H., GESSEL, S. P. and BINGHAM, F. T. 1949. Comparative study of decomposition rates of organic matter in temperate and tropical regions. Soil Sci., 68, No. 1.

JUNNER, N. R. 1940. Geology of the Gold Coast and Western Togoland. Accra. Geol. Survey Bull. No. 11.

JUNNER, N. R. 1943. The diamond deposits of the Gold Coast with notes on other diamond deposits in West Africa. Accra. Geol. Survey Bull. No. 12.

JUNNER, N. R. and HIRST, T. 1946. The geology and hydrology of the Voltaian basin. Accra. Geol. Survey Mem. No. 8.

KEAY, R. W. J. 1959. Vegetation map of Africa. London.

KELLOGG, C. E. 1941. Climate and soil. in Hambidge, Gove (Ed.) Climate and man. Washington. Yearbook of Dept. of Agriculture.

KELLOGG, C. E. 1948. Preliminary suggestions for the classification and nomenclature of great soil groups in tropical and equatorial regions. Proc. 1st. Common. Conf. on Trop. and Sub-Trop. Soils, 1948. Harpenden. Common. Bur. Soil Sci., Tech. Comm. 46.

KELLOGG, C. E. and DAVOL, F. D. 1949. An exploratory study of soil groups in the Belgian Congo. I.N.E.A.C. Ser. Sci. 46.

KINLOCH, D. and MILLER, W. A. 1949. Gold Coast timbers. Takoradi.

LANE, D. A. 1962. The forest vegetation. in Wills, J. B. (Ed.) Agriculture and land use in Ghana. London.

LEEPER, G. W. 1954. The classification of soils - an Australian approach. Trans. Vth. Int. Congr. Soil Sci.

MACGREGOR, W. D. 1940. First impressions of forestry in Sierra Leone. The Nigerian Forester, 1,

MARBUT, C. F. 1928. A scheme for soil classification. Proc. 1st. Int. Congr. Soil Sci., IV.

MARSHALL, R. C. M. 1945. Silvicultural notes on some of the more important Gold Coast trees. Accra.

MARTIN, F. J. and DOYNE, H. C. 1927a. Laterite and lateritic soils in Sierra Leone. J. Agric. Sci., 17.

MARTIN, F. J. and DOYNE, H. C. 1927b. Soil investigations with special reference to a soil survey of British West Africa. Proc. 1st. West Afr. Agric. Conf.

MARTIN, F. J. and DOYNE, H. C. 1930. Laterite and lateritic soils in Sierra Leone, II. J. Agric. Sci. 20.

MARTIN, F. J. and DOYNE, H. C. 1932. Soil survey of Sierra Leone. Freetown.

MILNE, G. 1935a. Some suggested units of classification and mapping, particularly for East African soils. Soil Res., 4.

MILNE, G. 1935b. Composite units for the mapping of complex soil associations. Trans. 3rd. Int. Congr. Soil Sci., I.

MILNE, G. 1936. A provisional soil map of East Africa. Amami Memoirs.

MILNE, G. 1940. A report on a journey to parts of the West Indies and the United States for the study of soils. Dar es Salaam.

MILNE, G. 1947. A soil reconnaissance journey through parts of Tanganyika territory, Dec. 1935 - Feb. 1936. J. Ecol., 35.

MOHR, E. C. J. and van BAREN, F. A. 1954. Tropical soils. London.

MONTGOMERY, C. W. 1952. Summary of descriptions of certain Gold Coast geological formations. Kumasi. Dept. of Soil and Land-Use Survey. Dept. Paper, No. 10.

MOORE, Decima and GUGGISBERG, F. G. 1909. We two in West Africa. London.

MOULD, A. W. S. 1957a. Report on the detailed soil survey of Kpeve agricultural station, Kpandu district, Trans-Volta Togoland. Kumasi. Dept. of Soil and Land-Use Survey. Tech. Rpt. 24.

MOULD, A. W. S. 1957b. Report on the semi-detailed soil survey of Akaa cocoa research station. Kumasi. Dept. of Soil and Land-Use Survey. Tech. Rpt. 27.

NYE, P. H. 1954. Some soil forming processes in the humid tropics l. A field study of a catena in the West African forest. J. Soil Sci., 5, No. 1.

NYE, P. H. 1955. Some soil forming processes in the humid tropics III. Laboratory studies on the development of a typical catena over granitic gneiss. J. Soil Sci., 6.

NYE, P. H. and GREENLAND, D. J. 1960. The soil under shifting cultivation. Harpenden. Common. Bur. of Soil Sci. Tech. Comm. 51.

