PUBLICATION Nº 93

SOIL MAP OF AFRICA SCALE 1 TO 5000000

Explanatory monograph

by

J.L. D'HOORE

Joint Project no. 11

LAGOS 1964

Commission for Technical Co-operation in Africa

Commission for Technical Co-operation in Africa

PUBLICATION No. 93

SOIL MAP OF AFRICA SCALE 1 TO 5 000 000

EXPLANATORY MONOGRAPH

BY

J.L. D'HOORE

Chargé de cours associé at the Catholic University of Louvain
Formerly Director of the Inter African Pedological Service
General co-ordinator of Joint Project no 11

Joint Project no. 11

LAGOS

1964

PREFACE

It is indeed a privilege for me to write the preface to this invaluable work which was begun ten years ago as Joint Project No 11 of the Commission's activities.

Over the years, Member Governments repeatedly confirmed their intention to reach agreement on the classification and definition of soils in Africa, and to present the assembled details as an atlas which, like the climatological atlas which has been published recently, would provide the necessary information for land use planning in development programmes. Thus the idea for the pedological map of Africa was born. It took some time to prepare the first, second and third drafts of this map, and in 1961 the fourth draft was completed by Dr D'Hoore with the assistance of correspondence exchanged as a result of a meeting held in 1959 at Dalaba. It then became necessary to meet again in order to consider the abovementioned draft. At a meeting in Paris, therefore, in September, 1961, eleven countries and three organisations participated in three days of technical discussions after which unanimous agreement was reached on all points as to what was to appear on the map and on definitions which had previously been the subject of certain differences. This agreement deserves special emphasis in that, several years ago, few people believed that agreement would ever be reached by pedologists from opposed schools of thought. Thus we have yet another pillar of support for the theory that African governments must agree to act in concert if they are to surmount the many obstacles on the way to attaining their goal : a better Africa for all.

The fifth and last version of the map was prepared during the months which followed and now the publication of this valuable work has been made possible by a grant from the US AID. Our deep gratitude therefore goes to the U.S. government for having appreciated and considered the endeavour valuable enough for financial support.

This work covers the entire continent of Africa, including North Africa, and consists of seven maps on a scale of 1/5,000,000, utilizing the base maps supplied by the Inter-African Correspondent for Cartography under another of the Commission's Joint Projects (No. 7).

I would like to avail myself of this opportunity to join others in the many tributes that have been paid to the outstanding work of Dr D'Hoore, whose authority and competence have aroused great admiration with pedologists throug-

hout Africa. The tireless devotion of Dr D'Hoore to the completion of this project should be noted with gratitude by all who will be using this very fundamental device for future planning in the development of Africa. His contribution to the advancement of scientific progress in Africa will remain as a monumental proof of what can be achieved when the finest minds are united to search for the solution to a given problem.

RICHELIEU MORRIS
Secretary General a.i. C.C.T.A.

LIST OF CONTENTS

FOREWORD

The soils map of Africa was constructed with the direct collaboration of the following authors :

GENERAL LEGEND: : G. Aubert, H. Greene, J.V. Botelho da Costa. AFRICA OCCIDENTAL ESPAÑOLA : P. Dutil. ALGÉRIE : J. Boulaine, J. Durand, P. Dutil. ANGOLA : J.V. Botelho da Costa, A.L. Azevedo, R. Pinto Ricardo, E.P. Cardoso Franco, E.M. Silva da Camara. BASUTOLAND : C.R. Van der Merwe, R.F. Loxton. BECHUANALAND : J.S. De Beer, R.F. Loxton, C.R. Van Straten, C.R. Van der Merwe. BURUNDI : A. Van Wambeke, R. Frankart. CAMEROUN : P. Segalen. CONGO (BRAZZAVILLE) : J.M. Brugière, G. Bocquier. CONGO (LÉOPOLDVILLE) : K. Sys, R. Frankart, P. Jongen, A. Van Wambeke, P. Gilson, J.M. Berce, A. Pecrot, M. Jamagne. CÔTE D'IVOIRE : N. Leneuf, B. Dabin, G. Riou. CÔTE FRANÇAISE DES SOMALIS : H. Besairie, J. Boulaine. DAHOMEY : R. Fauck, P. Willaime. ETHIOPIA : R.E.G. Pichi-Sermolli, Anonyme Doc. F.A.O. GABON : Y. Chatelin. GAMBIA : M. Brunt. GHANA : C.F. Charter, H. Brammer. GUINÉE : R. Maignien. GUINEA CONTINENTAL ESPAÑOLA : A. Hoyos de Castro, W. Kubiena. GUINÉ PORTUGUESA : P.J. da Silva Teixeira. HAUTE VOLTA : R. Maignien, M.G. Gaveau. KENYA : G.H. Gethin Jones, R. Scott, C.G. Trapnell, J. Thorp. LIBERIA : W. Reed. LIBYA : P. Dutil. MADAGASCAR : J. Riquier, J. Hervieu. MALI : B. Dabin, B.K. Kaloga. MAROC : J. Boulaine, P.B. Billaux, G.B. Bryssine. MAURITANIE : P.A. Audry, S.P. Perreira Barreto, M.G. Gaveau. MOÇAMBIQUE : G.D.H. Gouveia, A.L. Azevedo. NIGER : G. Bocquier, M.G. Gaveau. NIGERIA : H. Vine, G.M. Higgins, A.W.S. Mould, A.J. Smyth, P.R. Tomlinson, P.D. Jungerius, C.H. Obihara. NYASALAND : G. Jackson, A. Young. RÉPUBLIQUE CENTR'AFRICAINE : M. Benoit-Janin, P. Quantin. REPUBLIC OF SOUTH AFRICA : C.R. Van der Merwe, R.F. Loxton. RHODESIA (NORTHERN) : R. Webster, C.G. Trapnell. RHODESIA (SOUTHERN) : B.S. Ellis, J.G. Thompson, RWANDA : A. Van Wambeke, R. Frankart. SÉNÉGAL : P.B. Bonfils, C.C. Charreau, J. Maymard, R. Maignien, R. Fauck. SIERRA LEONE : A.R. Stobbs, R. Allbrook. SOMALIA : R.E.G. Pichi-Sermolli, R. Dudal. SOUTH WEST AFRICA : R. Ganssen, C.R. Van der Merwe, R.F. Loxton. SUDAN : G. Aubert, H. Greene, G. Worrall. SWAZILAND : G. Murdoch, C.R. Van der Merwe, R.F. Loxton. TANGANYIKA : G.H. Gethin Jones, W.E. Calton, R. Scott. TCHAD : J. Pias. TOGO : M. Lamouroux. TUNISIE : P. Roederer. UGANDA : E.M. Chenery, C. Ollier, J.F. Harrop, J.G. Wilson, S.A. Radwansky.

The greater part of the information was collected under the auspices of the Institut National pour l'Étude Agronomique au Congo (INEAC), the

Junta de Investigaçoes do Ultramar, the Office de la Recherche Scientifique et Technique Outremer (ORSTOM) and the local agricultural services.

It is a pleasant duty to be able to offer thanks here to Mr. F. JURION, Director-General and to Professor J. LEBRUN, Secretary-General of the National Institute of Agronomic Studies in the Congo who, since 1954, have made available every facility for the undertaking of this long and exacting work. Gratitude must also be expressed to Mr. T. PATON, Joint Director (from 1959 to 1960) of the Inter African Pedological Service (C.C.T.A.), for the part he played in the drafting of the third approximation of the map. The subsequent approximations and work connected with them were carried out, from 1960 to 1962, in the departments of Professor L. DE LEENHEER of the Institute of Agronomy of Ghent and of Professor R. TAVERNIER, of the University of Ghent. Especial recognition must be given to hospitality received from them at a particularly difficult moment. Professor R. MARECHAL of the University of Ghent gave excellent advice on the numerous problems inherent in the production of the map. Mr. E. GUSTIN, Department Head at the Military Geographic Institute at Brussels, is to be congratulated for the competence and diligence with which the work was performed by the specialized services of the Institute. This work could not have been done without the co-operation of Dr. S.P. JACKSON, Professor at the University of the Witwatersrand, Johannesburg, who provided the base maps, prepared two inset maps, and was a source of valuable climatological information. Especial thanks are also due to Mr. R. FRANKART, Chef de Travaux at the Centre for the Study of Tropical Soils at the University of Louvain, who checked many facts and whose critical reading of the manuscript has resulted in some important corrections. Finally thanks are due to Prof. Dr. E.L. SCHMIDT, University of Minnesota, who kindly helped with the translation of the monograph while on sabbatical leave at the University of Louvain.

GENERAL INTRODUCTION

A — Origin of the Project

The production of a new generalised soil map of Africa (*) based on regional surveys was recorded in the programme of the Inter african Pedological Service (S.P.I.) at the time of the inaugural meeting of its Administrative Council at Yangambi, in the Congo, in October 1953. Originally it was considered a long term proposal, but due to the rapid development of soil science in Africa, it soon gained in importance and the Second Inter-African Conference on soils, held the following August at Leopoldville, entrusted the S.P.I. to undertake the general co-ordination of the work (3). The second meeting of the Council, at Yangambi, in November 1955, recommended the production of a map on the scale of 1 to 5 000 000, in direct collaboration with the four Regional Committees for the Conservation and Utilisation of the Soil.

B — General Approach and Methodology

At the beginning the co-ordinating Service found itself faced with a number of major obstacles: the available maps were few and the important lacunae were many, the mapping units were characterized by criteria and levels of abstraction which often varied from one map to the next, definitions lacked precision, and the few common terms were not used consistently throughout.

The first consideration of the Service was, therefore, to promote the production of new soils maps covering entire countries and territories. Very few suggestions were made concerning the choice of units, because it was thought likely that they would agree better than those of earlier maps, In fact, during the period 1945-1955, pedology made remarkable progress and the work of many congresses brought together the various points of view. In Africa, soil survey showed real growth and many regional systems of classification based on an increasing number of converging morphological observations and analytical data, became more and more coherent, took form and evolved closer together.

The method followed for arriving at a generalised soil map with an integrated legend, that of "successive approximations" was, in a way, imposed by the circumstances. At the moment the map was begun the majority of African soils were still not very familiar but study of them was progressing. Since it

(*) Among the earlier generalised maps are those of Shantz and Marbut (1923) (10) and of Schokalskaya (1944) (11), both on scales of approximately 1 to 30 000 000.

was necessary to construct the legend stage by stage through close collaboration with correspondents, the problem became one of maintaining a compromise between the principal regional classifications which were evolving rapidly, while continually adapting the compromise to the general theme of the map. The method involved four distinct phases which were often concomitant. The first phase could be called *the formulation of the hypotheses*. It began as a draft of the presumed distribution of parent materials. In order to establish this distribution, data on lithological rather than structural geology, data on geomorphological elements which took account of the relative age of the "surfaces", and climatological and phytogeographical documents were assembled. The hypothetical distribution of parent materials served as a theoretical framework for the first pedological sketch from which the first correlations and extrapolations were made. Each of the five successive approximations could be considered as a new working hypotheses. A second phase was the gradual revision of the hypotheses. It consisted of confronting the theoretical framework with the reality of the regional maps. Though certain imperfections were thus revealed in the extrapolated areas of these maps, it was often necessary to adapt the theory to new facts, and these adaptations induced by a given map often had repercussions over all of the general map. A third phase could be called the *promotion of agreement* on the definition of units common to the different regional maps; this was followed by modifications of these maps by their authors so as to make them conform more closely to the new integrated legend. The fourth phase was seen as the *harmonisation* of all the facts and amended hypotheses into a drawing sufficiently advanced to warrant printing.

If the formulation of hypotheses and the final harmonisation were mainly the province of the co-ordinating Service, the revisions were borne almost exclusively by the new regional maps made by application of propositions issuing from the S.P.I. The definitions of the units were elaborated in the course of numerous working sessions and the compromises which resulted were to a very great extent the work of the many collaborators.

A first comparison between the French and Belgian systems of classification took place under the aegis of the Regional Committee of Central Africa for the Conservation and Utilisation of the Soil (CRACCUS) at Brazzaville in May 1958. Much effort was made, with a certain amount of success, to establish correlations between the varying mapping units presented, and some provisional definitions were drawn up. A first draft map with a legend containing 21 units was made, correlating the maps of the former French Equatorial Africa, French Cameroon, the former Belgian Congo and Ruanda-Urundi. In March 1959 it was distributed to the various soil scientists who took part in the meeting for critical review.

The area covered by this map extended from the borders of the Sahara (Tibesti) to beyond the humid regions of the Central Congo Basin (South Katanga), and from the low Atlantic Coast to the mountain regions of the center of the continent (Rwanda-Burundi). One could therefore assume that, allowing for some modifications and additions, the legend would be applicable to a much larger area. Those few soil maps of adjacent regions that were available then were taken into consideration and a schematic map with a legend containing 23 units was drawn up, covering about two thirds of Africa to the south of the twentieth parallel north. This was the *first approximation* of the generalised map. Inevitably its legend reflected more the Belgian and French concepts than those of British, Portuguese or South African soil scientists. The map was discussed by soil scientists in Kampala (Uganda) and in Pretoria (Republic of South Africa) in April and May, 1959, in meetings organised by the Regional Committee for the Conservation and Utilisation of the Soil in East Africa, and in Southern Africa (EARCCUS and SARCCUS) respectively. The discussions and constructive criticisms collected during and following these two important meetings made possible a number of additions and corrections both to the legend and to the spatial extensions of the units, which, added to the many new documents received, amply justified a new design.

The *second approximation*, the legend of which included 35 units, was presented to the Third Inter African Soils Conference (Dalaba, Republic of Guinea, November, 1959 (4). In the course of this, four working sessions were devoted to the elaboration of a third provisional legend and to the improvement of the definition of the adopted units. The new legend consisted of 45 elements of mapping units and was to be used for the establishment of the *third approximation*. This third approximation drawn up in Yangambi in January and February 1960, covered about 80% of Africa south of the Sahara; it was shown at the Seventh International Congress of Soil Science in Madison Wisconsin, U.S.A., in August, 1960 (5), (6).

The month of July 1960 was very difficult for the Interafrican Pedological Service (S.P.I.) with its base at the Research Centre of INEAC at Yangambi close to Stanleyville. Except for a copy of the third approximation and the explanatory text of the West African part, the whole basic documentation had to be abandoned.

At the end of September 1960 the S.P.I. was able to take up its activities again, thanks to the gracious hospitality of the Institute of Agronomy of Ghent, Belgium. The diligence of the correspondents allowed the essentials of the documentation to be reestablished and it was possible to prepare a *fourth approximation* with a legend of 52 units which was presented to a meeting of specialists organised by the C.C.T.A. in Paris in September, 1961. This fourth approximation covered the whole continent with exception of North Africa.

The definitions of the elements of mapping units were revised and some complementary units added in order to allow the inclusion of the soils situated to the north of the Sahara.The resultant new legend with 63 elements of mapping units, allowed the establishment of the *fifth approximation.* This was submitted to the meeting of C.C.T.A. on the Classification of the Soils of Inter Tropical Regions, their Correlations and their Interpretation (Leopoldville (Lovanium), May, 1963). At the end of this meeting several further pieces of information were recorded in the final map draft which thereafter was considered as definitive.

C — Scientific Value of the Map

Soil maps covering with a single legend entire continents or sub-continents, define the distribution of the large soil units and display the broad lines of relationship which connect their development to the soil forming factors. They also make it possible to assess the land resources of large regions and allow extrapolation of the results of agronomic research carried out in technologically advanced territories into other, less developed areas with comparable soils and climates.

The principal objectives of soil maps are geographical and pedogenetic, and the units of the legend which suit them are geographical associations, groupings of higher level categories of classification of which the distinctive criteria reflect more the effects of the broad climatic units, and the major variations of topography and of substrate, than the utilitarian value. The choice of such groupings will adapt itself to the particular physiography of the region mapped. Nevertheless, the greater the area under consideration the more it will approach, geographically and physiographically, an average sample of the earth's land surface. That is to say then that a general legend, adjusted for a great continent like Africa, can be applicable with certain adaptations to maps of similar scales in other large areas in similar latitudes.

All generalised maps contain numbers of extrapolations and hypotheses which tend to increase in inverse ratio to the scale used. The earliest of the maps in date were very theoretical and relied almost entirely on the presumed distribution of pedogenetic factors, especially the climatic ones, without taking account of soil surveys, which, it must be added, were few at that time. The modern general maps are based first and foremost on the actual distribution of soils. Theoretical considerations amended by the information given by regional soil maps serve in the first place for establishing the canvas, the *leitmotif* of the general map. They facilitate the solution of problems which are involved in the correlation of adjacent maps, established on more or less concordant legends. They also support the extrapolations which can be of two kinds. The first follow from similarities of landscape, geological substrate, climate, vegetation, or still more, of the relative age of the surfaces. The others, while taking account of these varying factors, moreover take into consideration the soil maps of contiguous regions and thereby offer additional guarantees.

The scientific value of a generalised soil map depends above all on the percentage of the total surface covered by regional soil maps, and of their quality. These local maps do not all have the same value, in fact, all have their own extrapolations and each major divergence between the partial legends involves new extrapolations at higher levels of correlation. The accuracy of geological, geomorphological, climatic and phytogeographical data on which the final extrapolations will be based, must also be taken into account.

If one judges the Soil Map of Africa on the scale of 1/5 000 000 according to the criteria defined above, one may ascertain that about half of the area is covered by partial maps of good quality with legends which conform quite closely to the general legend. About 30% of the area is based on less precise maps and 20% is extrapolated at the level of general correlation. As for non pedological data, their quality is at least comparable with that of analogous documents covering the other intertropical regions of the globe. ([1]), ([2]), ([7]), ([8]), ([9]).

REFERENCES GENERAL INTRODUCTION

1. AETFAT, *Carte de la végétation de l'Afrique — Vegetation map of Africa*, Oxford University Press, 1959.
2. BUREAU D'ÉTUDES GÉOLOGIQUES ET MINIÈRES COLONIALES, *Carte géologique Internationale de l'Afrique 1/5.000.000e*, Paris, 1952.
3. CCTA/CSA, *Comptes rendus de la IIe Conf. Interafr. Sols*, Léopoldville, Vol. I, pp. 88-89, Éd. Min. Col., Bruxelles, 1954.
4. CCTA/CSA, *Comptes rendus de la IIIe Conf. Interafr. Sols*, Dalaba, Vol. I, pp. 65-93, Éd. CCTA, Lagos Publ. n° 50, 1959.
5. J. D'HOORE, La carte des sols d'Afrique, *Pédologie*, X_1, pp. 191-204, 1 carte, 1960.
6. J. D'HOORE, The soils map of Africa south of the Sahara, *Trans. 7th Int. S. Sc. Congress*, Vol. IV, 11-19, 1960.
7. R. FURON, Esquisse structurale provisoire de l'Afrique, *Congr. Géol. Intnl. Ass. Serv. Géol. Africains*, Paris, 1958, 1 carte.
8. S.H. HAUGHTON, *Stratigraphic history of Africa South of the Sahara*, Oliver & Boyd, Edinburgh, London, 1963.
9. S.P. JACKSON, *Atlas Climatologique de l'Afrique — Climatological Atlas of Africa*, CCTA/CSA, Lagos, Nairobi, 1962.
10. Z.J. SCHOKALSKAYA, A new soil map of Africa, *Pochvovedenie*, 9, 424-475, 1944.
11. H.L. SHANTZ et C.F. MARBUT, *Vegetation and soils of Africa*, Am. Geograph. Soc., New York, 1923.

PART I

THE AFRICAN ENVIRONMENT

INTRODUCTION

The African continent, with Madagascar and its other neighbouring islands, covers an area of some 30 million square kilometers. About two thirds are covered with what can correctly be called soils, that is to say a more or less loose detrital layer containing living matter and supporting, or capable of supporting plants [27]. The remainder is occupied by desert detritus, bare rock, open water, and even by glaciers or perpetual snow (*). Many of these sterile surfaces will perhaps at some future time develop into true soils, and many sites which presently carry soil profiles may possibly at some former time have had the desolate appearance of soil-less regions, due to variations of climate or erosion.

Although the principal objective of this map is to provide a large inventory of the soils of Africa, it also demonstrates the degree of soil development reached by the principal parent materials under their particular topographical situations, climatic regimes and vegetation covers. This first part, given over to a description of the environmental factors (geology and geomorphology, climate, vegetation) will allow this to be stated more precisely. To this end the discussion has been limited to those elements which can affect the nature of the parent materials and the development of the soils which they carry, and which consequently influence the particular distribution of these parent materials and soils presented in Africa.

(*) Cfr Table II, Chapter 4, Part IV, page 200.
On our Soils map of Africa "not soils" cover the following surfaces :

	Madagascar		Continent	
	%	10^3 km^2	%	10^3 km^2
Rock	—	—	7.92	2322
Desert	—	—	20.15	5913
Water	0.06	1	0.76	222
Total	0.06	1	28.83	8457

CHAPTER 1

THE BROAD GEOLOGICAL FEATURES (*) (See Fig. 2)

For the pedologist the stratigraphical position of a rock is certainly of less importance than its properties: mineralogical constitution, resistance to weathering, products of decomposition, the texture of its less decomposable constituents and its porosity. However some correlation exists between stratigraphical position and the general character of the most widely distributed substrata, which makes it possible to review the chief lithological characters of the principal outcrops and overlying mantles in their normal stratigraphical sequence. In the map legend the lithological nature of the substrata is retained in order to sub-divide the majority of the categories at the third level of abstraction. Richness in ferromagnesian minerals and texture are the most frequently chosen criteria, followed in order of frequency, by recent alluvial deposits, lavas and volcanic ash, calcareous rocks and crusts, ferruginous crusts, and crystalline acid rocks.

THE CONTINENT

The greater part of the African continent can be considered as a Precambrian crystalline massif, bounded to the north by the Atlas chain (alpine movement) and to the south by the Cape system (Hercynian movement). A tectonic line separates the ancient geosynclinal of the Atlas from the crystalline socle and all the region to the north of this line consists of marine sedimentary rocks whose calcareous formations are dominant. To the north east the crystalline mass is edged by the tectonic deep of the Red Sea. Over all the remainder of its periphery it is girdled by a coastal fringe the width of which, with some important exceptions, does not exceed 100 km. It consists of marine sediments chiefly of sands with some calcareous sandstones or marls and is locally covered by recent to present-day fluvio-marine deposits.

THE BASEMENT COMPLEX (pre-Cambrian)

This formation crops out over about a third of the surface of the continent. The lower beds consist mainly of granite, gneiss and schists. They are covered by more characteristically sedimentary formations (quartzites, limestones,

(*) This chapter is largely inspired by the work of R. Furon [14].

dolomites and phylites), injected by important basic intrusions, such as the great dyke in Rhodesia. The Upper pre-Cambrian is made up mainly of sandstone but also contains some schistose formations, limestones and dolomites, The other two thirds of the crystalline base is covered by various sediments which, with the exception of primary sediments, are of continental origin.

THE PRIMARY SEDIMENTS

They are largely found in North Africa and the Sahara but the extension of their various formations towards the south is uneven. The Cambrian, which followed a glacial period, is indicated by the presence of tillites, and consists of conglomerates, limestones, schists, sandstones and volcanic veins. These are also found in Mauritania and Mali. The Ordovician, formed mainly of sandstones, extends considerably to the south into Guinea and the Volta basin in Ghana. The Silurian, formed to a great extent of graptolithic schists extends as far as Guinea but seems to be less widespread than the two previous formations. The Devonian, containing schists, limestones and sandstones, goes down as far as the Ghanaian coast. The Carboniferous is limited to North Africa. These outcrops of primary sediments, of which sandstones and schists are dominant, are relatively important in West Africa. The Voltaian sandstone for instance outcrops over half the surface of Ghana, in Togo and Dahomey. Analogous formations cover important areas in Mauritania, Senegal, Mali and Guinea. In contrast, vestiges of the primary era are rare or absent in equatorial and southern Africa.

THE SECONDARY SEDIMENTS

At the end of the primary era the greater part of the African mass seems to have remained above water. The only noteworthy incidents were the Cretaceous transgression which formed the Saharan Sea and the Jurassic transgression which covered the Somalias to the south east of the Ethiopian massif. The majority of the post-primary sediments which cover the African mass are of continental origin. The Permo-Triassic sediments of the Sahara consist of conglomerates, limestones, sandstones and banded clays with gypsum and salt. In Africa south of the equator the continental Karroo formations (Upper Carboniferous to Triassic) followed a very widespread glaciation : the associated tillites outcrop in numerous sites throughout the southern part of the continent. The lower beds of the Karroo, which are Permian in age and alluvial in origin, are transformed into clayey schists containing exploitable seams of coal. The upper beds end with sandstones and schists. The end of the Triassic period was characteristically one of great volcanic activity : traces of it are to be found in North Africa, in West Africa (intrusive dolerites in the primary formation), and especially in Southern Africa where basaltic lavas poured out into the Karroo formations to a thickness of some 2 000 m (the Basutoland massif). The only marine Jurassic formation of any importance which extends to the south of the Ethiopian massif consists of sandstone and gypsum-carrying clays. The continental Jurassic which makes up part of the "Continental intercalaire" outcrops in North Africa, the Sahara and Tanganyika. It includes conglomerates, sandstones, marls, limestones, arkoses, pelites and clays, but only occupies limited areas. The upper part of the" Continental intercalaire", corresponds to the continental lower Cretaceous and shows something very important and rather peculiar for Africa : it is remarkable for the unity of fauna and flora, implying a uniform climate from the north to the south of Africa and an imperceptible change from Jurassic to Cretaceous ([14]).

The Cretaceous transgression covered a relatively large surface. The water of the Mediterranean penetrated into the Sahara beyond the southern limit of the Hoggar massif and joined the Gulf of Guinea by way of the lower valleys of the Benue and the Niger. This gave rise to important deposits of limestones, sandstone, and gypsum clay in the Sahara, and to limestones and clays in Nigeria.

The tertiary sediments

The whole of the Tertiary formations of continental origin is often given the name of "Continental terminal". In North Africa and the Sahara the tertiary sediments consist of lacustrine limestones, marls, red sandstones, conglomerates and red detrital beds which could be the remains of ancient soils. In Africa south of the equator and to the west of longitude 30°E extend the Kalahari deposits, consisting of polymorphous sandstones, sands of fluviatile and aeolian origin, and in places, calcareous lenses of lacustrine origin. These formations outcrop very extensively in Bechuanaland, South West Africa, Rhodesia, Angola and in both Congo republics. Important vestiges of old tertiary surfaces subsist, partially covered and protected by ferruginous crusts, in West Africa to the south of the Niger and Chad basins, between the basins of the Chad, the Nile-Bahr el Ghazal, and the Congo, and around the basins of Lake Victoria and Lake Kioga. Debris of fossil crusts is found in the younger parts of the landscape. Although doubtless formed by pedogenic processes, these fossil crusts must be considered as rocks and rock debris of Tertiary age. The era is equally well represented by lava and basalt outflows principally in East Africa (Ethiopia, Kenya, Uganda, the Congo (Leopoldville), Rwanda, Tanganyika, Nyasaland); at the same time the important faulting which gave rise to the Rift Valleys was intensified. Tertiary volcanics are also formed in Tibesti and in the Cameroons.

THE QUATERNARY FORMATIONS

They constitute the greater part of the superficial deposits. The following can be distinguished:

Volcanic formations which on the continent border the faulted areas : the Hoggar, Tibesti, Jebel Mara, the Cameroons, Central Nigeria, Ethiopia, Uganda, Tanganyika, the Congo (Leopoldville), Rwanda, Nyasaland, Kenya.

Aeolian sand deposits which form the ergs of the Sahara and the South West African deserts, the loose formations at the southern edge of the Sahara, as well as those which cover the greater part of the Kalahari and extend towards the north to just beyond the equator (the east of Angola, the west of the Rhodesias, the southern half of the Congo basin).

Alluvial deposits of various ages of which the oldest have often been reworked by wind action, superficial erosion, and biological action.

Mantles of colluvial origin, often sufficiently thick to contain the entire profile providing the latter is limited to the depth on which the root system of the natural vegetation still has a marked effect (3 metres). Scree sheets (stone lines) and ferruginous crust debris are often found mixed with these deposits or intercalated between them and the material which they cover.

THE ISLANDS

The geological structure of Madagascar is very similar to that of the continent. The Precambrian crystalline massif outcrops over about three quarters of the island and is covered by a thick layer of weathering. It consists mainly of gneiss and granite but also contains schists and quarzites. As in Africa south of the equator, the primary sediments (pre-Karroo) are scarcely represented.

To the east, the crystalline massif forms a quasi-rectilinear coast. Towards the west, the massif is separated from the Mozambique Channel by a sedimentary band, the average width of which is about 150 km. Among its deposits ranging from the Carboniferous to the Jurassic and contemporary with those of the Karroo, are found schists, conglomerates, sandstones, red clays, limestones and marls. The Cretaceous deposits consisting of sandstones and limestones, show some important basalt intrusions. The Tertiary formations, mostly sandy and calcareous, are volcanic toward the north of the island; ferruginous crust formation seems to have been very much less pronounced than on the continent. The Quaternary is characterised by important volcanic eruptions, some of which are active, by lacustrine, fluvial and fluvio-marine sediments, and by coverings of colluvial origin.

Most of the other African islands are of volcanic origin : the islands of Cape Verde, Fernando Po, Principe, São Tome, Annobon, the archipelagoes of the Comoros and the Mascareignes. The summits of a Cretaceous ring dyke form the archipelago of Los in the Gulf de Guinea; Zanzibar, Pemba, Mafia and various islands of less importance in the Mozambique Channel are outcrops of Tertiary sediments.

CHAPTER 2

GENERAL LANDFORM

The continent

We have described the African continent as a huge crystalline mass surrounded by a sedimentary fringe. To the north, these sediments are folded, forming the Atlas chains, the altitude of which is between 1 500 and 3 600 m. The region of the High Plains, which separates the two principal chains is studded with numerous salt lakes, and varies in altitude from 900 to 1 200 m. In the extreme south, the Cape system, equally folded but older, has a relief which is lower and more rounded. Elsewhere (West Africa, North-West Africa and the Sahara, here with some important extensions) the sedimentary fringe has not been folded and the relief is less contorted.

Apart from some "accidents" of which more will be said later, the surface of the continental block is extremely level. Based on the concept of pediplanation, King ([20]) has distinguished a number of cycles of erosion in Southern

Africa, which he has dated with some approximation, and from which he has extrapolated an extension to beyond the equator. Although the spatial limits of these various "pediplanes" or "surfaces" do not remain unchallenged, their chronological delimitation seems acceptable to all ([21]). King recognised five major cycles:

— The Gondwanian cycle (Jurassic)
— The post-Gondwanian cycle (late Cretaceous)
— The African cycle (mid-Tertiary (Lower Miocene))
— The Vicotria Falls cycle (late-Tertiary (Upper Pliocene))
— The Congo cycle (Lower Pleistocene).

Among these surfaces, those which correspond to the African cycle are the most extensive: one of their characteristics is the frequency of crusts or of debris of old ferruginous crusts. Moreover the latter have often protected the surface from the attacks of later cycles of erosion.

The continental plateau of Africa is slightly sloping from S.E. to N.W.: in the S.E. its altitude is of the order of 1 500 m, whereas in the N.W. it is of the order of 300 m. It is crossed by rows of fractures of which the oldest date back to the Precambrian era. The most important however, and those which most influence the relief, are the most recent. The beginnings of the fractures were found in the Cretaceous period but they have undergone renewals up to the Pleistocene and their movements still continue at the present time. These zones of fractures generally have a mountainous relief scattered with volcanoes many of which are still active; they include the caved in and partially inundated Rift Valleys, thus forming the major part of the great African Lakes.

The first group of fault lines follows in general a S.W.-N.E. direction and is marked out by the islands of Annobon, Principe, São Tome, Fernando Poo, the volcanoes of the Cameroons and the mountainous region which forms the frontier between the Cameroons and Nigeria.

A second series of lines, the most important in Africa, forms the whole of the Rift Valleys. It starts in Syria, forms the Jordan Valley, the Dead Sea, the Gulf of Akaba, the Red Sea and penetrates into the African continent by way of the Awash Valley. On leaving the Abyssinian cleft it divides into two principal branches which pass round Lake Victoria : the easterly one, with Lake Rudolf and a string of less important lakes, the other one to the west, with the Lakes Albert, Edward, Kivu, Tanganyika and Rukwa. The two branches rejoin again at Lake Nyasa and leave the continent by the valleys of the Shire and of the Lower Zambesi. Though the general direction of this line of faults is obviously N.S., it breaks down into several sections running S.E.-N.W. or S.W.-N.E. The faultlines of the Rift just like those of the Gulf of

Guinea, are bordered by mountains and volcanic cones the altitudes of which are between 1 500 and 3 000 m. The highest summits of the continent, covered by perpetual snow, are found there (Kilimanjaro 6 010 m, Kenya 5 600 m, Ruwenzori 5 500 m).

Apart from these faults and the orogenic movements which accompanied them, the crystalline plateau is also marked by big tectonic basins which are very extensive, but slightly lower than the sills and domes which separate them. To the north can be distinguished the basins of the low Sahara, Taoudeni, Murzuk, and the Libyan desert; to the south of the Sahara, the Niger, Chad, Bahr-el-Chazal, White Nile and Congo basins, Lakes Victoria and Kyoga, and the two Kalahari basins.

The country which surrounds and separates the basins, especially the Niger, Chad, Bahr-el-Ghazal, White Nile, the Congo and the Lakes Victoria and Kyoga basins, carry numerous traces of ferruginous crusts which are often associated with Tertiary surfaces. If it is admitted that the greater part of the outstanding features of present day African geomorphology, such as the alpine foldings of the north, the great faults, and the marked subsidence of the continental depressions date back toward the end of the Tertiary, one must believe that during the Tertiary the African relief was even more level than now. This very unusual topography diminished the possibilities of external drainage and engendered soil formation where temporary or permanent water-logging played a predominant role, so long as the climate was not too arid. It is in such conditions that the phenomena of mobilisation, precipitation and accumulation of free iron are most intensive. It is sufficient to refer to the crust which forms at the present in the lowest parts of the Congo basin and in certain regions of West Africa which suffer periodical inundation during the rainy season ([9]) ([22]).

Although remains of ferruginous crusts are present practically everywhere on the Tertiary "surfaces" they do not occur uniformly throughout. This unequal distribution can be attributed to several causes. One contributing factor could have been the variations in ferromagnesian mineral content of the rocks. Another may have been the zonal or altitudinal distribution of climate, since a warm and humid climate would favour mobilisation of free sesquioxides, while a climate of a seasonal type would promote accumulation and induration. Finally, mention may be made of several examples where the old Tertiary crust exists at depth but has disappeared under a relatively thick bed of Pleistocene sediments (N.E. of Nigeria along Lake Chad, and the periphery of the Congo basin). It is equally possible that what we now see reflects more the intensity of erosive factors which may have been active at the end of the Tertiary era, than the scope of the phenomena of accumulation, strictly speaking. The very large distribution of ancient crust debris that can be distinguished from present day formations by their situation in the landscape and at times by their particular morphology, certainly supports the latter point of view.

The islands

Madagascar could perhaps be considered a lump of the crystalline continental mass bounded to the west by a sedimentary fringe. The crystalline mass with its broken relief forms approximately three quarters. The other quarter, sedimentary and relatively level, carries important alluvial deposits originating from the crystalline mass. No well marked traces of the great periods of pediplanation have been left in Madagascar, such as great level surfaces or important fossil ferruginous crusts.

The greater part of the still active volcanic islands have an excessive relief, whereas the older ones have a gentler outline (Mauritius, certain islands of the Cape Verde group). Finally, islands of sedimentary origin are generally very level.

* * *

The influence of landform on the evolution of loose materials and soils is exerted in many ways. Altitude controls the mean temperature, and the amplitude of thermal variation in the various horizons. The direction of slopes determines the amount of radiation and of total precipitation received to the extent that the latter is carried by the prevailing winds. The more uneven the landscapes the more their climates show local characteristics differing from the broad climatic type, proper to their latitude.

The relief also influences the extent of external drainage, the introduction of material by colluvial movements, and scouring by erosion. In the same landscape the elevated sites tend to lose materials to the benefit of the lower parts; in extreme cases the materials can be exported out of the landscape even to the sea.

From the pedogenetic point of view, all country which has relief consists of zones of departure, of transference, and of accumulation, the limits of which can be peculiar to each transferable constituent or to each group of constituents of comparable mobility. This applies equally to the most simple of landscapes and to great geomorphological units.

In the light of the above reasoning there can be distinguished in Africa zones which are essentially receptive, zones which are mainly of transference, and zones wherein the loss of constituents is the predominant phenomenon;

but of equal importance is the fact that there are zones which are very level, where the position allows for neither loss nor gain with the exception of wind action. These last level zones have thus become covered with altered materials, products of multiple soil-forming processes undergone along with climatic changes. They are essentially the central parts of the plateaux still not broken into by the recent cycles of erosion.

The zones which become enriched by solid sediments and by relatively mobile constituents (sesquioxides, siliceous colloids and/or soluble salts) are depressed, have little accentuated relief and are in unfavourable drainage conditions. The accumulation there evolves parallel with the degree of endoreism whereas exoreism favours movement of the most mobile constituents. These zones are the great continental depressions, the alluvial plains, the Rift valleys and the coastal sedimentary fringe.

The zones of transference, which are not easily distinguished clearly from the zones of departure, are found on the outskirts of the zones of accumulation, where the slopes are sufficient to prevent accumulations but insufficient to start erosion. These sites, the slopes of which are in equilibrium with the activity of the existing climates, may however be covered by products of erosion carried by an earlier cycle. This is more particularly the case when the protective shield of forest, responsible for the formation of very deep layers of alteration disappears: the mobile materials are scattered and re-establish slopes which are in equilibrium with the new eco-climatic conditions.

The departure zones have the most marked relief. In Africa they are the diverse mountainous formations which have been described and the edges of the continental plateau that supply the coastal fringe. The broken character of these edges is even more marked if their difference in level from the coastal fringe is greater.

CHAPTER 3

CLIMATE

A — **Present day climate of some broad regions of Africa** (See fig. 3 and 4)

The African continent which extends as far as the 35th degree of latitude on either side of the equator, forms a relatively plane surface without mountain ranges which constitute major climatic barriers. The distribution of climate must therefore tend towards the ideal: regions with Mediterranean climate at the extreme north and south, followed by, as the equator is approached, arid zones, semiarid zones, and finally subhumid which are joined by a single humid zone. In the zones with a Mediterranean climate rain falls during the winter, in the arid zones it is both very slight and unreliable, in the semi-arid and sub-humid regions, which cover the area between the tropics and the equatorial zone, the rainy seasons correspond to summer while the winters are characteristically the dry seasons. Towards the higher latitudes of the intertropical zone only a single rainy season is found, but toward the equator, between latitudes 3° and 15°, the wet period is broken by a short dry season during the summer. Finally, in the equatorial region there is no real dry season, properly speaking, but the rainfall shows two maxima, corresponding to the passage of the sun through the zenith (March and October). As for the air temperature, it decreases with altitude: mountainous regions and the high plateaus of the north and east of the continent are thus cooler than lower parts in the south west, the center, the north and the north-west.

Climate maps ([18]) show that apart from certain anomalies this theoretical division is valid over a great part of the continent. Trewartha ([26]) cites among the most important anomalies :

a) The very great extension in both latitude and longitude of the arid regions to the north of the equator compared with the corresponding zone to the south of the equator.

b) The abnormal dryness of all East Africa of low and medium altitude even though it is open to the Indian Ocean and its humid trade winds.

c) The semi-arid band of the Ghanaian and Togoland coast bordered by a humid tropical zone.

These anomalies can be attributed to various causes among which the following may be cited : (1) The asymmetry of north and south equatorial parts of the continent which confers upon the former a character much more continental brought into existence by its very great longitudinal extent and its nearness to the Eurasian continent. (2) The presence of sea currents flowing close inshore, (3) the particular position of the island of Madagascar, the relatively high east coast of which rises at a right angle to the direction of the south-east trade wind.

The following are complementary facts about the climate of various large regions of Africa ([18]), ([19]), ([25]), ([26]).

1. The Mediterranean zone

The climate of the Atlantic coast of Morocco is markedly influenced by the cold sea current from the Canaries. The temperature is relatively cool, the rains less frequent, but the humidity of the air is high enough to bring about fogs and dew. Between the coast and the Atlas the temperature extremes diverge more and summer rains become more rare. To the east of the Straits of Gibraltar, as far as the eastern coast of Tunisia, along the coastal zone the summers are very hot and very dry while in winter there is a relatively important amount of precipitation (400-700 mm). On the plateau of the Chotts, called also the "high plains" (alt. 1 000 m), winters are cold and summers hot. At Géryville temperature extremes of $-12°$ and $+42°C$ have been recorded. Precipitation (150-250 mm) is less than at the coast and tends towards a maximum in spring, and the difference between day and night temperature is considerable. The Atlas itself receives rather good rainfall, is partially wooded, and separates the habitable parts of North Africa distinctly from the enormous desert of the Sahara. The coasts of Libya and Egypt are not protected from the desert by mountain ranges and they lie, moreover, some degrees further to the south. The effect of the Mediterranean is felt there only for a width of some kilometers, and in many localities the desert reaches the coast.

2. The Sahara

The Sahara desert, the greatest in the world, extends over more than 13 degrees of latitude. The climatic conditions characterized by extreme dryness and very wide temperature variations, extend north over the Mediterranean in the summer, and toward the Gulf of Guinea in the winter. In winter, temperature minima at soil level can descend below 0°C while in summer these temperatures often exceed 43°C. Temperature of superficial soil layers can exceed 80°C in the sun. The dryness is associated with the trade winds blowing from the north east. In the absence of vegetation the weathering of the rocks is essentially physical and loose deposits are constantly disturbed by the wind. Several successive years may pass without a single drop of rain falling, but from time to time thunderstorms arise, accompanied by plentiful and heavy precipitation. The great erosive effect of such thunderstorms is evidenced by the extent of the desert pavements, transported (Ap′), on the soil map. In the mountain regions of the Sahara (Hoggar, Tibesti, Aïr) several violent thunderstorms occur each year. In the Hoggar a number of small watercourses with permanent water are found.

