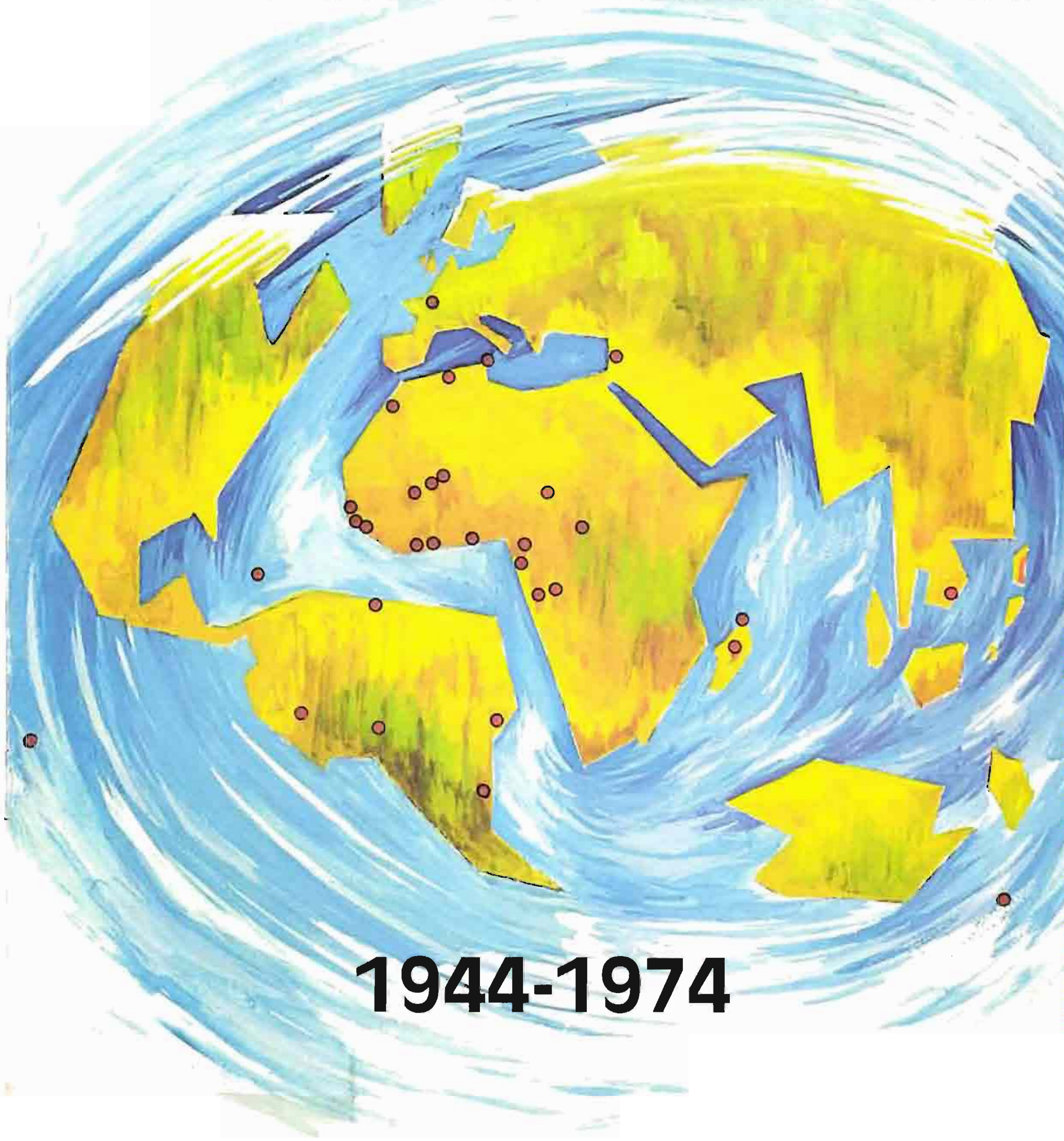
30 YEARS OF PEDOLOGY



1944-1974

OFFICE DE LA RECHERCHE SCIENTIFIQUE ET TECHNIQUE OUTRE-MER

THIRTY YEARS

OF

PEDOLOGY

1944-1974

OFFICE DE LA **R**ECHERCHE **S**CIENTIFIQUE ET **T**ECHNIQUE **O**UTRE-**M**ER

(OFFICE OF OVERSEAS SCIENTIFIC AND TECHNICAL RESEARCH)

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Preface

The year 1974 is an important date for members of the International Society of Soil Science, who are celebrating the Society's 50 th anniversary, and for our Soviet colleagues who are celebrating a hundred years of pedological studies since the work of V. DOKUCHAYEV.

It is also an anniversary for the research workers of ORSTOM, that of the appointment, on August 1, 1944 of the first pedologists to our newly created organization. Thus, it seems an appropriate time for the research staff of ORSTOM to take stock of their work and to review their results, their basic concepts and their progress, in the context of the world pedological scene.

This booklet is not strictly a report on activities. Rather, the intention is to outline concepts behind these activities, and to explain the reasons for their development and their adaptation as programmes have advanced, taking due account of the progress achieved by other pedologists, French and others.

The statutory objective of ORSTOM is to undertake basic research, oriented towards the development of tropical and Mediterranean countries. Consequently, research activity has been centred entirely on warm regions, principally in Africa and Madagascar, less frequently in certains countries of Latin America, Oceania and the Middle East. The observations made and the results obtained, with their special nature due to the climatic and other characteristics of the regions studied, have naturally influenced to a very strong degree our pedological conceptions. We have continuously striven, however, to make these observations and results applicable to soils of the world at large. We have sought close collaboration with other pedological bodies, French and others, and with international organizations having similar preoccupations.

This consciousness of a world perspective has been facilitated by the participation at our training centre, or in our research teams in France and overseas, of numerous young research workers and students. These have come mainly from Africa, Latin America and Asia, but sometimes from Europe, with the aim of furthering their specialized skills or improving and deepening their knowledge of certain aspects of their work.

The pedology section currently comprises nearly 100 research workers who have been trained by ORSTOM and who are distributed among its 19 centres and missions. In addition, since 1944, we have received as trainees or probationers more than 600 university students or research workers, many of whom have come from foreign countries.

Another aspect of our studies is that, while being as intensive as possible from the scientific point of view, they should at the same time try to respond to relevant practical problems or should lead to practical applications, principally in the field of agronomy. The preoccupations can be readily appreciated from consultation of ORSTOM'S publication lists.

A selection of the more significant soil studies which have highlighted these thirty years of pedology is given at the end of this review *.

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РЕЗЮМЕ

X-ый Конгресс Международного Объединения Почвоведов в Москве является поводом, для почвоведов ORSTOM , подытожить проведенные за тридцать лет исследования. Не представляя собой исчерпывающего итога, настоящий текст, в первой его части, даёт отчёт о произведенных во многих тропических областях Африки, Мадагаскара, Океании и Америки (4.500.000 км2) картографических работах. Перечень этот, после изложения использованной общей классификации, приводит к пересмотру примененных методов. Картография послужила основанием для многих исследований, а итоги геохимических и биохимических определений позволяет представить наиболее значительные из полученных результатов, в особенности что касается ферраллитного выветривания, распределения железа и известняка, неосинтезов глины, исследований по преобразованиям, андосолям и аморфным почвам, динамике почв под воздействием воды с растворимыми солями или без них, органическим компонентам. Отмечены новейшие работы в отношении биогеодинамических систем и механизмов дифференциации профилей в различных масштабах (микроскопический, профильный, ландшафтный) . Изложение научных результатов дополняется агрономической сводкой.