OLIPHANT, J. N. 1940. The need for research on soil-vegetation-climate relationships. Nigerian Forester, L, No. 2.

OWEN, G. 1951. A provisional classification of Malayan soils. J. Soil Sci., 2.

PENDLETON, R. L. 1962. Thailand. New York. Amer. Geog. Soc. Handbook.

PERNET, R. 1952. Evolution des sols de Madagascar sous l'influence de la vegetation. Mem. Inst. Sci. Madagascar, Ser. D., 6.

PRESCOTT, J. A. and PENDLETON, R. L. 1952. Laterite and lateritic soils. Harpenden. Common. Bur. Soil Sci. Tech Comm. 47.

RADWANSKI, S. A. 1956a. Soils associated with the late Tertiary peneplain and its erosion in the upper Tano drainage basin of the Gold Coast. Kumasi. Dept. of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. Soil Sci.

RADWANSKI, S. A. 1956b. Soils developed over ancient drifts in the forest zone of the Gold Coast with particular reference to the upper Tano basin. Kumasi. Dept, of Soil and Land-Use Survey. (cyclostyled) ; copy of paper submitted to VIth. Int. Congr. Soil Sci.

RADWANSKI, S. A. 1957. Cocoa soils of Western Ashanti, Ghana. Rpt. Cocoa Conf., London.

REED, W. E. 1951. Reconnaissance soil survey of Liberia. Washington. U.S. Dept. of Agric., Information Bulletin, 66.

RICHARDS, P. W. 1957. The tropocal rain forest. London.

ROBERTS, R. C. 1942. Soil survey of Puerto Rico. Washington. U.S. Dept. of Agric., Bur. Plant Indust. Ser. 1936, No. 3.

ROBINSON, G. W. 1951. Soils : their origin, constitution and classification. London.

SHANTZ, H. L. and MARBUT, C. F. 1923. The vegetation and soils of Africa. New York. Amer. Geog. Soc. Research Ser. 13.

SMITH, J. 1949. Distribution of tree species in the Sudan in relation to rainfall and soil texture. Khartoum. Agric. Pub. Committee, Min. of Agric. Bull. No. 4.

SOIL AND LAND-USE SURVEY DEPARTMENT. 1957. Report for the period 5th. June, 1951 to 31st. December, 1955.

SOIL AND LAND-USE SURVEY DEPARTMENT. 1958. Report for the year 1956.

STEPHENS, D. 1956. Fertiliser trials, 1948-51. New Gold Coast Farmer, Vol. 1, No. 1 and 2.

TANBURN, E. 1955. Cocoa in western Ashanti : interim analysis of intensive survey data and forecast production trends. Accra.

TAYLOR, C. J. 1952. The vegetation zones of the Gold Coast. Accra.

TEMPANY, H. and GRIST, D. H. 1958. An introduction to tropical agriculture. London.

TOTHILL, J. D. (Ed.) 1940. Agriculture in Uganda. London.

VAGELER, P. 1933. An introduction to tropical soils. Trans. by H. Greene. London.

VINE, H. 1953. Notes on the main types of Nigerian soils. Lagos. Agric. Dept. Spec. Bull. 5.

VINE, H. 1954. Is the lack of fertility of tropical African soils exaggerated ? Proc. 2nd. Inter-Afr. Soils Conf., I.

VINE, H. 1956a. A preliminary survey of Nigerian soils. Ibadan. Dept. of Agric. Western Region. Soil Survey Mem. No. 1.

VINE, H. 1956b. Studies of soil profiles at the W.A.I.F.O.R. main station and at some other sites of oil palm experiments. J. West Afr. Inst. Oil Palm Res., No. 4.

van der VOORT, M. 1950. The lateritic soils of Indonesia. Trans. IVth. Int. Congr. Soil Sci., I.

WAKSMAN, S. A. 1932. Principles of soil micro-biology. Baltimore.

WALDOCK, E. A., CAPSTICK, E. S. and BROWNING, A. J. 1951. Soil conservation and land use in Sierra Leone. Freetown.

WALKER, H. O. 1962. Weather and climate. in Wills, J. B. (Ed.) Agriculture and land use in Ghana. London.

WEST AFRICAN COCOA RESEARCH INSTITUTE. 1946. Annual Report.

WOOLNOUGH, W. G. 1927. Presidential address Part I : The chemical criteria of peneplanation : Part II : The duricrust of Australia. Proc. Roy. Soc. N.S.W., 61.

Map 1.

SOILS OF THE CLOSED FOREST ZONE OF GHANA.

Based on Crosbie 1957a. and Ahn 1961.