3. West Africa to the west of lake Chad

In this region four or five climatic zones, extending east to west in more or less parallel bands and following each other from north to south, can be distinguished; each tends to show a northerly or southerly drift according to the season. The first zone, the most northerly, is directly influenced by currents from the Sahara and has the principal characteristics of the Sahara. In January its southern limit has traveled south as far as the 8th parallel N., in July it has traveled back north as far as the 20th parallel N. The second climatic zone has a width of up to 2 to 3 degrees, follows the movements of the first one, and carries small thunder showers. The third covers 5 degrees of latitude and has a rainfall which is a little greater than the second, however the showers are very heavy. The passage of this band therefore corresponds with the period of greatest erosion during the year. The fourth zone, covering some 3 degrees of latitude, has a higher rainfall than any of the first three but the downpours are less heavy and better distributed. Finally, the fifth reaches the coastal region only in summer, from July to September. Its characteristics are overcast skies, gentle rain, and relatively moderate temperatures.

These climatic variations are fairly characteristic of the transition zone between the arid and the humid equatorial band; accordingly they fall into line with the ideal distribution of climate, at least with regard to the pluviometric regime. The isohyets nevertheless mark out several anomalies which have repercussions on the soil distribution. For example the existence of a narrow semiarid band running along the Ghanaian and Togoland littoral, where halomorphic soils, vertisols and ferruginous tropical soils are found, may be pointed out. Another anomaly is the sharp bend southwards of the isohyet of 1 200 mm which towards Toumodi in the Ivory Coast reaches latitude 6°30′ N. The fairly irregular line — the forest-savanna limit, shown on the soil map — clearly reflects this thrust of dry climate in the direction of the Guinean coast.

4. Ethiopia and the Somalias

The Ethiopian highlands (3 000 to 5 000 m), with an almost temperate climate which is very rainy (1 200 to 1 300 mm) in summer, contrast with the plain of Danakil, dry and desert-like. The transition zone toward the Somalian coast is semi-arid to arid, with erratic rainfall totaling 250 to 500 mm per annum. The coastal strip, lying along the Red Sea and the Gulf of Aden, receives less than 100 mm of rain and is very hot.

The dryness of the low-lying area of Somalia is due to oceanic interferences. Offshore resurgences of cold water, resulting in the frequent fogs seen in that part of the Indian Ocean ([26]), probably play some role.

5. East Africa

The relative dryness of this part of the continent constitutes one of the most striking anomalies of the distribution of climate in Africa, and the causes of it are still not well understood. Only the regions with high altitudes (the Highlands of Kenya, the great volcanoes, the Usambaras) are blessed with relatively humid climates (1 200-1 800 mm). Moreover, not only is the total precipitation distinctly lower everywhere than that which is normal for its geographical position, but, in addition, it is very irregular from one year to the next. The seasonal variation in precipitation however remains tied to the general pattern: around the equator the maxima follow a month or two after the equinoxes, and when one moves from the equator the winters are dry and the summers wet.

6. The Sudan

Three climatic zones can be distinguished in the Sudan. North of parallel 19°N, with the exception of the coastal strip, there is a desert climate with frequent sandstorms in winter. South of this latitude a tropical continental climate with the usual seasonal characteristics prevails, but always with a total rainfall markedly lower than that of neighbouring regions in the same latitudes. This is illustrated further by the southerly bend of the isohyet for 1 000 mm. The Red Sea coast and the western flanks of the Red Sea Hills come under the influence of the sea and receive some 100 mm of rain, falling almost entirely in winter.

7. The Central Congo Basin

This great region lies between the parallels 4°N and S and the meridians 16° and 26°E with a typical continental equatorial climate, very autonomous because the general atmospheric currents affect it only slightly. Only the south Atlantic monsoon has some effect. It conforms to the theoretical distribution pattern of two precipitation maxima with no dry season in the lower latitudes, and two dry seasons toward the higher latitudes. The mean annual temperature is of the order of 25 °C with, in the equatorial region, daily variations of 11 °C from the mean. This variation increases with latitude and reaches 21 °C toward latitude 7° (3).

8. The south western coastal area

This corresponds with the sedimentary fringe surrounding the African plateau and extends from the Cape of Good Hope to the mouth of the Congo River. The South Western Coastal Area is noticeably drier than the higher regions of the interior. This dryness is due to the continental winds (descending winds), and to the presence along the coast of the cold Benguela current which condenses some of the moisture in the winds from the sea. To the south of Angola and in South West Africa the climate of this strip is quite desertlike; here the continental winds are the south easterly trade winds, dried by their passage over some thousands of kilometers of land. The air still has a high relative humidity.

9. The Kalahari

Although the Kalahari region, which consists of Bechuanaland and the greater part of South West Africa, lies in latitudes similar to the Sahara desert, the drought is much less severe. The summer rainfall exceeds 150 mm, reaching as much as 500 mm per annum in the north.

10. The high plateaus of southern Africa

This groups together the very level regions with altitudes exceeding 1 000 m (south of Angola, Katanga, the Rhodesias, and a great part of the Republic of South Africa). The seasonal distribution conforms quite well with the ideal with long dry seasons in winter. The eastern border, facing the Indian Ocean, has the highest rainfall. The mean temperatures are distinctly less than those of the lower regions; and during the dry season, corresponding to winter in the south, the soil surface temperature is frequently below 0 °C.

11. The region of the Cape

This region enjoys a Mediterranean climate similar to that of North Africa so far as rainfall is concerned, but the summer temperatures are lower due to the influence of the cold Benguela current.

12. Madagascar

The central and southern parts of Madagascar are permanently influenced by the south eastern trade winds while the north and north-west have the seasonal variations characteristic of their latitude. The east coast is humid to per-humid throughout the whole year (1 500-3 500 mm). Under the influence of the N.E. trade winds, the northwestern portion during the early months of the year suffers a well-named rainy season (1 900 mm). By contrast the southern and southwestern regions which are low lying, and by this fact "below the wind" in relation to the high areas of the centre and east, have a semi-arid climate; in certain localities the precipitation is less than 500 mm per annum. For the same reasons these latter regions are also the hottest. From November to May many tropical cyclones beat upon the eastern coast of the island and on the neighbouring islands (Comoros, Mascareignes).

B — Climate as a Pedogenetic Factor

Temperature is one of the climatic factors which most directly effects soil formation. Africa is the hottest continent on the earth : the mean annual temperature (temperature of the air close to the soil) falls below 10 °C. only in the highest parts, and over the greater part it is above +20 °C. for nine months of the year. The magnitude of the daily and seasonal variations of temperature of the soil decreases with depth. In temperate countries temperature is quasi-constant at depths of from 7 to 10 m, while in intertropical regions this seems to occur at more shallow depths. However few precise facts are available on this matter. At Yangambi (Congo, Leopoldville) the soil temperature varies, in fact, only to a depth of 200 cms and daily variations become negligible from a depth of 50 cms.

Annual means of daily variations of soil temperature in two Congolese stations:

	Keyberg					Yangambi				
Hours	6	9	12	15	18	6	9	12	15	18
Depth										
10 cm	20.4	20.5	23.8	27.0	26.9	24.8	25.8	30.0	32.6	31.1
20 cm	22.6	22.2	22.5	23.8	24.8	26.6	26.4	27.6	29.7	30.4
50 cm	23.3	23.5	23.5	23.4	23.2	28.4	28.3	28.3	28.2	28.2

As an example the preceding table of the mean annual daily variations of soil temperature at two Congolese stations (5) is presented:

Yangambi	0°45′ N	24°29′ E	Altitude : 487 m.
Keyberg	11°44′ S	27°25′ E	Altitude : 1175 m.

This constant temperature of the soil at depth, sometimes called the mean temperature of the soil, primarily affects the pedogenetic processes which occur at depth (weathering, water movement, additions, precipitations, lixiviations...). However the most dynamic pedogenetic processes take place in the superficial layers where the largest temperature fluctuations are found.

The speed of the greater part of the non-biological pedogenetic reactions, although virtually stopped below O°C, increases with the temperature so long as other variables, as for example lack of water, are not limiting factors. For biological reactions the rate-temperature relationship has an optimum range, with reaction rates being insignificant at temperatures lower than 0 °C. Root systems of the greater part of the vegetation do not show further growth even at temperatures below +5 °C. Although in tropical conditions such low temperatures are only rarely recorded in the superficial horizons of profiles, temperatures above 45 °C, high enough to be inhibiting, can be reached under markedly seasonal type semi-arid or arid climates. In conjunction with the desiccation of these layers, such high temperatures can slow down or stop the biological changes just as effectively as can the low temperatures in the temperate zones.

In regions of low and intermediate altitude with hot and humid climates the intensity of these transforming processes is indicated by the depth of the weathered layers, by the very far-reaching changes to the minerals in profiles which can be interpreted geomorphologically as being relatively young, by stages reached by certain processes (mobilisation of iron, synthesis and decomposition of clay minerals), and by the low organic matter content despite the very large amount of raw organic material produced by photosynthesis.

In low and intermediate altitude regions with drier climates and with higher annual mean temperatures that show wide daily and seasonal fluctuations, the altered layers are shallower and the degree of alteration is smaller; lack of moisture, which is the limiting factor, diminishes the accelerating effect of the temperature. In spite of the fact that smaller amounts of raw material are brought in than in the humid regions, the organic matter content of the soils here is much higher and penetrates to a greater depth. This may perhaps be attributed in part to the fact that the material is principally brought in underground, and in part to a slower rate of decomposition.

On the high plateaux of the south, drier climates and lower temperatures co-operate to give a generalized slowing down of the alteration phenomena. This fact is again accentuated in regions of high mountains where recent scarcely altered soils and non-hydromorphic organic soils are found.

Water brought by *precipitations* is important in numerous ways. Water is not only an indispensible material in numerous mineral and organic syntheses but also the principal vector on the surface and within the soil, either in the free state or inside the circulatory systems of living organisms whose habitat is upon or inside the soil. Its role is therefore paramount among the phenomena of transformation and of transference whether they occur within the profiles (leaching) or outside them (lixiviation, removal by harvesting, incineration). Finally the damage which may be caused by running water should be noted. Sheet erosion will be of greater importance if the precipitation is intense, if the relief is very broken and if the soil is impermeable. FOURNIER ([13]) has constructed a map of the theoretical risk of erosion in Africa based on the first two variables. The damaging effect of precipitation is expressed by the relation $p^2/P = C$ where p is the amount of precipitation in the wettest month of the year and P is the mean annual total of rainfall. The adverse effect of topographical factors is expressed by the relation H^2/S where H is the mean height of the basin and S its projected surface. The study of many large river basins which are climatically and topographically different has revealed linear correlations between the value of C and the quantities of solids carried by the rivers. FOURNIER kept four linear functions, applicable to four given conditions of relief and climate; he thus was able to estimate, from the climatological and topographical data of a large number of stations, the theoretical amounts of earth which the erosion could remove each year. A simplified version of his map is included in the present work (fig. 5).

Only a fraction of the total precipitation which falls on a region, in general less than 70%, takes part in the development of its soils: some portion is retained by the vegetation, being assimilated or immediately evaporated, another portion is lost by runoff and is removed by the drainage system.

In principle all the water which penetrates into the soil could take part there in the pedogenetic reactions, but in fact only gravitational water, and that which can move by capillary action, travels into the interstices of the soil and only then when the humidity is relatively high. Thus a much too simplified view is taken if only the mean annual precipitation is taken account of when studying the distribution of soils. It is also necessary to take into consideration the distribution of wet and dry periods, the intensity of precipitation, the different factors in the balance of water (evapotranspiration, run-off, percolation) and periodically established water profiles.

In the greater part of Africa soil temperatures always favour rapid soil formation; the humidity of the soil permanently limits the action in the deserts (about 20% of the continent), and is limiting periodically in semi-arid and sub-humid regions which have dry seasons exceeding 3 months. As far as soil reactions are concerned desiccation is followed by a slowing down or a stoppage, whereas transferences rapidly come to a complete cessation. Through the loss of absorbed water certain other constituents decrease in volume causing gaps in the soil, packing, and cracking due to shrinkage. The dried out soils therefore increase in macroporosity so that when the first rains come a greater amount of water will penetrate than would infiltrate the same soils when moist and when all the constituents retain their volume. Such circumstances result in the downward movement of particles which in normal conditions of humidity would be immobile. In extreme cases (cracking due to shrinkage for example) the size of these washed down particles may attain that of structural elements. Moreover when these soils are re-wetted tensions will develop, due to the swelling of the hydratable constituents in the material trapped below; the greater the swelling of the hydratable constituents and the more material trapped within, the greater will be these tensions.

Aside from the ecological effect of the *winds* on the vegetation cover, the currents which disturb the layers of air next to the soil have a direct effect on the soil forming processes through their carrying, their building or their denuding action. They profoundly influence the water balance of the soil: evaporation at the surface of the profile is followed by upward capillary transport and drying of the surface layers. Desiccation beyond a certain limit slows down the greater part of the soil forming processes and starts up others such as mechanical reworking coupled with the decrease in volume of the hydrated constituents (clays, gels, organic matter).

Planetary winds (trade winds, monsoons) can be responsible for certain deposits but above all they influence profoundly the general pattern of distribution of precipitation. The presence of obstacles in their path always causes particular climatic conditions : rain shadows which occur on most of the volcanic islands and Madagascar, situated in zones swept by the S.E. trade winds of the Indian Ocean, are fine examples of this. Finally the planetary winds cause the big marine currents which are responsible for the particular climates of many of the coastal regions of Africa.

C — Climatic variations during the Pleistocene and their repercussions upon the distribution of parent materials and soils

It seems generally accepted that, at least during the course of the quaternary era, the broad regions of Africa had their own paleoclimatic sequences resulting partly from such local factors as topography, continentality, and marine currents ([23]). The great natural climatic zones that we know "have slid ceaselessly on the surface of the continent undergoing continual variations of form and position in the course of the last million years" ([4]). On the African continent which, without doubt, has always had a hot climate, these variations were essentially reflected by alternating humid and arid periods, and by rainfall regimes with varying penetrating or erosive power. Some were rather violent as is demonstrated by certain stratigraphical and paleontological facts. In addition, many anomalies in the distribution of plant groups and of great soil groups can be explained only by adopting the theory of climatic variation. The marks made by climatic variations of the past and preserved down to the present day in certain profiles and parent materials must necessarily be sought among the less reversible effects of the soil forming processes — an indispensable prerequisite to their maintenance in the course of pedogenetic viscissitudes to which they must have been subjected. Among the most spectacular remnants are incontestably the ferruginous crusts of which many indeed, date from the tertiary era. These crusts had at that time a greater extension than now but they were largely dismantled during the pleistocene, so that the parts of intertropical Africa where their debris, in the form of laterite gravel, no longer exists are rare indeed. Although the ferruginous accumulations can, in principle, develop under all somewhat humid climates, their induration seems to be favoured by a seasonal climate ([9]). The rain forest, and the humid climate with slight seasonal variations which favour its growth, are the most active factors for breaking up the cuirasses. In North West Africa sheets of old ground-water laterite now may be seen on high levels where dryness of climate resists their development as well as prevents their break up by a forest vegetation. By contrast, in the more humid forest zone all stages of their dismantling can be found, ranging from level crust-bearing summits surrounded by a forest which eats away at the edges, to soils where the debris of the ancient crust is distributed throughout the parent material. Between this zone of intact crusts and the forested zone of broken crusts there occurs a transition belt of crust debris, at times recemented by secondary deposits, covered by a savanna vegetation which could not be responsible for its breakup. The occurrence of this transition belt is particularly significant to the north of the equator where the change from steppe to humid climate occurs over the shortest distance. This may indicate that the remnants of intact tertiary crust mark the extreme limit of the migration of the rainforest during the pleistocene. The formation of certain covering materials, usually very much altered and sufficiently thick to contain the whole profile, has often been attributed to climatic variations. De Heinzelin ([16]) quotes Passarge who, as early as 1904, wrote that biological action could explain the formation of the major part of these covering materials. But it is necessary to take into account the variations in the aggressivity of climate and contrast the deep and well protected soil formation normal to isopluvial conditions with the easy scouring away under a displuvial regime (*). This brings to mind the terms biostasie and rhexistasie proposed by Erhart ([12]). The role of termites, which has been insufficiently studied, deserves particular attention. In the areas where they are active the erosion of termite mounds without doubt contributes to the formation of these sheets of covering materials. In regions where these sheets are found but where there presently is little evidence of termite action the argument of formerly wide-spread "fossil" termite mounds may appear facile, but it must be taken into consideration. Indeed in the rain-zone giant ancient termite mounds are found which are only partially inhabited, and by species which did not build them.

A final fact to be considered in relation to climatic variations is the existence of truncated profiles or of fossil soils ([16]). It should be noted that burial by lava or volcanic ash can be quite recent.

CHAPTER 4

VEGETATION

Even though climatic factors can be placed among the most active pedogenetic factors, their "momentum" on the superficial layers of the soil is generally diminished by the vegetation, which modifies the erosive potential of the climate and reduces the amplitudes of variations in temperature and humidity and so presents more favourable conditions for biological activity. In the superficial layers, where the very dynamic and complex soil forming processes linked to biological activities take place, the protective effect of vegetation is most clearly shown. Consequently one may expect a profound modification of the dynamics of the profile when a soil, developed under good protection by vegetation, is suddenly denuded as is the case after forest clearing ([11]).

(*) By "displuvial" Bernard (4) designates the tropical pluvial modality, the prefix "dis" expressing the idea of seasonal disparity and contrast in the rainfall pattern. "Isopluvial" indicates the equatorial modality, "iso" conveying the uniformity of rainfall pattern.

The protection given by vegetation cover depends above all on its particular structure (6). Dense, humid forests, with a closed stand of several strata and a groundcover of broad leaved species of grasses, acts in the most efficaceous and most continuous way. There is little variation in the temperature and humidity of the soil under such forest cover and consequently the speed and direction of the processes going on there vary little. The dry deciduous forest, with lower height and comprised of deciduous trees and even shrubs which lose their leaves in the dry season, is much poorer protection: the surface layers of the soil can dry out during a part of the year and the temperature variations may be very marked. With woodlands and savannas it is essential to mention the fire damage which has so profound an effect on the structure and development of there formations (15). The late fires are the most destructive and only resistant species survive, while the shrub vegetation is replaced by tufts of high grass and scattered, contorted looking trees. Although the early fires (at the start of the dry season) prevent or hinder natural regeneration of fire-sensitive species, they cause only limited damage to established species. The destruction of the aerial parts of the grass stratum by late fires, lays the soil bare to the first rain storms.

The steppes with their open vegetation, characteristic of semi-arid regions, give only slight protection in spite of the fact that they are usually not burnt.

Finally the desert regions, as the term is used here, are devoid of vegetation with the possible exception of some isolated and widely scattered plants.

It is interesting to notice that the protective power of the vegetation tends to diminish with the total annual rainfall, which, in Africa, generally coincides with an accentuation of the seasonal character. The erosive efficiency, which is mainly a function of the intensity of precipitation, thus reaches a maximum in a zone occurring between rain forest and steppe : the climate found there is marked by a clear cut seasonal character in which the sum total of the rains, still important, falls in a few months, These climates correspond to grass or tree savanna and to woodland, the limited protective power of which has been mentioned. It is therefore not a mere coincidence that in these regions mantles formed by distribution of polygenetic material are often found.

The soil forming action of the vegetation cover is not restricted to this protective and regulatory function. Plants take part in the fixation of certain wind-borne and alluvial parent materials. They provide the soil with raw organic matter, at the surface by shedding aerial parts and at depth by decay of roots. A large part of the raw material provided by the aerial structure decomposes before it can be incorporated into the soil, that supplied by the root system becomes humified within the soil. The distribution of organic matter in profiles developed under a dominantly grass vegetation is generally very even and spreads more deeply than in forest profiles where raw material is mainly superficial in distribution. In addition the vegetation removes mineral salts and silica from the zone exploited by its roots and liberates them at the surface on the death of its aerial parts. Nitrogen fixed by microbiological activity in the soil and assimilated by plants is treated in the same way. The selective transport by the vascular solutions of the plants, independent of gravity, is essential for the differentiation in horizons of the profiles. Acids and chelating radicals, provided directly or indirectly by the vegetation, facilitate the mobilisation of certain mineral constituents by the disintegration of rock particles, the dissolution of minerals and the formation of mobile sesquioxide complexes. The mechanical reworking caused by root growth and fall of trees are perhaps the principal causes of the homogeneity of the top 150 cms of most profiles under rain forest.

Fires, for which the vegetation cover provides the combustible matter, generally only affect the surface layers. The work of Pitot and Masson ([24]) has shown that at a depth of 2 cms the temperature rise is only of the order of a few degrees. However burning disturbs the normal return to the soil of those constituents removed temporarily by the vegetation, causes loss of nitrogen, renders silica insoluble and eventually brings about the lixiviation of ash.

The specific action of different vegetative covers is also shown by the breaking up under forest of ferruginous crusts which under savanna vegetation remain almost intact ([9]). It is also demonstrated by the parallelism observed between the distribution of the principal plant communities and that of the great soil units which they cover.

The correlation between the soil map and that of the vegetation of Africa ([1]) (see fig. 6) shows that the tropical rain forest covers ferrallitic soils, ferrisols, juvenile soils on riverine or lacustrine alluvium and hydromorphic soils. It is worth noting that this forest covering 2 400 000 square km, of which 500 000 are in West Africa and 100 000 in Madagascar, occupies a much more limited area in Africa than in South America, where, in Brazil alone, it is estimated at 4 160 000 square km (*) ([2]). Tree and grass savanna of the relatively humid type, together with woodland form the most widespread vegetation cover. They receive moderate annual precipitation (1 000 to 1 500 mm) but endure

(*) The savanna — tropical rain forest boundary (1) (8), is given on the soil map There, the forest covers the following areas, as measured by cutting and weighing (cfr Chapter 4, Part IV) :

Central Africa	1 794 324 sq. km
West Africa (to the west of the Cameroons)	509 657 sq. km
Madagascar	106 776 sq. km
	2 420 757 sq. km

dry seasons from 1 to 3 months in length. These communities, like the tropical rain forest, are found mainly on ferrallitic soils and ferrisols, but occur also on ferruginous tropical soils and on some vertisols. The relatively dry types of savanna occupy less important and more localised areas, often where there are special climates: ferruginous tropical soils, lithosols, vertisols, juvenile soils on recent alluvia, and halomorphic soils are dominant there. Under tree and grass steppe, a community as extensive as the rain forest, the following soils are mostly found : brown soils of arid and semi-arid tropical regions, vertisols, lithosols, halomorphic soils and ferruginous tropical soils on sandy parent materials. Finally, sub-desert steppes correspond to sub-desert soils.

CHAPTER 5

THE PARENT MATERIALS OF THE SOILS

As indicated in Chapter 1 of Part I, approximately three quarters of the rock outcrops of the continent of Africa is comprised of precambrian Basement complex (gneiss, granite and schists) and sedimentary rocks, mostly sandy, of pliocene to pleistocene age. The remainder of the surface consists either of postcambrian antequaternary rocks, principally sandstones and shales, or of recent more or less clayey alluvium. The crystalline basement rocks and the sediments which overlay them are frequently traversed by volcanic venues of all ages. Efflata and recent lavas are of minor importance: there are only about 50 active volcanoes in Africa.

The parent materials of the soils are not necessarily identical with the loose or indurated underlying rocks shown on the geological maps. Distinctions between parent materials and underlying rock are particularly important where surfaces on which soils are formed are flat, very old and have been exposed to climates conducive to active pedogenesis. This situation pertains throughout most of the African continent. Parent materials may have been introduced by colluviation, by biological action, or by combination of the two. In intertropical Africa most parent materials probably have undergone several soil formations and have been subjected to thorough mechanical reworking and lateral transport. Others have been enriched at the surface by aeolian deposits or in depth by lateral leaching, as with iron compounds. Relationships between profiles and their assumed parent materials have been verified by mineralogical study of primary minerals in some instances.

The weathered layer of the hard rock, which still retains features of the rock, is separated from the overlying loose mantle by stone lines ([17]) of varied (and often controversial) composition and origin. Stone lines are generally considered to be residual and detrital, although certain soil scientists postulate processes of localized neoformation. Particularly is this the case when ferruginous materials are involved. The composition and form of certain of the coarser elements (rolled gravel and cuirasse debris rounded and covered with smooth glossy patinas) do indeed support the hypothesis that the stone lines may have been exposed at the surface. This hypothesis is less plausible in relation to other of their constituents such as rubefied rock debris and quartz vein debris. The subsequent burial of stone lines or stone layers which have been exposed previously, and were at that time comparable to present day regs or desert pavements, may be attributed to aeolian deposition, colluviation, or biological action (termites). Such a stone line should be considered as much a feature of the parent material as would be a stratification. Stone layers that never were exposed may have been concentrated at certain levels as the result of colluviation or solifluction. They may have been concentrated also as the result of mechanical reworkings normally active in soil profiles, such as the periodic overthrow of trees followed by decay of stumps and roots, the work of burrowing animals, termites and worms, and the filling in of the voids by colluviation. The net effect of these combined actions may be the concentration of coarse materials originally dispersed throughout the parent material into the lower portion of the reworked layer. In such an instance the stone line would be a consequence of contemporary pedogenesis.

Due to the polygenetic character of many parent materials in tropical Africa it is frequently difficult to establish with certainty the nature and origin of the one or more stone lines that may be observed in the profiles. Nevertheless further study of the stone lines would certainly be interesting since, in all likelihood, many of them may preserve most important indications as to the climatic and pedologic antecedents of the profiles they traverse.

The concepts developed in preceding chapters make it possible to estimate the wealth of the alterable minerals in the different parent materials submitted to present day pedogenesis. One may distinguish (*a*) surfaces too level to permit important movements, (*b*) zones of accumulation, (*c*) zones of transference, and (*d*) the rejuvenated zones of Africa.

The residues of multiple pedogenesis, not carried away by erosion, cover large expanses and doubtless are among the poorest of parent materials. Even the clay minerals have weathered with the resultant relative accumulation of their free aluminum oxides added to those originating from the alteration of ferromagnesian minerals.

The richness of the alluvial deposits depends on the lithological composition of the zones of departure, the distances over which they were transported, the age of the deposits, and the climates they have encountered. Deposits nourished by basalt massifs are among the richest: the content of bases, silicious colloids, and alterable minerals is high. Vertisols of topographic depressions (Dj) and halomorphic soils (M) develop on such deposits under sub-humid to semi-arid climates. The Nile-Bahr el Ghazal basin is an outstanding example which probably represents the largest expanse of such black tropical clays in the world. It is fed partly by the Ethiopian basalt massif (blue Nile), and partly by the rim of the Rift valleys where volcanoes are active (white Nile). The Chad basin, bordered on the south by a few basic intrusions, also contains vertisols of topographic depressions. These soil formations are rare in the Niger and Kalahari basins which are influenced little or not at all by basic outcrops. The Congo basin, the only large continental depression that is wholly subjected to a humid climate, has no black tropical clay deposits. Despite the fact that some of its alluvia come from basic areas bordering the Rift valleys, the present day climate here is favorable to rapid alteration as is also the marked exoreic character, and only the very recent alluvia, such as alluvial islands show some abundance of alterable minerals.

In the basins of lakes Victoria-Kyoga the black tropical clays are found where expected on the more arid eastern shores that are also nearer to the basic venues of the castern branch of the Rift; they are lacking on the humid western shores.

The deltas of the large rivers provide other examples. The deposits of the Nile delta originate from the Rift valleys and the basic Ethiopian massif, and are relatively rich. These deposits were transported a long distance but always under a dry climate. Such is not the case for the Niger delta whose sediments come from more acid rocks and were transported and deposited under humid climates. The Zambezi delta occupies an intermediate position: its river originates from the sandy Kalahari formation; it is enriched while it flows through the Rhodesias and by its tributary the Shire (overflow of lake Nyasa), and the delta itself has a seasonal climate less humid than that of the Gulf of Guinea.

Recent alluvium is not the only parent material in the great continental depressions. Under arid climate the alterable mineral content will diminish only slightly with time in the ancient river terraces, dunes, and various colluvia that comprise the greater part of the superficial formations. Such would not be the case under more humid climate where evolution toward the ferrallitic stage proceeds inexorably.

The richness of the parent materials of the zones of transference is more difficult to evaluate. As the parent materials were reworked to some extent, part may be authigenous, and part may be made up of mantle material comparable ot that of the ancient surfaces. However they may also consist of young sediments proceeding slowly in the direction of proper zones of accumulation.

The richness of the zones of departure is essentially dependent on the mineralogical constitution of the materials that are being scoured. Source materials may be rocks, undisturbed weathered zones, or polygenetic materials untransported or transported by previous cycles of erosion. Of the rocks, quartzites are most resistant to physical and pedogenetic weathering and together with the sandstones they constitute the poorest zones of departure. Schistose rocks, whose resistance to weathering and erosion varies widely, usually are not particularly rich in alterable minerals but do furnish clay minerals. As will be noted later in the definition, mineralogical constitution of clay minerals has been retained to distinguish several units of the legend. The richness of crystalline rocks generally is inversely proportional to their quartz content, or their "acidity". Their resistance to weathering is variable, but in general it may be said that those richest in ferromagnesian minerals are the least resistant. The veins of ferromagnesian rock that outcrop in many areas may be considered as the main sources of free iron oxides, concentrated into cuirasses by relative or absolute accumulation ([10]). Rocks rich in ferromagnesian minerals may under certain climatic conditions become covered with indurated ferruginous cuirasses that protect them against erosion. This may give rise to real inversions of the landscape following a new cycle of erosion with the harder but unprotected rocks eroded more easily than the softer ones overlain by ferruginous cuirasse ([7]).

The richness of the materials brought in by aeolian action depends on their mineralogical composition. Volcanic ash is not necessarily rich as, for example, volcanic glass. Wind blown sand may provide some alterable minerals and clay aggregates but in most cases they consist mainly of quartz. This explains why the aeolian materials may be even poorer than the deeply weathered and leached polygenetic residues of the uneroded plateaux.

This very general characterisation of the parent materials currently exposed to pedogenesis in the African landscapes does not suggest the likelihood of great resources of alterable minerals, certainly not in the intertropical regions, at least. Exceptions are provided by certain soils derived directly from underlying rocks or volcanic ashes, the black tropical clays, and certain recent alluvia. Most of the parent materials are polygenetic residues, deeply weathered, thoroughly leached, reworked sediments generally exhausted, and nearly sterile sand deposits.

Conditions are more favourable on the volcanic islands, and also on Madagascar where the tertiary cuirasse occurs less frequently. In Madagascar the polygenetic residues of the plateaux are less wide-spread since the topography is more broken, the basic outcrops are found more frequently, and the main alluvial plains, fed by the crystalline massif, are spread out under relatively dry climates.

REFERENCES

1. AETFAT, *Carte de la végétation de l'Afrique — Vegetation map of Africa*, Oxford University Press, 1959.
2. A. AUBRÉVILLE, *Etude écologique des principales formations végétales du Brésil*, Centre Technique et Forestier Tropical, Nogent-sur-Marne (Seine), France, 1961.
3. E. BERNARD, *Le climat écologique de la Cuvette centrale congolaise*, INEAC, Coll. in 4°, 1945.
4. E. BERNARD, *Théorie astronomique des pluviaux et interpluviaux du Quaternaire africain*, Ac. Roy. Sc. Outremer, Mém. in 8°, T XII, fasc. 1, 1962.
5. *Bulletin Climatologique Annuel du Congo Belge et du Ruanda Urundi*, INEAC, Bruxelles 1959.
6. CCTA/CSA, Réunion de spécialistes du CSA en matière de Phyto-géographie, Yangambi. CCTA Lagos Publ. n° 22, 1956.
7. E. DE CHETELAT, Le modelé latéritique de l'Ouest de la Guinée française, *Géogr. Phys. Géol. Dyn.*, XI, 1, 1938.
8. R. DEVRED, La végétation forestière du Congo Belge et du Ruanda Urundi, *Bull. Soc. Roy. For. Belgique*, 65, 6, pp. 409-468, 1 carte, 1958.
9. J. D'HOORE, *L'accumulation des sesquioxydes libres dans les sols tropicaux*, INEAC, Bruxelles, Série Scientif., n° 62, 1954.
10. J. D'HOORE, The description and classification of free sesquioxide accumulation zones, *C.R. V^e Congr. Intl. Sc. Sol*, Léopoldville, Vol. IV, pp. 45-48, 1954.
11. J. D'HOORE, Influence de la mise en culture sur l'évolution des sols dans la zone de forêt dense de basse et moyenne altitude, *C.R. Colloque CCTA/UNESCO sur les relations entre la végétation et les sols*, Adiopodoumé, Côte d'Ivoire, 1959.
12. H. ERHART, *La genèse des sols en tant que phénomène géologique*, Masson et Cie, Paris, 1956.
13. F. FOURNIER, *Carte du danger d'érosion en Afrique au sud du Sahara*, CEE-CCTA, avril 1962.
14. R. FURON, *Géologie de l'Afrique*, Payot, Paris, 1960.
15. J. GUILLOTEAU, Le problème des feux de brousse et des brûlis dans la mise en valeur et la conservation des sols en Afrique au sud du Sahara, *Sols Africains — African Soils*, Vol. IV, n° 2, pp. 65-102, 1957.
16. J. DE HEINZELIN, *Sols, paléosols et désertifications anciennes dans le secteur nord-oriental du Bassin du Congo*, INEAC, Bruxelles, 1952.
17. J. DE HEINZELIN, *Observations sur la genèse des nappes de gravats dans les sols tropicaux*, INEAC, Série Scient., n° 64, 1955.
18. S.P. JACKSON, *Atlas climatologique de l'Afrique — Climatological atlas of Africa*, CCTA/CSA, Lagos, Nairobi, 1962.
19. W.G. KENDREW, *The climates of the continents*, Clarendon press, Oxford, 1953.
20. L.C. KING, *South african scenery*, Oliver and Boyd, Edinburgh, London, 1951.
21. J. LEPERSONNE, *Les aplanissements d'érosion du nord-est du Congo belge et des régions voisines*, Ac. Roy. Sc. Col., Mém. in 8°, T. IV, fasc. 7, 1956.
22. R. MAIGNIEN, *Le cuirassement des sols en Guinée, Afrique occidentale*, Thèse Université de Strasbourg, 1958.
23. G. MORTELMANS, Le Pleistocène africain et sa stratigraphie au 3^me Congrès pan-africain de préhistoire (Livingstone, juillet 1955), *Bull. Soc. Belge Géol.*, T. LXI, 1, 58-73, 1956.
24. A. PITOT et H. MASSON, Quelques données sur la température au cours des feux de brousse aux environs de Dakar, *Publ. IFAN*, 13 (3) 711-732, 1951.
25. G.T. TREWARTHA, *An introduction to climate*, Mc Grawhill, New York, 1954.
26. G.T. TREWARTHA, *The earth's problem climates*, The University of Wisconsin Press, Madison, 1961.
27. U.S. DEPARTMENT OF AGRICULTURE, *Soil classification. A comprehensive system*, 7th approximation, 1960.

PART II

THE MAPPING UNITS

INTRODUCTION

In this second part the 62 elements of the legend which make up the 275 cartographic units of the map will be reviewed. The cartographic units are either elements of the legend or associations of two or three of these, grouped according to criteria that are mainly geographic. So far as it has been feasible the elements of the legend are separated by genetic criteria. Thus it becomes possible to arrange them in order of increasing degree of development, and to integrate the sequence obtained into modern systems of classification. Corresponding to each grouping of elements in the legend, and occasionally for separate elements, the following features will be given:

1. The definition

The definitions are nearly identical to the compromises arrived at subsequent to the Meeting of Specialists, Joint Project CCTA/CSA number 11 (Paris, September, 1961) and to the CCTA/FAO Symposium on the Classification of soils of Intertropical Regions (Léopoldville, May 1963).

2. The associated units

Those combinations in which the elements appear on the map are listed, and this automatically excludes associations with limited extent. Consequently certain widely distributed elements such as the hydromorphic soils in the humid and sub-humid regions, or the halomorphic soils in the semi-arid and arid regions are listed in the associations only when represented significantly. The order in which the characterizing symbols are presented is purely alphabetical and does not reflect any suggestion of relative importance.

Calculation of the surface covered by each element of the cartographic units (see table II, chapter 4, Part IV) was based on the hypothesis that the components of the binary associations covered one half, and the ternary constituents one third of the areas indicated in table I of the same chapter, knowing that this was only an approximation. The listings, to follow, of the associations and the surfaces covered by them will give a better idea of the natural pedological environment in which each element is normally occurring.

3. Distribution

The list of countries in which each element has been mapped is presented with the same reservations as in the preceding section. Only those elements covering continuous surfaces of sufficient importance have been taken into account. This distribution list is complemented in Chapter 3, Part IV, by a listing of the elements that can be found on the map for each country. In addition to the distribution list which permits localisation of the elements geographically, a brief comment is included emphasizing the significance of prevailing pedogenetic factors.

4. Agricultural value

The information presented herein belongs to the area of applied research, and remarks are limited to some general information related specifically to land capability.

CHAPTER 1

RAW MINERAL SOILS

The term "soil" may scarcely be applied to those elements of the legend treated in this first chapter. The environmental conditions encountered here are so unfavourable to biological activities that living processes and the pedogenesis they promote are lacking almost completely. These are "pre-soils" or soils near zero time in soil formation.

In Africa the raw mineral "soils" are of particular importance because of the enormous surfaces (28.07 % of the entire continent) they cover, especially in the northern part.

A — **Rock and rock debris**

These are indurated materials, eventually broken down into coarse debris, mainly as the result of physical weathering. In the legend the rocks and rock debris have been differentiated according to lithological criteria. Their agricultural significance is negligible, but they cover extensive surfaces, especially to the north of the equator. The element covers approximately 23 000 000 km² which is nearly 8 % of the total area of the continent.

1. Rocks rich in ferromagnesian minerals — Aa

Definition

Dolerites, peridotites,... but mainly basalts

Associated units

AaAp : with desert pavements (regs) residual
AaBa : with lithosols on lava
AaBn : with juvenile soils on volcanic ash.
AaGb : with brown soils of arid and semi-arid tropical regions, not differentiated
AaHa : with eutrophic brown soils of tropical regions, on volcanic ash
AaOa : with organic soils of mountains
Ra : the unit is part of the volcanic islands complex

The first association, AaAp is by far the most important (500 000 km²) Like the following (AaBa 44 000 km²) it has been mapped only in the northern hemisphere. The total extent of the remaining equals only 10 000 km². With the exception of AaGb, these are found only on the south of the equator. The unit Aa, alone or in association, has not been reported in Madagascar.

Distribution

Algérie (Sahara) semi-desert region of northern Kenya and its continuation to the south of Ethiopia, Mali, Mauritania, Côte française des Somalis, Somalia, Sudan, Tanganyika, Tchad (Tibesti) and the volcanic islands of the Atlantic and Indian oceans.

This unit is generally found in rather extreme conditions of climate (deserts, high mountains) or of relief (steep slopes that permit rapid scouring of weathering products). Elsewhere the unit is limited to very recent rock formations (lavas). Given equal conditions of climate and topography, it should be noted that chemical weathering of rocks rich in ferromagnesian minerals is generally easier than that of other rocks.

Agricultural value

Nil. These rocks have been separated from the others because they are richer in plant nutrients. Any fine debris of these rocks that may accumulate in the lower parts of their landscapes will therefore have higher potential than similar materials in landscapes with Ab, Ab′ or Ac.

2. Ferruginous cuirasses and calcareous crusts

Although these units are rarely found in association, their genesis has several points in common. Both are secondary formations, sometimes recent but mostly ancient. Both are comprised of residual more or less inactive constituents and relatively mobile weathering products, deposited at their surface or in the pores of their mass. The weathering products are often imported — invariably in the case of calcareous crusts — but they can also be residual. If residual, their accumulations reflect the loss of the more mobile elements from the weathering zone. This is the case of the so-called relative accumulations [8].

If the mobile constituents which accumulate can serve as a binding material and later become indurated — which is not always the case — genuine secondary rocks will be formed. The secondary rocks will remain stable in the environmental conditions under which they were formed. As soon as the environmental conditions become conducive to their alteration they will change into parent materials, giving rise first to lithosols (Bc or Bc′) and then to more developed soils.

a) Ferruginous crusts [7] [17] — Ab

Definition

Secondary formations made up of various loose materials like weathering products of rocks, accumulation horizons of paleosols, alluvial deposits, etc., enriched with residual or imported sesquioxides, and subsequently indurated. The main binding agents are crystalline iron oxides [28].

It appears superfluous to attach too great an importance to the morphological characterization of these cuirasses :

a) A very wide range of parent materials can act as reception material including: sands, clays, gravels, rock debris, and debris of more ancient ferruginous cuirasses. The materials may be in homogeneous or heterogenous mixture, and sometimes may even be stratified.

b) The overall colour varies according to the constitution and the degree of hydration and crystallization of the binding agents and other accumulated mobile constituents. The colour varies from dark brown to yellow brown, including red- and purplish brown.

c) With the exception of some relatively coarse reception materials, impregnation by sesquioxides is rarely uniform. Commonly they exhibit reticular or sometimes laminated patterns, where the impregnated and therefore capable of hardening, partitions surround and separate non impregnated materials. Subsequent agents of erosion will empty the non-indurated inclusions and confer a slag-like structure. These slag-like cuirasses, when buried again, may refill with secondary precipitates.

Associated units

AbAc : with rock and rock debris, not differentiated
AbBd : with lithosols, not differentiated
AbBf : with sub-desert soils
AbGa : with brown soils of arid and semi-arid tropical regions, on loose sediments
AbHb : with eutrophic brown soils on rocks rich in ferromagnesian minerals
AbJd : with ferruginous tropical soils, not differentiated
AbLc : with ferrallitic soils, dominant color yellowish-brown, not differentiated
AbLm : with ferrallitic soils, dominant color red, on rocks rich in ferromagnesian minerals

Of these associations only AbGa (95 000 km^2) and AbJd (58 000 km^2) cover surfaces in excess of 50 000 km^2.

Distribution

Côte d'Ivoire, Dahomey, Guinée, Guiné Portuguesa, Haute Volta, Liberia, Mali, Niger, Sénégal, Sierra Leone.

On the map the unit has been designated only for a relatively restricted area of West Africa, located within the boundaries 5°N, 20°N, 10°E and 15°W. In this area not only are found the best developed cuirasses in Africa but perhaps the best of all intertropical areas of the globe. Ab designates only the cuirasses that have remained more or less intact : their debris, partly mapped as Bc (*), indicates that its extension has been much greater.

No attempt will be made to correlate the ancient formations mapped as Ab, with present day climatic conditions. It may be noted however that their existence in the broad sense is certainly related to the lithological constitution of the geological substratum associated with their landscapes. It is without

(*) Part of the unit Bc may be made up by present day accumulations. The data at our disposal did not permit us to distinguish them everywhere from debris of ancient cuirasses.

doubt this substratum that has liberated the enormous mass of sesquioxides that has accumulated in the cuirasses, whether the accumulation mechanism was one of export to zones formerly or presently in a low lying position, or one of relative enrichment subsequent to loss by leaching of the more mobile non-sesquioxides. In the latter case accumulation processes initiated in former geological periods may be active currently.