Вторая часть является критическим изложением научных подходов в течение времени, в свете приобретенных знаний и развития употребляемых исследователями понятий. Так, объясняется каким образом задачи трудов по почвоведению побудили исследователей поставить на обсуждение некоторые основные данные и методы. Это привело к лучшему осознанию дифференциации почв в масштабе экологических сред и времени развития, - факторов, значение которых существенно для умеренных зон. После попытки обобщения относительно почвенных систем и соотношений между биоклиматической зональностью и преобладанием почв в эволюционных сериях, перечисляются трудности сопряженные с установлением морфогенетической классификации. Наконец, существенная роль исследований по современным механизмам дифференциации профилей позволяет точнее выяснить значение придаваемое понятию организации почвенных компонентов.

Текст заканчивается кратким, но охватывающим различные районы деятельности почвоведов ORSTOM , библиографическим списком.

Zusammenfassung

Der zehnte moskauer Kongress der Internationalen Bodenkundlichen Gesellschaft gibt den ORSTOM-Pedologen Gelegenheit einen Rückblick auf die vollbrachte Arbeit der letzten dreissig Jahren zu geben. Ohne eine völlige Bilanz darzustellen gibt der erste Teil dieses Textes einen Überblick über die vollbrachten Kartographiearbeiten in vielen tropischen Gegenden Africas, Madagascar's, Oceaniens und Americas (4 500 000 km^2).

Anlässlich dieses Inventares wird die angewandte Bodenklassifikation erlaütert sowie die benutzten Methoden.

Die Kartographie war der Ausgangspunkt zahlreicher Forschungsarbeiten ; und eine geochemische und biochemische Bilanz erlaubt es die hauptsächlichsten Resultate zu zeigen im Gebiete der ferralitischen Verwitterung, der Verteilung des Eisens und des Kalkes, der Tonmineralien-synthese, der Studien über Vernettungs- und Umwendungsprozesse, der Andoböden und amorphen Substanzen, der Bodendynamik unter dem Wassereinfluss, mit oder ohne löslichen Salzen, und der Studien über die Humustoffe. Es werden ferner die jüngsten Arbeiten über die Biogeodynamischen Systeme angegeben sowie jene über die Prozesse der Bodenprofilausbildung in allen Skalen. Eine agronomische Bilanz vervollständigt diesen ersten Teil.

Der zweite Teil ist ein kritischer Rückblick auf die Entwicklung unserer wissenschaftlichen Methodik infolge besserer Kenntnisse und Forschritte in den Ideen.

Es wird erklärt wie manche Grundvoraussetzungen und Arbeitsmethoden durch die Pedologen während der notwendigen Geländearbeiten in Frage gestellt wurden.

Durch dieses erfolgte ein besseres Erkenntniss der Bodenausbildung in den verschiedenen Ökologischen Umgebungen und infolge der Entwicklungsdauer ; diese beiden Faktoren sind grundlegend in tropischen Gegenden.

Die Ausarbeitungsschwierigkeiten einer morphogenetischen Bodenklassifikation werden vorgetragen nach einem Zusammenfassungsversuch über die pedologischen Systeme und über die Zusammenhänge zwischen der bioklimatischen Zonalität und den vorherschenden Bodentypen in den evolutif Serien. Die umfangreichen Forschungsarbeiten über die aktuellen Ursachen der Bodenprofilausbildung erlaubt es besser, die Wichtigkeit die wir der Organisation der Bodenbestandteile geben, zu verstehen.

Zuletzt wird, kurz, das hauptsächlichste Schrifttum über die verschiedene Arbeitsgebiete der ORSTOM-Pedologen angegeben.

Introduction

At the world level, several differing definitions of soil are in use. These correspond to the different conceptions of the object studied. In order to understand the path followed by each school it is necessary to know the concepts on which work has been based. Our own position is outlined, from a historical perspective, in the following paragraphs.

At the time of the establishments of ORSTOM'S pedology section in 1944, there scarcely existed a school of pedology in France. The studies undertaken by French investigators were based on a strong agronomic tradition, characterized particularly by pin point studies. Qualitatively at least, the information obtained from this type of study appeared sufficient. Attention was initially directed to the plant, which seemed to provide the best reflection of the soil. However, economic considerations had already led, and are leading more and more, towards evaluation systems which include cartographic activities. It became necessary to know more about the properties and internal boundaries of the object (i. e. soil) that was to be surveyed.

The pedological concept was introduced into our country by V. AGAFONOFF and H. ERHART. In spite of the efforts of V. OUDIN, and A. DEMOLON, this concept developed very slowly to start with, even though soil mapping, very restricted in France, was already taking on greater importance in North Africa. Immediately after the war, and under the dynamic influence of G. AUBERT, pedological studies rapidly grew in number throughout the tropics. The need for development in these regions required urgent inventories of natural resources in general and, initially of soils. The first studies undertaken by ORSTOM started in 1945 in Madagascar and West Africa at the request of agronomists. Initially these investigations consisted of field studies leading to the production of maps, either regional or local and detailed in nature, depending on objectives. The early studies also included site observations and experimentation, and were supported by results of laboratory analyses on the more characteristic soils. These first steps in tropical pedology were based on DOKUCHAYEV's definition of soil.

The soil is considered as a totality, from its surface contact with the atmosphere down to the parent material and, frequently, to the parent rock from which it draws its essential constituent minerals. But although a soil is definable per se, its existence depends upon relations with its environment and, more particularly, with the soils which surround it. Soil is a three-dimensional body which changes through time and which is studied from individual soil profiles, each containing a number of horizons.

To know a soil, it is necessary to understand its genesis and evolution, in short its history, and to determine the respective roles of the different factors which intervene in such a system. Our concept is *genetic* in this respect. More particularly it is *morphogenetic,* since we believe that the mechanisms which give a soil its distinctiveness and character should be reflected in its morphology. Our first step is therefore to distinguish, to identify and then to classify the morphological features which most distinctly express all that is known about a soil. A complete morphological description should reveal all the processes that are involved. Finally, our conception is a *dynamic* one ; soils come into being, evolve and expire, and soil profiles represent nothing more than snapshots taken during a long sequence of temporal and spatial evolution.

These principles still condition our approach. The results obtained are considered not in isolation, but always in reference to a soil, to the factors of its formation and to parameters of the environment. Even from a more practical agronomic viewpoint, a soil cannot be defined only by certain analytical characteristics (depth, texture, structure, base saturation, pH etc.), nor even by a particular horizon (leached horizon, accumulation horizon, etc.). Rather, what is required is a whole collection of data which caracterizes the soil which affects its possibilities for use by man. Thus, at each stage of data treatment, interpretation is based on, and linked to, the immediately higher level ; for example, rudimentary soil structural arrangements to horizons, horizons to profiles, profiles to soils, soils to their distribution in the landscape. A similar procedure is adopted in considering different evolutionary stages.

These concept likewise determine the structure of our classification. Founded on the morphological study of soils, this classification is based on the processes of soil evolution, in terms of the factors of soil formation. Each classificatory stratum theoretically retains all the information relating to the levels immediately below. The classified groupings are orthotype (1) in nature. They differ in this from the taxonomic units of the American classification, which are all-embracing, with specifically defined boundary characteristics.

Soil classes are defined by the degree of evolution, by the development of the profile and by certain basic processes. These processes concern the form of weathering of the constituent minerals and neosyntheses derived from them, the type and distribution of organic matter, hydromorphism and halomorphism.

At a level immediately below this, the **sub-classes** are based more particularly on the effects of variations in the climatic factor.

The **groups,** which follow, are linked with some general processes of soil evolution : leaching, impoverishment, reworking and induration. The **sub-groups** are based on variable intensities of the processes which define soil groups or on the appearance in the soil of the effects of secondary evolutionary processes. Often within sub-groups it is possible to record **facies** with recognizable evolutionary trends, having particular value at the regional scale.