Agricultural value

Cuirasses which are not very thick, and which overlay loose materials, may be broken and followed by afforestation with satisfactory results.

b) Calcareous crusts — Ab′

Definition

Secondary formations made up of calcium carbonates or calcium sulfates deposited at the surface or within other materials to form compact and indurated masses. Durand (9) distinguishes the "travertine-like calcareous crust with zonal structure, very hard, with a colour range varying from white to salmon pink, that is found generally at the top of calcareous rocks" and "the incrustation which is a hard, more or less slaglike formation having the appearance of a sandstone. The cement may be calcium carbonate, gypsum or even salt according to the nature of the crust-forming material". Calcareous crusts are more readily concentrated in superficial zonal layers than the ferruginous formations, although certain laminated ferruginous formations, have been described. Manganiferous films are frequent.

Associated units

Ab′Bf: with sub-desert soils

Distribution

The unit covers great expanses in Algeria and Morroco. Most are surface crusts with zonated structure and not accumulations that have hardened within loose materials. The climatic conditions that would favour their formation has been the subject of several hypotheses. It is doubtful however that they could be formed under the present sub-desert or desert climatic conditions in which they are presently found. As with the ferruginous cuirasses Ab, they usually are to be considered as paleoclimatic remains. Under more humid climates, in northern as well as in southern Africa, these calcareous accumulations go over into soils (Bc′ : lithosols on calcareous crusts).

Agricultural value

Very low. As in the case of the ferruginous cuirasse, the calcareous crust may be pierced and planted with trees. In less arid parts of northern Africa where this crust frequently crops out and can be broken, many new vineyards have been planted. The method was already in use during the Roman period.

3. Rocks, not differentiated — Ac

Definition

Rocks other than those discussed in the preceding paragraphs. Granite and gneiss of the basement complex are the main elements.

Associated units

AbAc	: with ferruginous crusts
AcAo	: with clay plains of deserts
AcAp	: with desert pavements (regs), residual
AcBc	: with lithosols on ferruginous crusts
AcBd	: with lithosols, not differentiated
AcBf	: with sub-desert soils
AcCa	: with rendzinas and/or brown calcareous soils
AcGa	: with brown soils of arid and semi-arid tropical regions on loose sediments
AcGn	: with brown and reddish brown soils of arid and semi-arid Mediterranean regions
AcIa	: with red Mediterranean soils
AcIn	: with brown Mediterranean soils
AcJc	: with ferruginous tropical soils on crystalline acid rocks
AcJd	: with ferruginous tropical soils not differentiated
AcLc	: with ferrallitic soils, dominant colour yellowish-brown, not differentiated
AcBdJa	: with lithosols, not differentiated, and ferruginous tropical soils on sandy parent materials
AcBdJd	: with lithosols, not differentiated, and ferruginous tropical soils not differentiated
AcCaGn	: with rendzinas and/or brown calcareous soils, and brown and reddish brown soils of arid and semi-arid Mediterranean regions
AcDbIa	: with vertisols, lithomorphic, derived from calcareous rocks, and red Mediterranean soils

AcDjJd : with vertisols of topographic depressions and ferruginous tropical soils, not differentiated

AcDjMa : with vertisols of topographic depressions and solonetz or solodized solonetz

AcFaIn : with sols lessivés — Highveld pseudo-podsolic soils and brown Mediterranean soils

AcJdLc : with ferruginous tropical soils and ferrallitic soils, dominant colour yellowish brown, neither differentiated

AcJdNa : with ferruginous tropical soils, not differentiated, and mineral hydromorphic soils

The units AcAp (493 000 km;) AcBd (309 000 km^2) and AcBf (566 000 km^2) are the most important. They are found mainly (exclusively in the case of AcAp) to the north of the equator. The other associations individually account for less than 100 km^2.

Distribution

Africa Occidental Española, Algerie, Angola, Côte d'Ivoire, Ehtiopia. Ghana, Guinée, Guiné Portuguesa, Haute Volta, Libya, Mali, Maroc, Mauritanie, Niger, Rhodesia (Southern), Republic of South Africa, Sénégal, Sudan, South West Africa, Tanganyika, Tchad, Togo, Tunisie, United Arab Republic,

Agricultural value

Nil to very low.

B — Desert detritus

General definition

Loose materials of diverse particle size, bare of vegetation, subject to mechanical disturbance especially by wind, situated in hot climates with very low and erratic rainfall or with none. There is no profile development and mechanical disturbances have obliterated any possible remnant of previous soil organization, inherited from more favourable climatic cycles. In the legend these materials have been separated primarily by granulometric criteria.

1. Sands (ergs) — An

Definition

See general definition

Associated units

AnAp : with desert pavements (regs), residual
AnAp′ : with desert pavements (regs), transported
AnBf : with sub-desert soils

The association AnAp (132 000 km²) is by far the most important, the other two cover only negligible surfaces

Distribution

Africa Occidental Española, Algérie, Angola, Libya, Mali, Mauritanie, Niger, Sudan, South West Africa, Tchad, Tunisie, United Arab Republic.

The element is confined to two distinct zones : the Sahara and the southern Atlantic coast between 16°S and 28°S.

Agricultural value

Nil. Presence of water permits the installation of gardens (Oases — Br).

2. Clay plains — Ao

Definition

See general definition.

Associated units

AcAo : With rocks and rock debris, not differentiated
AoBf : with sub-desert soils.

Distribution

Mauritanie, Côte française des Somalis, Niger, Tchad.

This unit probably represents ancient lacustrine deposits. In the Chad area the clay plains occupy the deepest parts of the depression : the lake presently is retained at some 100 m above by sediments from the Chari river [13]. In Somalia the unit is found in depressions together with salt ponds.

Agricultural value

None. Their soluble salt content is often high so that, even in the presence of water it is difficult to install gardens (Oases — Br).

3. DESERT PAVEMENTS (REGS)

Desert pavements cover very important surfaces in the Sahara. Exclusive of those regs placed in the unit "Desert detritus, not differentiated — Ar" the surfaces mapped Ap and Ap′ total 2 257 000 km², whereas only 1 353 000 km² are covered by sands (An). Dutil [10] who provided most of the data given for the Sahara, makes a distinction between residual and transported regs.

a) Desert pavement (regs), residual — Ap

Definition

Coarse residual material, produced mainly by physical weathering, and accumulated as the result of efflation of the finer elements originally present.

Associated units

AaAp : with rocks and debris of rocks rich in ferromagnesian minerals
AcAp : with rock and rock debris, not differentiated
AnAp : with sands (regs)
ApGb : with brown soils of arid and semi-arid tropical regions, not differentiated.

The most important of these associations are AaAp and AcAp, each of which covers approximately 500 000 km². AnAp occupies 132 000 km², while ApGb situated under a less arid climate, covers only 32 000 km².

Distribution

Africa Occidental Española, Algérie, Libya, Mali, Maroc, Mauritanie, Somalia, Côte française des Somalis, Tchad, Tunisie.

The unit has been mapped only in the Sahara and in the desertic region of Somalia but probably its extension is much larger. In the absence of more precise data it was necessary to map the greater part of the Sahara to the west of 15°E as Ar: Desert, not differentiated.

Agricultural value

Nil.

b) Desert pavements (regs) transported — Ap′

Definition

Coarse products of physical weathering that have been transported, as for example, by temporary water courses.

Associated units

AnAp' : with sands (ergs)
Ap'Ar : with deserts, not differentiated

Distribution

Africa Occidental Española, Algérie, Libya, Niger.

This element, less extensive than Ap, is limited to low lying areas as closed basins and wadis.

Agricultural value

Nil.

4. DESERTS, NOT DIFFERENTIATED — Ar

Definition

All loose materials submitted to desert conditions (see general definition) which, for lack of data, have not been separated.

Associated units

Ap'Ar : with desert pavements (regs), transported
ArMe : with halomorphic soils, not differentiated

Distribution

Africa Occidental Española, Algérie, Angola, Ethiopia, Libya, Maroc, Mauritanie, Sudan, South West Africa, United Arab Republic.

Agricultural value

None.

CHAPTER 2

WEAKLY DEVELOPED SOILS

All elements treated in this chapter are classified with the order Entisols (USDA classification, 7th Approximation ([29])) except for the sub-desert soils (Bf) that belong in the order of the Aridisols. The soils have in common a low level of profile development, reflected in a very weak differentiation of horizons. Numerous factors may contribute to their poor development such as:

— Parent materials low in alterable or transferable minerals (material very rich in quartz, e.g.).
— Climate not conducive to chemical alterations and to movements inside the profiles (arid or very cold climates)
— Erosion processes that remove loose superficial layers as soon as they are formed (strong relief, intense rainfall).
— Local reworking processes that blot out horizontal differentiations induced by the other pedogenetic factors
— Continued import of fresh parent material (alluvial plains, regions submitted to aeolian deposits, volcanic or not)
— Youth of the deposits, brevity of the pedological time

A — **Lithosols (skeletal soils) and lithic soils**

General definition

Soils with very weak differentiation of genetic horizons, containing coarse elements and having solid rock within 30 cm depth. With the exception of the first two, Ba and Bb, these elements are widely distributed on both sides of the equator. They cover a surface on the continent estimated at about 3 366 000 km², which is more than 11% of the total surface. In Madagascar they comprise about 20% of the surface.

1. Lithosols on lava — Ba

Definition

See general definition.

Associated units

AaBa : with rocks and debris of rocks rich in ferromagnesian minerals.
BaHa : with eutrophic brown soils of tropical regions on volcanic ash.
Ra : the unit is part of the volcanic islands complex.

Only the first of these associations, AaBa, covers an important area, located principally in Kenya, under arid climate. Most of the areas mapped as Ba overlay recent to very recent lava flows.

Distribution

Cameroun, Kenya, Nigeria, Rwanda.

Agricultural calue

Low. May be forested if climate is sufficiently humid.

2. Lithosols on rocks rich in ferromagnesian minerals — Bb

Definition

See general definition.

Associated units

BbHb : with eutrophic brown soils of tropical regions on rocks rich in ferromagnesian minerals
BbJc : with ferruginous tropical soils on crystalline acid rocks
BbKa : with humic ferrisols
BbKb : with ferrisols on rocks rich in ferromagnesiam minerals
Ra : the unit is part of the volcanic islands complex.

With its 40 000 km^2, the association BbHb is by far the most important; all other associations together cover less than 10 000 km^2.

Distribution

Bechuanaland, Cameroun, Côte d'Ivoire, Guinée, Haute Volta, Mali, Madagascar, Niger, Rhodesia (Northern), Rhodesia (Southern).

Limited to outcroppings of basic rocks in landscapes that are more or less rough, and exposed to sub-humid to semi-arid climates.

Agricultural value

Generally low.

3. Lithosols on ferruginous crusts — Bc

Definition

See general definition.

This element is one of the most important on the map, due as much to the total surface it occupies (1 412 000 km^2 — 4.8 %) as to its area of distribution. However the group should be better characterized, for the nature of these cuirasses or the cuirasse debris is by no means the same everywhere. It can be accepted that most are ancient and that topographical and perhaps even climatic conditions, quite different from these prevailing now, may have been instrumental to their formation. But we also know that a few of these cuirasses and concretions are forming now. Consequently a lithosol Bc may indicate a loose parent material, or a developed profile in which a cuirasse is presently forming, or a cuirasse that is presently being broken up.

Associated units

AcBc : with rock and rock debris, not differentiated
BcDa : with vertisols derived from rocks rich in ferromagnesian minerals
BcGb : with brown soils of arid and semi-arid tropical regions, not differentiated
BcHb : with eutrophic brown soils of tropical regions on rocks rich in ferromagnesian minerals
BcJd : with ferruginous tropical soils not differentiated
BcKb : with ferrisols on rocks rich in ferromagnesian minerals
BcKc : with ferrisols not differentiated
BcLa : with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments
BcLc : with ferrallitic soils, dominant colour yellowish-brown, not differentiated
BcLm : with ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals
BcLn : with ferrallitic soils, dominant colour red, not differentiated
BcLx : with red and yellow ferrallitic soils on various parent materials
BcDjJd : with vertisols of topographic depressions and ferruginous tropical soils, not differentiated
BcDjLc : with vertisols of topographic depressions and ferrallitic soils, dominant colour yellowish-brown, not differentiated
BcJaJc : with ferruginous tropical soils on sandy parent materials and on crystalline acid rocks
BcJdLc : with ferruginous tropical soils and ferrallitic soils, dominant colour yellowish-brown, neither differentiated
BcJdLn : with ferruginous tropical soils and ferrallitic soils, dominant colour red, neither differentiated
BcKcLc : with ferrisols and ferrallitic soils, dominant colour yellowish-brown, neither differentiated

BcKcLn : with ferrisols and ferrallitic soils, dominant colour red, neither differentiated

BcKcLx : with ferrisols, not differentiated, and yellow and red ferrallitic soils on various parent materials

BcLaLx : with ferrallitic soils, dominant color yellowish-brown on loose sandy sediments and yellow and red ferrallitic soils on various parent materials

BcLsLt : with humic ferrallitic soils and ferrallitic soils with dark horizon.

Associations with ferruginous tropical soils and ferrallitic soils are most widespread. When associated with the former the mobility of the iron compounds, characteristic of ferruginous tropical soils, makes it likely that part of the soils mapped Bc are lithosols in which the cuirasse or the concretions are presently forming. In associations with ferrallitic soils, the geomorphological arguments and the nature of the vegetation cover generally support the conclusions that most of the material is ancient and that it is presently being broken up.

Distribution

Burundi, Centr'africaine (République), Cameroun, Congo (Léopoldville), Côte d'Ivoire, Dahomey, Gabon, Gambia, Ghana, Guinéa Continental Española, Guiné (Port), Guinée, Haute Volta, Kenya, Madagascar, Mali, Mauritanie, Moçambique, Nigeria, Rwanda, Rhodesia (Northern), Sénégal, Sudan, Tanganyika, Togo, Uganda.

The element has been mapped only between latitudes 17° north and south, with a predominance however in the northern hemisphere (887 000 km^2 against 525 000 km^2). Like the unit Ab from which they derive for the most part, Bc soils seem characteristic of tertiary surfaces.

Agricultural value

The agricultural value of soils where the cuirasse is presently forming may be just as precarious as that of the soils where the cuirasse is presently being broken. In both instances the value depends not only on the mineral reserve of the cuirasse proper, but also on other factors. The mineral reserve of the materials overlying the cuirasse and those of the materials underneath which plant roots will be able to exploit after having pierced the cuirasse, influence the agricultural potential as well.

In certain favourable conditions afforestation with protection against fires has been successful.

4. Lithosols on calcareous crusts — Bc'

Cfr. Part III, profile 1, page 129.

Definition

See general definition

As in the case of the lithosols on ferruginous cuirasses, it may be acknowledged for this element that the calcareous crust may still be forming and in this case is, in part then, a product of present day soil formation. In other cases the crust is a paleopedogenetic remnant and is to be considered a parent material.

In southern Africa (South West Africa, Republic of South Africa) they are found on loose sediments, generally in association with brown soils of arid and semi-arid tropical regions, and in areas with flat or slightly undulating relief. A thin layer of brown to red aeolian sand overlays a calcareous crust of variable thickness. The pH is neutral to slightly alkaline. In the clay fraction illite and montmorillonite are the dominant minerals. Of course these soils may be considered lithosols only in so far as the loose overlying layer is sufficiently thin (30 cm).

Associated units

Bc'Bf : with sub-desert soils, not differentiated

Bc'Ca : with rendzinas and/or brown calcareous soils

Bc'Ga : with brown soils of arid and semi-arid tropical regions on loose sediments

Bc'Gn : with brown and reddish-brown soils of arid and semi-arid Mediterranean regions

Bc'Me : with halomorphic soils, not differentiated.

The associations Bc'Ga and Bc'Gn are the most important and cover respectively 180 000 km^2 and 122 000 km^2. Together the others cover less than 20 000 km^2.

Distribution

Algérie, Maroc, Republic of South Africa, South West Africa, Tunisie.

This formation is limited to the relatively arid regions situated near the border of the deserts. In North Africa its presence seems linked to calcareous bedrock. In Southern Africa we find it on the Dolomite series around the Kalahari depression.

Agricultural value

These soils have a certain agricultural potential. In North Africa they often carry vineyards, in Southern Africa they are used for extensive grazing.

5. Lithosols, not differentiated — Bd

This is the most widely distributed and also the most extensive category of lithosols that has been mapped. On the continent it covers approximately 1 714 000 km^2 (6% of the total surface). On Madagascar it covers 119 000 km^2 which is more than 19% of the land surface. It is this element also that participates in the greatest number of associations.

Definition

See general definition.

Associated units

AbBd	:	with ferruginous crusts
AcBd	:	with rock and rock debris, not differentiated
BdBf	:	with sub-desert soils
BdCa	:	with rendzinas and/or brown calcareous soils
BdDa	:	with vertisols derived from rocks rich in ferromagnesian minerals
BdDj	:	with vertisols of topographic depressions
BdFa	:	with sols lessivés — Highveld pseudo-podsolic soils
BdGb	:	with brown soils of arid and semi-arid tropical regions, not differentiated.
BdHd	:	with eutrophic brown soils of tropical regions, not differentiated
BdIn	:	with brown Mediterranean soils
BdJa	:	with ferruginous tropical soils on sandy parent materials
BdJb	:	with ferruginous tropical soils on rocks rich in ferromagnesian minerals
BdJc	:	with ferruginous tropical soils on crystalline acid rocks
BdJd	:	with ferruginous tropical soils, not differentiated
BdKc	:	with ferrisols, not differentiated
BdLn	:	with ferrallitic soils, dominant colour red, not differentiated
BdLx	:	with red and yellow ferrallitic soils on various parent materials
AcBdJa	:	with rock and rock debris, not differentiated, and ferruginous tropical soils on sandy parent materials
AcBdJd	:	with rock, rock debris and ferruginous tropical soils, neither differentiated
BdBfMb	:	with sub-desert soils and saline soils, alkali soils and saline alkali soils
BdCaDb	:	with rendzinas and/or brown calcareous soils, and vertisols derived from calcareous rocks

BdCaIn : with rendzinas and/or brown calcareous soils and brown Mediterranean soils
BdDaJd : with vertisols derived from rocks rich in ferromagnesian minerals and ferruginous tropical soils not differentiated
FdFaJd : with sols lessivés—Highveld pseudo-podsolic soils and ferruginous tropical soils, not differentiated
BdHbJc : with eutrophic brown soils of tropical regions on rocks rich in ferromagnesian minerals and ferruginous tropical soils on crystalline acid rocks
BdJdKc : with ferruginous tropical soils and ferrisols, neither differentiated.
BdJdLn : with ferruginous tropical soils and ferrallitic soils, dominant colour red, neither differentiated
BdKbLm: with ferrisols and ferrallitic soils, dominant colour red, both on rocks rich in ferromagnesian minerals
BdKcLn : with ferrisols and ferrallitic soils, dominant colour red, neither differentiated
BdKcLx : with ferrisols, not differentiated, and red and yellow ferrallitic soils on various parent materials.

The associations BdBf (323 000 km^2), BdGb (581 000 km^2) and BdJd (210 000 km^2) are the most widely distributed. Those with ferrallitic soils are the least numerous.

Distribution

Algérie, Angola, Basutoland, Bechuanaland, Burundi, Cameroun, Côte d'Ivoire, Congo (Léopoldville), Ethiopia, Gabon, Ghana, Guinea Continental Española, Guiné Portuguesa, Kenya, Liberia, Mali, Madagascar, Maroc, Moçambique, Nigeria, Niger, Nyasaland, Rwanda, République Centr'africaine, Rhodesia (Northern), Rhodesia (Southern), Republic of South Africa, Sierra Leone, Somalia, Sudan, South West Africa, Swaziland, Tanganyika, Tchad, Togo, Tunisie, Uganda.

This element is characteristic of regions where erosion is important. On the map its presence may indicate excessive relief, climates with intense precipitation, or vegetative covers that afford only small protection.

Agricultural value

Generally low. Can be afforested when climate allows it. Elsewhere poor pastures and game reserves.

B — Sub-desert soils — Bf

Cfr. Part III profiles *2a* and *2b*, pages 130 and 131.

These soils are transitional between the desert detritus that is practically abiotic, and the brown soils of arid and semi-arid regions. Their surface totals approximately 2 000 000 km², roughly 7 % of the continent.

Definition

Soils very low in organic matter with slightly differentiated genetic horizons, sometimes with accumulation of carbonates or soluble salts slightly hardened at the surface and/or at some depth. They occur in hot climates with very low rainfall.

Pochon J. et al. ([22]) have studied a few samples taken near Béni-Ounif (31°42′N—1°32′W), which on our map is situated in an area mapped as Ab'Bf. The mean water content of the soils was only about 5°/₀₀. Biological activity was very low : the number of bacteria was less than 1 million per gram of soil and certain physiological groups, such as nitrogen fixers and nitrifiers, were entirely lacking.

Associated units

AbBf : with ferruginous crusts
Ab'Bf : with calcareous crusts
AcBf : with rock and rock debris, not differentiated
AnBf : with desert detritus (sands)
AoBf : with desert detritus (clay plains)
Bc'Bf : with lithosols on calcareous crusts
BdBf : with lithosols, not differentiated
BfBo : with juvenile soils on riverine and lacustrine alluvium
BfCc : with soils with high gypsum content
BfMe : with halomorphic soils, not differentiated
BdBfMb : with lithosols not differentiated and saline soils, alkali soils and saline alkali soils.
BfBoMe : with juvenile soils on riverine or lacustrine alluvium and halomorphic soils, not differentiated.

Among these associations, the most important are Ab'Bf (259 000 km²), AcBf (566 000 km²), AoBf (198 000 km²) and BdBf (323 000 km²), all of which indicate very well the transitional character of the unit Bf. Those associations with Ab', Ac and Ao occupy the drier areas, those with Bd the more humid areas. Bf is equally associated with calcareous crusts, with old ferruginous crusts and with halomorphic formations. In these regions with a potential for high evaporation and with highly deficient rainfall, halomorphy assumes greater importance than hydromorphy. Nowhere in the entire area covered by sub-desert soils is hydromorphy of sufficient importance to be mapped.

Distribution

Algérie, Angola, Ethiopia, Kenya, Libya, Mali, Maroc, Mauritanie, Niger, Republic of South Africa, Somalia, Sudan, South West Africa, Tchad, Tunisie, United Arab Republic.

In Africa they are found exclusively in a warm, arid climate: their "humid" limit is always below the 150 mm isohyet.

Agricultural value

Nutrient potential of these soils is generally high. Under irrigation they may yield good crops but their soluble salt content demands certain precautions. In their natural state they produce only poor pastures and certain products which may be collected such as resins, incense, and gum arabic.

C — **Weakly developed soils on loose sediments not recently deposited** — Bh

Cfr part III, profiles *3a* and *3b*, pages 132 and 133

Definition

Soils without clear differentiation of genetic horizons and having (A) C profiles developed from loose sediments, generally coarse in texture, and not of very recent deposition. The absence of well developed horizons may be ascribed to the aridity of the pedoclimate, or to the resistance of the parent material to pedogenetic factors.

In part III descriptions will be found of two profiles both of which occur under semi-arid climate; the first (Madagascar profile) is developed in relatively rich material, as shown by the saturation level of the complex, whereas the second (Nigeria) is derived from a poor parent material.

Associated units

BhDj	:	with vertisols of topographic depressions
BhJa	:	with ferruginous tropical soils on sandy parent materials
BhJd	:	with ferruginous tropical soils, not differentiated

BhMb : with saline soils, alkali soils and saline alkali soils
BhNa : with mineral hydromorphic soils
BhNb : with organic hydromorphic soils
BhCaMa: with rendzinas and/or brown calcareous soils and solonetz or solodized solonetz.

The most important associations are those with ferruginous tropical soils BhJa (26 000 km^2) and BhJd (24 000 km^2), and with vertisols of topographic depressions (20 000 km^2). The association with organic hydromorphic soils mapped in Mozambique (Machongos) should also be noted (31 000 km^2)

Distribution

Algérie, Madagascar, Moçambique, Nigeria, Republic of South Africa, South West Africa, Sudan, Tunisie.

The element Bh covers many ancient littoral dune formations, stabilized and submitted to a rather arid climate. Humid ocean air often brings in some occult precipitation such as dew which favourably influences the vegetative cover.

Agricultural value

The parent materials of these soils and their fertility are rather variable : When on rich parent materials their value will depend on the possibility of irrigation, drainage, or water level control. Without improvement they may be used only as range pasture with low capacity.

D — Juvenile soils on recent deposits

General definition

Soils without clear differentiation of genetic horizons and having (A) C profiles developed from various recently deposited materials. Absence of well developed horizons is mainly due to the brevity of the soil forming period.

1. Juvenile soils on volcanic ash — Bn

Cfr Part III, profile 4, page 134

Definition

See general definition
Parent materials are aeolian dust of volcanic origin.

Associated units

AaBn : with rock and rock debris rich in ferromagnesian minerals
BnHa : with eutrophic brown soils of tropical regions on volcanic ash
Ra : The unit is part of the volcanic islands complex.

Distribution

Congo (Leopoldville), Kenya, Tanganyika.

These soils are found in the neighbourhood of active volcanoes. The mean diameter of their particles is inversely proportional to the distance of the emitting cone, and this in the direction of the dominant winds ([21]).

Agricultural value

At his stage of pedogenetic development colonization by natural vegetation commonly is only incipient. Thus only about 10% of the soil Bn, described in part III is covered by vegetation (*Dactylotenium sp.*). Where deposits have been stabilized for a time and where new contributions are temporarily interrupted, they can carry crops. The combination of high permeability and low water holding capacity however limits their utilization.

2. Juvenile soils on riverine and lacustrine alluvium — Bo

Definition

See general definition.

The parent materials of these soils — whose deposition is still proceeding intermittently — are characterized by a great heterogeneity. They differ not only from one spot to another but also from flood to flood as reflected by the stratifications in the profiles. Moreover the age of the deposits is not the same throughout a given alluvial zone. For these reasons the alluvia are generally mapped as complexes.

In the most recent Bo soils, e.g. those forming on periodically inundated sandbars, humic horizons are often lacking whereas the gley horizon is barely discernible. Older formations covered by vegetation have humic horizons, give evidence of structural development and a gley horizon becomes perceptible.

Associated units

BfBo	:	with sub-desert soils
BoDj	:	with vertisols of topographic depressions
BoGn	:	with brown and reddish-brown soils of arid and semi-arid Mediterranean regions
BoMb	:	with saline soils, alkali soils and saline alkali soils
BoMe	:	with halomorphic soils, not differentiated
BoNa	:	with mineral hydromorphic soils
BoNb	:	with organic hydromorphic soils
BfBoMe	:	with sub-desert soils and halomorphic soils, not differentiated
BoDjMe	:	with vertisols of topographic depressions and halomorphic soils, not differentiated

The most widespread association is without doubt that with the hydromorphic soils. This follows as a consequence of the topographic situation in which the parent materials of Bo are normally deposited. The total area covered by the unit may be estimated at 535 000 km². Among the latter the most important are those with vertisols of topographic depressions and with halomorphic soils, all connected with similar topographic situations. A rather peculiar association is that with the brown and reddish brown soils of arid and semi-arid Mediterranean regions, mapped in Algeria, Tunisia and Morocco.

Distribution

The element Bo, although not the most extensive, is certainly one of the best distributed. It may be found under every climate near bodies of water which fluctuate periodically. As the deposited materials are introduced when the rivers are in flood, the Bo material will be found most frequently in regions where the precipitation is characteristically seasonal or along the rivers that drain those regions. This is also true for the Congo Basin where alluvia are deposited under a continuously humid equatorial climate, and for the Nile valley where alluvia are deposited under a desert climate; in both cases the floods originate in regions with humid seasonal climates.

Agricultural value

The agricultural potential is influenced largely by the composition of the sediments, which, in turn, are highly variable as affected by origin, transportation distance, and the speed of the transporting currents. Moreover the sediments are found under very different climates that induce different types of appropriate agriculture.

In a given region, alluvial plains often comprise the soils with the highest agricultural potential. It is seldom however that these favoured soils make up all of the alluvial deposits. Hence detailed soil mapping prior to reclamation is always useful.

3. Juvenile soils on fluvio-marine alluvium (mangrove swamps) — Bp

Cfr Part III, profile 5, p. 135

Definition

See general definition.

Parent materials are somewhat clayey deposits at the mouths of certain rivers.

Associated units

The unit has not been mapped in association.

Distribution

Angola, Cameroun, Congo (Brazzaville), Congo (Léopoldville), Côte d'Ivoire, Gabon, Gambia, Ghana, Guinée, Guinéa Continental Española, Guiné Portuguesa, Kenya, Madagascar, Moçambique, Nigeria, Sénégal, Sierra Leone, Somalia, Tanganyika.

The total area covered by mangrove soils is less than 56 000 km^2 on the continent and the major part of it (47 000 km^2) lies north of the equator, along the western coast.

Agricultural value

Although mangrove soils generally have relatively high agricultural potential due to the quality of their colloidal constituents and their available nutrients, they can not be used for agriculture in their natural state. They are fluvio-marine marshlands, periodically inundated by salt or brackish water at high tide, and often contain important quantities of sulfides, poly-sulfides, and even elementary sulfur. After reclamation, oxidation of these compounds may give rise to very strong acidifications, and to toxic concentrations of available iron, aluminium, and manganese.

Certain engineering works are necessary to isolate these soils from the action of the tides; the amount of protection needed depends on tidal amplitude and other hydraulic considerations. In West Africa and particularly in Portuguese Guinea, Guinea and Sierra Leone, conditions are such that rather simple structures are sufficient and desalinization may be effected through timely irrigations with the fresh water of the seasonal floods.

Those soils which received substantial additions of raw organic material during their formation are correspondingly high in sulfur. The sulfates periodically imported with the sea water are immobilized in the swamp soils by processes of biological reduction, promoted by constant imports of organic material. Research, carried out largely at the West African Rice Research Station at Rohkupr, Sierra Leone, has shown that this was particularly true for *Rhizophora racemosa* mangrove, the soils of which often show forbidding acidities a few years after their reclamation. *Avicennia nitida* mangroves do not have this drawback ([16]).

The soils are suited primarily to irrigated rice, and yields of 1 500 – 2 000 lbs/acre have been obtained.

4. Juvenile soils on wind-borne sands — Bq

Definition

See general definition

This unit, whose parent materials are mostly recent to very recent dunes, comes very close to unit Bh. The only distinctions reside in the age of the deposits and in the prevailing climate, which in the case of Bq, is more conducive to soil formation.

Associated units

BqDb : with vertisols derived from calcareous rocks
BqMe : with halomorphic soils, not differentiated
BqNb : with organic hydromorphic soils

The most important association is BqDb.

Distribution

Côte d'Ivoire, Dahomey, Liberia, Madagascar, Maroc, Nigeria, Sierra Leone, Somalia, Togo.

Agricultural value

Relatively low. In the intertropical zone these soils often support coconut groves.

5. Soils of oases — Br

Cfr Part III, profile 6, page 136

Definition

Soils of oases are man-made soils. The parent materials are desert detritus with sandy or clayey texture, but their location near water points has permitted irrigation. As a result of cultivation these soils have been enriched in organic matter, nitrogen, and soluble salts brought in by crop residues, goat manure, and by irrigation waters, the salinity of which is often marginal. Moreover irrigation techniques used in the oases are frequently rather primitive ([23]).

Associated units

The unit has not been mapped in association.

Distribution

Algérie, Libya, Côte française des Somalis, Tchad, Tunisie, United Arab Republic.

Agricultural value

Oases cover only restricted areas. They are irrigated gardens where a somewhat intensified agriculture is practiced with rotations and organic fertilizers. The most characteristic plant of the Sahara oases is without doubt the date palm (*Phoenix L.*) found only in the cultivated state. In the shadow of these date palms, vegetables, melons, watermelons, citrus fruit, olives, pomegranates, almonds and grapes are grown. ([11])

CHAPTER 3

CALCIMORPHIC SOILS, VERTISOLS AND SIMILAR SOILS

A — Calcimorphic soils

On the map these soils cover only 200 000 km^2. In the geological outline of Africa (Part I, chapter 1) it was indicated that calcareous outcrops were of some importance only in the sedimentary fringe and its extensions around the continent, and in the western part of Madagascar. Calcimorphic soils however may also develop on calco-alkaline metamorphic rocks and even, in volcanic regions, on extrusive rocks or on secondary calcareous formations.

Definition

Soils whose development has been influenced by the presence of large quantities of relatively soluble compounds of calcium (carbonates, sulphates, etc...). The principal members are rendzinas and brown calcareous soils. These soils retain appreciable amounts of free calcium carbonate at all depths and the exchange complex is generally rich in clays with 2:1 lattice structure. The exchange complex has a high content of bivalent cations, mainly calcium. Soils containing more than 15% gypsum are included under this heading.

1. Rendzinas and brown calcareous soils — Ca

Cfr Part III, profiles *7a* and *7b*, pages 137 and 138

Definition

See general definition.

In the 7th Approximation USDA ([27]) the rendzinas are found under two different orders: Inceptisols (rendollic eutrochrepts) and Mollisols (rendolls), according to the nature, thickness, and the saturation percentage of the humic horizons.

Associated units

AcCa	:	with rock and rock debris, not differentiated
Bc'Ca	:	with lithosols on calcareous crusts
BdCa	:	with lithosols, not differentiated
CaDa	:	with lithomorphic vertisols derived from rocks rich in ferromagnesian minerals
CaDb	:	with lithomorphic vertisols, derived from calcareous rocks
CaGa	:	with brown soils of arid and semi-arid tropical regions, on loose sediments
CaGb	:	with brown soils of arid and semi-arid tropical regions, not differentiated
CaGn	:	with brown and reddish-brown soils of arid and semi-arid Mediterranean regions
CaIa	:	with red Mediterranean soils

CaIn : with brown Mediterranean soils
CaJd : with ferruginous tropical soils, not differentiated
AcCaGn : with rock and rock debris, not differentiated, and brown and reddish-brown soils of Mediterranean regions
BdCaDb : with lithosols, not differentiated. and vertisols derived from calcareous rocks
BdCaIn : with lithosols, not differentiated and brown Mediterranean soils
BhCaMa : with weakly developed soils on loose sediments not recently deposited, and solonetz or solodized solonetz.

The most widely distributed associations are CaGn (20 000 km^2) and CaJd (35 000 km^2)

Distribution

Algérie, Angola, Madagascar, Maroc, Niger, Republic of South Africa, Somalia, Tanganyika, Tunisie.

Most of these soils are found under arid or semi-arid climate.

Agricultural value

Low to medium.

Generally very dry soils covered with sparse vegetation. Under irrigation they can yield good crops.

2. Soils with calcareous pans — Cb

Cfr Part II, profile 8, page 139

Definition

See general definition.

They are calcimorphic soils characterized by the presence of a horizon enriched with secondary calcium.

Associated units

CbIa : with red Mediterranean soils.

Distribution

CbIa has only been mapped in the south-western part of Madagascar.

Agricultural value

Low to medium, but can be improved by irrigation. They often yield good range land.

3. Soils containing more than 15% gypsum — Cc

Definition

See general definition

These soils are developed from parent materials rich in gypsum or in depressions of landscapes overlying rock rich in gypsum.

Associated units

BfCc : with sub-desert soils.

Distribution

Algérie, Somalia, Tunisie.

On the map this element covers important areas only in arid and sub-desertic areas. In addition there are certain small appearances in semi-arid to semi-humid regions, often associated with vertisols of topographic depressions (Dj).

Agricultural value

Very low.

B — Vertisols and similar soils

In continental Africa these soils cover approximatively 961 000 km² or more than 3% of the total area. They deserve particular attention in view of the possibilities they offer to agriculture, and the relatively small use that has been made of them thus far. Their definition is almost identical with that given by the USDA 7th approximation ([27]) with the exception of the expandable clay mineral content, which, according to the 7th approximation, should be greater than 35%. It has been shown recently that several African soils had all of the morphological characteristics of vertisols but the clay fraction was rather low in expandable minerals and consisted mainly of amorphous gels ([1]).

The subdivision into lithomorphic vertisols and vertisols of topographic depressions, used by several scientists who have worked in Africa, has been maintained. Each subdivision is related to distinct geomorphological features that can be mapped readily and correspond respectively to the usterts and aquerts of the USDA 7th Approximation ([27]).

General definition

Soils with an A1 horizon, at least 20 cm thick, and dark in colour even though the organic matter content is usually low. Calcareous accumulations are frequent. Permeability is slow and internal drainage is poor, at least at some depth, even though external drainage may be favourable. Profiles show the effect of mechanical reworkings such as dry season cracks, slickensides, and often by gilgai micro-relief. The structure is prismatic or coarse blocky throughout most of the profile. The surface horizon sometimes has a fine structure (self-mulching).

The reserve of weatherable minerals is often high. The clay fraction usually consists mainly of 2 : 1 lattice clays, especially the montmorillonite and mixed layer clay minerals. The cation exchange capacity of the complex is high and is generally more than 50 % saturated, mostly with bivalent cations (normal ammonium acetate at pH 7).

1. Vertisols of lithomorphic origin, derived from rocks rich in ferro-magnesian minerals — Da

Cfr Part III, profile 9, page 139

Definition

See general definition.

These vertisols developed from rocks rich in ferromagnesian minerals which provided all the elements needed for the synthesis of their clay minerals, and the subsequent saturation of these with bivalent cations.

Associated units

BcDa : with lithosols on ferruginous crusts
BdDa : with lithosols, not differentiated
CaDa : with rendzinas and/or brown calcareous soils
DaFa : with sols lessivés — Highveld pseudo-podsolic soils
DaGb : with brown soils of arid and semi-arid tropical regions, not differentiated

DaHb : with eutrophic brown soils of tropical regions on rocks rich in ferromagnesian minerals
DaJb : with ferruginous tropical soils on rocks rich in ferromagnesian minerals
DaJd : with ferruginous tropical soils not differentiated
DaKa : with humic ferrisols
DaLx : with yellow and red ferrallitic soils on various parent materials
DaMa : with solonetz and solodized solonetz
BcDaJd : with lithosols on ferruginous crusts and ferruginous tropical soils, not differentiated
Ra : the unit is part of the volcanic islands complex.

The association with humic ferrisols is the most extensive (DaKa). According to the map this unit covers a great part of the Ethiopian massif. It should be noted however that for a lack of local pedological maps, these regions have been extrapolated to a large extent. Elsewhere the unit is associated with ferrallitic soils, ferruginous tropical soils, and also with brown soils of arid and semiarid regions.

Distribution

Angola, Basutoland, Bechuanaland, Cameroun, Dahomey, Ethiopia, Ghana, Mauritanie, Moçambique, Nigeria, Rhodesia (southern), Republic of South Africa, Sénégal, Somalia, Tchad, Togo.

These soils are formed under a rather wide range of relatively dry climates. They can be found in southern Europe as well as in southern, northern, and intertropical Africa.

Though theoretically confined to basic rock outcrops the clay masses that most of them contain give them great mobility when saturated with water. Consequently their lateral displacement is favoured by solifluction, especially when relief is more or less undulating.

Agricultural value

Vertisols of lithomorphic origin derived from rocks rich in ferromagnesian minerals are included among the best soils of Africa. If their potential fertility is comparable to that of the other vertisols, their topographical situation generally prevents significant accumulations of soluble salts, and makes water table regulation less difficult. Moreover, several are developed under subtropical climates that are very favourable to agriculture. The most widely distributed crops are sugar cane and cotton, but also grain crops (corn, wheat, sorghum, rice), tobacco, and fodder crops. It may be noted that in Africa several of these soils are still uncultivated and are used for extensive pastures.

2. Vertisols of lithomorphic origin derived from calcareous rocks — Db

Cfr Part III, profile 10, page 141.

Definition

See general definition.

These vertisols are developed directly from calcareous rocks, often from marls, which have provided all the elements needed for the synthesis of their clay minerals and for saturation of these by bivalent cations.

Associated units

BqDb : with juvenile soils on wind-borne sands
CaDb : with rendzinas and/or brown calcareous soils
DbGb : with brown soils of arid and semi-arid tropical regions, not differentiated
DbIa : with red Mediterranean soils
DbJa : with ferruginous tropical soils on sandy parent materials
DbJd : with ferruginous tropical soils, not differentiated
AcDbIa : with rock and rock debris, not differentiated, and red Mediterranean soils
BdCaDb : with lithosols, not differentiated, and rendzinas and/or brown calcareous soils.

Distribution

Algérie, Angola, Dahomey, Kenya, Mali, Madagascar, Moçambique, Nigeria, Rhodesia (Southern), Sénégal, Somalia, Tanganyika, Togo, Tunisie.

This element which covers barely 55 000 km^2 on the continent is the only group of vertisols that is well represented on Madagascar. Remarks made previously in connection with displacement through solifluction of the lithomorphic vertisols (Da) derived from rocks rich in ferromagnesian minerals are also valid here. This displacement generally occurs here on a smaller scale since the topography of their landscapes usually is smoother. It may be recalled that calcareous sediments conducive to formation of these vertisols, crop out all around the border of the continent and that they are particularly important in northern Africa.

Agricultural value

Perhaps slightly lower than that of the vertisols Da. In Africa many of these soils are favourably located near the coast, and ready accessibility has promoted their occupation and their development.

3. Vertisols of topographic depressions — Dj

Cfr. Part III, profile 11, page 142.

The area occupied by vertisols of topographic depressions in Africa is twice as large (692 000 km^2) as that covered by vertisols of lithomorphic origin (269 000 km^2). The Sudan depression is probably the largest expanse of these soils in the world.

Definition

See general definition.

These soils are found in topographic depressions where poor external drainage aggravates the effects of inherently poor internal drainage. They seem to develop only under climates where potential evaporation is high during part of the year and on parent materials (often sediments) enriched in insoluble constituents derived directly or indirectly from surrounding higher land. Accordingly they are more commonly associated with soils having sodic, calcic or gypsic horizons than are the vertisols of lithomorphic origin.