Soil families are characterized in terms of the petrographic nature of the parent rock or parent material. The following level, which corresponds to the definition of **soil series,** is one of the most important, together with those of groups and sub-groups : « A soil series is the whole assemblage of soils with the same king of profile on a parent material of defined lithological composition and at a stipulated position in the landscape. The profiles of a given soil series are similar not only in the succession, appearance and general constitution of their different horizons, but also in the relative importance and thickness of each horizon. The order of relative importance of horizons reflects the possible influence of the presence of each horizon on general soil properties... ».

Finally, **soil types** and **phases** are distinguished, according to the definitive and more or less stable characteristics of surface horizons.

During our 30 years of research, a certain number of modifications have been made to the classification. These concern the initial content of the different levels and a regrouping and restructuring of certain units. On the other hand the broad framework, and the

(1) Orthotype : central concept, around which variations are permitted.

principles guiding its enunciation, have been retained from the beginning, in spite of certain difficulties (in the present period particularly) in reconciling the idea of soil as an independent object to the apparently continuous mantle of soil.

Nevertheless, our approach has been adapted and modifield during this period. An account of the evolution of our concepts across the range of our activities, and indeed the consequences of these concepts, appears to be due.

The review and analysis which follows is divided into two parts. In the first part a summarized inventory is attempted, to give results obtained in the fields of mapping, geochemistry, biochemistry and agronomy. In the second part an analysis is made of the different chronological stages in our scientific work, and of their influences on the modification and adaptation of concepts.

REVIEW OF THIRTY YEARS OF PEDOLOGY

1. Cartographic review

Early activities were based, first and foremost, on detailed studies undertaken to resolve land use problems. However, it very soon became apparent that reconnaissances were required in each of the countries concerned, in order to draw up as quickly as possible a general inventory of the main kinds of soil. This inventory began in 1946 with soil surveys undertaken at various scales. Progressively, it became oriented towards systematic mapping at scales from 1/50,000 to 1/1,000,000.

These field surveys and studied constituted, and still constitute, indispensable basic record for much of our research activity. It was during the course of implementing this inventory that the major themes of research activity emerged and that sites were located for detailed studies, capable of giving the best possible testing of research themes and hypotheses. It is in relation to this inventory that our amassed results should be interpreted, our preoccupations should be viewed and the adaptation of our methods should be evaluated.

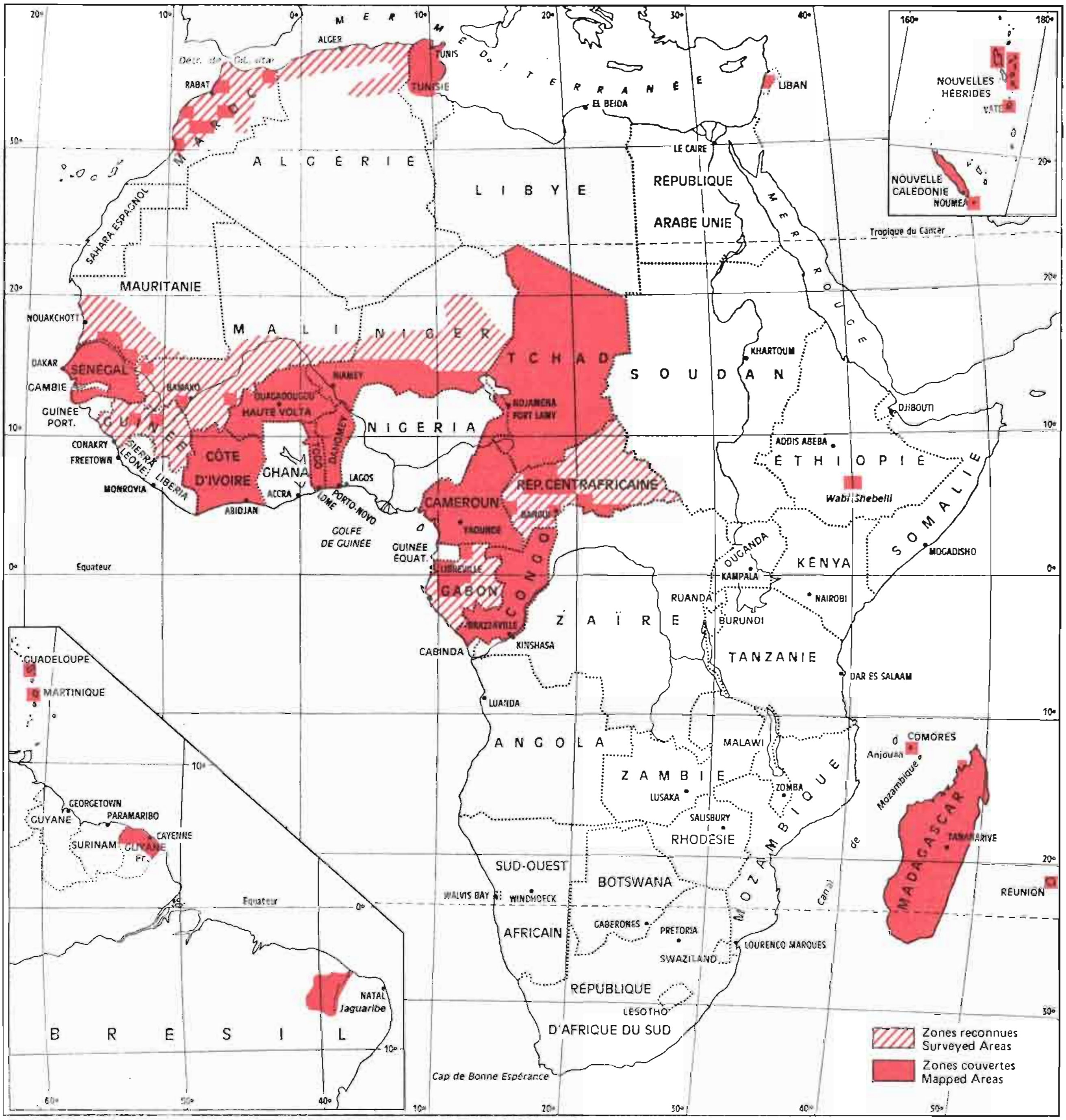
RESULTS ACHIEVED

Mapping activities can be grouped under two headings :

— Small and medium scale maps at scales less than 1/50,000. These concern either reconnaissance surveys or syntheses following research programmes of ORSTOM.

— Detailed maps, mostly at scales between 1/20,000 and 1/10,000, generally made at the request of the user and also (increasingly at the present time) as a support to basic research. To serve agronomy and agriculture, soil suitability maps complement the basic pedological cartography.

These maps are based on the French morphogenetic classification, the different stages in the elaboration of which are reflected in the series of maps that have been produced. The maps are accompanied by an explanatory brochure or by notes, giving much information of an agronomic nature. Since 1945 more than 1,000 different maps have been



SOIL SURVEY AND SOIL MAPPING
BY ORSTOM'S PEDOLOGISTS

produced, sometimes with the collaboration of pedologists of countries concerned. In the period January 1, 1968 to the present time, 187 maps have been issued, being distributed as follows :

- scale equal to or smaller than 1/500,000 24
- scales from 1/50,000 to 1/200,000.......... 141
- scales greater than 1/50,000 22

At the level of small-scale synthetic maps, practically all of French-speaking tropical Africa (with the exception of Zaire) is now surveyed through our efforts, as well as the whole of Madagascar, New Caledonia and the New Hebrides, much of North Africa and a large sector of Ethiopia.

TABLE SUMMARIZING THE AREAS THAT HAVE BEEN MAPPED

SCALES	Equalto or smaller than 1/500,000	1/200,000 to 1/100,000	1/50,000	Equalto or larger than 1/20,000
LAND AREAS	in Km^2	in Km^2	in Hectares	in Hectares
ANTILLES		2,600		268,000
CAMEROON	475,000	84,930	1,514,500	198,756
CENTRAL AFICAN REPUBLIC	617,000	124,112	15,000	16,500
CHAD	700,000	396,000	170,000	355,500
COMOROS		810		
CONGO (PEOPLE'S REPUBLIC OF)	375,660	43,330	496,000	20,100
DAHOMEY	115,662	123,065	435,700	67,250
FRENCH GUIANA		4,543	884,100	6,400
GABON	30,300	52,800	891,100	86,900
IVORY COAST	322,600	46,181	92,915	49,949
MADAGASCAR	592,000	114,290	750,000	180,000
MALI				50,000
MAURITANIA		9,800		35,700
MOROCCO	267,600	7,550	263,500	92,940
NEW CALEDONIA	18,653	720	108,200	
NEW HEBRIDES		11,800		
NIGER	250,000	8,000	11,400	
REUNION		2,500		
SENEGAL	210,000	52,212	351,000	42,000
TOGO	53,000	5,800	111,500	16,605
TUNISIA	82,000	5,287	1,962,200	95,312
UPPER VOLTA	274,000	13,600	31,500	39,800

At scales equal to or greater than 1/200,000, all of Dahomey and the south of Chad are mapped. Work is advanced in Senegal, North and Central Cameroon, Togo, Central African Republic, Gabon, Congo Brazzaville (People's Republic of the Congo) and Madagascar. In addition, there are numerous sheets for Pacific and Indian Ocean islands, the Antilles and French Guiana, as well as for Algeria, Morocco and Tunisia. Certain sheets have also been produced in Latin America (Brazil) and in Asia (Afghanistan, Lebanon). In all about 4,500,000 km² have been surveyed at a more or less detailed level.

METHODS

Since the inventory was started, soil survey techniques have developed to a considerable extent. About 1950, it became possible to establish methods adapted for covering extensive land areas. The conjunction of a first review of our pedological knowledge with the publication of good topographic base maps and the ready availability of aerial photographs resulted in considerable progress, as regards both quality and speed of operation in the execution of soil surveys. This conjunction also led to a more systematic and better coordinated planning of work. The exploitation of vertical aerial photographs, in particular through the use of photo-interpretation methods, has enabled the recognition of certain geographical features which can be linked more or less specifically to the distribution of soils. This explains the success of this approach, which is particularly adapted to the rapidity required for interpretation. These methods have not ceased to be improved, such as through the use of new emulsions (infra-red colour, false colour) and, at the present time, by teledetection techniques (scanners, thermic radar, etc.).

With respects to the regional concept, and in particular to plant cover, ORSTOM pedologists have elaborated certain novel techniques. Two directions have been followed.

The first, which suffers from some uncertainties, is that of « zones » or « control bands ». This fairly classical method has been improved through seeking, in a logical way, widths and orientations of bands that are highly representative of the environments studied. The improved method has been applied in forested regions of the Cameroon, the Ivory Coast and the People's Republic of the Congo (Congo Brazzaville), in habitats where the vegetation forms a screen when viewed laterally. Research on the relations between the appearance of photographic prints and the reality in the field (« ground truth ») requires more systematic and more detailed ground surveys and the rules of this study are subtle, involving analysis of slopes, hydrological networks, etc.

A second approach, more elaborate and more comprehensive, has been developed firstly for steppes, then for savannas, and finally for forests, and its use has progressively been extended. The basis of this work is field research on the particular or general principles explaining the distribution of soils in relation to the physiographic aspects of the environment. The boundaries thus defined are extrapoled on aerial photographs. Two programmes of work are involved. First it has been necessary to ensure definition of homogeneous map units based on precise and systematic morphological characterization. This effort in typology and terminology has revealed the necessity for new descriptive systems adapted to different levels of differenciation, and has resulted in the elaboration of glossaries for the description of horizons and of the environment which offer possibilities for computer interpretation of information. Then comes the study of the distribution of soil units in the landscape. This has provided recognition that certain soils can be matched in a regular manner with relief and land form, and that links can be established between them on historical or genetic grounds, or both.

Thus groupings of soils, sometimes called « pedological landscapes », have been elucidated, and indeed this method contributes as much to the delimitation of geographical natural units as to a better understanding of the soils which they contain.

From the methodological viewpoint, our first step now in any mapping exercise is to prepare a preliminary extensive inventory of the area and its surroundings. This facilitates the choice of axes which give the maximum differentiation (often toposequences). These axes are studied in detail, special attention being given to the boundary characteristics between soils. The patterns of the distribution of the soil units that are recognized are defined. These are then collated with source material that is available (topographic maps, other thematic maps, aerial photographs). The information gained permits sketch mapping based on boundaries recognized on the photographs. During subsequent systematic mapping in the field, the value of the draft is checked, and areas that have been delineated are studied and characterized in detail.

These activities thus lead towards a better understanding of « landscape units », which group together soils which are sometimes much removed from each other in contemporary classification frameworks. The study of these groupings opens the way for research into new genetic relationships among elements of the soil cover.

From the thematic standpoint, these results present problems as regards representation. In particular we have not yet succeeded in mapping « pedological landscapes ». There are difficulties in correlating pedogenetic groupings that are more or less continuous in time and space with classificatory units which simply interpret vertical differentiations (profiles). In order to try to express certain relations between profiles, new graphic treatments have been elaborated, focusing on, for example, representation of soil sequences, associations and complexes.

2. Geochemical and biochemical review

From the outset, it is necessary to record that the motivations for our studies are to be found in the field. We are, above all, naturalists. We try to analyse the phenomena underlying the differentiation of soils. It is obviously necessary, therefore, to confirm field observations trough more precise survey of the constituents of soil and their interrelationships. However, it is equally necessary to determine their mechanisms, to study their functioning and causes, first of all in simple natural systems, then in more and more complex situations. Finally, the value of the results obtained needs to be checked experimentally.

In practical terms, ORSTOM pedologists have inclined towards the first two parts of this approach, namely, the survey ol soil constituents and their organization and the study in situ of mechanisms. Only occasionally has recourse been made to experimental models, with the exception of lysimeter and erosion plot studies. Modelling activities have, generally speaking, been undertaken in association with specialists of other bodies, among which particular mention should be made of the « Institut National de la Recherche Agronomique » (INRA) (National Institute of Agronomic Research) at Versailles and the Geological Institute of the Louis Pasteur University at Strasbourg. This type of research is currently expanding within our organization.

For the presentation of results, it might perhaps be worthwile to deal first with problems of the mineral constituents, grouping these by processes and following a rough chronological sequence. It should be recognized that even so there is much overlapping and complementarity.

MINERAL CONSTITUENTS OF THE SOIL

Lateritic weathering

The first studies were directed at the processes of weathering in humid tropical forest areas. These studies have contributed to a better knowledge of Ferrallitic Soils. They were undertaken initially in Madagascar, then in the Ivory Coast, subsequently in Cameroon. They are currently under way in Gabon, Congo Brazzaville (People's Republic of the Congo), the Central African Republic, French Guiana and the South Pacific. They have enabled hydrolyses, neosyntheses and iron crusts to be distinguished. Under the influence of warm and abundant rains, silicates are totally hydrolysed and elements of rock minerals (Si, Al, Mg, Ca, K, Na) are liberated and, to a large degree, removed. These ions give rise to new products after contact and reation with water. In particular, silica may be completely eliminated or may combine with aluminium to produce kaolinite. The non-combined aluminium is manifested in hydroxide form, especially as gibbsite. The predominance of kaolinite or gibbsite is controlled by the drainage conditions. If drainage is good, silica is removed by water. If the drainage is impaired, silica is removed to a lesser extent and kaolinite dominates. Iron, which can be reduced and can form several compounds is susceptible to considerable movement and accumulates in the form of hematite or goetite. The dynamics of iron remain, however, dependent on the richness in silica of the material that is subject to weathering (as in ferrites, residual alterites, structures that are preserved on some Pacific islands).