Associated units

BdDj	: with lithosols, not differentiated
BhDj	: with weakly developed soils on loose sediments not recently deposited
BoDj	: with juvenile soils on riverine and lacustrine alluvium
DjGa	: with brown soils of arid and semi-arid tropical regions, on loose sediments
DjGb	: with brown soils of arid and semi-arid tropical regions, not differentiated
DjGn	: with brown and reddish-brown soils of arid and semi-arid Mediterranean regions
DjHc	: with eutrophic brown soils of tropical regions on alluvial deposits
DjIa	: with red Mediterranean soils
DjJa	: with ferruginous tropical soils on sandy parent materials
DjJb	: with ferruginous tropical soils on rocks rich in ferromagnesian minerals
DjJd	: with ferruginous tropical soils, not differentiated
DjKc	: with ferrisols, not differentiated
DjLa	: with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments
DjLc	: with ferrallitic soils, dominant colour yellowish-brown, not differentiated

DjLx : with yellow and red ferrallitic soils on various parent materials
DjMa : with solonetz and solodized solonetz
DjMb : with saline soils, alkali soils and saline alkali soils
DjMe : with halomorphic soils, not differentiated
DjNa : with mineral hydromorphic soils
AcDjJd : with rock and rock debris and ferruginous tropical soils, neither differentiated
AcDjMa : with rock and rock debris, not differentiated, and solonetz or solodized solonetz
BcDjJd : with lithosols on ferruginous crusts and ferruginous tropical soils, not differentiated
BcDjLc : with lithosols on ferruginous crusts and ferrallitic soils, dominant colour yellowish-brown, not differentiated
BoDjMe : with juvenile soils on riverine or lacustrine alluvium, and halomorphic soils, not differentiated
Ra : The unit is part of the volcanic islands complex.

The associations DjGb (365 000 km^2) and DjNa (250 000 km^2) are by far the most important. The former occupies the northern, the latter the southern part of the Sudan depression. Other important associations are those with eutrophic brown soils on alluvial deposits DjHc (86 000 km^2), with juvenile soils on riverine or lacustrine alluvium BoDj (57 000 km^2) and with halomorphic soils (74 000 km^2). Associations with ferrallitic soils could be the result of profile development on ancient ferrallitic materials.

Distribution

Algérie, Angola, Burundi, Cameroun, Congo (Léopoldville), Côte d'Ivoire, Ethiopia, Kenya, Mali, Maroc, Moçambique, Nigeria, Niger, Nyasaland, Rwanda, République Centr'africaine, Rhodesia (Northern), Somalia, Sudan, Tanganyika, Tchad, Tunisie, Uganda.

Of all the vertisols, the element Dj is the most characteristic of the intertropical area. It is found only in conditions of relatively well marked seasonal drought: three months of dry season and a mean annual rainfall of 1 000 mm or less. The Dj vertisols have a wider distribution than the vertisols Da and Db. Their formation is not necessarily linked to parent materials rich in bases but they are only well developed when such rocks feed or may have fed their landscapes. To illustrate this we may compare the Niger and Kalahari depressions, where Dj soils are rare, with the Sudan depression (near the Ethiopian massif) the Lake Victoria depression or the Rift valleys where Dj is one of the dominant soil units.

Agricultural value

Comparable, although inferior, to that of units Da and Db. Their topographic situation frequently associates them with calcimorphic or halomorphic formations, and impedes their drainage and their desalinization.

CHAPTER 4

PODSOLIC SOILS AND SOLS LESSIVÉS OR HIGHVELD PSEUDO-PODSOLIC SOILS

A — **Podsolic soils** — Ea

Cfr Part III, profiles 12*a* and 12*b*, page 146.

In the French classification (2) the unit Ea belongs to the class of the soils "à humus grossier", and to the group of the "podzols de nappe". In the USDA classification (27) they correspond to the sub-order of aquods. In Africa their extension is small but they are fairly widely distributed.

Definition

Soils with a layer of raw humus, an ash-like bleached A2 horizon, and a well developed humic B horizon. Under an equatorial or sub-equatorial climate these soils may be encountered wherever highly silicious and readily permeable material is affected by a water table with a maximum depth of less than 200 cm.

Associated units

The unit has not been mapped in association.

Distribution

The unit has been indicated in the coastal fringe of Côte d'Ivoire and in the Congo (Leopoldville) where a few examples have been described near Yangambi (Lilanda) (14).

Agricultural value

Low.

B — Sols lessivés — Highveld pseudo-podsolic soils — Fa

Cfr Part III, profile 13, page 148.

These soils are developed mainly on sedimentary rocks under temperate sub-humid climate. Their genesis and morphology may have been influenced by superficial sandy deposits of aeolian or colluvial origin.

Definition

Highveld pseudo-podsolic soils are of the ABC type with a textural B horizon. The A horizons are generally loose and friable and contain less than 20 per cent clay. The A_1 horizon is brown or dark grey and the weakly developed A_2 horizon is light in colour.

Between 40 and 90 cms depth there is a clear or abrupt change to a textural B horizon of blocky or prismatic structure often of a yellow brown colour. The clay content of horizon B is more than double that of horizon A. The zone of transition from A to B may present spots of pseudogley sometimes associated with concretions of iron and manganese.

The saturation of the exchange complex exceeds 50 per cent especially in horizon B. Horizon A is neutral or weakly acid and horizon B may be weakly alkaline.

The clay minerals of horizon A consist of more or less well crystallised kaolinite and illite. Horizon B contains chiefly illite, often with mixed layer clays and montmorillonite.

Depending on the topography and the composition of the underlying rock some calcareous concretions and a slight or moderate accumulation of soluble salts may be observed in horizons B/C or C. In some rather narrow zones transitional to a drier climate these soils interdigitate with solonetz and solodized solonetz.

Associated units

BdFa	:	with lithosols, not differentiated
DaFa	:	with vertisols derived from rocks rich in ferromagnesian minerals
FaIn	:	with brown Mediterranean soils
FaJb	:	with ferruginous tropical soils on rocks rich in ferromagnesian minerals
FaJd	:	with ferruginous tropical soils, not differentiated
AcFaIn	:	with rock and rock debris, not differentiated, and brown Mediterranean soils
BdFaJd	:	with lithosols and ferruginous tropical soils, neither differentiated.

Distribution

Algérie, Basutoland, Kenya, Maroc, Republic of South Africa, Tunisie.

This unit does not represent a tropical soil in the proper sense of the word. The area mapped as such in Kenya is situated at an altitude of approximately 2 000 m and is submitted to a climate that might be considered temperate.

Agricultural value

These soils are useful for grazing and also for intensive cultivation of grain crops with mechanization and use of fertilizers. They are however rather vulnerable to erosion under conditions of overstocking and unsuitable farming methods.

CHAPTER 5

BROWN AND REDDISH-BROWN SOILS OF ARID AND SEMI-ARID REGIONS

The surface covered by these soils amounts to about 2 700 000 km² on the continent (9 % of total surface). The majority, 2 579 000 km², are situated between the desert areas and the equatorial region. The remaining soils lie between these same desert regions and those with a Mediterranean climate and therefore have developed under rather different conditions, especially with regard to winter rainfall ([18]).

General definition

Brown or reddish soils darkened by organic matter in the greater part of the profile, under steppe vegetation, without A_2 horizon but having a textural, structural or colour B horizon. The reserve of weatherable minerals in the soils is often considerable and depends on the composition of the parent material. Ordinarily they contain appreciable quantities of clay minerals with 2 : 1 lattice. The cation exchange capacity of the mineral complex, medium to high, is more than 50 per cent saturated in horizons B and C (normal ammonium acetate at pH 7). These soils often contain free carbonates.

A — Brown soils of arid and semi-arid tropical regions

Definition

See general definition.

These soils are formed under hot and dry climates where annual rainfall rarely exceeds 500 mm. They are often formed on aeolian deposits. Where the climate is rather more humid a parent rock rich in bases and/or impeded external drainage seem to favour their development.

In these soils the total organic matter content is low (less than 1 %) but very well distributed throughout the profile. The French classification ([2]) subdivides the group of the "sols bruns subarides" into two subgroups: the brown soils proper and the red brown soils. The later differ from the former in that they are generally developed on sandy parent materials, have a greater thickness, generally do not contain any free carbonate, are lower in organic matter, and are neutral to weakly acid ([3,18]).

The subdivision of this unit into,

Ga: Brown soils on loose sediments and,

Gb: Brown soils, not differentiated

reflects, at least in part, the same distinction.

1. Brown soils of arid and semi-arid tropical regions on loose sediments — Ga

Cfr Part III, profile 14, page 149.

Definition

See general definition.

Associated units

AbGa	:	with ferruginous crusts
AcGa	:	with rock and rock debris, not differentiated
Bc'Ga	:	with lithosols on calcareous crusts
CaGa	:	with rendzinas and/or brown calcareous soils
DjGa	:	with vertisols of topographic depressions
GaGb	:	with brown soils of arid and semi-arid tropical regions, not differentiated
GaJa	:	with ferruginous tropical soils on sandy parent materials
GaMb	:	with saline soils, alkali soils, and saline alkali soils.

This element has been mapped as unassociated for the greater part. The main association, Bc'Ga, borders the Kalahari steppe in southern Africa. In northern Africa the unit is associated with ferruginous cuirasses (AbGa). In both cases the association has no genetic significance. Indeed the conditions of formation of the components of each of these associations are so different that it is necessary to bring in climatic variations and chronological successions to explain their present co-existence.

Distribution

Angola, Bechuanaland, Kenya, Mali, Mauritanie, Niger, Republic of South Africa, Sénégal, Sudan, South West Africa, Tchad.

Parent materials are not exclusively the aeolian sand deposits that border the desert regions but include weathered sandstones or paleopedological mantle material as well.

Agricultural value

Generally these soils are suitable only for extensive grazing but under irrigation they also produce millet and cotton. The good structure and permeability they have in the natural state tend to deteriorate under cultivation. Cultivation practices should attempt to maintain or even to increase organic matter content, and should avoid excessive irrigation which could trigger such phenomena detrimental to structure as compaction and hydromorphy.

2. Brown soils of arid and semi-arid tropical regions, not differentiated — Gb

Cfr Part III, profile 15, page 150.

Definition

See general definition.

As most of the brown soils, developed on loose materials, have been separated in Ga, the majority of Gb is composed of brown soils developed on miscellaneous rocks.

Associated units

AaGb : with rock and rock debris rich in ferromagnesian minerals
ApGb : with desert pavements (regs), residual
BcGb : with lithosols on ferruginous cuirasses

BdGb : with lithosols, not differentiated
CaGb : with rendzinas and/or brown calcareous soils
DaGb : with vertisols, derived from rocks rich in ferromagnesian minerals
DbGb : with vertisols derived from calcareous rocks
DjGb : with vertisols of topographic depressions
GaGb : with brown soils of arid and semi-arid tropical regions, on loose sediments
GbJa : with ferruginous tropical soils on sandy parent materials
GbJc : with ferruginous tropical soils on crystalline acid rocks
GbJd : with ferruginous tropical soils, not differentiated
GbNa : with mineral hydromorphic soils
GbJdMa : with ferruginous tropical soils, not differentiated, and solonetz or solodized solonetz.

Unlike the element Ga, most soils Gb are mapped in association. The most important of these are BdGb (581 000 km^2) and DjGb (365 000 km^2), both of which illustrate the weak stage of development and also the semi-arid climate under which they are found.

Distribution

Angola, Bechuanaland, Ethiopia, Kenya, Mali, Mauritanie, Moçambique, Niger, Nyasaland, Rhodesia (Southern), Republic of South Africa, Sénégal, Somalia, Côte française des Somalis, Sudan, South West Africa, Swaziland, Tanganyika, Tchad, Uganda.

Agricultural value

Low. See corresponding paragraph under element Ga.

B — Brown and reddish-brown soils of arid and semi-arid Mediterranean regions — Gn

In the French classification [2] these soils belong to the group of the "Sols bruns steppiques subtropicaux".

Definition

See general definition.

The organic matter content of these soils, may be as much as 3 per cent. The exchange capacity of the mineral complex is more than 80 per cent saturated by bivalent cations. The pH is 7 or slightly more. Sometimes leached of carbonates in the upper horizon, the soils often have at depth a horizon of accumulation of calcium carbonate either in concretions or finely diffused, as well as a clay content higher than in the surface horizon. The structure is often more marked than in the brown soils of the arid and semi-arid tropical regions but on the other hand the content of free iron may be less.

Associated units

AcGn	:	With rock and rock debris, not differentiated
Bc'Gn	:	with lithosols on calcareous crusts
BoGn	:	with juvenile soils on riverine or lacustrine alluvium
CaGn	:	with rendzinas and/or brown calcareous soils
DjGn	:	with vertisols of topographic depressions
GnIa	:	with red Mediterranean soils
AcGaGn	:	with rock and rock debris, not differentiated, rendzinas and/or brown calcareous soils.

Distribution

Algérie, Libya, Maroc, Tunisie.

These soils have only been mapped in the Mediterranean coastal area; their presence in South Africa is not to be excluded.

Agricultural value

Good.

CHAPTER 6

EUTROPHIC BROWN SOILS OF TROPICAL REGIONS

All elements grouped together under this heading barely cover 148 000 km² or 0.5 % of the continent. The main reason for their separation is their agricultural potential, which is generally much higher than that of the surrounding lands.

General definition

Soils of which the A_1 horizon is often rich in organic matter and is sometimes saturated to more than 50 per cent of its cation exchange capacity. There is a textural, structural or colour B horizon. These soils, which are generally rich in plant nutrients, are formed in sub-humid or humid tropical regions (mean annual precipitation 700 to 1 700 mm) especially on volcanic ash, crystalline basic rock and alluvial deposits. Their reserve of weatherable minerals is often large; their clay fraction consists mainly of 2 : 1 lattice minerals but those soils that are developed on volcanic materials may contain allophane. The soils are generally well structured and very permeable. The cation exchange capacity of the mineral complex is medium to high and may be more than 50 per cent saturated in horizons B and C. (normal ammonium acetate at pH 7). The cation exchange capacity may be much greater and the degree of saturation lower in the case of soils rich in allophane.

The eutrophic brown soils are to be considered as relatively young soils situated in conditions favourable to rapid soil formation, i.e. under a warm and humid climate. This paradoxical situation is generally due to a rejuvenation of parent material, either by importation (alluvium, volcanic dust) or by scouring away of the surface layers at a speed comparable to that of the progression of the soil profile into the unweathered rock. In many cases it is therefore possible to establish valid hypotheses as to the soil types toward which a eutrophic brown soil would have developed if its normal development had not been retarded.

According to their parent materials, these genuine authigenous and lithomorphic soils have been subdivided into four elements of cartographic unit.

1. Eutrophic brown soils on volcanic ash — Ha

Cfr. Part III, profile 16, page 151.

Definition

See general definition. These soils correspond approximately to the andepts of the USDA classification [27].

Associated units

AaHa : with rocks rich in ferromagnesian minerals
BaHa : with lithosols on lava
BnHa : with juvenile soils on volcanic ash
HaKa : with humic ferrisols
HaKb : with ferrisols on rocks rich in ferromagnesian minerals
Ra : the unit is part of the volcanic islands complex.

Distribution

Cameroun, Congo (Léopoldville), Kenya, Madagascar, Nigeria, Rwanda, Tanganyika, Uganda.

The element is limited to active volcanic regions.

Agricultural value

Most of these soils are situated at high altitudes which exclude certain crops. At low and medium altitude they are mostly under bananas and coffee. At high altitudes they are suited for intensive cultivation, comparable to that in use in humid temperate regions (pastures, grain crops). At the highest levels they are under pasture or forested.

2. Eutrophic brown soils on rocks rich in ferromagnesian minerals — Hb

Cfr. Part. III, profile 17, page 153.

Definition

See general definition.

Associated units

AbHb : with ferruginous crusts
BbHb : with lithosols on rocks rich in ferromagnesian minerals
BcHb : with lithosols on ferruginous crusts
DaHb : with vertisols derived from rocks rich in ferromagnesian minerals
HbKa : with humic ferrisols
BdHbJc : with lithosols, not differentiated, and ferruginous tropical soils on crystalline acid rocks.

Distribution

Cameroun, Côte d'Ivoire, Dahomey, Ghana, Guinée, Haute Volta, Liberia, Mali, Nigeria, Niger, Sudan.

The element is limited to basic rock outcrops in landscapes with more or less broken ground.

Agricultural value

The fertility of these soils is almost always superior to that of the surrounding lands and makes them suitable for more exacting crops. Where climatic conditions are favourable they provide excellent cocoa soils.

3. Eutrophic brown soils on alluvial deposits — Hc

Definition

See general definition.

Associated units

DjHc : with vertisols of topographic depressions
HcNa : with mineral hydromorphic soils.

Distribution

Congo (Leopoldville), Sudan, Tanganyika, Uganda.

The soils are found in low lying but seldom inundated landscapes under semi-humid to semi-arid climates.

The categories Ha and Hb are generally associated with rock and lithosols, or with ferrisols, and occupy a position intermediate between those two stages of evolution. Eutrophic brown soils on alluvial deposits are associated with vertisols of topographic depressions and hydromorphic soils.

Agricultural value

Good.

4. Eutrophic brown soils not differentiated — Hd

Definition

See general definition.

In part these soils correspond to the "sols recents" of the Congo classification (INEAC) [24].

Associated units

BdHd : with lithosols, not differentiated.

Distribution

Burundi, Congo (Leopoldville) Rwanda.

On both sides of the Rift valley around lakes Kivu and Tanganyika.

Agricultural value

In principle, the soils designated by Hd may comprise all categories of eutrophic brown soils previously described, and have good agricultural value. In certain areas where Hd has been mapped, the good quality is often depressed because of the rather rough relief and the altitude.

CHAPTER 7

RED AND BROWN MEDITERRANEAN SOILS

The term "Mediterranean" must be taken here in its broadest sense : soils developed under Mediterranean types of climate with hot dry summers and temperate humid winters. It may be recalled that as the tropical and intertropical latitudes are approached, precipitations show equinoxial maxima during the summer period. The Mediterranean climate is felt at the extreme north and extreme south of the continent (Cape province).

General definition

Red and brown Mediterranean soils have ABC profiles of which the B horizon is textural. The colour has a high chroma. The cation exchange capacity of the mineral complex is more than 35% saturated, or becomes increasingly saturated with depth. Horizons A and B are leached of carbonates. Horizon B has blocky or prismatic structure. The clay fraction consists of 2 : 1 lattice minerals with some proportion of 1 : 1 lattice minerals. The profile is seldom more than 100 cm deep and transition from the humic horizon to the underlying horizon is clear.

A — **Red Mediterranean soils** — Ia

Cfr Part III, profile 18, page 154

Definition

See general definition.

The colour of the B horizon is red or reddish-brown (5 YR or redder). Clay coatings on the surface of aggregates of the B horizon are often thick and continuous. Cationic saturation of the mineral complex of horizon B is generally over 60 per cent and can reach 90 per cent. The pH is approximately 7.

These soils correspond approximately with the rhodustalfs of the USDA 7th approximation ([27]). They are generally found on calcareous rocks. Certain authors consider them as relicts of old soils, reworked and transported by erosion, wherein new profiles have developed ([9]). As may be remembered from introductory material in Part I, the same mechanism has been postulated to explain certain ferrallitic materials. Other authors consider this viewpoint as excessive ([25]).

Associated units

AcIa : with rock and rock debris, not differentiated
CaIa : with rendzinas and/or brown calcareous soils
CbIa : with soils on calcareous crusts
DbIa : with vertisols derived from calcareous rocks
DjIa : with vertisols of topographical depressions
GnIa : with brown and reddish-brown soils of arid and semi-arid Mediterranean regions
AcDbIa : with rock and rock debris, not differentiated, and vertisols derived from rocks rich in ferromagnesian minerals.

Of these associations, GnIa is the most widespread.

Distribution

Algérie, Libya, Madagascar, Maroc, Tunisie.

It should be noted that the area mapped as CbIa in Madagascar does not have a Mediterranean type climate.

Agricultural value

In the Mediterranean area these soils are considered as good, and suitable for several crops. Their capability depends on the thickness of their profile. They are easily eroded and therefore certain of their landscapes are almost denuded whereas in the depressions (dolines) thick layers have been accumulated to a degree suitable for market gardening, grain crops and vineyards. Thinner soils may be terraced and planted with citrus orchards, whereas the more denuded areas should be forrested. These soils are often poor in phosphate, and fertilizer use, especially under irrigation, is generally economic. ([9])

In Madagascar the soils mapped as Ia in association with Cb (soils with calcareous crusts) are used for extensive grazing. They have not been mapped in the Cape province where calcareous formations do not occur frequently.

B — **Brown Mediterranean soils** — In

Cfr Part III, profile 19, page 155.

Definition

See general definition.

The colour of these soils is brown or yellowish-brown (less red than 5YR); the blocky or prismatic structure is less marked than in the red Mediterranean soils and the cationic saturation of the mineral complex is slightly lower. The pH of horizon B varies between 5.5 and 7. Soils thus mapped in South Africa reach a depth of 80 cm. The content of organic matter is low and texture is often gravelly, with rock debris in the surface horizons.

In the USDA classification, 7th approximation [27] these soils could be classified among the typustalfs. They develop under the same climates as the preceding ones but are associated with non calcareous rocks. Throughout their distribution these soils are considered as authigenous which is not nessarily the case for red Mediterranean soils (Ia).

Associated units

AcIn : with rock and rock debris, not differentiated
BdIn : with lithosols, not differentiated
CaIn : with rendzinas and/or brown calcareous soils
FaIn : with sols lessivés-Highveld pseudo-podsolic soils
AcFaIn : with rock and rock debris, not differentiated, and sols lessivés-Highveld pseudo-podsolic soils
BdCaIn : with lithosols, not differentiated, and rendzinas and/or brown calcareous soils

The association BdIn, with lithosols, is the most widespread.

Distribution

Algérie, Maroc, Republic of South Africa.
Regions with Mediterranean type climates, included the Cape area.

Agricultural value

Inferior to that of the red Mediterranean soils, as may be concluded from pH values, per cent saturation of the exchange complex and structural properties. Often they are still found under natural forest or have been afforested.

CHAPTER 8

FERRUGINOUS TROPICAL SOILS (fersiallitic soils)

On the map the ferruginous tropical soils total approximately 3 295 000 km² on the continent (more than 11 %). About 2 025 000 km² of this area are north and 1 270 000 km² are south of the equator. In Madagascar they cover more than 27% of the surface (166 000 km²). They are found between isohyets 500 and 1 200 mm which in Africa, corresponds to a characteristic tropical climate with a well separated dry season in winter and a wet season in summer.

Several of the ferruginous tropical soils are developed from the crystalline rocks of the Basement Complex (granite, gneiss). They have not been described on volcanic ash, on ultrabasic rocks, or on calcareous rocks (12).

In the French classification (2) the sub-class of the "sols ferrugineux tropicaux" (related at class-level with the "sols rouges méditerranéens" and the "sols ferrallitiques") is further subdivided at group level, into "sols ferrugineux tropicaux non ou peu lessivés" and "sols ferrugineux tropicaux lessivés". It was difficult however to translate this classification into legend elements applicable to the entire map. Indeed, the partial documents that were available for the area south of the equator all separated the ferruginous tropical soils according to parent material. Since in most cases this parent material was known also for the ferruginous tropical soils north of the equator, a lithological subdivision has been adopted. A certain analogy even exists between "sols ferrugineux tropicaux non lessivés" and the ferruginous tropical soils on sandy parent materials of the legend.

B – argillic – ustalfs
– cambic – ustropepts

General definition

Soils with ABC profile of which some have an A_2 horizon and a textural B horizon showing nuciform or weakly prismatic structure. There is frequently observed a marked separation of free iron oxides, which may either be leached out of the profile or precipitated within the profile in the form of spots or concretions. The reserve of weatherable minerals is often appreciable. The silt/clay ratio (20/2 microns) determined by repeated dispersion, sedimentation and separation of the supernatant suspension is generally above 0.15. Their clay is mostly kaolinitic but often contains small amounts of 2:1 lattice clays. Gibbsite is generally absent. The SiO_2/Al_2O_3 ratio is near 2 or slightly higher while the SiO_2/R_2O_3 ratio is always below 2. The cation exchange capacity of the mineral complex is low but higher than that of ferrisols and ferrallitic soils having comparable (granulometric) clay content. Cationic saturation of horizon B generally exceeds 40 per cent (normal ammonium acetate at pH 7).

As compared to the ferrallitic soils that often overlay weathered layers several meters thick, the ferruginous tropical soil profiles are seldom thicker than 250 cm. The thickness of the altered layers that separate them from the fresh rock is always less than 100 cm over crystalline acid rocks (Jc).

Colours are duller than those of ferrallitic soils, and fall in the 10 YR and 7.5 YR range, exceptionally in the 5 YR range. There is generally a difference of 2 to 3 points in value and chroma between colour of wet and dry soil.

In the USDA 7th approximation ([27]) several of these soils would be included within the ultustalfs.

1. Ferruginous tropical soils on sandy parent materials — Ja

Cfr Part III, profile 20, page 156.

Definition

See general definition.

In so far as they correspond with "sols ferrugineux tropicaux non lessivés", these soils on sandy parent materials do not have a textural B horizon.

Associated units

BdJa	:	with lithosols not differentiated
BhJa	:	with weakly developed soils on loose sediments not recently deposited
DbJa	:	with vertisols derived from calcareous rocks
DjJa	:	with vertisols of topographic depressions
GaJa	:	with brown soils of arid and semi-arid tropical regions, on loose sediments
GbJa	:	with brown soils of arid and semi-arid tropical regions, not differentiated
JaJc	:	with ferruginous tropical soils on crystalline acid rocks
JaJd	:	with ferruginous tropical soils, not differentiated
JaLa	:	with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments
JaMb	:	with saline soils, alkali soils and saline alkali soils
JaNa	:	with mineral hydromorphic soils
JaNb	:	with organic hydromorphic soils
AcBdJa	:	with rock, rock debris and lithosols, neither differentiated
BcJaJc	:	with lithosols on ferruginous crusts and ferruginous tropical soils on crystalline acid rocks
JaLaMe	:	with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments, and halomorphic soils, not differentiated.

Distribution

Angola, Bechuanaland, Cameroun, Gambia, Haute Volta, Mali, Madagascar, Moçambique, Nigeria, Niger, République Centr'africaine, Rhodesia (Northern) (Southern) Republic of South Africa, Sénégal, Somalia, Sudan, South West Africa, Tanganyika, Tchad, Uganda.

As was the case for the brown soils of arid and semi-arid tropical regions, the distribution of these soils appears to be very zonal; this effect is reinforced by the very large distribution of the sand covers. (cfr Part I, Chapters 1 and 5).

Agricultural value

In West Africa these soils are used largely for groundnut production. Although relatively poor they are suitable for mechanized agriculture and give good response to fertilizers.

2. Ferruginous tropical soils on rocks rich in ferromagnesian minerals — Jb

Cfr Part III, profile 21, page 158.

Definition

See general definition.

These soils are the least represented of the ferruginous tropical soils on the continent. In Madagascar however the surface they cover is equal to that covered by ferruginous tropical soils on sandy parent materials.

Associated units

BdJb	:	with lithosols, not differentiated
DaJb	:	with vertisols derived from rocks rich in ferromagnesian minerals
DjJb	:	with vertisols of topographic depressions
FaJb	:	with sols lessivés-Highveld pseudo-podsolic soils
JbJc	:	with ferruginous tropical soils on crystalline acid rocks
JbJd	:	with ferruginous tropical soils, not differentiated
JbKa	:	with humic ferrisols
JbMa	:	with solonetz and solodized solonetz
Ra	:	The unit is part of the volcanic islands complex.

The best represented associations are those with the vertisols whose development also appears to be promoted by the sub-humid to semi-arid climates.

Distribution

Bechuanaland, Kenya, Madagascar, Moçambique, Nigeria, Rhodesia (Northern) (Southern), Sénégal, Tanganyika.

On the map the element Jb reflects the frequent outcrops of more or less basic veins that traverse the pre-Cambrian Basement Complex and the post-Cambrian sediments that cover it locally. In climatic zones more humid than those favourable to the formation of ferruginous tropical soils, such outcrops give rise to ferrisols or ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals.

Agricultural value

Average.

Their high content of alterable ferruginous minerals may give rise to important liberations of iron and frequently to formation of iron crusts at slight depth. Moreover, like all save the most permeable of the ferruginous tropical soils, they are very vulnerable to erosion.

3. Ferruginous tropical soils on crystalline acid rocks — Jc

Cfr Part III, profile 22, page 159.

Probably the extent covered by these soils is larger than that shown on the map, many having been included in unit Jd.

Definition

See general definition.

Because of the high quartz content of their parent materials, these soils are generally lighter than those of unit Jb. As they contain less iron they are less frequently iron crusted but their leaching may be important and often leads to a textural B horizon.

Associated units

AcJc	:	with rock and rock debris, not differentiated
BbJc	:	with lithosols on rocks rich in ferromagnesian minerals
BdJc	:	with lithosols, not differentiated
GbJc	:	with brown soils of arid and semi-arid tropical regions, not differentiated
JaJc	:	with ferruginous tropical soils on sandy parent materials
JbJc	:	with ferruginous tropical soils on rocks rich in ferromagnesian minerals

JcKc	:	with ferrisols, not differentiated
JcLc	:	with ferrallitic soils, dominant colour yellowish-brown, not differentiated
JcLm	:	with ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals
JcMa	:	with solonetz and solodized solonetz
JcMe	:	with halomorphic soils, not differentiated
BcJaJc	:	with lithosols on ferruginous crusts and ferruginous tropical soils on sandy parent materials
BdHbJc	:	with lithosols, not differentiated, and eutrophic brown soils of tropical regions on rocks rich in ferromagnesian minerals.

The association with the ferrisols (JcKc) is most widespread to the north of the equator (West Africa) whereas to the south the association with the yellowish-brown ferrallitic soils (JcLc) is dominant.

Distribution

Angola, Cameroun, Côte d'Ivoire, Dahomey, Ghana, Guinée, Kenya, Mali, Madagascar, Mauritanie, Nigeria, Niger, Rhodesia (Southern), Republic of South Africa, Sénégal, Swaziland, Tchad, Togo.

Agricultural value

Low to average.

These very erodible soils are used almost exclusively for annual crops that provide only slight protection. Many rotation systems have been tried, including that of grazed fallow, and many of these soils respond well to fertilizers.

4. Ferruginous tropical soils, not differentiated — Jd

See general definition and the complementary data of preceding paragraphs.

Associated units

AbJd	:	with ferruginous crusts
AcJd	:	with rock and rock debris, not differentiated
BcJd	:	with lithosols on ferruginous crusts
BdJd	:	with lithosols, not differentiated
BhJd	:	with weakly developed soils on loose sediments not recently deposited
CaJd	:	with rendzinas and/or brown calcareous soils
DaJd	:	with vertisols derived from rocks rich in ferromagnesian minerals

DbJd	: with vertisols derived from calcareous rocks
DjJd	: with vertisols of topographic depressions
FaJd	: with sols lessivés — Highveld pseudo-podsolic soils.
GbJd	: with brown soils of arid and semi-arid tropical regions, not differentiated
JaJd	: with ferruginous tropical soils on sandy parent material
JbJd	: with ferruginous tropical soils on rocks rich in ferromagnesian minerals
JbKb	: with ferrisols on rocks rich in ferromagnesian minerals
JdKc	: with ferrisols, not differentiated
JdLc	: with ferrallitic soils, dominant colour yellowish-brown, not differentiated
JdLn	: with ferrallitic soils, dominant colour red, not differentiated
JdMe	: with halomorphic soils, not differentiated
JdNa	: with mineral hydromorphic soils
AcBdJd	: with rock, rock debris and lithosols, neither differentiated
AcDjJd	: with rock and rock debris, not differentiated, and vertisols of topographic depressions
AcJdLc	: with rock, rock debris, and ferrallitic soils, dominant colour yellowish-brown, neither differentiated.
AcJdNa	: with rock and rock debris, not differentiated, and mineral hydromorphic soils
BcDjJd	: with lithosols on ferruginous crusts and vertisols of topographic depressions
BcJdLc	: with lithosols on ferruginous crusts and ferrallitic soils, dominant colour yellowish-brown, not differentiated
BcJdLn	: with lithosols on ferruginous crusts, and ferrallitic soils, dominant colour red, not differentiated
BdDaJd	: with lithosols, not differentiated, and vertisols derived from rocks rich in ferromagnesian minerals
BdFaJd	: with lithosols, not differentiated, and sols lessivés — Highveld pseudo-podsolic soils
BdJdKc	: with lithosols and ferrisols, neither differentiated
BdJdLn	: with lithosols and ferrallitic soils, dominant colour red, neither differentiated
GbJdMa	: with brown soils of arid and semi-arid tropical regions, neither differentiated, and solonetz and/or solodized solonetz.
JdLcMe	: with ferrallitic soils, dominant colour yellowish-brown, and halomorphic soils, neither differentiated.

Among these numerous associations, that with lithosols on ferruginous crusts is the most important. Other more or less widespread associations are : GbJd, with brown soils of arid and semi-arid tropical regions, and BdJd, with lithosols not differentiated.

Distribution

Angola, Bechuanaland, Cameroun, Dahomey, Ethiopia, Gambia, Ghana, Guinée, Guiné Portuguesa, Haute Volta, Kenya, Mali, Madagascar, Mauritanie, Moçambique, Nigeria, Niger, Nyasaland, République Centr'africaine, Rhodesia (Northern) (Southern), Republic of South Africa, Sénégal, Somalia, Sudan, Swaziland, Tanganyika, Tchad, Togo, Uganda.

Agricultural value

See preceding paragraphs.

CHAPTER 9

FERRISOLS

Like the eutrophic brown soils of tropical regions, the ferrisols are a transitional group which are evolving under a hot and humid climate and whose normal development is retarded compared with that of neighbouring soils. In the case of the ferrisols this is effected mainly by surface erosion which forces the profile to develop in depth at the expense of less weathered parent material. The ferrisols, just as the eutrophic brown soils of tropical regions, are distinguished from neighbouring soils by their higher exchangeable base content, their better structure, their higher biological activity and therefore by their higher fertility. More widespread than the eutrophic brown soils of tropical regions (917 000 against 150 000 km^2) they also develop under more humic climates. It may be noted that subsequent to this level of the map legend the nature of parent rock becomes much less important : only the ferromagnesian mineral content and the texture retain their influence.

General definition

Ferrisols have a profile closely resembling that of ferrallitic soils *sensu stricto*, often having a structural B horizon, with aggregates having glossy surfaces. These coatings are not always evident when a profile has become dry. They are not necessarily coatings of clay but may be due to the presence of mixed alumino-silica gels. The reserve of weatherable minerals is generally low but may exceed 10 per cent of the 50-250 micron fraction. The silt/clay ratio (20/2 microns) determined by repeated dispersion, sedimentation and separation of the supernatant suspension is generally above 0.20 over alluvium and sedimentary rocks and generally above 0.15 over igneous and metamorphic rocks.

The clay fraction consists almost entirely of kaolinite, free iron oxides and amorphous gels sometimes with small quantities of 2 : 1 lattice clays and gibbsite. The SiO_2/Al_2O_3 ratio is near 2, mostly slightly below 2. The cation exchange capacity of the (granulometric) clay fraction of horizon B generally exceeds 15 meq per 100 gr and is intermediate between that of ferruginous tropical soils and that of ferrallitic soils *sensu stricto*. The saturation of horizons B and C is less than 50 per cent (normal ammonium acetate at pH 7).

The term ferrisol as used in the legend is in general agreement with the similar term in the Congo soil classification as defined by Sys ([24]). It is slightly more restrictive as it covers only the sub-orders of hygro- and hygro-xero-ferrisols. The hydro-ferrisols have been mapped with the mineral hydromorphic soils whereas the xero-ferrisols were generally included in the ferruginous tropical soils as JbKa, JbKb, JcKc and JdKc, associations of ferruginous tropical soils and ferrisols.

As for their place in the USDA 7th approximation ([27]), the absence of oxic horizons requires that they be classified provisionally among the Ultisols although certain objections might be raised to the truly argillic nature of their B horizon.

1. Humic ferrisols — Ka

Cfr Part III, profile 23, page 161.

Definition

See general definition.

Humic ferrisols are ferrisols distinguished by A_1 horizons more than 10 cm thick. The value/chroma of their Munsell colour is equal or inferior to 3/2 and the organic carbon content is higher than 2%. When lower than 2% the A_1 horizon should be more than 20 cm thick. The organic carbon content over a depth of 1 meter is more than 180 tons/ha ([24]).

Associated units

BbKa : with lithosols on rocks rich in ferromagnesian minerals

DaKa : with vertisols derived from rocks rich in ferromagnesian minerals
HaKa : with eutrophic brown soils of tropical regions on volcanic ash
HbKa : with eutrophic brown soils of tropical regions on rocks rich in ferromagnesian minerals
JbKa : with ferruginous tropical soils on rocks rich in ferromagnesian minerals
KaLm : with ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals
KaLs : with humic ferrallitic soils
KaLt : with ferrallitic soils with dark horizons
KaLx : with red and yellow ferrallitic soils on various parent materials
Ra : the unit is part of the volcanic islands complex.

The remark made for unit Da is also valid here. The great extension of the association DaKa in Ethiopia must be viewed with certain reservations as the pedological data on this region were rather limited.

Distribution

Burundi, Cameroun, Congo (Léopoldville), Ethiopia, Kenya Nigeria, Nyasaland, Rwanda, Tanganyika, Uganda.

In the equatorial zone these soils are generally found at altitudes higher than 1 600 m.

Agricultural value

Although these soils are higher in plant nutrients than ferrallitic soils sensu-stricto, they appear to be relatively poor soils as compared to the eutrophic brown soils of tropical regions which have developed on similar parent materials. When climate, landform and altitude permit, they are suitable for coffee, tea, tung, quinquina,...

2. Ferrisols on rocks rich in ferromagnesian minerals — Kb

Cfr Part III, profile 24, page 162.

Definition

See general definition.

It is on this parent material that the most typical ferrisols are found.

Associated units

BbKb : with lithosols on rocks rich in ferromagnesian minerals

BcKb : with lithosols on ferruginous crusts
HaKb : with eutrophic brown soils of tropical regions on volcanic ash
JdKb : with ferruginous tropical soils, not differentiated
BdKbLm: with lithosols, not differentiated, and ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals
Ra : The unit is part of the volcanic islands complex.

Distribution

Burundi, Côte d'Ivoire, Congo (Léopoldville), Ethiopia, Ghana, Guinée, Mali, Madagascar, Nyasaland, Rwanda, Sénégal, Sudan, Tanganyika.

Agricultural value

Higher in agricultural value than ferrallitic soils derived from similar parent material. Suitable for most of the great industrial crops.

3. Ferrisols, not differentiated — Kc

Cfr Part III, profile 25, page 163.

This element, which has the greatest extension among the ferrisols, is essentially a medium and low altitude formation. The Congo classification (24) introduces a further distinction based on the lithology of parent material as, for example, ferrisols on Karroo formations, but it was not possible to generalize its application for the whole of the continent.

Definition

See general definition.

Associated units

BcKc : with lithosols on ferruginous crusts
BdKc : with lithosols, not differentiated
DjKc : with vertisols of topographic depressions
JcKc : with ferruginous tropical soils on crystalline acid rocks
JdKc : with ferruginous tropical soils, not differentiated
KcLa : with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments

KcLb : with ferrallitic soils, dominant colour yellowish-brown, on more or less clayey sediments

KcLc : with ferrallitic soils, dominant colour yellowish-brown, not differentiated

KcLn : with ferrallitic soils, dominant colour red, not differentiated

KcLx : with yellow and red ferrallitic soils on various parent materials

BcKcLc : with lithosols on ferruginous crusts, and ferrallitic soils, dominant colour yellowish-brown, not differentiated

BcKcLn : with lithosols on ferruginous crusts and ferrallitic soils, dominant colour red, not differentiated

BcKcLx : with lithosols on ferruginous crusts and yellow and red ferrallitic soils on various parent materials

BdJdKc : with lithosols and ferruginous tropical soils, neither differentiated

BdKcLn : with lithosols and ferrallitic soils, dominant colour red, neither differentiated

BdKcLx : with lithosols, not differentiated, and red and yellow ferrallitic soils on various parent materials

KcLaNa : with ferrallitic soils, dominant colour yellowish-brown, on sandy parent materials, and mineral hydromorphic soils.

The most widely distributed associations are those with the various ferrallitic soils and with the ferruginous tropical soils on crystalline acid rocks. Ferrisols often mark the rougher, rejuvenated parts of the landscapes, but also form on parent materials with a higher content of alterable minerals.

Distribution

Angola, Burundi, Cameroun, Congo (Brazzaville), Congo (Léopoldville), Côte d'Ivoire, Gabon, Ghana, Guinée, Guinea Continental Española, Kenya, Mali, Madagascar, Moçambique, Nyasaland, Rwanda, République Centr'africaine, Rhodesia (Northern) (Southern), Tanganyika, Togo, Uganda.

Agricultural value

See preceding paragraphs.

In general, ferrisols are better soil resources than neighbouring ferruginous tropical soils or ferrallitic soils. Despite the fact that they often cover rough terrain they are less vulnerable to erosion than ferruginous tropical soils. They are in demand for exacting crops like cocoa.

CHAPTER 10

FERRALLITIC SOILS (sensu stricto)

On the African continent ferrallitic soils cover approximately 5 338 000 km² or more than 18 % of the total surface. In Madagascar their extension is of the order of 210 000 km², which is more than 34 % of the surface. Consequently the ferralitic soils are the most extensive group of soil units in Africa (desert detritus, less homogeneous, with 5 913 000 km², can hardly be considered soil). Ferralitic soils reflect the final stages of weathering and leaching, wherein only the least mobile and least weatherable constituents remain, and where kaolinite and even quartz may become altered.

Notwithstanding their apparently zonal distribution, a major part of these soils are not exclusively the result of present day soil formation. Many are polygenetic, i.e. recent soils developed in old weathered layers that have undergone ferrallitic pedogenesis, and which have remained in place or have been reworked and redistributed according to the new relief of the rejuvenated landscapes. Such ferrallitic mantles are most frequent in intertropical Africa, where they persisted due to the flatness of the relief of the major part of the continental massif.

The subdivision that has been maintained is a compromise among the different systems of classification that were in use in Africa at the moment when the partial maps were established. It is based on criteria that at first glance may appear somewhat ill-assorted and where colour occupies a paramount place.

General Definition

Definition

Soils that are often deep, whose horizons are only slightly differentiated with diffuse or gradual transitions, but sometimes having an A_2 or textural B horizon. This B horizon may have slight structure in the more clayey profiles but the aggregates do not show clearly developed glossy surfaces as are described for the ferrisols. The structural elements are often very fine subangular blocky peds, more or less coherent and forming a very friable, porous mass.