The differential elimination of a large number of elements results in a concentration of newly formed constituents. Their physico-chemical properties influence to a major degree the soils of the region concerned.

In summary, the crucial point about ferrallitic weathering is a leaching and a transformation of the original mineral through differential removal. The least leached elements settle into neoformations, the principal of which are goethite, gibbsite and kaolinite. It is the relationships of these new materials, more than the weathering processes themselves, which characterize ferrallitic soils. Nonetheless the intensity of hydrolysis explains the convergence of different evolutionary sequences towards a relatively simple form, hence the apparently monotonous appearance of these soils. In the most intense cases, even quartz can be partially dissolved.

Distribution of iron

A second batch of investigations are centred on the study of the distribution of iron. These have been carried out mainly in the Sudano-Guinean climate regions of West Africa. The first inventories quickly demonstrated the importance and the wide extent of iron accumulations in tropical soils. It was recognized that these « crusts » or « cuirasses » were not necessarily linked to « laterization ». Cuirasse formation is a secondary, optional phenomenon within ferrallitically weathered profiles. It results from the immobilization of iron transported in part by downward leaching but also, indeed especially, by the lateral circulation of water within weathering layers. It can be produced in all permeable formations pervaded by water charged with soluble iron (such as a variety of soils, alluvial terraces, sand dunes, screes, etc.) and depends on the hydrodynamic properties of the landscape and underground environment in question.

The conditions of release, mobilization, migration and immobilization have been analysed and detailed. The interpretation of African landscapes with cuirasses, often fossilized and preserved in ancient forms, is thus facilitated. The information forthcoming from these studies is especially interesting.

Particularly, they highlight the oblique transport of materials. « Vertical migrations exist but » these must be channeled through an outlet, and outlets are usally lateral in orientation « therefore the pedologist can no longer afford to ignore oblique dynamics ». The ideas have opened new avenues for studies on the history of the soil mantle in the African continent. Many cuirasses date from the beginning of the Tertiary, if not the upper Cretaceous. They more or less strongly reflect or emphasize the various Quaternary surfaces. In addition, they facilitate reconstructions of landscape development and perception of the important role of past events in present-day processes. These results can be extensed to temperate regions of the world.

Soil erosion and reworking

The third group of studies relates to the erosion and reworking of soils. The introduction of mechanical techniques into African agriculture in the years following the World War II exarcerbated the phenomenon of soil erosion, in particular through the action of water. The sometimes catastrophic consequences, as regards soil loss, have provoked numerous research investigations, with many of which ORSTOM pedologists have been associated. Our research has been based on several stations for the study of soil conservation, developed since 1954 in West Africa and in the Central African Republic. These studies have led to the establishment of methods of measuring run-off and soil loss. They have facilitated the elaboration and quantification of erosion factors, and the clarification of the relative importance in soil conservation of plants, of agricultural techniques and of cropping systems. These studies are presently being extensed in the Ivory Coast and Upper Volta through more precise analysis of the factors affecting run-off in natural systems and on experimental (rain simulator) plots.

At an early stage, the processes of water erosion were linked and related to those of the reworking of surface layers. Reworking is very widespread in the intertropical zone, and is associated with the presence of coarse material in surface soil horizons, a feature observed particularly in humid equatorial and Guinean climates. Surface reworking, appears to be linked to differential erosion mechanisms, namely the loss of fine particles transported away by water action and the general « impoverishment » of the horizon. A residuum of coarse material can also, however, be produced by accumulation, along a layer often fairly deep down in the profile, of a variety of resistant debris, designated a « stone line ». Numerous studies have been made of stone lines, including detailed descriptions, similarity of covering and underlying material, relations with geological conditions and the system as a whole. Different schools of thought have approached this problem in different ways. Some have put forward the idea of autochthony (relative accumulation mechanisms through differential erosion, the role of termites, the sinking of coarse material in viscous media). Others have suggested a «catastrophic» type of allochthonous development (erosion and deposition phases linked to abrupt climatic changes), while still others have had recourse to the idea of allochthonous development which is restricted to the scale of a hill (slope retreat, deforestation). Whatever their history, these reworkings are linked to successive planations of the large landmasses of intertropical Africa. On the peneplains, the upper part of the soil profile, and even on occasion the parent material too, have frequently undergone lateral movement resulting from successive pedogeneses and reworkings. Many African sediments were thus affected, as were vestiges of materials that had been drastically altered (ferrallitized), eroded and transported, e. g. the Continental Terminal deposits and Tertiary sands. Evidence of earlier pedogeneses are preserved in extensive alluvial zones such as Western Madagascar and the interior delta of the Niger. These findings help to clarify the influence of earlier features, which sometimes mask differentiations attributable to later pedogeneses and which often restrict more recent soil formation processes.

Soil formation in particulcar drainage situations

The previously described studies concern mainly soils in the more humid regions. However, much pedological research has also been undertaken in tropical and subtropical regions having a drier and seasonally more contrasted climate. The studies have resulted in the recognition and characterization of various soils which are very markedly different : Tropical Ferruginous Soils, Fersiallitic Soils, Eutrophic Brown Soils, Vertisols, Planosols and Solodized Solonetz to name but some of the commoner.

Vertisols are characterized by their high concentrations of cracking and swelling clays (montmorillonite in particular). On the other hand, the rest of the soils have a range of intermediate clay minerals and/or a mixture of kaolinite and montmorillonite. These findings have resulted in the distinction of two kinds of pedogenetic environment. First, there are those leached environments in which water circulates freely and drains away through some sort of outlet, where the materials that are in a soluble state are constantly being diminished. Secondly, there are those confined environments, the closed-system landscapes, where percolating water escapes more or less slowly or not at all. Here the continuity of hydrostatic levels is assured by evaporation and products entering the system in solution tend to accumulate. According to the water balance (that is to say, according to rainfall, slope characteristics, temperature, nature of the rock and its porosity) soil evolution leads either towards gibbsite and kaolinite in more leached and acid environments or towards montmorillonite in more accumulative and neutral to basic environments. The duration of the evolutionary stages is superimposed on these processes. In particular on basic rocks young soils retain montmorillonite. These are the Eutrophic Brown Soils which, with time and depending on the local environment, evolve towards one extreme or the other.

This duality facilitates understanding of one of the reasons for the predominance, in tropical regions, of kaolinite or gibbsite soils on well-drained higher areas and the predominance of soil with 2/1 clays in areas where there is impeded drainage.

As a whole our results indicate the existence of significant migrations, mainly oblique or diagonal, of substances in solution coming from upland areas. These results complement those obtained in studies on the distribution of iron in the landscape. However, these lateral differenciations can be more or less obscured, indeed obliterated, through erosion. Thus it is difficult to assess the relative importance of the respective causal mechanisms.

Soil differentiation in calcareous areas

In Mediterranean, with their subtropical to warm temperate climate, relationships are observed, though on a different scale, generally more restricted because of the gentler rainfall and lower temperatures. On the wetter highlands soluble ions are removed and illite and chlorite in the rocks give place to vermiculite in derived soils. At lower, and often drier, localities there is enrichment in silica and a trend towards illite and montmorillonite clays.

Still more characteristic of Mediterranean areas is the evolution of limestone. It tends to be worn away rapidly on highlands, after the initial surface weathering of the hardest rocks has been effected, and the insoluble fraction of «impurities» accumulates from year to year to provide material for Fersiallitic Soils. The latter are therefore, to a large extent, the result of relative accumulation and of the in situ evolution of residual silicates. These processes seem to be very much more of a present-day, active nature than is currently admitted and recognized.

Calcium carbonate in solution migrates through permeable rock or by surface run-off. It accumulates in the drier areas, forming specific horizons in soils characterized by free lime in their profiles.

It has been shown that the formation of these accumulation horizons is in accordance with general principles comparable to those involved in the formation of ferruginous crusts. The calcium migrates, at one and the same time, in a direction with vertical and oblique components and is trapped within toposequences or sets of slope elements. The same morphological sequence can be observed laterally on these as in the differenciation, from bottom to top, of soil profiles. Thus diffuse, precipitations are succeeded by clusters, granules, nodules without then with a patina, crusts and pavements. The appearance of fibrous clay minerals such as attapulgite is associated with line accumulation.

It is in this way that the information gleaned from previous studies is elaborated and refined, particularly with respect to pedological differentiations linked to lateral transport.

Biogeodynamic systems

Studies considered to date have related to profiles or to landscapes. We must bring together these two foci of attention in order better to understand how, in various circumstances, the pedological « continuum » is constituted. It becomes necessary to study the ways by which one soil can change into another soil, and to try to ascribe quantitative limits to these changes. Research of this kind has been undertaken in Chad, and the information gained has been considerable. Related work is currently underway in Upper Volta and Cameroon.

For these studies have had, first of all, to assess the scale of the differentiations between profiles. This has led to examination of rows of deep (several metres) and very close-set (a few metres apart) cuttings and pits along short, contrasted toposequences (of the order of a hundred metres).

In the study areas having comparable climatic conditions, but underlain by different substrata, a constant soil succession is observed ; that is to say, from the top to the bottom of slopes, leached Tropical Ferruginous Soils, Hydromorphic Soils, Planosols, Solodised Solonetz, Vertisols. This succession thus comprises leached and acid uplands with a more basic zone of accumulation downslope. It is known that the boundary between the two areas is oblique and stepped in nature, and that the valley sections are pinched out towards the heads of catchments.

Numerous analyses and detailed computations, confirmed by micromorphological observations, show that the leached horizons of the higher soils in the chain « feed » the accumulation horizon of lower slopes. Hydrolysis at higher levels leads to neoformations of kaolinite : slopefoot accumulations give rise to montmorillonite either by transformation or by neoformation. Interstratified clay minerals are found along the boundary between these two zones.

It seems that the zones are interdependent. In fact while the upper level feeds the lower level, the latter is progressively transformed, as accumulation takes place, by modifications in its hydrodynamic and physico-chemical characteristics. This in turn leads to changes in the condition of immediately adjacent upslope soils. Thus we come to the concept of « systems ». In the example given, there is a « biogeodynamic » structure with each part influencing the whole of the system. Migrating material is successively subjected to attrition and then amassed, according to the different geodynamic barriers encountered. These barriers are thus displaced upslope, to an extent complementary to pedological development lower in the toposequence. One might thus speak of the « upward invasion of montmorillonite ». All other things (climate, parent rock, erosion) being equal, the system contains within itself the mechanisms for its ongoing development. However, if one of the external factors influencing development changes, the equilibrium is upset in one direction or another. The equilibrium may even be completely destroyed.

Finally, it has been shown that certain relief forms result directly from pedological actions, as for example leached slope elements with Tropical Ferruginous Soils and accumulation landsurfaces with Vertisols.

In total, these results confirm and define the mechanisms of pedological differenciation, horizontally as well as vertically. We thus reinforce our tenet that a soil is closely linked to its environment and, in particular, to its neighbouring soils.

These conclusions oblige us to devote a proportion of our research effort to the continued survey and study of various pedological systems.

Andosols and amorphous materials

For a fair number of years, our attention has been attracted by the peculiarities of pedological differenciation on volcanic rocks. While these soils occupy a relatively small total area, their generally high fertility has provided an added stimulus for understanding them more completely.

Studies have been undertaken particularly in the West Indies, Latin America, Madagascar, Cameroon and the New Hebrides. The soils can, for the most part, be classed as ANDOSOLS. Their physical and chemical properties are not found in most other soils. This has provoked an intensive mineralogical and chemical analysis of their constituents. It should be noted that these soils contain a high proportion of substances apparently amorphous when X-rayed, generally designated by the term allophane.

Study of the factors influencing the evolution of these soils has elucidated an important factor, in addition to the role of rocks rich in volcanic glass. This factor is climatic in nature. Soils with most allophane are found in high rainfall, persistently humid regions.

Good internal drainage facilitates both the rapid turnover of solutions in the soil and the formation of allophane, which develop on young material (Late Quaternary). Thus, in Cameroon, separation can be made between Andosols overlying recent volcanic formations and Ferrallitic Soils overlying old basalts. This evolution is also facilitated by the fineness of the parent material.

The process of understanding these soils has been aided by the application of new techniques specially adapted to assess their characteristics, in particular ultra-sonic dispersion and kinetic methods of breaking down amorphous materials. The extraction possibilities offered by kinetic methods extend moreover to the study of other soils (Fersiallitic and Ferrallitic Soils for example).

The findings are many. In Cameroon, in the humid tropical region, the geochemical evolution of silicates has been reconstructed : volcanic rocks, allophanes, halloysites, metahalloysites and then two end products, either gibbsite or kaolinite. Under the influence of the dry season, in part through the breakdown of organic matter, halloysite is formed, which evolves progressively towards the kaolinite of typical Ferrallitic Soils.

In the New Hebrides, it is a progressive variation of climatic conditions together with the relief which produces covarying modifications in weathering processes. In passing from the climatically most humid area (perhumid summits) to the driest (leeward lower slopes) the following succession can be observed : desaturated and gibbsitic Andosols, base saturated Andosols, Eutrophic Brown Soils, and either Ferrallitic or Fersiallitic Soils. Pedological time-sequences have also been recognized. These present the same differentiation successions, according to the age of the parent materials.

In this way frameworks outlined in earlier studies are substantiated. Regions of recent orogenesis, generally dissected, support young soils which bear the stamp of the underlying rocks. Vertical differentiation is more evident than lateral. However, on old African surfaces which have been subject to a very long history and to multiple and often extreme climatic conditions, the soils are the result of varied processes, suggesting important lateral transport. Oblique differentiations are widespread. Numerous legacies, such as ironstone caps, stand out as landmarks of these migrations, and complicate the more their interpretation.

Equally, the vertical and lateral duality is a function, both of the amount of water received (role of rainfall) and of the possibilities of percolation through the soil mantle (role of porosity and of land slope). In arid environments where water drains only to a shallow depth, pedological differentiation is above all vertical. Increased leaching initiates lateral differentiation, of greatest extent towards humid regions. In the latter, such differentiation can transcend slope elements and even major landscape units, and requires studies that are not too localized in scope.

Contemporary soil dynamics involving water and soluble salts

Of the more recent preoccupations, a final sector of research is focused on investigations into present-day soil dynamics under the action of water. These studies relate to two main fields : first, that of the circulation of water on and within the soil and within soil systems ; secondly, that of the pedogenesis of young soils subject to an excess of water (Hydromorphic Soils) and/or to the action of soluble salts (Halomorphic Soils). These two types of study share a common objective, to elucidate the relationships between soil morphology and the behaviour of water. Given this objective, studies are oriented to problems raised in soil surveys based on morphological studies. They should result in a better interpretation of observed facts for practical purposes, in particular for agronomy.

Results on water circulation have in the main been obtained in Ivory Coast and in Chad, where two complementary approaches have been adopted. First, some studies have centred on the soil water regime through establishment of seasonal water profiles. Secondly, another group has concentrated on the measurement of vertical drainage through lysimeters (sometimes associated with measurement of run-off and of oblique drainage), in order to try to discern directly the nature of the water balance and to determine, both qualitatively and quantitatively, the elements transported by water.