There is little or no reserve of weatherable minerals. The silt/clay ratio (20/2 microns) determined by repeated dispersion, sedimentation and separation of the supernatant suspension is generally less than 0.25 in horizons B and

C. Clay minerals are predominantly of the 1:1 lattice type and are mostly associated with large quantities of iron oxides. Although they are generally associated with hydrated oxides of aluminium, gibbsite, one of the crystalline forms, is not an essential constituent though frequently present. The SiO_2/Al_2O_3 ratio is sometimes near 2 but usually below. The cation exchange capacity of the (granulometric) clay fraction is generally below 20 meq per 100 grs and the level of saturation in horizons A and B is generally below 40 per cent (normal ammonium acetate at pH 7).

It must be noted that this definition is slightly more restrictive than that of the French classification (2) which includes the ferrisols as they were defined in a previous chapter. In the USDA classification, 7th Approximation, (27) certain ferrallitic soils could be ranged among the Oxisols but the absence of oxic horizons excludes many others which tend toward the Ultisols.

1. Ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments — La

Cfr Part III, profile 26, page 164.

Definition

See general definition.

These soils with an A-C or A-D profile generally have a very weak A_1 horizon and the A_2 horizon is often absent. Parent material contains less than 15% clay (granulometric) over a depth of more than 1 meter. Often iron oxide streaks are observed extending as low as 10 meters. On the Munsell chart their colour is more yellow than 7.5 YR.

Associated units

BcLa	:	with lithosols on ferruginous crusts
DjLa	:	with vertisols of topographic depressions
JaLa	:	with ferruginous tropical soils on sandy parent materials
KcLa	:	with ferrisols, not differentiated
LaLc	:	with ferrallitic soils, dominant colour yellowish-brown, not differentiated
LaLl	:	with ferrallitic soils, dominant colour red, on loose sandy sediments
LaNa	:	with mineral hydromorphic soils
BcLaLx	:	with lithosols on ferruginous crusts and yellow and red ferrallitic soils on various parent materials.
JaLaMe	:	with ferruginous tropical soils on sandy parent materials and halomorphic soils, not differentiated
KcLaNa	:	with ferrisols, not differentiated, and mineral hydromorphic soils.

The associations KcLa, JaLa, and LaLl are the best distributed. In the case of KcLa, the unit Kc forms in the cuts in the landscape whereas La is developed on the sand cover, i.e. on a different parent materials. In the case of the other two associations, the similarity of parent materials is the main basis of the association.

Distribution

Angola, Bechuanaland, Cameroun, Congo (Brazzaville), Congo (Léopoldville), Côte d'Ivoire, Gabon, Guinée, Guinea Continental Española, Nigeria, Nyasaland, Rhodesia (Northern) (Southern), Sierra Leone, Uganda.

This unit is much more prevalent to the south of the equator (1 434 000 km²) than to the north (74 000 km²), and is characteristic of the very widespread Kalahari beds which reach the equator in the Congo basin. With few exceptions these soils are restricted in the northern hemisphere to the sandy deposits of the coastal fringe.

Agricultural value

The low agricultural value of these soils follows from their low alterable mineral and clay content. A few seasons after clearing, the arable layer is exhausted by the crops. The more sandy members of this unit are among the poorest soils of Africa.

2. Ferrallitic soils, dominant colour yellowish-brown, on more or less clayey sediments — Lb

Cfr Part III, profile 27, page 165.

Definition

See general definition. Munsell colour is 7.5 YR or yellower.

Associated units

KcLb : with ferrisols, not differentiated
LbNa : with mineral hydromorphic soils

Distribution

Cameroun, Congo (Brazzaville), Congo (Léopoldville), Madagascar, République Centr'africaine, Rhodesia (Northern), Tanganyika.

The element is mapped about equally to the north and to the south of the equator. Although distributed between latitudes 4°N and 14°S, it has essentially a continental character and is found on ancient riverine and lacustrine alluvia, that may date back to more humid periods. Certain of these alluvia have been reworked by aeolian action, or have been transported and deposited around the depressions, the bottom of which is often still inundated.

Agricultural value

Under humid tropical climate these soils are suitable for several industrial tree crops such as rubber, coffee, and oil palm. Certain deficiencies have been noted, as for example magnesium. Without fertilizers the yield of annual crops falls rapidly after the second or the third year, and long fallow periods (15-20 years) are necessary to restore the initial fertility.

3. Ferrallitic soils, dominant colour yellowish-brown, not differentiated — Lc

Cfr Part III, profile 28, page 167.

Definition

See general definition. Munsell colour 5 YR or yellower.

Associated units

AbLc	:	with ferruginous crusts
AcLc	:	with rock and rock debris, not differentiated
BcLc	:	with lithosols on ferruginous crusts
DjLc	:	with vertisols of topographic depressions
JcLc	:	with ferruginous tropical soils on crystalline acid rocks
JdLc	:	with ferruginous tropical soils, not differentiated
KcLc	:	with ferrisols, not differentiated
LaLc	:	with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments
LcNa	:	with mineral hydromorphic soils
AcJdLc	:	with rock, rock debris and ferruginous tropical soils, neither differentiated
BcDjLc	:	with lithosols on ferruginous crusts and vertisols of topographic depressions

BcJdLc : with lithosols on ferruginous crusts and ferruginous tropical soils, not differentiated
BcKcLc : with lithosols on ferruginous crusts and ferrisols, not differentiated
JdLcMe : with ferruginous tropical soils and halomorphic soils, neither differentiated.

The association with the lithosols on ferruginous crusts is the most frequent. In most cases this involves debris of ancient cuirasses whose formation is therefore not in any way concerned with present day pedogenetic conditions. Another well distributed association is that with ferruginous tropical soils, not differentiated, (JdLc) which covers the less humid parts of the ferrallitic area. The association with ferrisols (KcLc) is third in importance, at least so far as surface is concerned.

Distribution

Angola, Cameroun, Congo (Brazzaville), Congo (Léopoldville), Côte d'Ivoire, Gabon, Ghana, Guinée, Guinea Continental Española, Guiné Portuguesa, Liberia, Moçambique, Nigeria, Nyasaland, Rhodesia (Northern) (Southern), Sierra Leone, Tanganyika, Uganda.

These soils are better represented to the south than to the north of the equator and cover approximately 10% of the southern half of the continent; in the south-east they are found as far as the 21st parallel. The area covered by this element is probably larger than that indicated on the map, as part of it is included in Lx, which like Lc, has its greatest extension to the south of the equator.

It may be said of ferrallitic soils with dominant colour yellowish-brown that they make up less than one third of total ferrallitic soils in the northern hemisphere whereas in the southern hemisphere they account for approximately two thirds.

Agricultural value

The low fertility level of these soils varies with their clay content (20-60%), with the nature of the rock from which they are directly or indirectly derived, with the present-day climate that ranges from per-humid to sub-humid, and with the vegetation the climate has induced.

Due to their low base saturation, the quantity of bases that must be added to increase yields in a significant manner is often rather high and under current circumstances, often prohibitive.

4. Ferrallitic soils, dominant colour red, on loose sandy sediments — Ll.

Definition

See general definition. Munsell colour 5 YR or redder.

Associated units

LaLl : with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments

Distribution

Angola, Côte d'Ivoire, Dahomey, Gambia, Ghana, Guiné Portuguesa, Mali, Nigeria, République Centr'africaine, Sénégal, Togo.

This element is as equally well distributed to the north as to the south of the equator but the total surface occupied is much less than that under yellowish-brown ferrallitic sandy soils (La), even though both units cover similar geological formations.

Agricultural value

Comparable to that of yellowish-brown ferrallitic soils on loose sandy sediments.

5. Ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals — Lm

Cfr Part III, profile 29, page 168

Definition

See general definition. Munsell colour redder that 5 YR. These soils, developed from dolerites, amphibolites, gabbros and amphibole/granites in the humid tropical areas, occur rather rarely in the per-humid areas. The clay content is often high and profiles frequently have a structural B horizon whose peds do not exhibit the characteristic coatings of the ferrisols.

Associated units

AbLm : with ferruginous crusts
BcLm : with lithosols on ferruginous crusts
JcLm : with ferruginous tropical soils on crystalline acid rocks
KaLm : with humic ferrisols
BdKbLm: with lithosols, not differentiated, and ferrisols on rocks rich in ferromagnesian minerals

Ra : The unit is part of the volcanic islands complex.

The most frequent association is that with lithosols on ferruginous crusts.

Distribution

Angola, Cameroun, Côte d'Ivoire, Ghana, Guinée, Madagascar, République Centr'africaine, Rhodesia (Southern), Sierra Leone.

Agricultural value

These soils are to be considered as among the best ferrallitic soils; indeed several of their properties approach those of ferrisols developed on similar parent material.

6. Ferrallitic soils, dominant colour red, not differentiated — Ln

Definition

See general definition and remarks under Ll and Lm. Several of these soils are developed in materials altered during previous pedogenetic cycles. It is often difficult to determine the nature of the rock from which they are derived, as they generally have been reworked and transported. It seems to be well established though that these transports have been made only over short distances in most cases. In general these soils occupy the highests parts of the landscapes where they constitute then the highest terms of catenary complexes in the sense attributed to them by Milne ([19]).

Associated units

BcLn : with lithosols on ferruginous crusts
BdLn : with lithosols, not differentiated
JdLn : with ferruginous tropical soils, not differentiated
KcLn : with ferrisols, not differentiated
LnNa : with mineral hydromorphie soils
BcJdLn : with lithosols on ferruginous crusts and ferruginous tropical soils, not differentiated
BcKcLn : with lithosols on ferruginous crusts and ferrisols, not differentiated
BdJdLn : with lithosols and ferruginous tropical soils, neither differentiated
BdKcLn : with lithosols and ferrisols, neither differentiated.

The association with the lithosols on ferruginous crusts is the best represented, followed by that with ferrisols, not differentiated.

Distribution

Angola, Cameroun, Congo (Brazzaville), Congo (Léopoldville), Ghana, Madagascar, Moçambique, Nigeria, République Centr'africaine, Rhodesia, (Northern) (Southern), Republic of South Africa, Sudan, Tanganyika, Togo.

This element (687 000 km²) is particularly well represented on the slightly raised domes that separate the Congo basin from the basins of the Chad, the Nile – Bahr el Ghazal, and of the Victoria-Kyoga lakes. An important expanse is also situated in southern Tanganyika. Just as is the case for the debris of ancient crusts that they contain, these soils are generally associated with the ancient tertiary surfaces.

Agricultural value

Low to very low. The agricultural value depends mainly on the clay mineral content, as an important part of the colloidal fraction of these soils may be made up of free oxides. Most of these soils are now under climates with a well marked dry season, and under a savanna vegetation.

7. HUMIC FERRALLITIC SOILS — Ls

Cfr Part III, profile 30, page 170.

Definition

See general definition.

Ferrallitic soils that, in the natural state, have A_1 horizons rich in organic matter, similar to those described for the humic ferrisols.

In the Congo classification (Sys ([24])), the A_1 horizon must be thicker than 10 cm, with an organic carbon content higher than 2 %, and with value/chroma equal or lower than 3/2 (Munsell). In A_1 horizons thicker than 20 cm, the carbon content may be lower. In equatorial latitudes these soils are found higher than 1 400 m.

Associated units

KaLs : with humic ferrisols
LsLt : with ferrallitic soils with dark horizons
BcLsLt : with lithosols on ferruginous crusts and ferrallitic soils with dark horizons.

Distribution

Burundi, Congo (Léopoldville), Côte d'Ivoire, Madagascar, Rwanda, Republic of South Africa, Swaziland, Uganda.

Agricultural value

The agricultural value of these soils not only depends on the thickness of the epipedons ([27]) but also, and perhaps even more importantly, on the quality of organic matter formed in them. Under relatively cool and humid climates the organic reserve is more stable than under warmer climates. Under savanna vegetation these soils are frequently incinerated.

8. Ferrallitic soils with dark horizon — Lt

Cfr Part III, profile 31, page 171.

Definition

See general definition.

These are ferrallitic soils which, below horizon B (distinguished on the basis either of its texture or of its consistency), have a horizon darker in colour than the horizons immediately above or below. Its colour is often the same as that of the surface humic horizon. This dark horizon may have well developed, medium to large, blocky structure with thick coatings often black and glossy, but it may also be powdery and without structure. Its presence in the profile is often accompanied by an increase in the C/N ratio of at least 1 unit generally reaching a value of 15. The average organic carbon content of this horizon is about 0.7 per cent.

It can be added that these profiles seem to develop only at altitudes higher than 1 300 m (at least in equatorial latitudes) and that their parent materials are always thoroughly weathered.

Associated units

KaLt	:	with humic ferrisols
LsLt	:	with humic ferrallitic soils
BcLsLt	:	with lithosols on ferruginous crusts and humic ferrallitic soils

Distribution

Burundi, Congo (Léopoldville), Rwanda, Uganda.

Agricultural value

Very low. Where they have been reclaimed (arabica coffee, tea), it has been found that the presence of a dark horizon at shallow depth gives rise to lower yields.

9. Yellow and red ferrallitic soils on various parent materials — Lx

On the continent this element occupies one fifth of the total area covered by ferrallitic soils. In Madagascar the proportion is approximately 30%.

This complex comprises mainly soils of the categories La, Lb, Lc, Ll, Lm, and Ln. It has been mapped in areas where information was too fragmentary, or where the soil mosaic of red and yellow ferrallitic soils was too broken to be mapped separately at the chosen scale. This was the case for the numerous areas covered by catenary complexes, with red soils on the higher grounds, yellow soils on the slopes, and hydromorphic soils on the ill-drained bottomlands.

Definition

See general definition, and preceding complementary definitions.

Associated units

BcLx	:	with lithosols on ferruginous crusts
BdLx	:	with lithosols, not differentiated
DaLx	:	with lithomorphic vertisols derived from rocks rich in ferromagnesian minerals
DjLx	:	with vertisols of topographic depressions
KaLx	:	with humic ferrisols
KcLx	:	with ferrisols, not differentiated
LxNa	:	with mineral hydromorphic soils
BcKcLx	:	with lithosols on ferruginous crusts and ferrisols, not differentiated
BcLaLx	:	with lithosols on ferruginous crusts and ferrallitic soils, dominant colour yellowish-brown on loose sandy sediments
BdKcLx	:	with lithosols and ferrisols, neither differentiated.

The association with lithosols on ferruginous crusts is markedly dominant.

Distribution

Angola, Burundi, Cameroun, Congo (Léopoldville), Congo (Brazzaville), Côte d'Ivoire, Gabon, Ghana, Guinée, Guinea Continental Española, Kenya, Liberia, Madagascar, Moçambique, Rwanda, République Centr'africiane, Rhodesia (northern), Sierra Leone, Tanganyika, Uganda.

The element Lx, like Ln, is widely present on the old tertiary surfaces of the continent. In Madagascar, Lx covers the whole eastern part of the island, which has very rough relief, is forested, and is submitted to a high total rainfall. It is not associated with ferruginous crusts in Madagascar.

Agricultural value

Low. See preceding paragraphs of this chapter. Many of the yellow and red, more or less clayey ferrallitic soils carry rich forests and savannas, where the humidity of the climate compensates for the poverty of the substrates. An important part of the mineral reserve is concentrated in the vegetation and in the superficial soil layers where the plant wastes are continually added and decomposed. After clearing, the reserve accumulated in these layers is rapidly exhausted by annual crops such as food crops and cotton, and can only be restored by long fallow. In the forest region the perennial crops such as oil palm, coffee, rubber can be maintained economically for a limited number of years. All other conditions being equal, the agricultural potential of forest soils is higher than that of soils under savanna.

CHAPTER 11

HALOMORPHIC SOILS

On the map these soils barely cover 1 % of the total surface of Africa (2 % of Africa south of the equator, less than 1 % north of the equator.)

GENERAL DEFINITION

Soils whose morphology is mainly due to the presence in the profile of soluble salts and of exchangeable cations notably sodium. These constituents may be derived either from weathering of the parent material or from import.

According to a later definition by the U S Salinity Laboratory (4) (26) they are soils that "have been adversely modified for the growth of most crop plants by the presence or action of soluble salts". This includes "soils having an excess of soluble salts, or an excess of exchangeable sodium or both".

1. SOLONETZ AND SOLODIZED SOLONETZ — Ma

Cfr Part III profile 32 page 173.

Definition

Halomorphic soils with a textural B horizon of columnar structure in the case of solonetz, and with at least one of the B horizons more than 15% saturated with sodium. The upper horizons are generally alkaline, except in the solodized solonetz.

Associated units

DaMa : with vertisols derived from rocks rich in ferromagnesian minerals
DjMa : with vertisols of topographic depressions
JbMa : with ferruginous tropical soils on rocks rich in ferromagnesian minerals
JcMa : with ferruginous tropical soils on crystalline acid rocks
AcDjMa : with rock and rock debris, not differentiated, and vertisols of topographic depressions
BhCaMa : with weakly developed soils on loose sediments not recently deposited, and rendzinas and/or brown calcareous soils
GbJdMa : with brown soils of arid and semi-arid tropical regions and ferruginous tropical soils, neither differentiated.

All associated soils are typical of semi-arid to sub-humid climates, and the associations with vertisols are most widely distributed.

Distribution

Kenya, Republic of South Africa, Tanganyika.

Agricultural value

Reclamation of solonetz and solodized solonetz with moderate salinity can be undertaken when certain precautions are observed. The process may require important investments since a preliminary leaching of soluble salts and/or exchangeable cations is often necessary. Reclaimed soils are frequently used for cotton or sugar cane.

2. Saline soils, alkali soils and saline alkali soils — Mb

Cfr Part III profile 33 page 174.

Definition

Saline soils are those throughout which the conductivity of the saturation extract exceeds 4 millimhos/cm at 25°C. Alkali soils have 15% or more of the exchange capacity saturated with sodium. Saline alkali soils have both of these characteristics. Takyrs are a special case of saline soils, sometimes only in depth, having a compact surface horizon with a characteristic polygonal structure. According to the later definition of the U. S. Salinity Laboratory (4), the term sodic soil is preferable to alkali soil, the definition remaining unchanged.

Associated units

BhMb : with weakly developed soils on loose sediments not recently deposited
BoMb : with juvenile soils on riverine and lacustrine alluvium
DjMb : with vertisols of topographic depressions
GaMb : with brown soils of arid and semi-arid tropical regions on loose sediments
JaMb : with ferruginous tropical soils on sandy parent materials
BdBfMb : with lithosols, not differentiated, and sub-desert soils.

Distribution

Algérie, Burundi, Ethiopia, Ghana, Kenya, Libya, Mauritanie, Nigeria, Niger, Congo (Léopoldville), Republic of South Africa, Rwanda, South West Africa, Tanganyika, Tunisie, Uganda.

Agricultural value

In the natural state many of these soils are unfit for use. In most cases the excessive salts in the upper layers come from a water table near to the surface which is submitted to intensive evaporation. All reclamation practice must attempt to lower this water table and to desalinize the arable layer by the application of excess soft water at the surface and by underground drainage of the percolate. It must be noted that irrational irrigation methods may convert arable soils into saline soils.

3. Soils of sebkhas and chotts — Mc

Definition

Very saline soils, bare of vegetation, occupying depressions flooded after the rains and subject to intense evaporation during the dry season. Accordingly formation of a salty crust and erosion by wind are frequent.

Associated units

This unit has not been mapped in association.

Distribution

Africa Occidental Española, Algérie, Mali, Mauritanie, Côte française des Somalis, Tunisie.

The unit has only been mapped in very arid (desertic to subdesertic) areas.

Agricultural value

None.

4. Soils of lunettes - Md

Definition

Soils developing on materials deposited by wind after being carried from chotts and sebkhas. They progressively lose their halomorphic characteristics.

Associated units

This unit has not been mapped in association.

Distribution

Algérie.

Agricultural value

None.

5. Halomorphic soils, not differentiated — Me

Definition

See general and complementary definitions. Most of the soils mapped as Me belong to units Ma and Mb.

Associated units

ArMe : with desert detritus, not differentiated
Bc'Me : with lithosols on calcareous crusts
BfMe : with sub-desert soils

BoMe : with juvenile soils on riverine and lacustrine alluvium
BqMe : with juvenile soils on wind-borne sands
DjMe : with vertisols of topographic depressions
JcMe : with ferruginous tropical soils on crystalline acid rocks
JdMe : with ferruginous tropical soils, not differentiated
MeNb : with organic hydromorphic soils
BfBoMe : with sub-desert soils and juvenile soils on riverine and lacustrine alluvium
BoDjMe : with juvenile soils on riverine and lacustrine alluvium, and vertisols of topographic depressions.
JaLaMe : with ferruginous tropical soils on sandy parent materials and ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments
JdLcMe : with ferruginous tropical soils, and ferrallitic soils, dominant colour yellowish-brown, neither differentiated.

Distribution

Algérie, Angola, Bechuanaland, Cameroun, Gambia, Madagascar, Maroc, Mauritanie, Moçambique, Nigeria, Niger, Rhodesia (Northern) (Southern), Sénégal, South West Africa, Tanganyika, Tchad, Tunisie, United Arab Republic

Agricultural value

See preceding paragraphs.

CHAPTER 12

HYDROMORPHIC SOILS, ORGANIC NON HYDROMORPHIC SOILS AND THE COMPLEX OF VOLCANIC ISLANDS

A — Hydromorphic soils

1. Mineral hydromorphic soils — Na

Definition

Soils, other than vertisols and similar soils, whose development and characteristics (presence of gley and/or pseudo-gley in at least one of their horizons) are influenced by permanent or seasonal waterlogging. Some of these soils have a relatively high level of cation saturation.

Associated units

BhNa : with weakly developed soils on loose sediments not recently deposited
BoNa : with juvenile soils on riverine and lacustrine alluvium
DjNa : with vertisols of topographic depressions
GbNa : with brown soils of arid and semi-arid tropical regions, not differentiated
HcNa : with eutrophic brown soils of tropical regions on alluvial deposits
JaNa : with ferruginous tropical soils on sandy parent materials
JdNa : with ferruginous tropical soils, not differentiated
LaNa : with ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments
LbNa : with ferrallitic soils, dominant colour yellowish-brown, on more or less clayey sediments
LcNa : with ferrallitic soils, dominant colour yellowish-brown, not differentiated
LnNa : with ferrallitic soils, dominant colour red, not differentiated
LxNa : with red and yellow ferrallitic soils on various parent materials
AcJdNa : with rock, rock debris and ferruginous tropical soils, not differentiated
KcLaNa : with ferrisols, not differentiated, and ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments.

Among these numerous associations, the one with juvenile soils on riverine and lacustrine alluvium (BoNa) is the most widely distributed. Moreover the element Na is often associated with ferrallitic soils on ancient lacustrine sediments (Lb) and with vertisols of topographic depressions (Dj).

Distribution

Algérie, Angola, Bechuanaland, Cameroun, Congo (Brazzaville), Congo (Léopoldville), Côte d'Ivoire, Dahomey, Ethiopia, Gabon, Gambia, Ghana, Guinée, Guiné Portuguesa, Guinea Continental Española, Haute Volta, Kenya, Mali, Madagascar, Mauritanie, Moçambique, Nigeria, Niger, Nyasaland, République Centr'africaine, Rhodesia (Northern) (Southern), Republic of South Africa, Rwanda, Sénégal, Sierra Leone, Sudan, South West Africa, Tanganyika, Tchad, Tunisie, Uganda, United Arab Republic.

From the climatic point of view, their distribution is not as extensive as that of the juvenile soils on riverine and lacustrine alluvium with which they are most frequently associated. In more arid regions hydromorphy is replaced by halomorphy.

Agricultural value

Several of these soils have relatively high agricultural value, especially those that are waterlogged either temporarily or seasonally. Their reclamation may necessitate control of the water level. They are much used for rice and sugar cane, and when well drained they are suitable also for intensive cultivation of bananas.

2. ORGANIC HYDROMORPHIC SOILS — Nb

Cfr Part III, profile 34, page 175.

Definition

Hydromorphic soils of which the upper horizon to a depth of 50 cm in the natural state or to a depth of 30 cm after artificial drainage contains more than 20 per cent organic matter (sandy substratum) or more than 30 per cent (clayey substratum). Some of these soils have a relatively high level of cation saturation.

Associated units

BhNb	: with weakly developed soils on loose sediments not recently deposited
BoNb	: with juvenile soils on riverine and lacustrine alluvium
BqNb	: with juvenile soils on wind-borne sands
JaNb	: with ferruginous tropical soils on sandy parent materials
MeNb	: with halomorphic soils, not differentiated.

Distribution

Cameroun, Congo (Léopoldville), Dahomey, Ethiopia, Gabon, Kenya, Madagascar, Moçambique, Nigeria, Niger, Nyasaland, Rhodesia (Northern), Sudan, Tanganyika, Tchad, Togo.

Most of these soils are now under sub-humid to semi-arid climates as indicated by the elements with which they are associated. The plants that form them belong to two main types : Papyrus (*Cyperus papyrus* L) and Phragmites (*Phragmites communis* Trin.)

Agricultural value

Studies in Uganda on the reclamation of Papyrus swamps have shown that clearing and lowering of the water table level leads rapidly to the development of acidity in the upper soil layers to values not tolerated by most plants (pH 2.5). The acid reaction was caused by the oxidation of sulfides and sulfurous organic compounds ([6]) ([15]). It will be recalled that a similar phenomenon was mentionned for mangrove soils (Bp) The reclamation of the Phragmites swamps of Mozambique (Machongos) ([20]) seems not to present the same difficulties.

Conservation of organic matter requires that the water level be maintained near the surface, and hence often necessitates important engineering work. Indeed, drying out may be followed by rapid oxidation, acidification and often irreversible changes in the physical properties of the organic colloids which markedly alter their water retention capacity. Decomposition may result in subsidence and thus render costly constructions useless; moreover it should also be noted that dried out organic soils can burn. When properly reclaimed, these soils are suitable for intensive cultivation of vegetables and bananas.

B — **Organic non-hydromorphic soils** — Oa

Cfr Part III, profile 35, page 176.

Definition

Soils in which the upper layer to a depth of 30 cm has an organic matter content of more than 20 % in the case of a sandy substratum, or more than 30 % for a clayey substratum.

Associated units

AaOa : with rock and rock debris, rich in ferromagnesian minerals
Ra : the unit is part of the volcanic islands complex.

Distribution

Congo (Leopoldville), Kenya, Tanganyika, Uganda.

This element has only a very small extension, confined to a few mountain tops. It borders on bare rocks, glaciers, and perpetual snow, none of which may be considered as soils in the proper sense of that term, as characterized in the Introduction to Part I of this work.

Agricultural value

None

C — Complex of volcanic islands

Most volcanic islands located near the Africa coast are too small to be mapped in detail at a 1/5 000 000 scale. As they are situated in latitudes extending from the subtropics to the equator, and are submitted to highly varied climatic conditions including extremes of rainfall and aridity one may expect to encounter all elements of the legend but more in particular the following :

Aa : rock and rock debris rich in ferromagnesian minerals
Ba : lithosols on lava
Bb : lithosols on rocks rich in ferromagnesian minerals
Bn : juvenile soils on volcanic ash
Da : vertisols derived from rocks rich in ferromagnesian minerals
Dj : vertisols of topographic depressions
Ha : eutrophic brown soils on tropical regions on volcanic ash
Jb : ferruginous tropical soils on rocks rich in ferromagnesian minerals
Ka : humic ferrisols
Kb : ferrisols on rocks rich in ferromagnesian minerals
Lm : ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals
Oa : organic soils of mountains.

Distribution

I. Canarias, I. do Cabo Verde, Fernando Poo, São Tome, Principe, Annobon, Réunion, Mauritius, Rodriguez, Comores, Seychelles.

Agricultural value

Cfr that of the different elements of mapping units comprised in the complex.

During the last three centuries several intertropical volcanic islands, easily accessible and rightly considered to be very fertile, were cleared and reclaimed with methods that were not conservative. In rough reliefs the excessive clearing, perhaps induced by population pressures, has often triggered spectacular erosion. Many such islands however are still excellent agricultural areas renowned for their spices, sugar cane, coffee, cocoa and bananas.

REFERENCES

1. ABDULLAHI ABDEL RAHIM TAHIR, *Mineralogical studies on soils of Equatoria Province, The Republic of the Sudan*, Thesis Inst. Agron. Univ., Louvain, 1962.
2. G. AUBERT, La classification pédologique française 1962. Cahiers ORSTOM, *Pédologie*, n° 3, pp. 1-7, 1963.

3. G. Bocquier et R. Maignien, Les sols bruns subarides d'Afrique de l'ouest. Sols Africains, *African Soils*, Vol. VIII, n° 3, p. 371, 1963.
4. C.A. Bower, W.G. Harper et C.D. Moodie, Report of the nomenclature Committee appointed by the board of collaborators of the U.S. Salinity Laboratory, *S. Sc. Soc. Am. Proc.*, **22**, p. 270, 1958.
5. C.C.T.A., Colloque CCTA-FAO sur la classification des sols des régions intertropicales. Sols Africains, *African Soils*, Vol. IX, n° 1, pp. 55-74, 1964.
6. E.M. Chenery, Acid sulfate soils in central Africa, *Trans. 5th Int. Congr. Soil. Sc.*, Vol. 4, pp. 195, 1954.
7. J. D'hoore, *L'accumulation des sesquioxydes libres dans les sols tropicaux*, Publ. Inst. Nat. Et. Agron. Congo, Série Scientifique, n° 62, Bruxelles, 1954.
8. J. D'hoore, The description and classification of free sesquioxide accumulation zones, *Trans. 5th Int. Congr. Soil. Sc.*, Vol. 4, pp. 45-48, 1954.
9. J.H. Durand, *Les sols rouges et les croûtes en Algérie*, Direction de l'hydraulique et de l'équipement rural, Birmanreis, Alger, 1959.
10. P. Dutil, *Carte des matériaux superficiels du Sahara* (manuscrit), 1/2.000.000, 1962.
11. V.A. Evreinoff, Contribution à l'étude du dattier, *J. Agr. Trop. et de Bot. appl.*, n° 3-4, pp. 328-333, 1956.
12. R. Fauck, Les sous-groupes des sols ferrugineux tropicaux lessivés à concrétions. Sols Africains, *African Soils*, Vol. VIII, n° 3, p. 407, 1963.
13. R. Furon, *Géologie de l'Afrique*, Payot, Paris, 1960.
14. P. Gilson, J. Jongen et A. Van Wambeke, *Notice explicative de la carte des sols de Yangambi*, planchette 3, Lilanda, Publ. Inst. Nat. Et. Agron. Congo, Bruxelles, 1957.
15. J.F. Harrop, *The soils of the western province of Uganda*, Department of Agriculture, Kampala (mimeograph), 1960.
16. H.D. Jordan, The utilization of saline mangrove soils for rice growing. *III[e] Conf. Interafr. Sols*, CCTA, Dalaba, Guinée, Vol. I, pp. 327-331, 1959.
17. R. Maignien, *Le cuirassement des sols en Guinée, Afrique occidentale*, Thèse Université de Strasbourg, 1958.
18. R. Maignien, Tropical subarid brown soils of west Africa, *First soil correlation seminar for south and central Asia*, Tashkent, Usbekistan, U.S.S.R., pp. 36-44, 1962.
19. G. Milne, Some suggested units of classification and mapping, *Soil Res.*, **4**, p. 183, 1935.
20. J. Montalvão Marques, *Esboço para uma monografia agricola do postosede dos Muchopes e de alguns regulados do Chibuto (Moçambique)*, Junta de exportação de algodão CICA, Mém. n° 39, Lourenço Marques, 1961.
21. A. Pecrot, Quelques grands groupes de sols des régions montagneuses du Kivu, *Pédologie* (Gand) Vol. IX, pp. 227-237, 1959.
22. J. Pochon, H. Barjac et J. de Lajudie, Recherches sur la microflore des sols sahariens, *Ann. Inst. Pasteur*, **92**, pp. 833-836, 1957.
23. G. Repp et Ch. Killian, Recherches écologiques sur les relations entre les climats, les sols et les plantes irriguées des oasis sahariennes, *J. Agr. Trop. et de Bot. appl.*, n° 3-4, pp. 109-141, 1956.
24. Ch. Sys, La carte des sols du Congo Belge et du Ruanda-Urundi, *Pédologie* (Gand), Vol. X, n° 1, pp. 48-116, 1960.
25. R. Tavernier, Sur quelques sols des régions méditerranéennes, *Pédologie* (Gand), Vol. VII, pp. 348-364, 1957.
26. U.S. Department of Agriculture, *Diagnosis and Improvement of saline and alkali soils*, Handbook n° 60, 1954.
27. U.S. Department of Agriculture, *Soil Survey Staff. Soil classification — A comprehensive system*, 7th Approximation, 1960.
28. U.S. Department of Agriculture, *Genesis and hardening of laterite in soils*. Lyle T. Alexander and John G. Cady, Technical Bulletin n° 1282, 1962

PART III

CHARACTERISTIC PROFILES AND ANALYTICAL DATA

The elements of the legend represent very large pedological units that are difficult and often impossible to characterise satisfactorily by a limited number of profiles. Descriptions and analytical data that are included in Part III are therefore to be considered as illustrations and not as tentative characterizations of type profiles. References cited in the bibliography provide more detailed information.

1. Lithosols on calcareous crusts

Symbol Bc′ (cfr page 64).

Réference : J.H. Durand [4].

General

Well Daya I, at Ain Skhouna, north of the Chott el Chergui, Algeria Upper part of the slope at 120 m to the east of the well. Profile 247.

Profile description

0-18 cm	Very fine brown sand, sandy structure, friable
18-32 cm	Soft limestone, very pale brown.
32-35 cm	Zonal crust, pink, hard.
+ 35 cm	Soft limestone, pink, friable.

Analytical data

Depth. cm	0-18	18-32	32-35	+35
Part. size distr. <0.002 mm %	9	10.5	—	—
C.E.C. meq./100 g	11.9	9.45		
Extractable cations meq./100 g				
Ca	67.9	98.3		
Mg	—	—		
K	7.1	1.7		
Na	24.9	—		

2.a. SUB-DESERT SOILS

Symbol : Bf (cfr. page 67).

Reference : C.F. Hemming and C.G. Trapnell (9).

General

Turkana desert, NW Kenya. Altitude 730 m. Mean annual rainfall 145 mm. Vegetation : widely spaced bushes of *Acacia misera* and *Sericocomopsis hildebrandtii.*

Profile description

0-30 cm Compacted, somewhat cemented chestnut sand — 5 YR 4/6. Some slight vertical fissuring; slight lumpiness on cleavages.

30-45 cm Hard and cemented duller chestnut-brown sand — 5 YR 4/4-7.5 YR 4/4.

45-90 cm Very hard cemented sand, of a dull somewhat ochreous-brown colour — 7.5 YR 4/4-5/6 — giving a pale surface when sliced by the hoe. Small flecks of $CaCO_3$ present and increasing from 61 cm onwards.

Analytical data

Depth cm	0-15	15-30	30-45	45-60	60-75	75-90
Part. size distr.						
2. -0.2 mm %	48.3	56.0	42.1	46.9	46.3	40.7
0.2 -0.02 mm %	43.5	35.8	49.7	44.9	45.1	51.2
0.02-0.002 mm %	0.9	2.9	1.8	3.9	4.1	3.8
< 0.002 mm %	7.1	5.1	6.1	4.1	4.3	4.1
pH	9.6	8.1	8.8	9.3	9.9	9.9
C.E.C. meq./100 g				78.5		
Ca CO_3 %	0.7	1.0	1.0	0.7	1.0	1.0

2.b. Sub-desert soils

Symbol : Bf (cfr 67)

Reference : C.R. Van der Merwe. [18].

General

20°45′ E, 31°20′ S, 38 miles to the south of the river Sak, Republic of South Africa. Weakly undulating relief. Altitude 3 200 ft (975 m). Mean annual rainfall 127 mm. Parent material : schists of the Ecca series. Sparse vegetation of *Mesembrianthemum.*

Profile description

Surface	Horizon A_0. Angular shale fragments and stones cover the surface (desert pavement) but the desert pigment is not so conspicuous here.
0-15 cm	Horizon A. Light yellowish-brown sandy clay loam; vesicular, and easily crushed to powder; roots few and thin; organic matter absent.
15-45 cm	Horizon B. Light reddish-brown with whitish tint, coarse sandy clay loam; fairly dense; occasional calcium carbonate concretion. Underlying the above is a platy undecomposed rock not sampled.

Analytical data

Depth cm	0-15	15-45
Part. size distr. :		
> 2. mm %	17	16
2. -0.13 mm %	45.7	34.4
0.13 -0.05 mm %	16.1	15.6
0.05 -0.005 mm %	8.4	12.9
0.005-0.002 mm %	6.1	8.0
< 0.002 mm %	23.5	29.5
pH	8.5	8.1
C %	0.16	0.15
N %	0.05	0.04

3.a. Weakly developed soils on loose sediments not recently deposited

Symbol : Bh (Cfr p. 68).

Reference : J. Hervieu (10).

General

Ambovombe district, Erakoky, Madagascar.
Semi-arid climate with little or no excess of precipitation in summer.
Stabilized dunes.

Profile description

0-20 cm Yellowish-brown, slightly humiferous, coarse sand, structureless (single grain).
20-150 cm Homogeneous, yellowish coarse sand, structureless (single grain).

Analytical data

Depth cm	0-20	+20
Part. size distr.		
2. -0.2 mm %	52.6	53.3
0.2 -0.02 mm %	34.6	31.1
0.02-0.002 mm %	2.4	5.6
< 0.002 mm %	9.2	8.7
pH	7.8	7.8
C.E.C. meq./100 g	3.3	2.7
Extractable cations meq./100 g		
Ca	1.7	1.0
Mg	4.4	5.2
K	0.2	0.1
Sum	6.3	6.3
Saturation %	100	100
C %	0.56	0.24
N %	0.029	0.017
P_2O_5 ‰	0.02	0.02

3.b. Weakly developed soils on loose sediments not recently deposited

Symbol Bh (cfr. p. 68).

Reference : P.R. Tomlinson (17).

General

North-east Bornu, Gudumbali area. Dune crest. Cultivated.

Profile description

Surface	Loose sand
0-7 cm	Pale brown, 10 YR 6/3, coarse sand; dry; loose.
7-30 cm	Idem, sand; dry; slightly hard.
30-95 cm	Idem, sand; dry; loose.
95-170 cm	Very pale brown, 10 YR 7/3, sand; dry; loose.
170-230 cm	Very pale brown, 10 YR 7/3, sand with many faint brownish-yellow mottles in thick horizontal bands; moist, loose.

Analytical data

Depth cm	0-7	7-30	30-95	95-170	170-230
Part. size distr.					
2. -0.2 mm %	41.4	56.6	54.6	50.6	60.4
0.2 -0.02 mm %	54.6	33.4	33.4	39.4	31.6
0.02-0.002 mm %	—	2.0	2.0	2.0	2.0
< 0.002 mm %	4.0	8.0	10.0	8.0	6.0
pH	6.7	5.0	4.8	5.1	5.7
C.E.C. meq./100 g	13.6	14.4	17.6	25.6	32.8
Extractable cations meq./100 g					
Ca	0.15	0.20	0.45	0.93	1.40
Mg	0.69	0.01	0.07	0.85	0.85
K	0.093	0.165	0.104	0.149	0.130
Na	0.49	0	0	0.024	0.016
Sum	0.98	0.38	0.62	1.95	2.40
Saturation %	7	3	4	8	7
C %	0.17	0.11	0.11	0.11	0.11
N %	0.015	0.022	0.014	0.013	0.010

4. Juvenile soils on volcanic ash

Symbol : Bn (cfr. p. 69).

Reference : G.D. Anderson (1).

General

Angata Salei, Eastern Serengeti plains, Tanganyika.
Dune ridges to the west of the volcano Oldoinyo.

Vegetation

90 % bare ground with *Dactyloctenium sp.* encroaching from surrounding depressions.

Profile description

0-15 cm Very dark grey, 5 YR 3/1, with some particles dark greyish-brown, 2.5 Y 4/2.
30-45 cm Dark grey, 5 Y 4/1, with some dark greyish-brown, 2.5 Y 4/2.

Analytical data

Depth cm	0-15	30-45
pH	7.9	8.0
Extractable cations meq./100 g		
Ca	26.5	47.8
Mg	1.6	1.4
K	9.92	10.56
Na	4.75	2.38
Saturation %	100	100
C %	0.09	0.73

5. Juvenile soils on fluvio-marine alluvium (Mangrove swamps)

Symbol Bp (cfr. p. 72).

Reference : J. Hervieu (10).

General

Belo district, Tsiribihina delta near Tsimanadrafozana, Madagascar.

Vegetation

Avicennia marina.

Profile description

0-60 cm Yellowish-brown, clayey, plastic and adherent, rich in roots and rhizophores.

60-100 cm Progressive transition to a greyish-blue horizon with sulfur-yellow or rusty-orange mottles and cavities more or less hardened (iron sulfides), fine sandy clay, plastic.

+ 100 cm Pale grey, fine sandy, rich in mica and dark minerals.

Analytical data

Depth cm	0-60	60-100	+100
Part. size distr.			
2.00-0.200 mm %	2.9	4.8	26.7
0.20-0.020 mm %	16.9	30.8	70.8
0.02-0.002 mm %	32.3	29.5	0.5
< 0.002 mm %	45.3	33.7	1.7
pH	7.2	6.5	5.4
C.E.C. meq./100 g	35.5	25.0	3.4
Extractable cations meq./100 g			
Ca	1.85	0.40	0.90
Mg	12.6	3.75	0.05
K	2.65	1.80	0.23
Na	12.65	8.15	0.50
Sum	29.7	14.1	1.7
Saturation %	82.2	56.4	50.0
C %	0.6	1.21	0.08
N %	0.061	0.048	0.012
P_2O_5 ‰	0.05	0.04	—

6. Soils of Oases

Symbol : Br (cfr. p. 74).

Reference : G. Repp and Ch. Killian [15].

General

n° 1 : Fendi, irrigated soil
n° 2 : Fendi, non-irrigated soil
n° 3 : Melias, irrigated soil
n° 4 : Aïn Sefra, non-irrigated soil
n° 5 : Zenaga pass, edge of oasis, formerly irrigated
n° 6 : Zenaga pass, edge of oasis, non-irrigated.

Profile description

Each sample represents the surface layer of a different profile.