Both of these approaches have required the elaboration of new techniques. The ERLO lysimeter for oblique erosion and leaching is one example. Improvements in this field are continually being made.

Considerable amounts of data have been amassed, some of which are still to be interpreted. The information gained has already facilitated more precise appreciation of the importance and intensity of the depletion of fine particles in Ferrallitic Soil environments, the loss of nutrient elements under various crops, and the mechanisms of water uptake by plants.

Studies on the pedogenis of young soils under hydromorphic or halomorphic conditions are focused mainly on the influence of variations in the water regime, on a seasonal basis as well as between periods of several years. Three types of soil development are under study, as follows :

— The first is that of the polders on the edges of Lake Chad. This illustrates the effect of the pedological structure acquired by sediments, after their emergence, on the regional salt dynamics. The study is aimed at building up a geochemical balance of the accumulation of the elements Na, K, Ca, Mg, Si, Fe, Mn, etc. in a confined, humus-rich, continental area with a semi-arid climate. Comparable studies on gypseous soils are underway in Tunisia.

— The second concerns mangrove soils in Senegal, where the factor conditioning development is the transformation of sulphur compounds in an organic environment where reduction prevails over oxidation.

— The third type concerns an annual alternation, of varying extent, between submersion and drying out. This type of evolution is that of hydromorphic soils. The work, undertaken in Chad and Madagascar, has shown the importance of the physical phenomena of swelling and shrinking.

It is too early finally to report upon these programmes. It is possible, however, to record that these ongoing projects have :

— provided a better understanding of the cycle of salts in arid zones and of the characterization and balance of sulphur compounds ;

— revealed the importance of the iron cycle in these environments and the influence of iron on morphology, thus improving the descriptive tools used by pedologists (for example, ideas about Gley and Pseudogley) ;

— elucidated the mechanisms of neoformation and transformation of clay minerals in young materials, spatially confined, more or less, and at the beginning of their development.

ORGANIC MATTER

ORSTOM pedologists have always paid particular attention to the organic constituents of the soil, whether this be in the description of upper horizons or of certain horizons of accumulation, or from the analytical viewpoint. Except in certain recent examples, however, there have been few studies entirely devoted to organic matter. In any case, organic matter has not been considered in isolation, but rather as a constituent which interacts in a complex manner with morphological, physical or chemical factors.

Consequently, work on organic matter has generally consisted of establishing correlations between, on the on hand, the variations in such and such a fraction of the organic matter, either in the profile or at the surface, and on the other hand the time factor or soil properties such as fertility, structure and various mineral elements.

One has thus been able to illustrate the respective importance of the organic fractions as regards overall fertility, surface accumulation of bases and phosphorus and sulphur, structural stability, retention of water, permeability, colloidal impoverishment of surface layers and the movement and redistribution of sesquioxides at depth.

Relatively few experimental studies have been undertaken for the direct demonstration of these phenomena. Biochemically oriented studies, required to elucidate the nature of the organic constituents or their links with mineral material, have been developed only to a limited extent. Where these studies have been undertaken, they have for the most part been made in liaison with the pedobiological laboratory of the C. N. R. S. (Centre National de la Recherche Scientifique) at Nancy. The increased use of more elaborate techniques, for example C 14 labelling has only taken place in the last few years.

The first research undertaken enabled recognition of the relationships between the organic material of soils and their fertility, this work being linked with pot experiments and field trials. These studies have also facilitated the elucidation of the evolution of this organic material through time, in longterm field trials and by means of erosion study plots.

Studies on the role of soil organic matter have been undertaken in the Central African Republic, Mali, Ivory Coast, Congo Brazzaville, Cameroon and Madagascar. Soil properties such as water retention, permeability and base exchange capacity have been correlated with organic matter content. Statistical correlations have shown the importance of the action of different humus fractions on soil structure, whether this be positive action of insoluble fractions in alkali soils or, on the other hand, negative action of the more mobile fractions (fulvic acids).

Within the framework of studies on pedogenesis, it has also become apparent that these fractions influence leaching of bases, eluviation of clay and, in a more complex fashion, mobilization of sesquioxides. These influences are most evident in regions having a humid tropical climate. In more arid regions, they have an important influence on the mobilization of lime.

Among the more specialized studies, mention should be made or research focused on the relations between various types of humus and the evolution of soils under different climatic conditions. This kind of study has, for example, been undertaken on Ivory Coast Tropical Ferruginous Soils and forested Ferrallitic Soils, on Podzols, Ferrallitic Soils and coastal Hydromorphic Soils of French Guiana and Brazil, and on the Isohumic Soils of Iran, Morocco, Tunisia, Niger and Ethiopia.

Moreover, attention should be drawn to studies on relationship between organic matter in Hydromorphic Soils, on the one hand, and oxidation-reduction processes and the history of elements such as sulphur or iron and of soluble salts, on the other. Such studies have been undertaken on Hydromorphic Soils in Chad, Senegal and Madagascar, in particular.

Results appear to show that the humus of humid tropical regions resembles, as regards chemical composition, the forest mull of temperate climates, but with a lesser degree of polymerization, in spite of an often high amount of humin. Types resembling moder and even, but very rarely, more are occasionally observed under the climax vegetation of certain sites at high elevations, or on very sandy substrata, or in drastically leached very acidic soils, as for example in French Guiana, among other equatorial regions. Andosols also show a very marked accumulation of organic matter strongly linked to their mineral composition.

There seems to be a certain zonality of humus according to climate. The length of the dry season in relation to that of the rainy season favours physiochemical maturation processes, which follow on from organic decomposition. In the more humid evergreen forest regions, the rate of removal of alkali soluble humic material is relatively high, while the fulvic acid fraction dominates. Grey humic acids account for less than 50 % of the total humic acids, and the socalled « over-developed » humin fraction is low. Progressing towards more arid regions, these characteristics change in the direction of a relative increase in the insoluble fraction, and an augmentation of large molecule humic acids and of the « over-developed » humin fraction. The soluble or fulvic acid fraction progressively decreases in relation to the humic acids in those regions which have a more contrasted climate with a long dry season. In the latter cases, the texture of the subsoil, particularly if it contains montmorillonite, plays a significant role in determining the nature of the humus.

In deep soils, organic matter is relatively inactive the level of primary alteration of the parent rock. On the other hand, organic matter appears to facilitate, in the upper horizons of Ferrallitic Soils, a secondary degradation of kaolinite through the action of acid organic compounds. Likewise, organic matter plays an important role in the accumulation and leaching of bases, and in the migration of sesquioxides and perhaps also of clay, in the soil profile.

For a recent study carried out in collaboration with Salvador de Bahia University, Brazil, advantage has been taken the variable quantities of natural C 14 occurring in the atmosphere, subsequently to monitor in the soil, using very precise measurements, the time of formation and the periodicity of relatively stable compounds of organic carbon in each fraction of the humus. Thus one has been ab'e to illustrate the relative youthfulness of the humin fraction of upper soil layers, whereas that of the underlying horizons is much more ancient.

Biological research, while important for the understanding of organic constituents, does not really fall under the competence of pedologists. A soil biology section has therefore been set up within ORSTOM to develop this particular field of study. It is, however, apposite here to record the main directions of biological research insofar as they relate to the problems which are more specifically the concern of pedologists.

In a first phase, programmes were directed to the study of microbial activity and its possible applications in agronomy (nitrogen cycles, biodynamics of organic matter).

In a second phase, which more or less overlapped the first, attention was directed to the intensive study of microbial processes which appeared to be particularly important within the framework of problems of economic development, such as the extension of rice farming in Senegal.