Sample no. Depth cm	1 0-10	2 0-10	3 0-10	4 0-10	5 0-10	6 0-10
Part. size distr.						
2. -0.2 mm %	2.5	4.0	4.1	16.0	37.0	49.4
0.2 -0.02 mm %	80.7	70.3	53.2	51.9	38.1	17.2
0.02-0.002 mm %	6.6	9.0	31.0	8.3	9.7	31.1
< 0.002 mm %	11.1	15.6	17.3	22.8	13.8	0.6
Soluble salts %	1.5	0.38	1.76	1.35	1.05	0.44
Cl %	0.006	0.075	0.017	0.710	0.151	0.006
SO_4 %	1.0	1.1	0.44	Tr	1.2	Tr
K_2O mg/100 g	69.2	31.2	57.6	50.4	61.8	61.8
Na_2O mg/100 g	116	142	226	326	330	198
$CaCO_3$ %	14.1	20.0	34.6	15.5	44.5	31.9
CaO %	8.2	13.6	21.6	8.4	25.7	17.0
MgO %	1.81	1.82	1.97	1.62	0.97	1.87
C %	0.87	0.80	1.35	0.29	0.83	0.55
N %	0.064	0.028	0.145	0.037	0.025	0.033
P_2O_5 mg/100 g	1.9	10.6	16.0	2.4	Tr	5.3

7.a. CALCIMORPHIC SOILS : RENDZINAS AND/OR BROWN CALCAREOUS SOILS

Symbol : Ca (cfr. p. 75).

Reference : J. Vieillefon [10].

General

Analalava district, between Ampasindava and Ambalantsingy.
Parent material : soft chalky limestone.
Vegetation, not very dense with *Heteropogon contortus.*
J. Vieillefon describes this profile as " sol rendzinoïde sur calcaires crayeux ".

Profile description

0-20 cm dark grey silty clay, crumb to granular structure.
20-50 cm White-grey, silty clay, with limestone fragments.
+ 50 cm White limestone.

Analytical data

Depth cm	0-20	20-50
Part size distr.		
2. -0.2 mm %	6.9	1.3
0.2 -0.02 mm %	19.1	24.7
0.02-0.002 mm %	8.0	35.8
< 0.002 mm %	66.0	38.2
pH	8.0	8.8
C.E.C. meq./100 g	68.5	24.0
Extractable cations meq./100 g		
Ca	53.10	37.50
Mg	1.08	0.64
K	1.65	0.65
Na	0.34	0.26
Sum	56.17	39.05
Saturation %	82	100
C %	3.36	0.67
N %	0.296	0.063
P_2O_5 ‰	0.01	—

7.b. Calcimorphic soils: rendzinas and/or brown calcareous soils

Symbol : Ca (cfr p. 75).

Reference : P. Segalen ([10]).

General

Diego Suarez district, near Tsimarenimakia.
Parent material : Basalt debris cemented by secondary limestone.
Vegetation : Savanna with *Ziziphus jujuba* and *Heteropogon contortus.*
P. Ségalen describes this profile as "sol calcaire brunifié sur roche mère riche en argile et limon".

Profile description

0-30 cm	Dark greyish-brown, clayey, moderate angular to subangular blocky structure.
30-70 cm	Olive-brown, clayey, with basalt debris. Dry season cracks. Weak angular blocky structure; a few small lime concretions.
+ 100 cm	Basalt boulders cemented by secondary limestone.

8. Soils with calcareous pans

Symbol : Cb (cfr. p. 76).

Reference : J. Hervieu (10).

General

Manja district, near Ranganaomby, road Manja — Beharona.
Parent material : Senonian sandy marls.
Vegetation : dense *Cynodon dactylon* grassland.
J. Hervieau describes this profile as "sol calcaire brunifié à engorgement temporaire".

Profile description

0-20 cm	Dark brown, hard, weak angular blocky structure.
20-65 cm	Dark grey with large ill-delimited yellowish-brown mottles, massive, clayey, plastic.
65-85 cm	Yellowish to white loamy sand, calcareous, a few iron oxide mottles, slightly plastic.

Analytical data

Depth cm	0-20	20-65	85-120
Part. size distr.			
2. -0.2 mm %	16.3	18.6	3.5
0.2 -0.02 mm %	46.1	42.7	67.6
0.02-0.002 mm %	7.6	6.7	12.4
< 0.002 mm %	28.5	31.3	16.0
pH	6.9	8.4	8.5
C.E.C. meq./100 g	35.71	32.85	37.71
Extractable cations meq./100 g			
Ca	18.85	26.00	38.50
Mg	5.20	5.20	5.80
K	0.55	0.65	0.50
Na	0.17	0.17	0.17
Sum	24.75	32.02	44.97
Saturation %	69.3	93.7	100
C %	1.32	0.36	
N %	0.075	0.011	
$CaCO_3$ %	Tr	Tr	29.55

9. Vertisols derived from rocks rich in ferromagnesian minerals

Symbol : Da (cfr. p. 78).

Reference : J.V. Botelho da Costa et al (3).

General

Huila district, Angola.
Parent material : gabbro-plagioclase complex.
Vegetation : *Berlinia-Brachystegia-Combretum* woodland with *Colophospermum mopane.*
Semi-arid to dry subhumid tropical climate.

Generalized profile description

0-5 cm Very dark grey (10 YR 3/1 — 7.5 YR 3/0), dark grey (5 Y 4/1 — 2.5 YR 4/0) or grey (10 YR 5/1 — 7.5 YR 5/0-6/0) clay or sandy clay often with rock debris, rich in feldspars or in quartz, in variable proportions. Normally medium to fine crumb structure, sometimes structureless. Consistency hard. Calcareous precipitations; few roots.

5-20 cm Very dark grey (10 YR 3/1 — 7.5 YR 3/0), dark grey (5 YR 4/0) or grey (10 YR 5/1 — 7.5 YR 5/0) clay or sandy clay with rock debris. Sometimes very coarse prismatic structure, weakly developed. Fine, medium or wide vertical cracks. Very compact, hard; calcareous precipitations; few roots.

20-120 cm Similar to overlying horizon, but increasingly humid with depth. Sometimes slightly cracked. Structureless. Slightly less compact than overlying horizon, consistency hard. Calcareous precipitations. Little or no roots.

+ 120 cm Strongly weathered rock, more or less impregnated with calcareous material, and intermixed with soil similar to that of the overlying horizon.

Analytical data

Depth cm	0-3	3-25	25-55	55-90	90-125
Part. size distr.					
> 2. mm %	7.2	7.1	4.5	5.9	3.9
2. -0.2 mm %	11.3	12.9	12.2	11.9	11.4
0.2 -0.02 mm %	19.7	18.6	17.4	17.1	17.4
0.02-0.002 mm %	21.7	20.6	19.5	19.9	17.6
< 0.002 mm %	47.5	48.5	51.6	51.9	52.8
pH	7.5	7.7	8.0	8.0	8.2
C.E.C. meq./100 g	44.3	42.1	41.7	44.2	44.9
Saturation %	99.1	99.0	100	100	100
C %	0.84	0.70	0.59	0.58	0.55
N %	0.057	0.045	0.031	0.033	0.028
$CaCO_3$ %	0.1	0.1	0.2	0.3	0.7

10. Vertisols derived from calcareous rocks.

Symbol Db (cfr p. 80).

Reference : R. Maignien [12].

General

Dakar, Senegal.
Parent material : marl.
Vegetation : *Acacia ataxa.*
Dry tropical climate.

Profile description

0-10 cm	Brown-black clay, enriched with organic matter; coarse subangular blocky structure with glossy ped surfaces. Stable, rather porous; soil fauna very active. Consistency strong.
10-50 cm	Black clay; well marked platy structure; not porous; consistency strong; not calcareous.
50-100 cm	Black clay, few diffuse brown mottles, angular blocky and platy structure, more massive, very hard, strong consistency; non calcareous.
100-200 cm	Brown-black clay, small ferruginous streaks, well developed platy structure. Numerous small calcareous nodules.
+ 200 cm	Marl.

Analytical data

Depth cm	0-10	100-200
Part. size distr.		
2. -0.2 mm %	Tr	8.7
0.2 -0.02 mm %	41.0	38.7
0.02-0.002 mm %	10.8	8.5
< 0.002 mm %	38.8	36.5
pH	7.8	7.5
Saturation %	100	100
C %	0.76	0.59
N %	0.077	0.050
$CaCO_3$ %	0.8	Tr

11. Vertisols of topographic depressions

Symbol : Dj (cfr p. 81).

Reference : W.A. Blokhuis and L.H.J. Ochtman (2). (abbreviated)

General

Gezira Research Station, Wad Medani, Sudan.
Vegetation : *Cymbopogon nervatus* Chiov., *Ipomea cordofana* Choisy and *Momordica tuberosa* Congn.

Profile description

0-2 cm The surface consists of a dry friable flaky crust, 3-4 mm thick and composed of fine sedimented layers. Brown clay (10 YR 5/3 dry, 10 YR 4/3 moist). The flakes overlay a very slightly moist, friable, dark brown (10 YR 3/4, dry and moist) clay. Weakly developed very fine subangular blocky structure. Very sticky and very plastic when wet. Both the crust and the underlying clay contain many dark grey nodules of $CaCO_3$ (1-10 mm diam.) frequently extending above the surface. Many roots, a few shell fragments.

2-15 cm Dark brown clay (10 YR 3/3 dry, 10 YR 3/3.5 moist). Very moist. Very friable, structureless, massive. Very sticky and very plastic when wet. Frequent dark grey nodules of $CaCO_3$ (1-5 mm diam.); many fine roots. In the dry season this part of the profile is very slightly moist.

15-40 cm Similar to overlying horizon but with widely separated sparse accumulations of very fine white flecks of $CaCO_3$. They have roughly a vertical arrangement. Frequent dark grey nodules of $CaCO_3$ (1-5 mm diam.). Frequent fine roots. In the dry season this part of the profile is slightly moist.

40-60 cm Dark brown clay (10 YR 3/3 dry, 7.5 YR 3/2 moist). Almost wet, very friable. Very sticky and very plastic when wet. The soil has a faint fine horizontal lamination. The laminae are wavy and form a fine network of lines. In the dry season this horizon is still moist but the exposed surface exhibits a moderately developed, fine angular blocky structure. A few dark grey nodules of $CaCO_3$ (1-3 mm diam.). Widely separated, sparse accumulations of very fine white flecks of $CaCO_3$, vertically arranged. Frequent fine roots, some shell fragments.

60-90 cm Dark brown clay (7.5 YR 4/2 dry, 7.5 YR 3.5/2 moist). From 60 to 75 cm the horizon contains inverted tongues of dark greyish brown clay (10 YR 4/1.5 dry and moist); these tongues have an irregular appearance and frequency and are 2-4 cm wide. Occasionally they extend upwards from this horizon to 30 cm below the surface of the soil. From 75 to 90 cm, the dark brown clay forms an intensive and coarse network in a matrix of dark greyish-brown clay. The veins of brown clay are 1-2 cm wide.

This horizon is transitional and contains both the dark brown clay of the horizon above and the dark greyish-brown clay of the next horizon. The boundaries between the two clays within the transitional horizon are sharply delineated.

Moist and friable soil, even during the dry season. Very sticky and plastic when wet. Fine lamination as in overlying horizon: in the dark brown clay very faint, in the dark greyish-brown clay distinct; otherwise no structural units appear. A few dark grey nodules of $CaCO_3$ (1-3 mm diam.); frequent very fine white flecks of $CaCO_3$. Few fine roots. Tunnels of soil fauna, mainly or exclusively termites.

90-130 cm Dark greyish-brown clay (10 YR 4/1.5 dry and moist) with a net-work of dark brown clay (7.5 YR 4/2 dry, 7.5 YR 3.5/2 moist) incorporated in it. The width of the dark brown veins decreases with depth; it varies between 0.5 and 2 cm. Moist friable soil. Very sticky and very plastic when wet. Horizontal lamination as in overlying horizon : distinct in the dark greyish-brown clay and very faint in the dark brown veins. When the soil dries out it develops a very fine angular blocky structure, splitting along some of the laminae and preserving others within each unit. The greatest dimension of the aggregates is in a horizontal direction. It is not, however, a platy structure in the ordinary sense of the term. The aggregates have shiny faces, but no coatings. Gypsum accumulates mainly in the upper part of this horizon in many regularly distributed nests (3-5 mm diam.) of fine crystals. Dark grey nodules of $CaCO_3$ as in the overlying horizons. Some cream coloured, soft $CaCO_3$ concretions (1-2 cm diam.) accumulate at the bottom of this horizon. Many holes produced by soil fauna, apparently formed mainly by action of termites. In the tunnels there are often dry fragments of roots and grasses, probably brought down by the termites. The tunnels are up to 5 mm wide. It was observed that a fungus had developed on the debris in one of those tunnels. A few shell fragments.

130-165 cm Brown clay (10 YR 4.5/3 dry, 10 YR 5/3 moist). Very slightly moist and very hard all the year round. Weakly developed, fine angular blocky structure. The structural elements have a distinct metallic-like bluish coating. Very sticky and very plastic when wet. Considerable accumulation of coarse lens-shaped gypsum crystals (2-5 mm). Frequent both soft and hard cream-coloured $CaCO_3$ concretions (1-3 cm). Many termite holes with fragments of roots and grasses as in the horizon above.

165-185 cm Brown clay (10 YR 5/3 dry, 10 YR 5/3.5 moist). Very slightly moist and very hard all the year round. Weakly developed fine angular blocky structure; coatings as in overlying horizon but more frequent and more distinct. Some reddish Fe-coatings. Very sticky and very plastic when wet. Gypsum accumulation as in the horizon above, but in greater abundance. Cream coloured, soft and hard $CaCO_3$ concretions as in the horizon above. Termite holes.

185-220 cm Brown clay (10 YR 5/3 dry, 10 YR 5/4 moist). Very slightly moist and very hard all the year round. Weakly developed, fine-medium subangular blocky structure; coatings as in the horizon above. Very sticky and very plastic when wet. Gypsum accumulates as coarse lens-shaped crystals and in nests of fine crystals (as in horizon 90-130 cm). There is less gypsum than in the overlying horizon. Cream coloured $CaCO_3$ concretions as in the horizon above. Termite holes.

220-250 cm Brown clay (10 YR 5/3 dry, 10 YR 5/4 moist). Very slightly moist and very hard all the year round. Weakly developed, fine-medium subangular blocky structure. Very sticky and very plastic when wet. No gypsum. Cream coloured $CaCO_3$ concretions as in the horizon above; they appear to have a soft outer surface and a hard center. Frequently bluish coatings on the aggregates (a "metallic" lustre) and also reddish Fe-coatings. Some fine tunnels with blue coatings on the inside which might be former root tunnels. Frequent fine termite tunnels, often filled with debris.

Remarks

This profile is characterized by three major horizons :

— 0-60/90 cm dark brown clay
— 60/90-130 cm dark greyish-brown clay
— >130 cm brown clay.

Analytical data

Depth cm	0-2	2-40	40-60	60-90	90-110	110-130	130-165	165-185	185-220	220-250
Part. size distribution										
> 2. mm %	3	2	2	1	1	1	1	1	1	1
2. -0.2 mm %	7	6	6	5	4	4	4	3	3	2
0.2 -0.02 mm %	20	17	17	18	15	15	13	14	14	13
0.02-0.002 mm %	13	15	14	16	16	16	21	20	19	20
< 0.002 mm %	56	61	61	60	64	64	61	63	64	65
pH	9.2	9.4	9.6	9.6	8.4	8.5	8.2	8.2	8.3	9.1
C %	0.344	0.287	0.306	0.306	0.402	0.402	0.359	0.205	0.186	0.114
N %	0.0301	0.0217	0.0228	0.0224	0.0263	0.0263	0.0228	0.0154	0.0160	0.0140
Soluble salts %	0.039	0.060	0.060	0.075	0.285	0.300	0.330	0.321	0.300	0.165

12.a. Podsolic soils, not differentiated

Symbol Ea (cfr. p. 83).

Reference : P. Gilson, P. Jongen, A. Van Wambeke (7).

General

Lilanda, Yangambi, Congo (Leopoldville).
Very light sandy parent material.
Vegetation : Swamp forest with *Entendrophragma palustre*, Stanner.
Humid equatorial climate.

Generalized description

a) Thick structureless humic horizon.
b) Pale coloured structureless leached horizon.
c) Horizon enriched in organic matter and clay, indurated, dark brown, 10 to 25 cm thick.
d) Structureless sandy horizon, where groundwater level has left no clear marks.

12.b. Podsolic soils, not differentiated

Symbol Ea (cfr p. 83).

Reference : J. Hervieu (10).

General

Moramanga district, near village Befotsy, Madagascar.
Parent material : alluvial sand.
Humid climate with little or no water deficiency in winter.
Vegetation : *Philippia, Aristida similis, Hyparrhenia.*
J. Hervieu describes this profile as "podzol humique".

Profile description

0-7 cm Dark coloured humic horizon, rich in partially decomposed plant debris, sandy, structureless (single grain)
7-25 cm Greyish-white, sandy, structureless (single grain). Few roots.

25-30 cm Accumulation of dark coloured organic matter in irregular streaks. Organic matter coats the sand grains and adheres to the fingers. Structureless (massive and single grain). Few roots.

30-37 cm Pale yellow with chocolate-brown or dark rusty mottles and root tunnels. No roots. Compact and hardened. Spotty accumulation.

37-130 cm Yellowish-brown clayey sand, coherent, slightly plastic.

+ 130 cm Idem, with small brick-red well delimited mottles (fossil mottled zone in ancient alluvium).

Analytical data

Depth cm	0-7	7-25	25-30	30-37	37-130
Part. size distr.					
2. -0.2 mm %	47.5	45.1	46.7	34.8	35.3
0.2 -0.02 mm %	28.1	46.0	44.5	52.7	39.0
0.02-0.002 mm %	7.6	4.6	4.1	6.4	6.8
< 0.002 mm %	7.6	1.8	2.2	5.2	17.6
pH	5.7	5.6	5.1	5.5	5.4
C.E.C. meq./100 g	7.4	2.0	31,0	31.4	4.0
Extractable cations meq./100 g					
Ca	1.15	1.35	1.20	0.45	1.65
Mg	0.60	0.70	0.50	0.75	0.45
K	0.10	0.03	0.11	0.15	0.06
Na	—	—	—	—	—
Sum	**1.85**	**2.08**	**1.81**	**1.35**	**2.16**
Saturation %	25.0	100	5.8	4.2	54.0
C %	2.10	1.36	4.00	1.92	0.38
N %	0.073	0.012	0.190	0.065	0.015

13. Sols lessivés — Highveld pseudo-podsolic soils

Symbol : Fa (cfr p. 84).

Reference : C.R. Van der Merwe (18).

General

10 km to the west of Senekal; Myrtle farm. Republic of South Africa. Undulating relief. Altitude 1 460 m. Mean annual rainfall : 610 mm. Parent material : Beaufort beds. Vegetation : *Themeda triandra.*

Profile description

0-20 cm	Horizon A_1. Dark greyish-brown friable sandy loam, containing an occasional small iron oxide concretion; organic material fairly poor and grass roots abundant, binding the soil material.
20-36 cm	Horizon A_2. Grey friable sandy clay loam, otherwise similar to A_1 but contains less humus and more iron oxide concretions; few roots.
36-61 cm	Horizon B_1. Yellowish-grey, mottled brown, gravelly clay. Fairly dense and granular; abundant iron oxide concretions; few roots.
61-133 cm	Horizon B_2 or G. Yellowish-brown with bluish tint, mottled brown clay; fairly compact, cloddy when dry, with a column-like structure fairly well developed; a bluish-grey colloïdal material has been deposited on the walls of the vertical fissures.
133-168 cm	Horizon C. Light grey clay; compact and cloddy, partly decomposed sandstone rock. When moist the material is tough and plastic.

Analytical data

Depth cm	0-20	20-36	36-61	61-133	133-168
Part. size distr.					
> 2. mm %	1	1.6	4.4	0	0
2. -0.13 mm %	12.0	11.7	11.1	6.1	6.1
0.13 -0.05 mm %	47.8	46.9	37.0	13.5	9.5
0.05 -0.005 mm %	20.5	19.3	17.8	10.8	9.4
0.005-0.002 mm %	3.4	2.8	1.9	0.3	0
< 0.002 mm %	16.6	19.4	31.9	69.0	75.9
pH	5.3	5.4	5.3	5.8	7.0
C %	0.88	0.56	0.55	0.35	0.40
N %	0.07	0.05	0.05	0.04	0.04

14. Brown soils of arid and semi-arid tropical regions on loose sediments

Symbol : Ga (cfr p. 86).

Reference : Botelho da Costa et al (3).

General

Tchipa, Huila district, Angola.
Parent material : Upper Kalahari unconsolidated pleistocene sediments.
Semi-arid tropical climate.
Vegetation : *Colophospermum mopane*, *Acacia sp.* and *Spirostachys africana.* (Woodland).
The authors have classified this profile with the "solos pardo-avermelhados semiaridos compactos."

Generalized profile description

0-10 cm	Very dark grey-brown (10 YR 3/2), dark brown or brown (10 YR 4/3-7.5 YR 4/2). Generally sandy with some quartz gravel. Structureless, not compacted, numerous roots.
10-65 cm	Brown-red (5 YR 5/4) or dark brown-red (5 YR 3/3). Generally clayey sand with a little quartz gravel. Structureless. A few fine vertical cracks. Not very compact, consistency slightly hard. Not very porous. Roots and rootlets not very numerous.
65-120 cm	Grey (10 YR 6/1-5/1) or pale grey (10 YR 7/1) with rusty mottles Generally clayey sand with a variable proportion of quartz gravel. Structureless. Sometimes finely cracked. Consistency very hard. A few small ferruginous concretions, indurated or not indurated.
120-165 cm	Pale grey (10 YR 7/1-7/2), generally clayey sand. Structureless, very compact, consistency hard. A few ferruginous concretions. Often calcareous material (soft concretions or small particles). Few roots.

Analytical data

Depth cm	0-7	7-15	15-30	30-53	53-85	85-130	130-165
Part. size distr.							
> 2. mm %	0.8	0.9	1.2	—	1.8	3.2	3.8
2. -0.2 mm %	51.0	43.9	51.0	39.7	51.2	48.9	32.9
0.2 -0.02 mm %	33.8	35.1	24.1	35.6	23.8	22.5	32.6
0.02-0.002 mm %	5.0	5.3	5.7	5.0	4.5	4.4	6.6
< 0.002 mm %	9.5	14.6	19.3	19.7	20.3	23.8	28.0
pH	6.4	6.1	5.8	5.7	5.8	6.3	8.0
C.E.C. meq./100 g	6.3	9.3	10.3	9.6	10.0	11.0	15.2
Saturation %	90.5	88.2	86.4	84.4	86.0	91.8	100
C %	0.40	0.50	0.42	0.28	0.18	0.11	0.05
N %	0.041	0.051	0.041	0.040	0.028	0.012	0.006
P_2O_5 ‰	0.04	0.04	0.05	0.04	0.04	0.02	0.03
$CaCO_3$ %	—	—	—	—	—	—	0.6

15. Brown soils of arid and semi-arid tropical regions, not differentiated

Symbol : Gb (cfr p. 87).

Reference : J.V. Botelho da Costa et al. (3).

General

Huila district, Angola.
Parent material : crystalline acid rock.
Semi-arid tropical climate.
Vegetation : *Colophospermum mopane* woodland.
The authors have classified this profile with the "solos pardo-avermelhados semi-aridos" on rocks rich in quartz.

Generalized description

0-5 cm — Dark brown (7.5 YR 4/4) brown-red (5 YR 5/4) or ochre (5 YR 5/6) sand or seldom clayey sand with variable proportions of quartz gravel or quartz and feldspathic gravel. Structureless, not very compact, massive, few roots.

5-20 cm — Ochre (5 YR 4/6-5 YR 4/8) or red (2.5 YR 4/6) clayey sand with variable proportions of quartz gravel, structureless, massive, slightly or moderately compact, sometimes a few small ferruginous concretions, few roots.

20-60 cm	Ochre (5 YR 4/6 – 5 YR 4/8) or red (2.5 YR 4/6) generally clayey sand with a variable proportion of quartz gravel, structureless, massive, moderately to very compact, consistency hard, sometimes a few iron concretions, generally few roots.
+ 60 cm	Strongly weathered rock, with clay material in the upper part of the horizon, but becoming more and more consistent with depth.

16. Eutrophic brown soils of tropical regions on volcanic ash

Symbol : Ha (cfr. p. 90).

Reference : A. Pécrot [14].

General

N.W. of lake Kivu, Congo (Leopoldville) 29°02′ E, 1°25′ S. Altitude 2.170 m.

Vegetation : Savanna with *Beckeropsis*.

Profile description

0-30 cm	Sandy (loamy sand), moderate medium crumb structure, numerous roots, loose, lower limit gradual and regular, very dark brown (10 YR 2/2).
30-50 cm	Sandy, weak medium to coarse angular blocky structure, with local crumbs around roots. Root activity moderate. Consistency friable. Lower limit gradual and regular. Very dark grey-brown (10 YR 2/3).
50-80 cm	Sandy, structureless (single grain), weak root activity, loose, lower limit distinct and regular, dark brown (10 YR 3/3).
80-170 cm	Sandy, weak coarse angular blocky structure, with locally very thin clay skins. Root activity weak, consistency friable, lower limit distinct and regular, dark brown (10 YR 3/3-3/4).
170-230 cm	Fine gravelly sand with pockets of very coarse black ash in the lower part of the horizon (two samples). Dark brown (10 YR 3/3).
+ 230 cm	Sandy, gravelly with white efflorescences when dry. Dark brown (10 YR 3/3).

Analytical data

Depth cm	0-30	30-50	50-80	80-170	170-230	170-230	+ 230
Part. size distr.							
2. -1.0 mm %	10.2	19.2	20.8	7.0	11.2	47.5	9.5
1. -0.5 mm %	32.6	37.3	38.0	23.3	34.3	43.8	44.1
0.5 -0.25 mm %	8.7	10.0	19.0	14.6	13.2	3.3	15.7
0.25-0.1 mm %	7.5	6.2	6.2	8.5	9.5	0.2	7.5
0.1 -0.05 mm %	3.0	2.6	1.6	10.6	4.7	0.3	4.7
0.05-0.02 mm %	5.6	4.2	2.0	9.3	7.0	0.3	4.8
0.02-0.002 mm %	5.8	3.4	2.5	6.0	4.0	0.3	2.1
< 0.002 mm %	26.6	17.1	9.9	20.7	16.1	4.6	11.6
pH	6.7	6.8	6.6	6.6	6.6		6.8
C.E.C. meq./100 g	24.2	13.8	10.9	16.8	15.8		4.2
Extractable cations meq./100g							
Ca	19.0	14.9	10.2				
K	0.65	0.74	0.65				
C %	4.70	2.38	1.51				
N %	0.75	0.46	0.25				

17. Eutrophic brown soils of tropical regions on rocks rich in ferro-magnesian minerals

Symbol : Hb (cfr p. 91).

Reference : B. Dabin [13].

General

Divo — Tiassalé road, (Ivory Coast) lat 6°N, long. 5°2′ W. Altitude 150 m. Rainfall 1 500 mm, two rainy seasons. Mean annual temperature about 25°C. Country with pronounced hilly features. Parent rock : amphibolite. Utilization : cocoa plantation.

Profile description

0-50 cm Brown (10 YR 4/3), humiferous, with great quantity of weathered rock debris mixed in clayey mass. Moderate fine angular blocky structure, plastic, very porous.

50-100 cm Dark yellow-brown (10 YR 5/6) clayey silt, rock fragments weathered in situ, schistose debris with greenish cracks and coated with blackish manganese oxides.

+ 100 cm Amphibolite, weathered *in situ*.

Analytical data

Depth cm	0-10	30-40	60-80
Part. size distr.			
> 2, mm %	1.5	58.4	
2, -0,2 mm %	9.9	27.1	
0,2 -0,02 mm %	33.0	23.9	
0,02-0,002 mm %	25.5	15.2	
< 0,002 mm %	24.7	30.2	
pH	7.7	7.3	7.6
C.E.C. meq./100 g			
Ca	33.0	15.9	16.5
Mg	6.38	6.64	21.18
K	0.68	0.06	0.04
Na	0.11	0.13	0.38
Sum	40.17	22.73	38.10
C %	2.63		
N %	0.36		

18. Red Mediterranean soils

Symbol : Ia (cfr p. 93).

Reference : J.H. Durand (4).

General

West of Tlemcen (Algeria) on steep, well drained slope. The present soil may be considered as developed in a fossil soil derived from jurassic limestone. Slight erosion, Karst features.

Profile description

0-20 cm	Brown-red loam, coarse blocky structure, relatively hard with numerous roots.
20-50 cm	Dark red clay, blocky structure, plastic, numerous roots.
50-80 cm	Dark red clay, blocky structure, plastic, roots.
80-160 cm	Red clay loam, blocky structure with glossy ped surfaces, plastic, roots and numerous calcareous nodules.
+ 160 cm	Sub-lithographic limestone.

Analytical data

Depth cm	0-20	20-50	50-80	80-160
Part. size distr.				
2. -0,2 mm %	1	1	—	13
0.2 -0,02 mm %	41	31	27	30
0.02-0,002 mm %	34	27	20	22
< 0,002 mm %	24	41	53	35
pH	7.6	7.3	7.3	7.7
C.E.C. meq./100 g	33.1	34.3	36.2	33.6
Extractable cations meq./100 g				
Ca	76.6	77.9	81.4	85.0
K	5.9	2.8	2.7	2.2
Na	3.2	2.4	1.6	2.1
C %	3.11	1.70	0.98	0.37
$CaCO_3$ %	1	—	—	31

19. Brown Mediterranean soils

Symbol : In (cfr p. 94).

Reference : C.R. Van der Merwe [18].

General

To the north of the village Rivier sonder end, S.W. of Cape Province, Republic of South Africa. Rather steep slope. Altitude 180 m.
Mean annual rainfall : 356 mm.
Parent material : Bokkeveld schists. Vegetation : wheat.

Profile description

0-13 cm Horizon A — B_1. Greyish-brown, crumbly to slightly loose gravelly sandy clay loam, the gravel consisting of small pebbles of "ouklip" (*) concretions, mixed with quartz grit and small angular shale fragments. The A horizon under development has been contaminated with material from the B_1 horizon as a result of cultivation. Its humus is deficient, while the thin roots are plentiful in the surface 4-inch layer and medium in the lower section of the horizon.

13-63 cm Reddish-brown gravelly clay; crumbly when dry and fairly compact when wet; the stones and gravel consist of angular hard and soft shale fragments.

63-79 cm Horizon C_1. Yellowish-brown, mottled reddish-brown partly decomposed, rather soft shale containing an appreciable amount of clay.

79-150 cm Horizon C_2. Slightly weathered greyish-brown shales, moderately soft.

Analytical data

Depth cm	0-13	13-63	63-79	79-150
Part. size distribution				
> 2. mm %	57	59	60	100
2. -0.13 mm %	36.2	5.7	8.3	
0.13 -0.05 mm %	14.3	5.8	6.8	
0.05 -0.005 mm %	21.7	36.5	33.9	
0.005-0.002 mm %	5.5	8.9	8.4	
< 0.002 mm %	22.2	43.1	43.9	
pH	6.4	6.6	6.6	
C %	0.69	0.31	0.13	
N %	0.074	0.100	0.066	

(*) "Ouklip" is the afrikaans term for ferruginous crust.

20. Ferruginous tropical soils on sandy parent materials

Symbol : Ja (cfr p. 97).

Reference : R. Fauck [5].

General

Sedhiou, Experimental station, Sefa, Casamance, Sénégal.
12°45′ N, 15°30′ W. Mean annual rainfall 1 350 mm.
Parent material : sand and sandstones of the "Continental terminal".
Vegetation : grass fallow.

Profile description

0-6 cm	Grey-brown (5 YR 5/3), humiferous, sandy, fine blocky structure, slightly compact, good internal drainage, tubular porosity, numerous roots and insect tunnels.
6-13 cm	Light grey-brown (5 YR 6/2) clayey sand, fine angular to subangular blocky structure, still somewhat humiferous, more compact than overlying horizon, good porosity, numerous roots.
13-31 cm	Yellow to yellow-brown (5 YR 6/4), slightly humiferous, slightly clayey sand, blocky structure, macroporosity due to roots and insects, moderately or very compact.
31-79 cm	Yellowish-brown to reddish-yellow, darker shaded (5 YR 8/4) clayey sand or sandy clay. Very distinct clay accumulation (B_2). Subangular blocky structure, very compact, low to medium porosity, of the fine tubular type.
79-117 cm	Yellow to yellowish-brown (5 YR 7/6) clayey sand angular to subangular blocky structure, moderately compact. Incipient individualization of clearly defined red ferruginous mottles.
117-150 cm	Yellowish-brown (5 YR 8/4) background colour variegated with red and ochre splashes. Clayey sand, coarse angular to subangular blocky structure; moderately compact, aggregate porosity weak to moderate. Numerous mottlings and concretions of low to medium density, red, dark red or sometimes dark violet. Towards the bottom the ochre patches become progressively more extensive and present soft concretions with slightly hardened ochre coloured centres.
+ 150 cm	From 150 cm on, the mottling becomes continuous on the same yellowish-brown background. Light grey patches appear without

clearly defined limits and also numerous red or rust-coloured concretions that can be crushed between fingers, leaving a hard core. Weak subangular blocky structure, permeability irregular due to the presence of aggregates, aggregate porosity medium, moderately to strongly coherent.

Analytical data

Depth cm	0-6	6-13	13-31	31-79	79-117	117-150
Part. size distr.						
2. -0.2 mm %	26.1	31.1	23.3	21.3	16.6	17.0
0.2 -0.02 mm %	58.2	53.7	48.8	36.5	32.4	35.7
0.02-0.002 mm %	4.0	4.1	4.9	5.3	5.3	5.6
< 0.002 mm %	9.4	9.4	21.5	35.1	43.7	40.1
pH	6.5	5.6	5.6	6.2	6.3	6.3
C.E.C. meq./100 g	4.80	4.05	4.45	5.15	4.65	4.85
Extractable cations meq./100 g						
Ca	2.25	1.70	1.70	2.10	1.30	1.70
Mg	1.05	0.65	1.05	1.50	2.30	1.85
K	0.15	0.10	0.05	0.05	0.05	0.05
Na	0.05	0.05	Tr	Tr	0.05	Tr
Sum	**3.50**	**2.50**	**2.80**	**3.65**	**3.70**	**3.60**
Saturation %	73	62	63	71	80	74
C %	1.05	0.68	0.38	0.33	0.29	0.20
N %	0.075	0.053	0.032	0.035	0.034	0.030

21. Ferruginous tropical soils on rocks rich in ferromagnesian minerals

Symbol : Jb (cfr p. 98).

Reference : J.V. Botelho da Costa et al. (3).

General

Slightly undulating relief. *Berlinia-Brachystegia-Combretum* woodland. Parent material: Diabase. Humid tropical climate.

Generalized description

0-5 cm	Very dark grey-brown (10 YR 3/2) to dark grey-brown (10 YR 4/2) clayey sand to sandy clay. Generally structureless, sometimes medium to coarse "anisoform" structure. Slightly compact, almost massive, sometimes with a few ferruginous concretions. Variable proportion of rootlets and medium-sized roots.
5-20 cm	Transition.
20-120 cm	Dark brown (7.5 YR 4/4) or brown-yellow (10 YR 5/4) clay or sandy clay, structureless. Sometimes a few fine vertical cracks. Moderately, (seldom very) compact, almost massive, normally with a few ferruginous concretions. Variable proportion of large and medium-sized roots, sometimes a few rootlets.
120 cm	From this depth onwards, the parent rock may be encountered.

Analytical data

Depth cm	0-12	12-30	30-80	80-140
Part. size distr.				
2. -0.2 mm %	16.9	11.9	11.7	12.0
0.2 -0.02 mm %	44.6	42.6	40.5	40.6
0.02-0.002 mm %	7.0	5.7	6.4	6.9
< 0.002 mm %	28.8	38.8	41.9	40.4
pH	6.0	5.9	6.1	6.5
C.E.C. meq./100 g	16.0	14.4	12.1	13.9
Saturation %	68.8	61.8	75.2	81.3
C %	1.95	1.10	0.54	0.38
N %	0.120	0.077	0.044	0.031
P_2O_5 Total ‰	0.05	0.04	0.03	0.02

22. Ferruginous tropical soils on crystalline acid rocks

Symbol : Jc (cfr p. 99).

Reference : R. Fauck [5].

General

Dongas, Dahomey. (9°40′ N, 1°50′ E). Mean annual rainfall 1 350 mm.
Parent material : deposited material on weathered biotite gneiss.
Vegetation : fairly dense tree savanna.

Profile description

0-5 cm	Grey sand, structureless (single grain), friable, slightly compact, numerous rootlets, moderately rich in organic matter.
5-15 cm	Horizon of gradual transition.
15-30 cm	Yellowish-brown, slightly clayey sand, platy structure, a few bright red patches, small black and harder red concretions. Moderately compact.
30-50 cm	Yellowish-brown clayey sand, very numerous fairly hard concretions ½ cm thick. Some larger concretions have a very hard core. Rich in Mn.
50-70 cm	Generalized mottling of horizon which becomes richer in clay with depth, and more and more compact. Very numerous fairly hard concretions.
70-120 cm	Considerable mottling, with red as dominating colour and some yellowish-brown and ochre. Fairly large black concretions, some large pieces of quartz, a few concretions with hard core.
120-200 cm	Mottling with more ochre and grey. Silty clay rich in white mica, some black patches; rock texture not recognizable. Pegmatite vein at 180 cm.
260 cm	Weathering gneiss rich in greenish biotite. Ochre patches.
320 cm	Idem but greyer.

Analytical data

Depth cm	0-5	5-15	15-30	30-50	50-70	70-120	120-200	260	320
Part. size distr.									
2. -0.2 mm %	39.7	39.5	35.0	34.5	25.3	30.1	19.9	29.4	30.1
0.2 -0.02 mm %	38.3	41.8	41.0	34.7	31.4	30.9	29.9	29.0	34.2
0.02-0.002 mm %	6 0	5.0	5.2	6.7	8.5	9.9	16.3	15.8	13.4
< 0.002 mm %	12.5	11.8	17.7	23.1	33.5	27.5	32.7	24.8	21.4
pH	7.2	6.8	6.6	6.3	6.3	6.2	5.6	5.4	5.3
C.E.C. meq./100 g	—	—	—	3.60	4.45	4.35	4.90	4.35	
Extractable cations meq./100 g									
Ca	5.95	—	—	1.40	1.70	1.50	1.00	0.80	
Mg	1.55	—	—	0.80	1.15	1.20	1.75	1.95	
K	0.25	—	—	0.15	0.20	0.25	0.20	0.20	
Na	0.05	—	—	0.05	0.05	0.05	—	—	
Sum	7.80			2.40	3.10	3.00	3.00	2.90	
Saturation %				67	70	69	61	67	
C %	1.47	0.72							
N %	0.084	0.053							
Free Fe_2O_3 %				2.49	4.18	7.03	5.12	2.00	

CEC/[illegible] 16 18 16 15

23. Humic ferrisols

Symbol : Ka (cfr p. 103).

Reference : K. Sys ([16]).

General

Ituri, Congo (Leopoldville) Altitude : 1 650 m. Mean annual rainfall 1 100 mm. Four months dry season. Savanna. Parent material : schists.

Profile description

0-6 cm Very dark brown (10 YR 2/2) silty clay, fine well developed crumb structure, loose, moist, numerous roots.

6-18 cm Dark brown (7.5 YR 3/2) silty clay, well-developed medium blocky structure with crumb structure around roots. Roots numerous. Gradual transition.

18-29 cm Dark brown (7.5 YR 4/2) silty clay, well developed fine blocky structure with continuous very dark brown (7.5 YR 3/2) coatings friable, numerous roots, gradual transition.

29-57 cm Ochre-red (5 YR 5/6), slightly micaceous silty clay, well developed medium blocky structure with thick and continuous brown-red (5 YR 4/4) coatings, firm, moderate root activity, gradual transition.

57-95 cm Ochre-red (5 YR 5/5) micaceous silty clay, well developed fine blocky structure with distinct coatings, rather friable.

95-120 cm Ochre-red silty clay with schist fragments.

Analytical data

Depth cm	0-6	6-18	18-29	29-57	57-95	95-120
Part. size distr.						
2. -1. mm %	0.5	0.5	1.3	0.7	1.2	1.0
1. -0.5 mm %	1.7	2.0	1.7	1.5	2.0	1.7
0.5 -0.25 mm %	2.0	2.0	1.7	1.3	2.0	1.2
0.25-0.1 mm %	9.2	10.7	11.0	8.5	11.0	7.6
0.1 -0.05 mm %	12.5	14.6	13.7	15.3	14.2	16.1
0.05-0.02 mm %	3.3	2.8	3.6	3.4	3.5	7.1
0.02-0.002 mm %	9.7	10.5	11.8	15.0	16.0	23.0
< 0.002 mm %	61.1	56.9	55.2	54.3	50.1	42.3
pH	5.1	4.5	4.8	4.9	4.9	4.9
C.E.C. meq./100 g	12.5	9.6	6.7	5.0	4.3	3.4
Extractable cations meq./100 g						
Ca	1.60	0.65	0.50	0.55	0.45	
K	0.59	0.29	0.21	0.13	0.13	
C %	4.22	2.66	1.23	0.53	0.41	
N %	0.38	0.24	0.12	0.05	0.05	

24. Ferrisols on rocks rich in ferromagnesian minerals

Symbol : Kb (cfr p. 104).

Reference : N. Leneuf and G. Riou [11].

General

Divo, Ivory Coast 5°55′ N, 4°55′ W.
Top of hillock, altitude 140 m. Mean annual rainfall 1 500 to 1 800 mm.
Vegetation : cocoa plantation. Parent material : amphibolite schist.

Profile description

0-10 cm	Dark reddish-brown sandy clay, humiferous, fine blocky structure, roots very numerous.
10-30 cm	Dark reddish-brown sandy clay, medium blocky structure.
30-110 cm	Dark red, fairly numerous ferruginous glossy concretions, clayey, blocky structure (clay coatings on peds).
110-200 cm	Brighter red, clayey, very homogeneous, few ferruginous concretions, clay coatings on peds.
200-250 cm	Red with diffuse greyish streaks (mottled clay ?). *In situ* quartz veins in the horizons between 110 and 250 cm.

Analytical data

Depth cm	0-20	30-40	100	200
Part. size distr.				
> 2. mm %	4.2	—	63.1	0.5
2. -0.2 mm %	9.8	6.8	12.5	3.5
0.2 -0.02 mm %	37.6	28.9	15.9	23.9
0.02-0.002 mm %	16.2	13.0	8.7	21.7
< 0.002 mm %	34.0	42.2	59.5	49.5
pH	7.1	5.5	5.8	5.6
C.E.C. meq./100 g				
Ca	15.90	6.36	3.80	1.00
Mg	5.52	1.68	2.80	2.24
K	0.70	0.12	0.06	0.03
Na	0.11	0.11	0.12	0.13
Sum	22.23	8.27	6.78	3.40
C %	2.54	0.71		

25. Ferrisols, not differentiated

Symbol : Kc (cfr p. 105).

Reference : K. Sys [16].

General

East of Walikale, Congo (Leopoldville) altitude 850 m. Mean annual rainfall 2 000 mm. Vegetation : dense rain forest. Parent material : sandstone schist.

Profile description

0-10 cm Dark greyish-brown (10 YR 4/2) sandy clay loam, weak medium crumb structure. Friable, slightly plastic, slightly adherent; great root activity. Lower limit diffuse and regular.

10-35 cm Dark yellowish-brown (10 YR 4/3) sandy clay, moderate medium blocky structure with fairly abundant and continuous coatings, root activity moderate, moderately plastic, slightly adherent. Lower limit gradual and regular.

35-100 cm Brown sandy clay (7.5 YR 4/4), well developed medium to fine blocky structure with abundant thick and continuous coatings. Weak root activity, rather firm, moderately plastic, slightly adherent; distinct transition.

+ 100 cm Quartz gravel.

Analytical data

Depth cm	0-10	10-35	35-100
Part. size distr.			
2. -1. mm %	2.2	2.5	2.6
1. -0.5 mm %	12.5	11.6	10.6
0.5 -0.25 mm %	13.6	12.2	10.6
0.25-0.1 mm %	13.0	12.5	10.5
0.1 -0.05 mm %	8.3	7.0	6.7
0.05-0.02 mm %	4.3	5.1	4.3
0.02-0.002 mm %	8.7	8.5	8.0
< 0.002 mm %	37.4	40.6	46.7
pH	4.4	4.6	4.6
C.E.C. meq./100 g	8.0	5.8	6.4
Extractable cations meq./100 g			
Ca	0.8	0.7	0.75
K	0.10	0.03	0.03
C %	1.58	0.63	0.44
N %	0.139	0.056	0.050

26. Ferrallitic soils, dominant colour yellowish-brown, on loose sandy sediments

Symbol : La (cfr p. 108).

Reference : K. Sys (16).

General

Lodja, Congo (Leopoldville) altitude 600 m. Mean annual rainfall 1 750 mm. Vegetation : tropical rain forest. Parent material : Salonga type sands.

Profile description

5-0 cm	Well decomposed litter, mainly fine rootlets and some dark coloured sand.
0-8 cm	Very dark grey-brown (10 YR 3/2) sand, structureless, loose, numerous rootlets, gradual limit.
8-23 cm	Dark brown (10 YR 4/3) sand, structureless, grey patches and grey sand grains, gradual limit.
23-38 cm	Yellow (10 YR 5/5) sand, structureless, loose, less rootlets, few grey sand grains, diffuse limit.
38-85 cm	Yellow (10 YR 5/6) sand, loose, fluffy, diffuse limit.
85-200 cm	Yellow-brown (10-7.5 YR 5/8) sand.

Analytical data

Depth cm	0-8	8-23	23-38	38-85	85-200
Part. size distr.					
2. -1. mm %	0.3	0.3	0.5	0.6	0.3
1. -0.5 mm %	5.2	4.0	4.0	4.5	4.6
0.5 -0.25 mm %	17.7	15.3	13.7	16.2	15.2
0.25-0.1 mm %	44.0	48.2	35.0	41.7	40.0
0.1 -0.05 mm %	19.5	19.7	27.6	19.5	20.6
0.05-0.002 mm %	1.5	1.4	2.1	2.0	1.7
< 0.002 mm %	11.8	11.1	17.1	15.5	17.6
pH	4.1	4.1	4.2	4.3	4.5
C.E.C. meq./100 g	4.25	2.95	2.10	1.60	1.5
Extractable cations meq./100 g					
Ca	0.85	0.35	0.80	0.50	0.55
K	0.06	0.04	0.03	0.06	0.06
C %	1.32	0.80	0.30	0.14	0.12
N %	0.10	0.05	0.02	0.01	0.01

27. Ferrallitic soils, dominant colour yellowish-brown on more or less clayey sediments

Symbol : Lb (cfr p. 109).

Reference : K. Sys [16].

General

Befale, Congo (Leopoldville), centre of Congo basin. Altitude : 375 m. Mean annual rainfall 2 000 mm. Tropical rain forest. Parent material: loose sediments.

Profile description

3-0 cm	Litter of more or less decomposed leaves with roots and rootlets.
0-8 cm	Dark brown (10 YR 4/3) clayey sand, moderately developed medium to coarse granular structure, friable, fairly numerous roots, distinct lower limit.
8-23 cm	Dark brown (10 YR 4/3) clayey sand, moderately developed fine blocky structure with crumblike elements, friable, moist., not plastic, moderate root activity, gradual lower limit.
23-37 cm	Yellow-brown (10 YR 5/4) clayey sand, moderately developed medium subangular blocky structure. Somewhat firm, moist; gradual lower limit.
37-70 cm	Yellow (10 YR 5/6) clayey sand, weakly developed medium blocky structure; firm; distinct rounded granules present; not plastic; moderate to weak root activity; gradual lower limit.
70-100 cm	Idem, but friable to slightly firm.
100-150 cm	Yellow (7.5 YR 5/6) clayey sand, weakly developed structure, friable.

Analytical data

Depth cm	0-8	8-23	23-37	37-70	70-100	100-150
Part. size distr.						
2. -1. mm %	1.0	0.6	1.5	1.5	3.0	
1. -0.5 mm %	9.2	6.6	8.0	7.7	10.0	
0.5 -0.25 mm %	19.8	16.2	13.7	13.3	13.1	
0.25-0.1 mm %	34.2	33.5	25.2	26.5	23.5	
0.1 -0.05 mm %	11.2	10.5	13.0	10.0	9.8	
0.05-0.002 mm %	3.4	3.2	3.3	3.3	3.2	
< 0.002 mm %	21.2	29.1	35.4	37.7	37.4	
pH	4.7	4.6	4.7	4.8	4.8	4.9
C.E.C. meq./100 g	5.15	3.35	2.70	2.15	2.40	2.00
Extractable cations meq./100 g						
Ca	2.10	1.20	0.85	1.00	0.70	1.00
K	0.14	0.09	0.06	0.07	0.07	0.08
C %	1.31	0.60	0.35	0.30	0.22	0.20
N %	0.12	0.06	0.05	0.04	0.03	0.03

CEC 7,6 5,1 6,4

28. Ferrallitic soils, dominant colour yellowish-brown, not differentiated

Symbol : Lc (cfr p. 110).

Reference : N. Leneuf and G. Riou [11].

General

Bia, Ivory Coast, 5°35′ N, 3°10′ W.
Top of hillock. Mean annual rainfall 1 800 to 2 000 mm. Vegetation : rain forest. Parent material : microgranite.

Profile description

0-1 cm	Litter.
0-12 cm	Grey-brown clayey sand, humiferous, crumb structure.
12-70 cm	Yellow-brown sandy clay, blocky structure.
at 70 cm	Layer of quartz gravel and ferruginous concretions.
70-150 cm	Light yellow-brown and very pale brown clayey sand, blocky structure.
150-300 cm	Pale yellow-brown sandy clay, blocky structure.
300-400 cm	Pink loamy sand with yellow-brown mottles and fragments of weathered rock.
400 cm	Weathered rock.

Analytical data

Depth cm	0-10	70	300	350
Part. size distr.				
2. mm %	2.9	2.9	—	—
2. -0.2 mm %	26.2	16.7	13.4	37.7
0.2 -0.02 mm %	23.1	21.4	14.0	41.5
0.02-0.002 mm %	12.7	10.0	15.0	11.5
< 0.002 mm %	28.2	50.7	55.5	9.5
pH	4.1	4.5	4.9	4.5
C.E.C. meq./100 g	6.24	3.69	4.35	1.71
Extractable cations meq./100 g				
Ca	0.40	0.14	0.14	0.14
Mg	0.46	0.14	0.30	0.04
K	0.09	0.02	0.01	0.01
Na	0.02	0.01	0.06	0.02
Sum	0.97	0.31	0.51	0.21
C %	1.16			
N %	0.11			

29. Ferrallitic soils, dominant colour red, on rocks rich in ferromagnesian minerals

Symbol : Lm (cfr p. 112).

Reference : R. Frankart. (6)

General

Paulis, Uele, Congo (Leopoldville). Mean annual rainfall 2 000 mm. Tropical rain forest. Parent material : amphibolite.

Profile description

0-6 cm	Ap — Clay. Well developed crumb structure. Red brown (2.5 YR 4/2). Dense root mat. Transition distinct and regular.
6-19 cm	B_1 — Clay. Well developed coarse granular structure. Brown-red (2.5 YR 3/4). Numerous rootlets. Limit gradual and regular.
19-45 cm	(B_2)—Clay. Strong medium blocky structure. Dark reddish-brown (2.5 YR 3/4). Numerous rootlets. Limit gradual and regular.
45-74 cm	B_3 — Clay. Well developed medium blocky structure. Dark reddish-brown (2.5 YR 3/4). Few rootlets. Transition gradual and regular.
74-100 cm	C_1 — Clay. Weak blocky structure. Some ferruginous concretions and weathered rock debris. Dark reddish-brown (2.5 YR 3/4). Few rootlets. Diffuse lower limit.
100-128 cm	C_2 — Idem, but more ferruginous concretions and weathered amphibolite debris. Rootlets rare. Distinct and regular transition.
+ 128 cm	D — Heterogeneous loose gravel. Ferruginous concretions, amphibolite fragments weathered and rubefied, a few angular quartz fragments. Rootlets rare.

Analytical data

Depth cm	0-6	6-19	19-45	45-74	74-100	100-128	+128
Part. size distr.							
> 2. mm %	—	—	—	—	—	Tr	80
2. -1. mm %	3.2	2.1	1.6	1.6	2.0	3.3	5.6
1. -0.5 mm %	2.5	2.5	2.0	1.5	2.0	2.2	2.5
0.5 -0.25 mm %	2.7	2.3	2.0	1.6	1.7	1.6	1.6
0.25-0.1 mm %	5.6	4.6	4.0	3.3	2.5	3.2	3.3
0.1 -0.05 mm %	2.6	2.5	1.6	2.2	2.6	2.2	2.0
0.05-0.02 mm %	3.7	2.0	2.4	2.6	2.7	2.7	3.1
0.02-0.002 mm %	10.3	18.6	5.0	5.5	4.8	4.9	4.7
< 0.002 mm %	69.4	65.4	81.4	81.7	81.7	79.9	77.2
pH	6.1	5.6	5.4	5.5	5.5	5.1	5.0
C.E.C. meq./100 g	12.8	7.9	6.1	5.5	4.9	4.3	3.9
Extractable cations meq./100 g							
Ca	9.8	4.6	3.0	2.4	2.1	1.2	1.3
K	0.21	0.14	0.12	0.09	0.12	0.10	0.19
C %	2.20	1.12	0.64	0.41	0.35		
N %	0.292	0.139	0.092	0.064	0.063		
P_2O_5 (Truog) ppm	4	Tr	Tr	Tr	Tr		
Free Fe_2O_3 %	12.0	13.0	12.5	14.0	14.2	12.8	14.0

30. Humic ferrallitic soils

Symbol : Ls (cfr p. 114).

Reference : K. Sys [16].

General

Ituri, Congo (Leopoldville). Altitude 1 600 m. Mean annual rainfall 1 200 mm. Vegetation : Savanna. Parent material : crystalline rocks of Basement complex : granite, gneiss.

Profile description

0-20 cm Dark brown-red (5 YR 2/2) sandy clay, weak medium crumb structure; friable; great root activity; lower limit distinct.

20-36 cm Infiltration of organic matter and gradual transition.

36-87 cm Red (2.5 YR 5/6) clay with quartz gravel. Weak medium subangular blocky structure. Slightly firm; weak root activity; lower limit gradual.

87-200 cm Red (2.5 YR 5/8) clay, very friable; no blocky structural elements, a few very stable granules looking like clay concretions.

Analytical data

Depth cm	0-20	20-36	36-87	87-200
Part. size distr.				
2. -1. mm %	16.0	17.0	19.0	21.0
1. -0.5 mm %	19.7	17.0	10.0	11.5
0.5 -0.25 mm %	7.8	8.2	4.0	4.0
0.25-0.1 mm %	7.5	9.0	6.2	5.6
0.1 -0.05 mm %	4.7	4.7	4.0	4.2
0.05-0.02 mm %	3.2	3.8	2.7	3.6
0.02-0.002 mm %	7.8	6.5	5.5	5.0
< 0.002 mm %	33.3	33.8	48.6	45.1
pH	4.2	4.3	4.5	4.6
C.E.C. meq./100 g	13.75	10.65	7.20	4.60
Extractable cations meq./100 g				
Ca	0.80	0.55	0.50	0.70
K	0.29	0.25	0.16	0.18
C %	4.10	2.24	0.98	
N %	0.38	0.25	0.13	

31. Ferrallitic soils with dark horizon

Symbol : Lt (cfr p. 115).

Reference : K. Sys [16].

General

Ituri, Congo (Leopoldville). Altitude 1 750 m. Mean annual rainfall 1 400 mm. Vegetation : savanna. Parent material; granite.

Profile description

0-16 cm	Very dark grey (5 YR 4/1) clay. Well developed fine to medium crumb structure. Friable. Moist. Strong root activity. Gradual lower limit.
16-46 cm	Dark red-brown (5 YR 3/3) clay; weak coarse to medium subangular blocky structure; friable; medium to strong root activity; gradual transition.
67-94 cm	Dark red (2.5 YR 3/6) clay. Weak to moderate fine subangular blocky structure. A few very stable granules. Friable; low root activity; gradual transition.
94-151 cm	Dark horizon. Red-brown (2.5 YR 4/4) clay. Weak medium subangular blocky structure. Many rounded and very stable granules. Friable; few roots.
151-200 cm	Dark red (2.5 YR 3-4/6) clay; Many rounded granules in a structureless matrix; friable.

Analytical data

Depth cm	0-16	16-46	46-67	67-94	94-151	151-175
Part. size distr.						
2. -1. mm %	1.2	0.6	1.2	0.5	0.7	1.6
1. -0.5 mm %	7.2	6.6	6.0	6.2	5.7	5.7
0.5 -0.25 mm %	7.0	7.7	4.7	7.3	6.2	6.3
0.25-0.1 mm %	9.0	12.0	12.0	11.3	11.0	12.0
0.1 -0.05 mm %	5.5	6.6	8.0	6.8	7.6	7.6
0.05-0.02 mm %	2.1	2.2	2.2	2.1	2.3	2.5
0.02-0.002 mm %	6.4	6.4	6.0	5.9	5.3	5.3
< 0.002 mm %	61.6	57.9	59.9	59.9	61.2	59.0
pH	5.5	5.1	5.1	5.1	5.0	5.0
C.E.C. meq./100 g	15.6	9.0	6.8	5.95	—	—
Extractable cations meq./100 g						
Ca	4.10	0.80	0.65	0.60		
K	0.35	0.16	0.14	0.14		
C %	5.96	2.01	1.19	0.89	1.08	0.68
N %	0.42	0.16	0.11	0.07	0.07	0.05

32. Solonetz and solodized solonetz.

Symbol : Ma (cfr p. 117)

Reference : J. Vieillefon [10].

General

Ihosy district, Menarahaka valley, near Analasoa, Madagascar. Subhumid climate. Parent material : old riverine and lacustrine alluvia. Bottom of valley. Vegetation : *Heteropogon, Hyparrhenia, Sporobolus pyramidalis* and *Cyperus articulatus.*

Profile description

0-20 cm Dark coloured clayey sand, crumb structure.
20-40 cm Light grey clayey sand, compact, massive.
40-80 cm Grey clay with ochre mottles, massive, hard.

Analytical data

Depth cm	0-20	20-40	40-80
Part. size distr.			
2. -0.2 mm %	11.6	25.0	12.0
0.2 -0.02 mm %	49.0	44.0	20.0
0.02-0.002 mm %	17.2	15.6	9.7
< 0.002 mm %	18.0	14.8	51.0
pH	6.1	6.3	8.7
C.E.C. meq./100 g	32.3	15.7	28.8
Extractable cations meq./100 g			
Ca	7.5	4.0	9.8
Mg	5.7	2.1	13.1
K	0.7	0.3	1.0
Na	0.9	0.05	6.1
Sum	**14.8**	**6.5**	**30.0**
Saturation %	46	42	100
C %	4.12	0.33	0.05
N %	0.31	0.03	
P_2O_5 ‰	0.05		0.01
Soluble salts ‰	1.8	0.9	9.2

33. Saline soils, alkali soils, saline alkali soils

Symbol : Mb (cfr p. 118).

Reference : J. Hervieu and J.D. Rakotomiraho [10].

General

Morondava district, lower Morondava plain, near Ambatosoratra.
Semi-arid climate. Parent material : recent alluvium. Vegetation : *Scirpus maritimus*.

Profile description

0-20 cm	Dark grey clay, hard, cracked, with rust coloured streaks. Blocky structure; salt crystals; numerous roots.
20-40 cm	Mottled grey clay to sandy clay, containing plant debris. Blocky structure, few roots. Traces of calcium carbonate.
40-80 cm	Light grey, plastic, mottled clay.
+ 80 cm	Bluish grey sandy clay, mottled, plastic, adherent. Salty water table at 1.10 m.

Analytical data

Depth cm	0-20	20-40	40-80	+80
Part. size distr.				
2. -0.2 mm %	1.4	0.4	0.3	0.8
0.2 -0.02 mm %	28.8	47.9	30.5	36.4
0.02-0.002 mm %	13.7	13.0	18.2	15.7
< 0.002 mm %	50.0	36.2	33.5	44.1
pH	8.7	9.0	8.8	7.6
C.E.C. meq./100 g	40.0	36.1	—	—
Extractable cations meq./100 g				
Ca	22.3	21.5		
Mg	13.6	0.7		
K	1.55	1.60		
Na	14.8	23.45		
Saturation %	100	100		
C %	2.92	0.81		
N %	0.11	0.07		
P_2O_5 ‰	0.25			
Soluble salts ‰	22.0	10.5	11.0	11.7

34. Organic hydromorphic soils

Symbol : Nb. (cfr p. 123).

Reference : J. F. Harrop [8].

General

Nyanza swamp, 12 miles from Kabale on the Kampala road. Papyrus swamp.

0-2.5 cm Very dark greyish-brown granular peat, containing sporadic orange-brown ferruginous nodules which are probably old root trace material hardened and broken up; quite wet.

2.5-23 cm Similar to above but mottled and splotched with orange-yellow ferric oxide.

23-38 cm Pale greyish-brown rooty peat with bright orange-red organic remains like rotten wood giving the appearance of mottling in cross-section but the redness is not ferruginous.

38-46 cm Dark brownish-grey rooty peaty clay with occasional yellowish-brown splotches of decayed wood. Slight smell of hydrogen sulfide at beginning of sampling, but not much after a few minutes. Water oozes from 24 inches downwards but the true water table was only 6 to 7 inches from the surface.

46-155 cm After a few hours this material appeared quite black in colour.

35. Organic non hydromorphic soils — organic soils of mountains

Symbol : Oa (cfr p. 124).

Reference : J.F. Harrop (8).

General

Ruwenzori, Busuwagumu, 12 miles north of Nyabiringo, Uganda. Level site. Altitude 11 000 ft (3 350 m). Mean annual rainfall 60-65 inch. — (1 550-1 650 mm). Vegetation : *Helichrysum*, *Senecio.*, etc.

Profile description

0-30 cm Very dark grey-brown peat, almost completely humified.
30-51 cm Pale grey morainic material with some humus staining and rusty blotches.

Analytical data

Depth cm	15	30	51
Part. size distr.			
0.02-0.002 mm %	6	6	6
< 0.002 mm %	5	5	11
pH	3.5	3.2	3.2
C.E.C. meq./100 g	36.40	50.28	21.21
Extractable cations meq./100 g			
Ca	0.6	< 0.3	< 0.3
Mg	0.9	< 0.6	< 0.6
K	1.50	1.08	0.31
Na	0	0	0
Sum	**3.00**	**1.08**	**0.31**
Saturation %	8.2	2.1	1.5
C %	10.30	11.27	2.75
P_2O_5 ppm	40	28	19

REFERENCES

1. G. D. ANDERSON, Some weakly developed soils of the eastern Serengeti plains, Tanganyika, *Sols Africains — African Soils*, Vol. VIII, n° 3, p. 339, 1963.
2. W. A. BLOKHUIS et L. H. J. OCHTMAN, *Profile of the Gezira clay soil, Wad Medani, Sudan*, miméograph, Gezira Research Station, 1960.
3. J. V. BOTELHO DA COSTA, L. ARIO AZEVEDO, E. P. CARDOSO FRANCO et R. PINTO RICARDO, *Carta Geral dos solos de Angola I. Distrito da Huila*, Mémorias da Junta de Investigações do Ultramar, Lisboa, 1959.
4. J. H. DURAND, *Les sols rouges et les croûtes en Algérie*, Direction de l'hydraulique et de l'équipement rural, Birmanreis, Alger, 1959.
5. R. FAUCK, Les sous-groupes des Sols ferrugineux tropicaux lessivés à concrétions, *Sols Africains — African Soils*, Vol. VIII, n° 3, p. 407, 1963.
6. R. FRANKART, *Notice explicative de la carte des sols de l'Uélé*, Public. Inst. Nat. Et. Agron. Congo, Bruxelles, 1960.
7. P. GILSON, J. JONGEN et A. VAN WAMBEKE, *Notice explicative de la carte des sols de Yangambi*, Planchette 3 : Lilanda. Public. Inst. Nat. Et. Agron. Congo. Bruxelles 1957.
8. J. F. HARROP, *The soils of the Western Province of Uganda*, Department of Agriculture, Kampala (miméograph), 1960.
9. C. J. HEMMING et C. G. TRAPNELL, A reconnaissance classification of the soils of the south Turkana desert, *J. Soil Sc.*, Vol. 8, n° 2, pp. 167-183, 1957.
10. J. HERVIEU, *Profils types de sols malgaches* (Inventaire provisoire), ORSTOM-IRSM, Tananarive, 1961.
11. N. LENEUF et G. RIOU, Sols rouges et sols jaunes de Côte d'Ivoire, *Sols Africains — African Soils*, Vol. VIII, n° 3, p. 451, 1963.
12. R. MAIGNIEN, Sur les sols d'argiles noires tropicales d'Afrique occidentale, *Bull. de l'Assoc. fr. pour l'Et. du sol*, pp. 131-144, 1961.
13. R. MAIGNIEN, Les sols bruns eutrophes tropicaux, *Sols africains — African Soils*, Vol. VIII, n° 3, p. 491, 1963.
14. A. PÉCROT, *Notice explicative de la Carte des sols de la dorsale du Kivu*. Inst. Nat. Et. Agron. Congo, Bruxelles 1960.
15. G. REPP et Ch. KILLIAN, Recherches écologiques sur les relations entre le climat, les sols et les plantes irriguées des oasis sahariennes, *J. Agr. Trop. et de Bot. appl.*, n° 3-4, pp. 109-141, 1956.
16. K. SYS, La carte des sols du Congo Belge et du Ruanda-Urundi, *Pédologie* (Gand), Vol. X, n° 1, pp. 48-116, 1960.
17. P. R. TOMLINSON, *Classification of the northern Nigerian soils in terms of the legend of the soils map of Africa*, 4th approximation (manuscrit), 1962.
18. C. R. VAN DER MERWE, *Soil groups and subgroups of South Africa*, Government printer, Pretoria, 1941.

PART FOUR

THE MAP

INTRODUCTION

The data presented in this section in the form of tables or lists complete those given in the first three parts of this memoir. The first chapter gives the elements of cartographic units that make up the general legend of sheet 7 and the partial legends of the other map sheets. Chapter 2 explains the graphic representation of these elements as simple units, or as binary or ternary associations. Chapter 3 gives an inventory for each country of the elements mapped there which is complementary to the distribution lists that are found in the different chapters of part II. In chapter 4, the most important, we have estimated for each element and for each association the percentage of total surface and the surface in thousands of km². This summation is given for the entire continent, for the continent to the north and to the south of the equator, and for Madagascar.

CHAPTER 1

THE LEGEND

RAW MINERAL SOILS		page
	Rock and rock debris	
Aa	Rocks rich in ferromagnesian minerals	51
Ab	Ferruginous crusts	52
Ab′	Calcareous crusts	54
Ac	Not differentiated Rocks	55
	Desert detritus	
An	Sands (ergs)	56
Ao	Clay plains	57
Ap	Desert pavements, residual	58
Ap′	Desert pavements, transported	58
Ar	Not differentiated	59

	BROWN AND REDDISH-BROWN SOILS OF ARID AND SEMI-ARID REGIONS	page
	Brown soils of arid and semi-arid tropical regions	
Ga	On loose sediments	86, 149
Gb	Not differentiated	87, 150
	Brown and reddish-brown soils of arid and semi-arid Mediterranean regions	
Gn	Not differentiated	88
	EUTROPHIC BROWN SOILS OF TROPICAL REGIONS	
Ha	On volcanic ash	90, 151
Hb	On rocks rich in ferromagnesian minerals	91, 153
Hc	On alluvial deposits	92
Hd	Not differentiated	92
	RED AND BROWN MEDITERRANEAN SOILS	
Ia	Red Mediterranean soils, not differentiated	93, 154
In	Brown Mediterranean soils, not differentiated	94, 155
	FERRUGINOUS TROPICAL SOILS (fersiallitic soils)	
Ja	On sandy parent materials	97, 156
Jb	On rocks rich in ferromagnesian minerals	98, 158
Jc	On crystalline acid rocks	99, 159
Jd	Not differentiated	100,
	FERRISOLS	
Ka	Humic	103, 161
Kb	On rocks rich in ferromagnesian minerals	104, 162
Kc	Not differentiated	105, 163
	FERRALLITIC SOILS (sensu stricto)	
	Dominant colour : yellowish-brown	
La	On loose sandy sediments	108, 164
Lb	On more or less clayey sediments	109, 165
Lc	Not differentiated	110, 167

Note : for the other associations comprising two or three of the units mentioned above, see table I, Chapter IV, Part III.

CHAPTER 2

REPRESENTATION OF THE UNITS ON THE MAP

The general legend of the map (see previous chapter) comprises 63 elements of mapping units, recorded either by a colour, or by a colour with a surcharge, or by a symbol for the units of small expanse (podzols, oases). Each element has its symbol, made up of a capital and a lower case letter. The capital letter indicates the higher categories of the legend, (see previous chapter), the lower case letter the under-categories.

These elements of mapping units are recorded on the map either as simple units (57), in binary association (181) or in ternary association (37) which gives a total of 275 cartographic units. Associations are labeled by placing side by side, in alphabetical order, the symbols of their constituents. Recording of simple units raises no problem but that of the various associations requires adoption of conventional rules. The following are the ones that have been retained :

1. Binary associations

a) Associations having their own colour are recorded as such.

b) Two elements each represented by a colour are recorded as vertical parallel strips of each colour alternately.

c) One element represented by a colour, the other by a colour with a surcharge : the colour of the first element is covered by the surcharge of the second one.

d) Two elements each represented by a colour with a surcharge : the colour of the element which comes first in alphabetical order is covered by the surcharge of the second one.

2. Ternary associations

a) Association of a binary unit, represented by its own colour with a third element is recorded.

- — either by parallel strips if the third element is represented by a simple colour
- — or by the colour of the binary unit and the surcharge of the third element if it has one.

b) Associations of three elements, two of which are represented by a simple colour and the third one by a colour with surcharge : the first two colours in parallel strips and the surcharge of the third element.

c) Association of three elements, one of which is represented by a simple colour and the others by a colour with surcharge : parallel strips of the simple colour and the colour of the element with surcharge that comes first in alphabetical order, the surcharge of the third element.

CHAPTER 3

TERRITORIAL DISTRIBUTION OF THE UNITS

Africa Occidental Española (Sahara Español)
Ac, An, Ap, Ap′, Ar, Mc.

Algérie
Aa, Ab′, Ac, An, Ap, Ap′, Ar, Bc′, Bd, Bf, Bh, Bo, Br, Ca, Cc, Db, Dj, Fa, Gn, Ia, In, Mb, Mc, Md, Me, Na.

Angola
Ac, An, Ar, Bd, Bf, Bo, Bp, Ca, Da, Db, Dj, Ga, Gb, Ja, Jc, Jd, Kc, La, Lc, Ll, Lm, Ln, Lx, Me, Na.

Basutoland
Bd, Da, Fa.

Bechuanaland
Bb, Bd, Bo, Da, Ga, Gb, Ja, Jb, Jd, La, Me, Na.

Burundi
Bc, Bd, Dj, Hd, Ka, Kb, Kc, Ls, Lt, Lx, Mb.

Cameroun
Ba, Bb, Bc, Bd, Bo, Bp, Da, Dj, Ha, Hb, Ja, Jc, Jd, Ka, Kc, La, Lb, Lc, Lm, Ln, Lx, Me, Na, Nb.

Centr'africaine (République)
Bc, Bd, Bo, Dj, Ja, Jd, Kc, Lb, Ll, Lm, Ln, Lx, Na.

Congo (Brazzaville)
Bo, Bp, Kc, La, Lb, Lc, Ln, Lx, Na.

Congo (Léopoldville)
Bc, Bd, Bn, Bo, Bp, Dj, Ea, Ha, Hc, Hd, Ka, Kb, Kc, La, Lb, Lc, Ln, Ls, Lt, Lx, Mb, Na, Nb, Oa.

Côte d'Ivoire
Ab, Ac, Bb, Bc, Bd, Bo, Bp, Bq, Dj, Ea, Hb, Jc, Kb, Kc, La, Lc, Ll, Lm, Ls, Lx, Na.

Dahomey
Ab, Bc, Bo, Bq, Da, Db, Hb, Jc, Jd, Ll, Na, Nb.

Ethiopia
Aa, Ac, Ar, Bd, Bf, Bo, Da, Dj, Gb, Jd, Ka, Kb, Mb, Na, Nb.

Gabon
Bc, Bd, Bo, Bp, Kc, La, Lc, Lx, Na, Nb.

Gambia
Bc, Bo, Bp, Ja, Jd, Ll, Me, Na.

Ghana
Ac, Bc, Bd, Bo, Bp, Da, Hb, Jc, Jd, Kb, Kc, Lc, Ll, Lm, Ln, Lx, Mb, Na.

Guiné Portuguesa
Ab, Ac, Bc, Bd, Bp, Jd, Lc, Ll, Na.

Guinéa Continental Española
Bc, Bd, Bp, Kc, La, Lc, Lx, Na.

Guinée
Ab, Ac, Bb, Bc, Bd, Bo, Bp, Hb, Jc, Jd, Kb, Kc, La, Lc, Lm, Lx, Na.

Haute Volta
Ab, Ac, Bb, Bc, Bo, Hb, Ja, Jd, Na.

Kenya
Aa, Ba, Bc, Bd, Bf, Bn, Bo, Bp, Db, Dj, Fa, Ga, Gb, Ha, Jb, Jc, Jd, Ka, Kc, Lx, Ma, Mb, Na, Nb, Oa.

Liberia
Ab, Bd, Bq, Hb, Lc, Lx.

Libya
Ac, An, Ap, Ap′, Ar, Bf, Br, Gn, Ia, Mb.

Madagascar
Bb, Bc, Bd, Bh, Bo, Bp, Bq, Ca, Cb, Db, Ha, Ia, Ja, Jb, Jc, Jd, Kb, Kc, Lb, Lm, Ln, Ls, Lx, Me, Na, Nb.

Mali
Aa, Ab, Ac, An, Ap, Bb, Bc, Bd, Bf, Bo, Db, Dj, Ga, Gb; Hb, Ja, Jc, Jd, Kb, Kc, Ll, Mc, Na.

Maroc
Ab′, Ac, Ap, Ar, Bc′, Bd, Bf, Bo, Bq, Ca, Dj, Fa, Gn, Ia, In, Me.

Mauritanie
Aa, Ac, An, Ao, Ap, Ar, Bc, Bf, Bo, Da, Ga, Gb, Jc, Jd, Mb, Mc, Me, Na.

Moçambique
Bc, Bd, Bh, Bo, Bp, Da, Db, Dj, Gb, Ja, Jb, Jd, Kc, Lc, Ln, Lx, Me, Na, Nb.

Niger
Ab, Ac, An, Ao, Ap′ Bb, Bd, Bf, Bo, Ca, Dj, Ga, Gb, Hb, Ja, Jc, Jd, Mb, Me, Na, Nb.

Nigeria
Ba, Bc, Bd, Bh, Bo, Bp, Bq, Db, Dj, Ha, Hb, Ja, Jb, Jc, Jd, Ka, La, Lc, Ll, Ln, Mb, Me, Na, Nb.

Nyasaland (Malawi)
Bd, Bo, Dj, Gb, Jd, Ka, Kb, Kc, La, Lc, Na, Nb.

Rhodesia (northern) (Zambia)
Bb, Bc, Bd, Bo, Dj, Ja, Jb, Jd, Kc, La, Lb, Lc, Ln, Lx, Me, Na, Nb.

Rhodesia (southern)
Ac, Bb, Bd, Da, Db, Gb, Ja, Jb, Jc, Jd, Kc, La, Lc, Lm, Ln, Me, Na.

Rwanda
Ba, Bc, Bd, Dj, Ha, Hd, Ka, Kb, Kc, Ls, Lt, Lx, Mb, Na.

Sénégal
Ab, Ac, Bc, Bo, Bp, Da, Db, Ga, Gb, Ja, Jb, Jc, Jd, Kb, Ll, Me, Na.

Sierra Leone
Ab, Bd, Bp, Bq, La, Lc, Lm, Lx, Na.

Somalia
Aa, Ap, Bd, Bf, Bo, Bp, Bq, Ca, Cc, Da, Dj, Gb, Ja, Jd.

Somalis (Côte française des)
Aa, Ao, Ap, Bo, Br, Gb, Mc.

South Africa (Republic of)
Ac, Bc′, Bd, Bf, Bh, Ca, Da, Fa, Ga, Gb, In, Ja, Jc, Jd, Ln, Ls, Ma, Mb, Na.

South West Africa
Ac, An, Ar, Bc′, Bd, Bf, Bh, Bo, Ga, Gb, Ja, Mb, Me, Na.

Sudan
Aa, Ac, An, Ar, Bc, Bd, Bf, Bh, Bo, Dj, Ga, Gb, Hb, Hc, Ja, Jd, Kb, Ln, Na, Nb.

Swaziland
Bd, Gb, Jc, Jd, Ls.

Tanganyika
Aa, Ac, Bc, Bd, Bn, Bo, Bp, Ca, Db, Dj, Gb, Ha, Hc, Ja, Jb, Jd, Ka, Kb, Kc, Lb, Lc, Ln, Lx, Ma, Mb, Me, Na, Nb, Oa.

Tchad
Aa, Ac, An, Ao, Ap, Bd, Bf, Bo, Br, Da, Dj, Ga, Gb, Ja, Jc, Jd, Me, Na, Nb.

Togo
Ac, Bc, Bd, Bo, Bq, Da, Db, Jc, Jd, Kc, Ll, Ln, Nb.

Tunisie

Ac, An, Ap, Bc′, Bd, Bf, Bh, Bo, Br, Ca, Cc, Db, Dj, Fa, Gn, Ia, Mb, Mc, Me, Na.

Uganda

Bc, Bd, Bo, Dj, Gb, Ha, Hc, Ja, Jd, Ka, Kc, La, Lc, Ls, Lt, Lx, Mb, Na, Oa.

United Arab Republic

Ac, An, Ar, Bf, Bo, Br, Me, Na.

CHAPTER 4

SURFACES COVERED BY EACH UNIT AND ASSOCIATION

The zenithal meridional equal area projection (projection zénithale méridionale équivalente) of the base map makes it possible to measure with a satisfactory approximation the surfaces covered by each mapping unit. In this projection the differences between real distance and that measured on the map are relatively small. The real distance/measured distance ratio equals 1 in the centre of the projection, which is the intersection of the equator and meridian 18° E. This ratio increases with latitude and decreases with longitude. Extreme differences however do not exceed 3% linear as compared with theoretical distances and on a great part of the area latitudinal and longitudinal divergences, which have opposite signs, compensate each other. This means that the real area of units mapped at the extreme north and the extreme south of the continent is in fact more important than that shown on the map, although the difference does not exceed 6%. The contrary is true for units mapped at the eastern or western extremes where real area is smaller than that measured on the map.

Areas recorded in the tables have been obtained by cutting out and weighing, and it is therefore important to take into account the imperfections inherent to this method. The map that was cut out was printed on good quality and homogeneous paper. The cut out parts were brought into equilibrium with surrounding humidity and rapidly weighed on an automatic balance. The area/weight ratios were determined in the same conditions on a number of known areas, cut out in the coloured part of the map. It was indeed found that the weight per unit of area of colour loaded paper differed appreciably from that of blank paper.

From the ratios thus established it was found that in the average I g of map was equal to 224 890 km²; The limit of precision was arbitrarily fixed at I mg = 225 km² = 9 mm². Data recorded on the following tables have been rounded of to 1 000 km².

It seemed interesting to separate the cuttings for Madagascar from those for the continent to the north and to the south of the equator. Total weight of cuttings from each of these subdivisions, multiplied by the above factor gave the following total surfaces

Madagascar	606 903 km²
Continent N of the equator	19 954 116 km²
Continent S of the equator	9 377 767 km²
Entire continent	29 331 883 km²
Continent + Madagascar	29 938 786 km²

Table I gives for each of these great subdivisions and for the entire continent the percentages of total surface occupied by each cartographic unit and their approximate area in thousands of km². Table II gives the same data for the different elements of cartographic units. To do this, it was necessary to postulate that components of binary and ternary associations each occupied either one half or one third of the association's area. Because of these two additional hypotheses data of table II are less precise than those of table I.

TABLE I

Percentage of total surface and surface in thousands of square kilometres covered by each cartographic unit

	Madagascar
N	Continental Africa north of the Equator
S	Continental Africa south of the Equator
N + S	Continental Africa

Unit	Madagascar		Continent					
			N		S		N+S	
	%	$10^3 km^2$	%	$10^3 km^2$	%	$10^3 km^2$	%	$10^3 km^2$
Aa	—	—	0.69	137	—	—	0.47	137
AaAp	—	—	2.64	528	—	—	1.80	528
AaBa	—	—	0.22	44	—	—	0.15	44
AaBn	—	—	—	—	0.06	6	0.02	6
AaGb	—	—	0.01	1	—	—	<0.01	1
AaHa	—	—	—	—	0.01	1	<0.01	<1
AaOa	—	—	—	—	0.01	1	<0.01	1
Ab	—	—	0.15	31	—	—	0.10	31
AbAc	—	—	0.12	23	—	—	0.08	23
AbBd	—	—	0.24	48	—	—	0.16	48
AbBf	—	—	0.21	42	—	—	0.14	42
AbGa	—	—	0.47	95	—	—	0.32	95
AbHb	—	—	<0.01	<1	—	—	<0.01	<1
AbJd	—	—	0.29	58	—	—	0.20	58
AbLc	—	—	0.12	23	—	—	0.08	23
AbLm	—	—	0.04	9	—	—	0.03	9
Ab′	—	—	—	—	—	—	—	—
Ab′Bf	—	—	1.30	259	—	—	0.88	259
Ac	—	—	3.51	700	0.59	54	2.57	754
AcAo	—	—	0.33	65	—	—	0.22	65
AcAp	—	—	2.47	493	—	—	1.68	493
AcBc	—	—	0.02	4	—	—	0.01	4
AcBd	—	—	0.99	197	1.19	112	1.05	309
AcBf	—	—	2.83	565	0.01	<1	1.93	566
AcCa	—	—	0.36	71	—	—	0.24	71
AcGa	—	—	—	—	0.07	6	0.02	6
AcGn	—	—	0.02	3	—	—	0.01	3

TABLE 1 (cont.)

Unit	Madagascar		Continent					
			N		S		N+S	
	%	10³km²	%	10³km²	%	10³km²	%	10³km²
AcIa	—	—	0.07	13	—	—	0.05	13
AcIn	—	—	0.05	11	—	—	0.04	11
AcJc	—	—	—	—	0.04	4	0.01	4
AcJd	—	—	—	—	0.02	2	0.01	2
AcLc	—	—	0.04	8	—	—	0.03	8
AcBdJa	—	—	—	—	0.21	20	0.07	20
AcBdJd	—	—	—	—	0.41	39	0.13	39
AcCaGn	—	—	0.05	10	—	—	0.04	10
AcDbIa	—	—	0.01	2	—	—	0.01	2
AcDjJd	—	—	—	—	0.06	5	0.02	5
AcDjMa	—	—	—	—	0.15	14	0.05	14
AcFaIn	—	—	0.08	17	—	—	0.06	17
AcJdLc	—	—	—	—	0.14	13	0.04	13
AcJdNa	—	—	—	—	0.02	2	0.01	2
An	—	—	6.45	1286	0.72	67	4.61	1353
AnAp	—	—	0.66	132	—	—	0.45	132
AnAp′	—	—	<0.01	<1	—	—	<0.01	<1
AnBf	—	—	0.01	2	—	—	0.01	2
Ao	—	—	0.18	35	—	—	0.12	35
AoBf	—	—	0.99	198	—	—	0.68	198
Ap	—	—	7.37	1470	—	—	5.01	1470
ApGb	—	—	0.16	32	—	—	0.11	32
Ap′	—	—	0.81	162	—	—	0.55	162
Ap′Ar	—	—	0.32	65	—	—	0.22	65
Ar	—	—	9.94	1984	0.45	42	6.91	2026
ArMe	—	—	0.10	20	0.01	<1	0.07	21
Ba	—	—	0.01	1	—	—	<0.01	1
BaHa	—	—	—	—	0.05	5	0.02	5
Bb	0.55	3	0.05	9	0.20	19	0.10	28
BbHb	—	—	0.20	40	—	—	0.14	40
BbJc	0.11	<1	—	—	—	—	—	—
BbKa	—	—	<0.01	<1	—	—	<0.01	<1
BbKb	—	—	0.04	7	—	—	0.02	7
Bc	—	—	0.15	30	—	—	0.10	30
BcDa	—	—	0.07	14	—	—	0.05	14
BcGb	—	—	0.27	55	—	—	0.19	55
BcHb	—	—	0.01	1	—	—	<0.01	1
BcJd	—	—	1.55	310	0.35	33	1.17	343
BcKb	—	—	0.50	99	—	—	0.34	99
BcKc	—	—	0.03	6	—	—	0.02	6

TABLE I (cont.)

Unit	Madagascar		Continent					
			N		S		N+S	
	%	10³km²	%	10³km²	%	10³km²	%	10³km²
BcLa	—	—	0.10	20	—	—	0.07	20
BcLc	—	—	—	—	3.42	321	1.09	321
BcLm	—	—	0.17	35	—	—	0.12	35
BcLn	0.03	<1	2.20	439	—	—	1.50	439
BcLx	0.39	2	3.06	610	4.97	466	3.67	1076
BcDjJd	—	—	—	—	0.03	2	0.01	2
BcDjLc	—	—	—	—	0.16	15	0.05	15
BcJaJc	—	—	0.39	78	—	—	0.27	78
BcJdLc	—	—	—	—	1.46	137	0.47	137
BcJdLn	—	—	—	—	0.49	46	0.15	46
BcKcLc	—	—	0.05	10	0.14	13	0.08	23
BcKcLn	—	—	0.28	56	—	—	0.19	56
BcKcLx	—	—	0.18	36	0.81	76	0.38	111
BcLaLx	—	—	—	—	0.44	41	0.14	41
BcLsLt	—	—	—	—	0.15	14	0.05	14
Bc′	—	—	0.01	2	—	—	0.01	2
Bc′Bf	—	—	0.04	8	—	—	0.03	8
Bc′Ca	—	—	0.05	9	—	—	0.03	9
Bc′Ga	—	—	—	—	1.92	180	0.61	180
Bc′Gn	—	—	0.61	122	—	—	0.42	122
Bc′Me	—	—	0.01	2	—	—	0.01	2
Bd	9.76	59	3.06	610	1.62	152	2.60	762
BdBf	—	—	—	—	3.44	323	1.10	323
BdCa	—	—	0.20	40	—	—	0.14	40
BdDa	—	—	—	—	0.37	34	0.12	34
BdDj	—	—	0.01	2	—	—	0.01	2
BdFa	—	—	0.04	8	—	—	0.03	8
BdGb	—	—	1.40	279	3.22	302	1.98	581
BdHd	—	—	—	—	0.04	4	0.01	4
BdIn	—	—	—	—	0.18	17	0.06	17
BdJa	0.29	2	—	—	—	—	—	—
BdJb	2.08	13	—	—	—	—	—	—
BdJc	—	—	0.17	35	—	—	0.12	35
BdJd	6.55	40	0.40	80	1.39	131	0.72	211
BdKc	—	—	0.03	5	0.07	7	0.04	12
BdLn	—	—	0.25	51	0.03	2	0.18	53
BdLx	10.80	66	0.03	5	0.09	8	0.05	13
BdBfMb	—	—	—	—	1.02	96	0.33	96
BdCaDb	—	—	—	—	0.10	10	0.03	10
BdCaIn	—	—	0.15	30	—	—	0.10	30
BdDaJd	—	—	—	—	0.06	5	0.18	5
BdFaJd	—	—	—	—	0.02	2	0.01	2
BdHbJc	—	—	0.06	11	—	—	0.04	11
BdJdKc	—	—	—	—	0.36	34	0.11	34
BdJdLn	—	—	—	—	0.18	17	0.06	17

TABLE I (cont.)

Unit	Madagascar		Continent					
			N		S		N+S	
	%	$10^3 km^2$	%	$10^3 km^2$	%	$10^3 km^2$	%	$10^3 km^2$
BdKbLm	—	—	—	—	0.03	3	0.01	3
BdKcLn	—	—	—	—	0.15	14	0.05	14
BdKcLx	—	—	—	—	0.39	37	0.12	37
Bf	—	—	5.79	1155	0.11	10	3.97	1165
BfBo	—	—	0.20	40	—	—	0.14	40
BfCc	—	—	0.65	130	—	—	0.44	130
BfMe	—	—	0.08	15	—	—	0.05	15
BfBoMe	—	—	0.22	44	—	—	0.15	44
Bh	—	—	0.04	8	0.24	23	0.10	31
BhDj	—	—	0.10	20	—	—	0.07	20
BhJa	—	—	0.13	26	—	—	0.09	26
BhJd	3.92	24	—	—	—	—	—	—
BhMb	—	—	—	—	0.04	4	0.01	4
BhNa	—	—	—	—	<0.01	<1	<0.01	<1
BhNb	—	—	—	—	0.33	31	0.11	31
BhCaMa	—	—	—	—	0.12	11	0.04	11
Bn	—	—	0.01	1	0.26	25	0.09	26
BnHa	—	—	—	—	0.08	7	0.03	7
Bo	0.06	<1	0.46	93	0.23	21	0.39	114
BoDj	—	—	0.15	29	0.30	28	0.20	57
BoGn	—	—	0.06	12	—	—	0.04	12
BoMb	—	—	0.03	7	—	—	0.02	7
BoMe	1.94	12	0.11	22	0.58	54	0.26	76
BoNa	1.77	11	1.73	345	2.03	190	1.82	535
BoNb	—	—	<0.01	<1	—	—	<0.01	<1
BoDjMe	—	—	0.37	75	—	—	0.26	75
Bp	1.07	6	0.24	47	0.10	9	0.19	56
Bq	0.68	4	0.06	12	<0.01	<1	0.04	12
BqDb	—	—	—	—	0.07	7	0.02	7
BqMe	—	—	<0.01	<1	—	—	<0.01	<1
BqNb	—	—	<0.01	<1	—	—	<0.01	<1
Ca	0.25	1	0.07	14	0.06	6	0.07	20
CaDa	—	—	—	—	0.06	5	0.02	5
CaDb	—	—	0.01	2	—	—	0.01	2
CaGa	—	—	—	—	0.02	2	0.01	2
CaGb	—	—	—	—	0.01	<1	<0.01	<1
CaGn	—	—	0.10	20	—	—	0.07	20
CaIa	—	—	0.01	2	—	—	0.01	2
CaIn	—	—	0.01	2	—	—	0.01	2
CaJd	—	—	0.17	34	0.01	<1	0.12	35
Cb ?	—	—	—	—	—	—	—	—

TABLE I (cont.)

Unit	Madagascar		Continent					
			N		S		N+S	
	%	10³km²	%	10³km²	%	10³km²	%	10³km²
CbIa	2.57	16	—	—	—	—	—	—
Cc	—	—	0.04	8	—	—	0.03	8
Da	—	—	0.16	33	0.32	30	0.22	63
DaFa	—	—	—	—	0.43	40	0.14	40
DaGb	—	—	—	—	<0.01	<1	<0.01	<1
DaHb	—	—	0.03	7	—	—	0.02	7
DaJb	—	—	—	—	0.23	22	0.07	22
DaJd	—	—	—	—	0.05	5	0.02	5
DaKa	—	—	0.82	164	—	—	0.56	164
DaLx	—	—	—	—	0.02	2	0.01	2
DaMa	—	—	—	—	0.06	6	0.02	6
Db	1,31	8	0.11	21	0.08	8	0.10	29
DbGb	—	—	—	—	0.05	5	0.02	5
DbIa	—	—	0.01	2	—	—	0.01	2
DbJa	—	—	0.01	1	0.26	25	0.09	26
DbJd	—	—	0.01	2	—	—	0.01	2
Dj	—	—	0.36	72	0.36	34	0.36	106
DjGa	—	—	—	—	0.04	4	0.01	4
DjGb	—	—	1.80	359	0.06	6	1.24	365
DjGn	—	—	0.05	10	—	—	0.03	10
DjHc	—	—	0.41	82	0.05	4	0.29	86
DjIa	—	—	0.01	1	—	—	<0.01	1
DjJa	—	—	0.02	5	—	—	0.02	5
DjJb	—	—	0.02	4	0.18	17	0.07	21
DjJd	—	—	0.81	161	0.31	29	0.65	190
DjKc	—	—	—	—	0.02	2	0.01	2
DjLa	—	—	0.02	4	—	—	0.01	4
DjLc	—	—	—	—	0.05	4	0.01	4
DjLx	—	—	—	—	0.02	2	0.01	2
DjMa	—	—	—	—	0.38	35	0.12	35
DjMb	—	—	0.03	6	0.19	18	0.08	24
DjMe	—	—	0.04	7	0.09	8	0.05	15
DjNa	—	—	1.25	250	—	—	0.85	250
Fa	—	—	0.02	5	0.73	68	0.24	73
FaIn	—	—	0.02	4	—	—	0.01	4
FaJb	—	—	—	—	0.01	<1	<0.01	<1
FaJd	—	—	—	—	0.34	31	0.11	31
Ga	—	—	3.21	640	7.61	713	4.61	1353
GaGb	—	—	—	—	0.10	10	0.03	10
GaJa	—	—	—	—	0.06	5	0.02	5
GaMb	—	—	0.04	7	0.07	7	0.05	14

TABLE I (cont.)

Unit	Madagascar		Continent					
			N		S		N+S	
	%	10³km²	%	10³km²	%	10³km²	%	10³km²
Gb	—	—	1.57	313	1.15	108	1.44	421
GbJa	—	—	—	—	0.70	65	0.23	65
GbJc	—	—	—	—	0.17	16	0.06	16
GbJd	—	—	0.05	10	1.57	147	0.54	157
GbNa	—	—	0.02	4	—	—	0.01	4
GbJdMa	—	—	—	—	0.04	4	0.01	4
Gn	—	—	0.08	17	—	—	0.06	17
GnIa	—	—	0.21	43	—	—	0.15	43
Ha	0.03	<1	0.02	3	0.22	20	0.08	23
HaKa	—	—	0.02	4	—	—	0.01	4
HaKb	—	—	—	—	0.08	8	0.03	8
Hb	0.05	<1	0.14	28	—	—	0.10	28
HbKa	—	—	0.04	7	—	—	0.03	7
Hc	—	—	0.01	3	0.03	3	0.02	6
HcNa	—	—	—	—	0.04	3	0.01	3
Hd	—	—	—	—	—	—	—	—
Ia	—	—	0.02	3	—	—	0.01	3
In	—	—	<0.01	<1	—	—	<0.01	<1
Ja	9.73	59	2.34	568	3.47	326	3.05	894
JaJc	—	—	—	—	<0.01	<1	<0.01	<1
JaJd	—	—	0.23	47	0.50	46	0.32	93
JaLa	—	—	—	—	1.24	117	0.40	117
JaMb	—	—	0.05	10	—	—	0.04	10
JaNa	—	—	0.29	58	—	—	0.20	58
JaNb	—	—	—	—	0.13	12	0.04	12
JaLaMe	—	—	—	—	0.30	28	0.10	28
Jb	7.99	48	0.02	5	0.12	11	0.05	16
JbJc	0.54	3	—	—	0.01	1	<0.01	1
JbJd	0.65	4	—	—	0.07	6	0.02	6
JbKa	—	—	—	—	0.04	4	0.01	4
JbMa	—	—	—	—	0.06	6	0.02	6
Jc	0.86	5	3.63	725	0.71	67	2.70	792
JcKc	—	—	0.76	151	0.12	11	0.55	162
JcLc	—	—	—	—	0.75	70	0.24	70
JcLm	0.95	6	—	—	—	—	—	—
JcMa	—	—	—	—	0.03	3	0.01	3
JcMe	—	—	—	—	0.31	29	0.10	29

TABLE I (cont.)

Unit	Madagascar		Continent					
			N		S		N+S	
	%	10³km²	%	10³km²	%	10³km²	%	10³km²
Jd	0.13	<1	0.77	153	1.84	172	1.11	325
JdKb	1.19	7	—	—	—	—	—	—
JdKc	—	—	—	—	0.01	<1	<0.01	<1
JdLc	—	—	—	—	2.03	191	0.65	191
JdLn	—	—	—	—	0.22	21	0.07	21
JdMe	—	—	—	—	0.12	12	0.04	12
JdNa	—	—	—	—	0.10	10	0.03	10
JdLcMe	—	—	—	—	0.41	38	0.13	38
Ka	—	—	0.21	43	0.61	58	0.34	101
KaLm	—	—	0.02	4	—	—	0.02	4
KaLs	—	—	—	—	0.04	4	0.01	4
KaLt	—	—	0.06	12	0.06	6	0.06	18
KaLx	—	—	—	—	0.02	2	0.01	2
Kb	4.56	28	0.20	39	0.10	9	0.16	48
Kc	0.06	<1	0.35	70	0.92	87	0.53	157
KcLa	—	—	0.02	4	1.58	148	0.52	152
KcLb	—	—	—	—	0.08	7	0.02	7
KcLc	—	—	—	—	1.45	136	0.46	136
KcLn	0.48	3	0.35	69	0.64	60	0.44	129
KcLx	—	—	0.04	7	0.95	89	0.33	96
KcLaNa	—	—	—	—	0.25	23	0.08	23
La	—	—	0.30	60	13.11	1229	4.40	1289
LaLc	—	—	—	—	0.07	6	0.02	6
LaLl	—	—	—	—	0.80	75	0.26	75
LaNa	—	—	—	—	0.02	2	0.01	2
Lb	0.42	3	0.70	140	1.27	119	0.88	259
LbNa	—	—	0.53	106	0.84	78	0.63	184
Lc	—	—	1.59	317	5.37	504	2.80	821
LcNa	—	—	—	—	0.07	6	0.02	6
Ll	—	—	1.08	216	0.86	80	1.01	296
Lm	1.39	8	0.29	57	0.02	2	0.20	59
Ln	8.96	54	1.09	217	1.00	94	1.06	311
LnNa	—	—	0.10	20	—	—	0.07	20
Ls	0.19	1	0.04	8	0.62	58	0.23	66
LsLt	—	—	—	—	0.07	7	0.02	7
Lt	—	—	—	—	0.02	2	0.01	2

TABLE I (cont.)

Unit	Madagascar		Continent					
			N		S		N + S	
	%	$10^3 km^2$	%	$10^3 km^2$	%	$10^3 km^2$	%	$10^3 km^2$
Lx	17.34	105	0.78	156	1.83	172	1.11	328
LxNa	—	—	0.03	6	—	—	0.02	6
Ma	—	—	—	—	0.41	38	0.13	38
Mb	—	—	0.14	28	0.01	1	0.10	29
Mc	—	—	0.17	33	—	—	0.11	33
Md	—	—	<0.01	<1	—	—	<0.01	<1
Me	—	—	0.08	16	—	—	0.05	16
MeNb	—	—	0.08	16	—	—	0.05	16
Na	—	—	0.09	18	—	—	0.06	18
Nb	0.32	2	0.30	59	0.25	24	0.28	83
Oa	—	—	0.01	1	0.02	2	0.01	3
Water	0.06	<1	0.32	63	1.70	159	0.76	222

TABLE II

Percentage of total surfaces and surface in thousands of square kilometres covered by each of the elements of cartographic units

	Madagascar
N	Continental Africa north of the Equator
S	Continental Africa south of the Equator
N + S	Continental Africa

Unit	Madagascar		Continent					
			N		S		N+S	
	%	10^3km^2	%	10^3km^2	%	10^3km^2	%	10^3km^2
Aa	—	—	2.12	423	0.04	4	1.46	427
Ab	—	—	0.90	180	—	—	0.62	180
Ab′	—	—	0.65	130	—	—	0.44	130
Ac	—	—	7.20	1437	1.58	148	5.40	1585
An	—	—	6.78	1353	0.72	67	4.84	1420
Ao	—	—	0.84	167	—	—	0.57	167
Ap	—	—	10.34	2062	—	—	7.03	2062
Ap′	—	—	0.97	195	—	—	0.66	195
Ar	—	—	10.16	2027	0.45	42	7.05	2069
Ba	—	—	0.12	23	0.03	2	0.09	25
Bb	0.60	4	0.16	33	0.20	19	0.18	52
Bc	0.21	1	4.44	887	5.60	525	4.80	1412
Bc′	—	—	0.37	73	0.96	90	0.56	163
Bd	19.61	119	5.01	999	7.62	715	5.84	1714
Bf	—	—	9.02	1800	2.17	204	6.83	2004
Bh	1.96	12	0.15	31	0.47	44	0.25	75
Bn	—	—	0.01	1	0.33	31	0.11	32
Bo	1.91	12	1.80	360	1.68	157	1.76	517
Bp	1.07	6	0.24	47	0.10	9	0.19	56
Bq	0.68	4	0.06	12	0.04	4	0.05	16
Ca	0.25	1	0.59	118	0.18	17	0.46	135
Cb	1.29	8	—	—	—	—	—	—
Cc	—	—	0.36	72	—	—	0.25	72
Da	—	—	0.63	125	0.95	89	0.73	214
Db	1.31	8	0.13	26	0.31	29	0.19	55
Dj	—	—	2.84	567	1.33	125	2.36	692

TABLE II (cont.)

Unit	Madagascar		Continent					
			N		S		N+S	
	%	10^3km^2	%	10^3km^2	%	10^3km^2	%	10^3km^2
Fa	—	—	0.08	16	1.12	105	0.41	121
Ga	—	—	3.46	691	8.75	820	5.15	1511
Gb	—	—	3.42	683	4.11	385	3.64	1068
Gn	—	—	0.63	125	—	—	0.43	125
Ha	0.03	<1	0.03	5	0.33	31	0.12	36
Hb	0.05	<1	0.30	60	—	—	0.20	60
Hc	—	—	0.22	43	0.08	7	0.17	50
Hd	—	—	—	—	0.02	2	0.01	2
Ia	1.29	8	0.17	35	—	—	0.12	35
In	—	—	0.12	24	0.09	9	0.11	33
Ja	9.88	60	3.34	667	5.09	477	3.90	1144
Jb	9.62	58	0.04	7	0.42	40	0.16	47
Jc	1.66	10	4.25	847	1.43	134	3.35	981
Jd	6.28	38	2.53	504	6.60	619	3.83	1123
Ka	—	—	0.70	139	0.82	76	0.74	215
Kb	5.15	31	0.46	92	0.15	14	0.36	106
Kc	0.30	2	1.13	225	3.96	371	2.03	596
La	—	—	0.37	74	15.29	1434	5.14	1508
Lb	0.42	3	0.97	193	1.73	162	1.21	355
Lc	—	—	1.68	336	10.06	944	4.36	1280
Ll	—	—	1.08	216	1.26	118	1.14	334
Lm	1.87	11	0.41	81	0.02	2	0.28	83
Ln	9.21	56	2.63	525	1.73	162	2.34	687
Ls	0.19	1	0.04	8	0.76	71	0.27	79
Lt	—	—	0.03	6	0.16	15	0.07	21
Lx	22.93	139	2.42	483	5.41	508	3.38	991
Ma	—	—	—	—	0.78	73	0.25	73
Mb	—	—	0.21	42	0.51	48	0.31	90
Mc	—	—	0.17	33	—	—	0.11	33
Md	—	—	<0.01	<1	—	—	<0.01	<1
Me	0.97	6	0.48	96	0.79	74	0.58	170
Na	0.88	5	2.07	412	1.63	153	1.93	565
Nb	0.32	2	0.34	67	0.48	45	0.38	112
Oa	—	—	0.01	1	0.02	2	0.01	3
Water	0.06	<1	0.32	63	1.70	159	0.76	222

INDEX

Note : For authors' names the reader should consult the foreword (page 9) and the lists of references on pages 15, 46, 125 and 177. Names of countrics are cross-indexed in chapters 1 and 3 of Part IV (pages 181-184 and 186-190).

P

Q

R

S

T

U

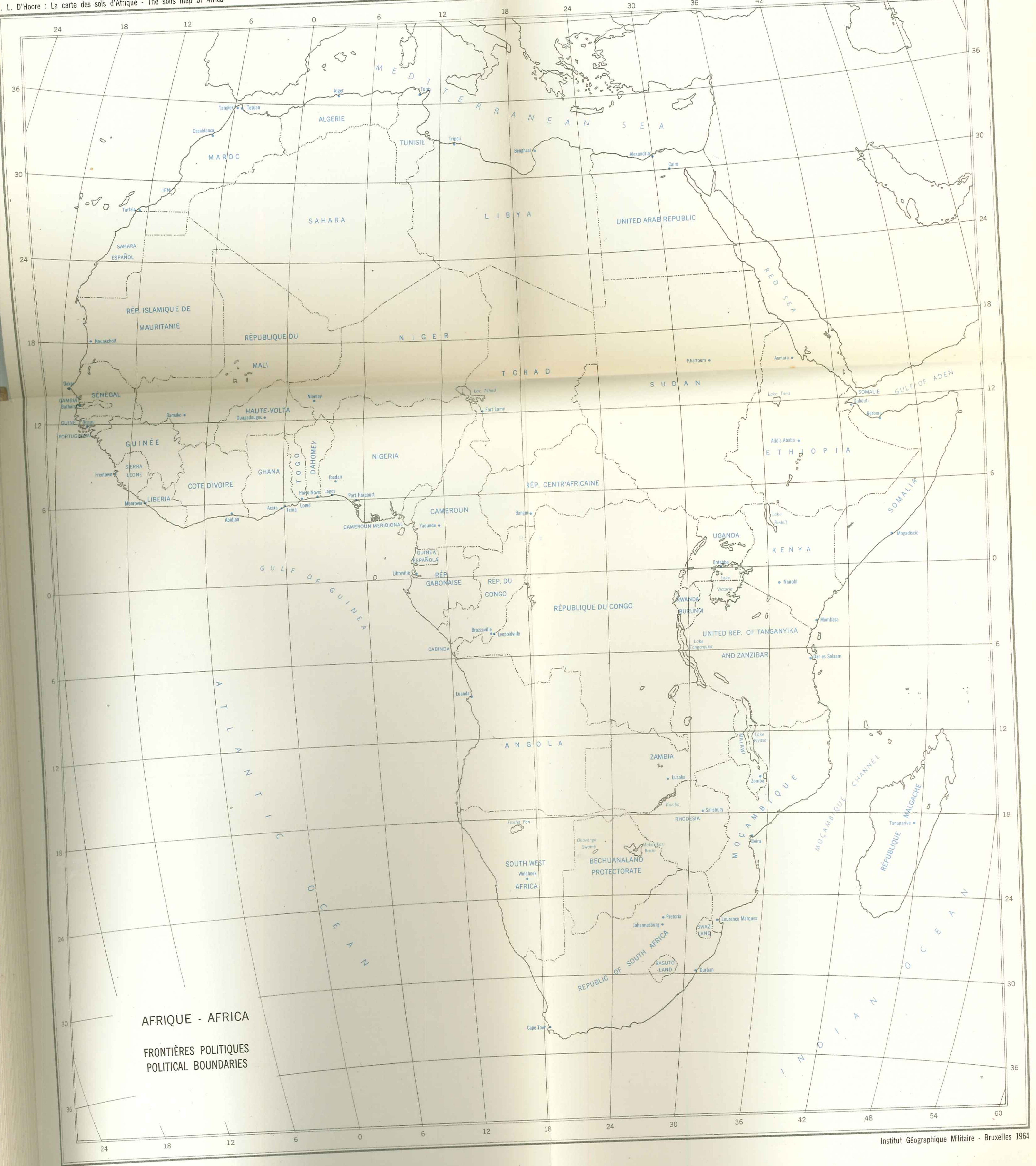
V

W

Z

(B399) Imprimé en Belgique par Ceuterick s c
153 rue de Bruxelles Louvain
Dir. L. Pitsi Bertemsebaan 25 Veltem-Beisem

Fig. 1



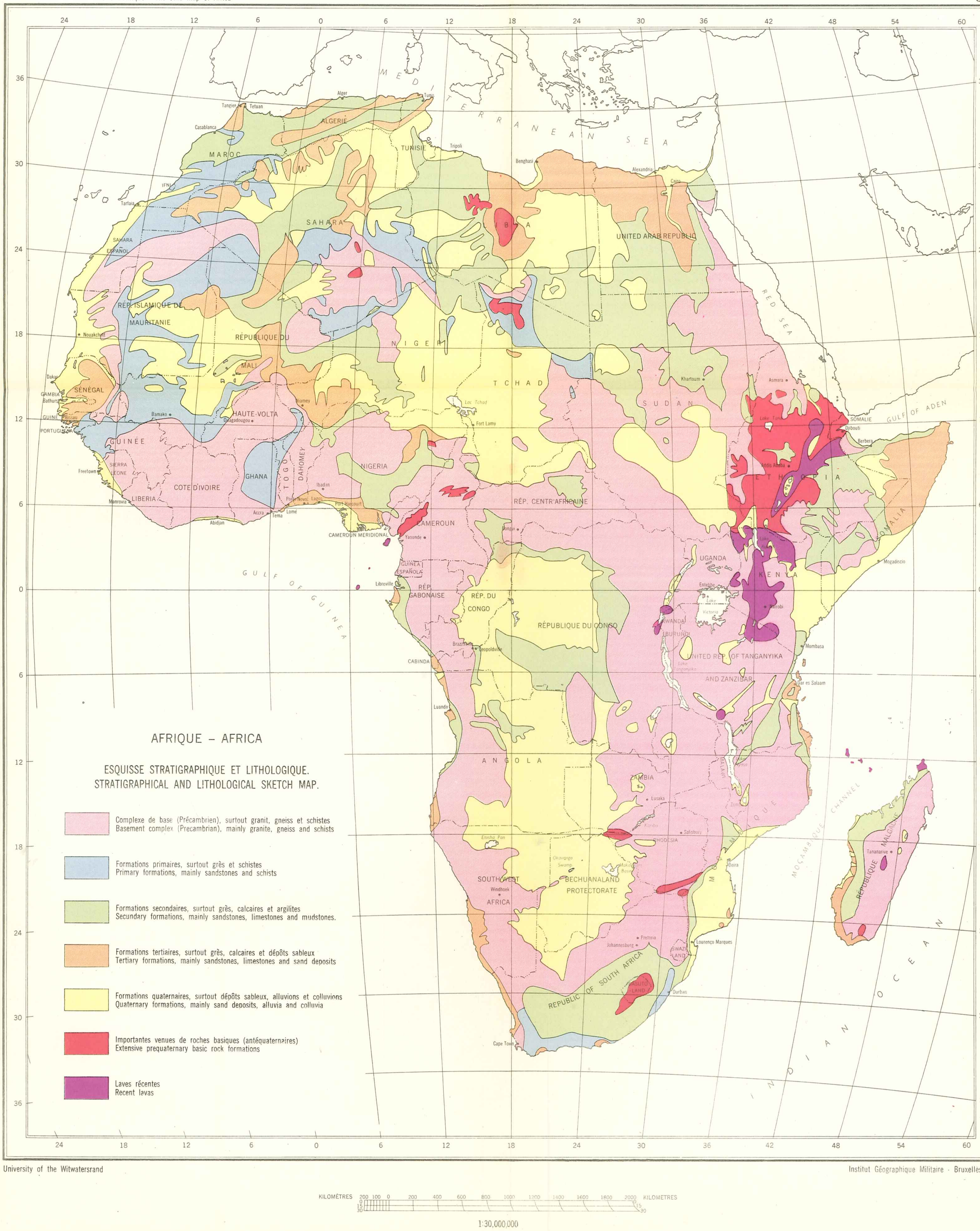
Institut Géographique Militaire - Bruxelles 1964

University of the Witwatersrand

KILOMÈTRES 200 100 0 200 400 600 800 1000 1200 1400 1600 1800 2000 KILOMETRES

1:30,000,000

Fig. 2



Institut Géographique Militaire - Bruxelles 1964

J. L. D'Hoore : La carte des sols d'Afrique - The soils map of Africa

Fig. 3

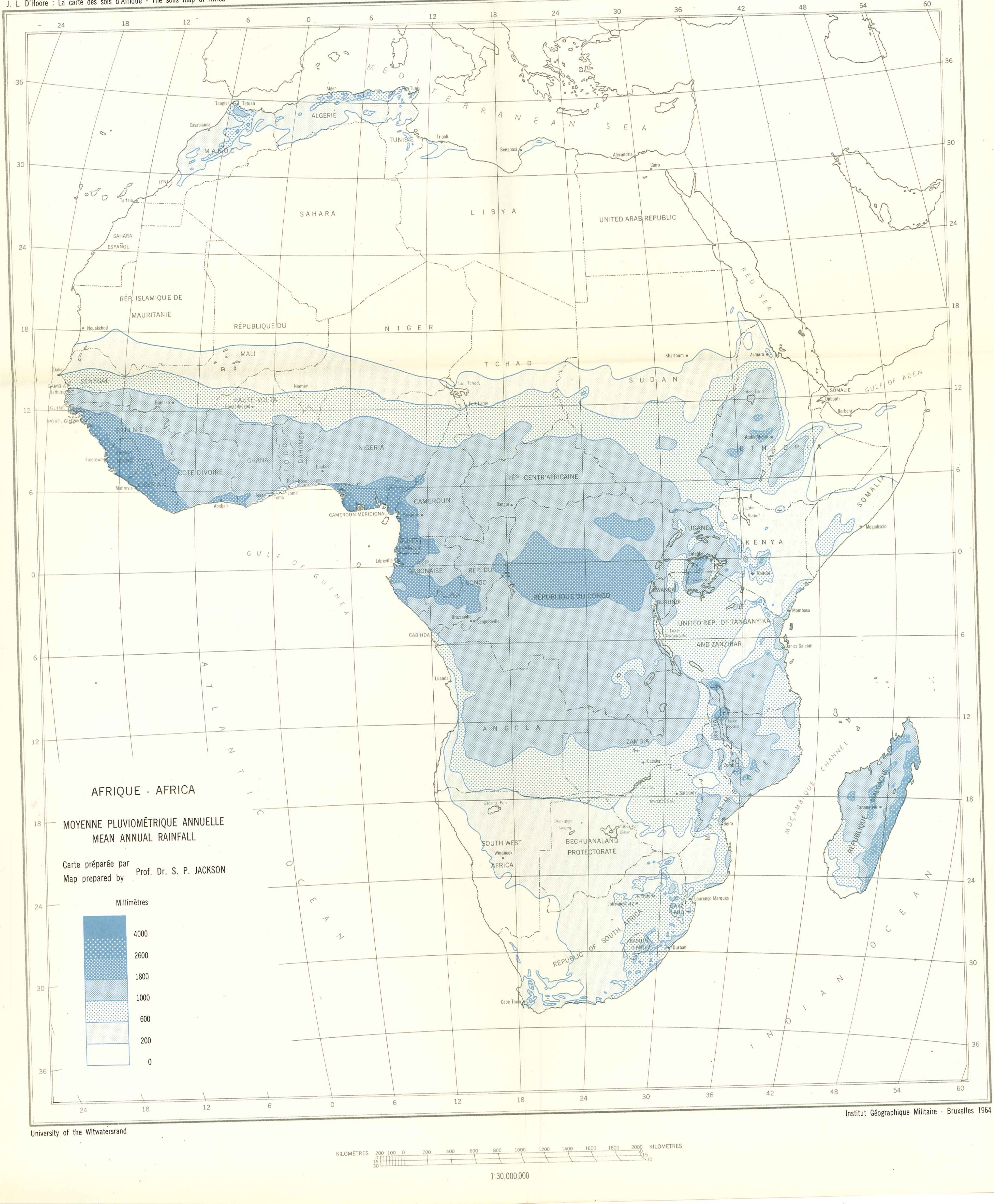
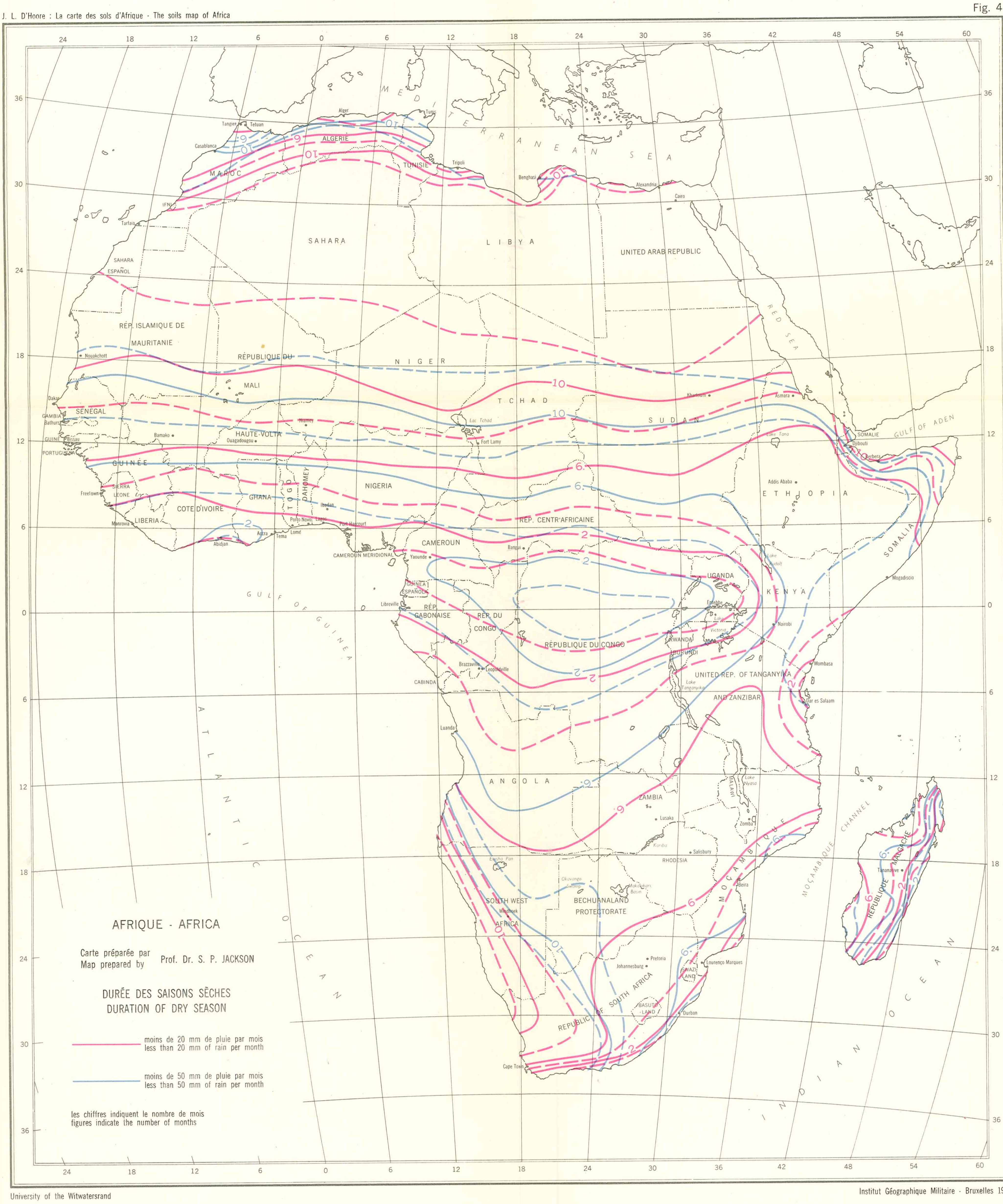


Fig. 4

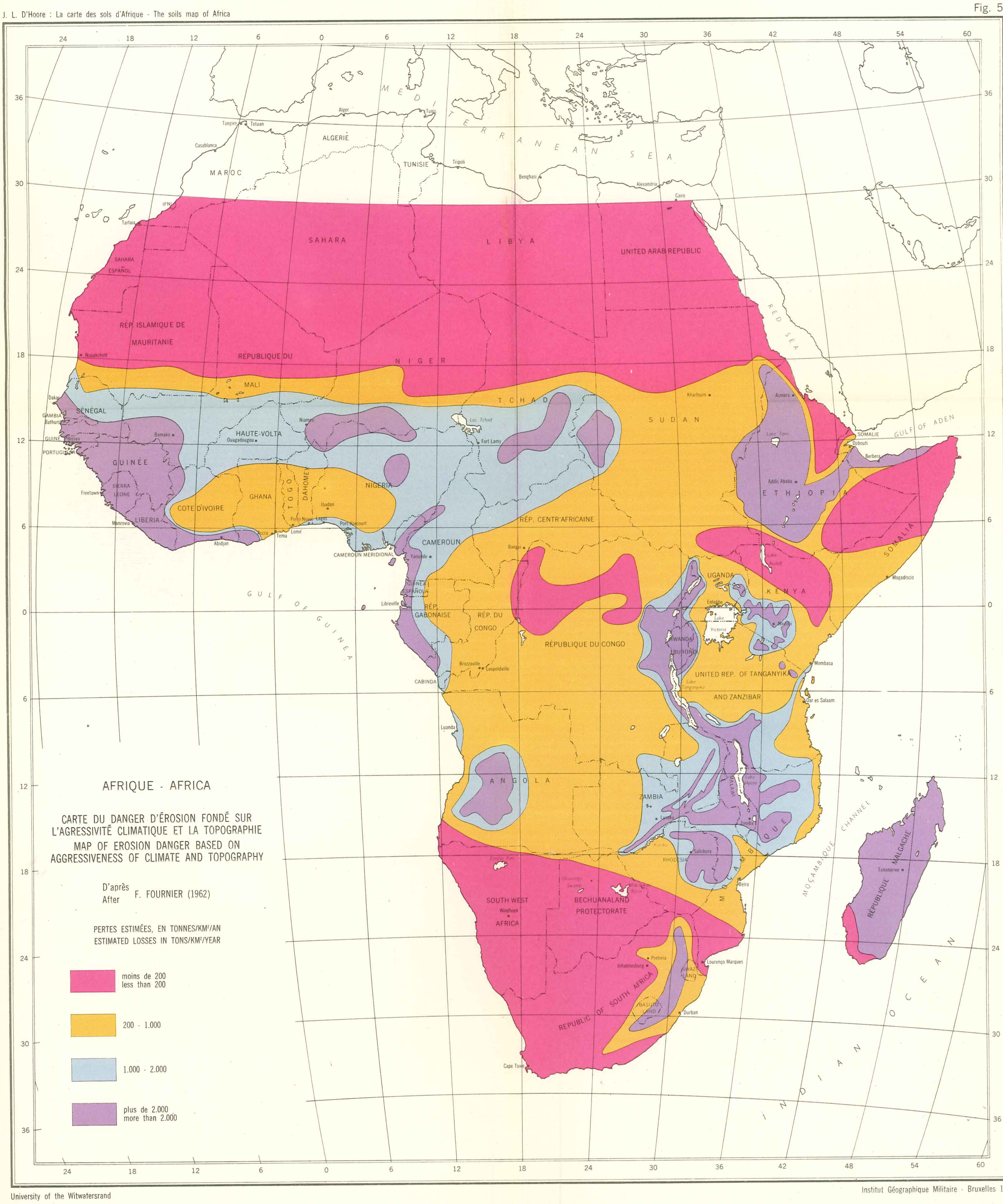


University of the Witwatersrand

Institut Géographique Militaire - Bruxelles 1964

KILOMÈTRES 200 100 0 200 400 600 800 1000 1200 1400 1600 1800 2000 KILOMETRES

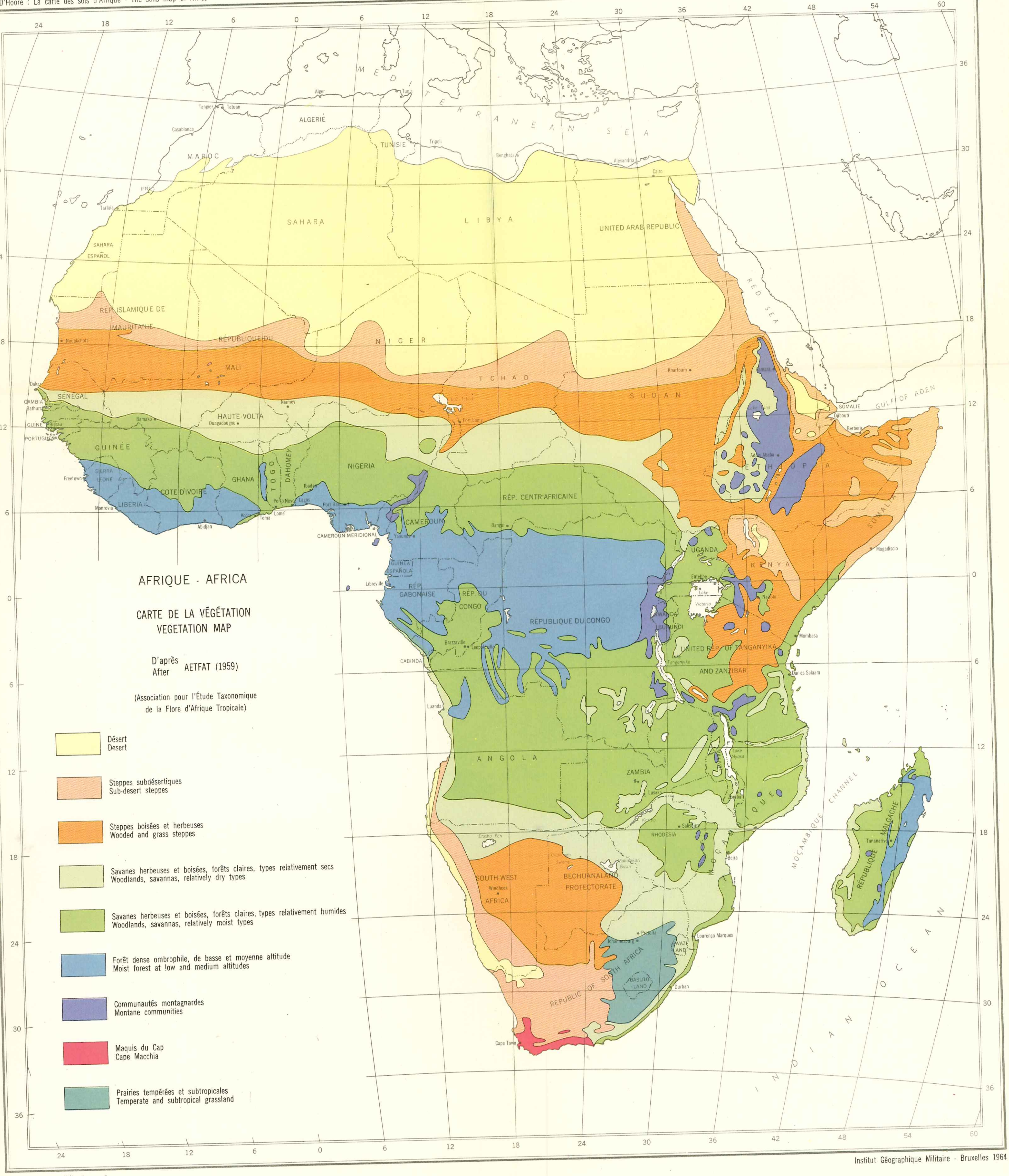
1:30,000,000



KILOMÈTRES 200 100 0 200 400 600 800 1000 1200 1400 1600 1800 2000 KILOMETRES

1:30,000,000

Fig. 6



Institut Géographique Militaire - Bruxelles 1964

KILOMÈTRES 200 100 0 200 400 600 800 1000 1200 1400 1600 1800 2000 KILOMETRES

1:30,000,000