As a final point, it should be mentioned that study of the pedological action of soil fauna has developed only relatively recently. First there was a review of the literature and some lecturing, along with the elaboration and refinement of techniques. Subsequently this has given rise, on the one hand, to laboratory studies, particularly of the effect of living and dead animals on humification processes and, on the other hand, to field observations, particularly of earthworms and termites.

3. Agronomic review

From their first activities, ORSTOM pedologists have studied the possibilities of using soils for crops, both irrigated and rainfed, and have assessed the influence of soil characteristics on crop yields. Over the years, our pedologists have undertaken these studies jointly with other bodies, French and foreign, to such an extent that it is difficult to apportion the findings which are attributable to ORSTOM pedologists alone and those which are the products of collaboration. It is nevertheless necessary to emphasize a policy to which our pedologists have attached particular importance. That is, on the one hand, to relate all local experimentation to a particular soil type and, if possible, to a unit defined on the soil map, and, on the other, to correlate soil properties with fertility factors.

The pedologists of ORSTOM initially followed, for and with existing technical services, two mains directions of activity :

— Soil suitability maps for crops. This work has gone forward in Madagascar and also, to varying extents, in most of tropical Africa, for example Congo Brazzaville, Ivory Coast, Cameroon, Dahomey, Mali, Senegal, Chad, and the Central African Republic, as well as for the French West Indies and Reunion. The areas studied, like the scales adopted (1/10,000 to 1/100,000), were very variable and depended essentially on the requests received. This type of activity has also been undertaken in North Africa, particularly in Morocco and Tunisia, where pre-development studies were largely entrusted to our personnel. These studies were mostly at 1/50,000 in Tunisia and at larger scales (1/5,000 to 1/50,000) in Morocco.

— Soil fertility. In a field still little explored as yet in tropical countries, the main objective of our research activities has been to determine the performance and suitability of crops and to verify the ability of soils to support one or several successive crops. As examples, there are the studies made on groundnuts in Senegal and Congo Brazzaville, on bananas in Guinea and Cameroon, on cocoa in Ivory Coast, on coffee in the Central African Republic and on irrigated crops (particularly rice and cotton) in Mali and Morocco.

There was a certain slowing down of these studies from 1958, onwards. Except for two studies, covering large areas of Togo and Ivory Coast, soil suitability mapping at large scales has been radically reduced. It is, however, continuing in North Africa. On the other hand more general studies, still aimed at solving agricultural problems, have been developed. Maps of recommended soil use and maps indicating the potential for agriculture, livestock and forestry have been produced for major ecological zones, namely in Niger for Sahelian areas and in Ivory Coast for the forest and the moister savanna. The physical characteristics of soil have also been studied. They include porosity, permeability and structural stability, and the effects of these on the changes, through time, in arable land, both cropped and fallow. Experimental plots established for following erosion phenomena have facilitated testing of different land use systems, of cropping practices and of recovery patterns when fallowed, in relation to surface run-off and soil loss. Such work has been undertaken in Ivory Coast, Dahomey, Madagascar, Central African Republic, Senegal and Chad. It has been shown, for instance that the clay fraction and fresh organic matter are the first to be removed. Their depletion has important repercussions on the stability of aggregates, which they themselves condition to a large extent.

A start has been made with very detailed studies of the dynamics of colloidal particles and of mineral elements under the action of percolating water. These studies entail use of a specially designed chamber and are underway at the Adiopodoumé station (Ivory Coast) as well as in Chad, under crops and fallow and natural vegetation.

In arid and semi-arid climates (Morocco, Chad, Tunisia) problems linked to the presence of salts, to the exploitation of saline soils and to the use of saline waters for irrigation have been investigated. These studies were undertaken with the dual aim of improving irrigated soils and of assessing irrigability for specified crops.

Particular mention should be made of very detailed studies on the possibilities for regeneration of cedar and cork oak, and for the development of eucalyptus plantations in Morocco. The results obtained show the influence of soil factors in governing water relationships during summer, in particular the temporary hydromorphism exhibited by certains horizons.

Finally, studies of soil evolution under crops (irrigated and rainfed) and under fallow in North Africa, Senegal, Congo Brazzaville and Cameroon have elucidated some of the physical and chemical processes involved in the exhaustion cultivated soils and their recovery through fallow, fertilizers and soil ameliorants.

The natural fertility of a soil under continuous cultivation diminishes rapidly during the early years after clearing, but then it tends to become stabilized. It is therefore necessary ascertain, by suitable farming practices, the threshold level of fertility beyond which acceptable returns are unlikely to accrue.

In parallel research, our chemists continue to study the dynamics of the biotic elements in the soil. They are trying to find analytical techniques better adapted to tropical soils than the tests previously used. Refinement of the techniques for determining available phosphorus is one example. The application in the field of new analytical methods and verifications, is also being undertaken, in the West Indies, Ivory Coast and Cameroon.

Recently, without giving up the work mentioned above, activities have been coordinated around the following general theme : study of the conditions and mechanisms of soil evolution under the influence of land use practices. The main objective is to determine the evolutionary processes of various kinds of soil when subjected to different uses by man, so as to understand with greater precision the forms of intervention which will lead to the maintenance and even improvement of the productivity potential.

Though it is somewhat premature to judge the results of this approach, mention might be made of certain findings on the basic rotations of cotton and groundnuts in the Ivory Coast, Cameroon and Chad. Moreover, in Lebanon particular attention has been paid to the dynamics of lime affected by irrigation water. In Tunisia, a similar study has focused on gypsum. Furthermore, comprehensive data collection has been initiated as regards fertility characteristics of tropical soils and possibilities for their improvement. Finally, analytical tools and techniques continue to be improved, particularly concerning the determination of sulphur, phosphorus and gypsum, as well as the fractionation of organic matter.

SCIENTIFIC PROCESSES EVOLUTION OF CONCEPTS

The preceding review highlights a succession of pedological activities over the course of the years. Initially these activities reflected the variety of the needs of clients, but they resulted also from a progressive evolution in requests. The early ORSTOM pedologists approached the study of soils through the physical, chemical and biological aspects of the profiles that they observed. This initial pattern, at the time fairly characteristic of French agronomy, has little by little been superseded, and even then in a manner that owes more to intuition than to reasoned deliberation, by a more specifically pedological approach. Our research workers strove in the first place to study the soil in its totality (profile, pits, extended profiles and, later, geographical distribution) and in relation to environmental factors, and only at a second stage was attention given to the constituents of the soil and its resulting properties.

Even by invoking principles of the theory of knowledge it is difficult to appreciate completely the principal steps in this development. However, three periods can be distinguished chronologically, namelly 1944-1954, 1954-1966 and 1966 to the present. Nevertheless, too great a significance should not be attached to these dates. Thus, it should be emphasized that the different concepts regarding soil evolution do not follow a simple succession. They can be placed along an extended sequence of pedological work, in course of which the state of the science from time to time demanded new frameworks which recognized the inadequacy of previously held principles and which stimulated the search for more satisfactory interpretations. In short, this development has been a progressive and sinuous one. The dates proposed above should not be taken too literally, since they will differ e. g. according to the region under consideration.

From the beginning of their studies, ORSTOM pedologists have retained the concept of morphogenesis. The reasoning is that the morphology of soils should be able to reveal the manner of their formation since it records the consequences of the processes which enter into this evolution. The totality of the phenomena of transformation and redistribution of the various constituents of soil results in the differentiations between and within soils that are observed.

The objectives are to study soils for an understanding of the manner of their formation, to analyse their properties and hence to place them in the context of their evolution. The basic point of departure is the overall study of their differentiations, in order better to understand the laws of the distribution of matter within the soil mantle. This should facilicate the formulation of hypotheses about physio-chemical processes and about the transfer of materials that are aid in explaining pedogenesis. These hypotheses depend upon the basic data and understanding that are available within each of the relevant scientific disciplines. At the present time this kind of approach continues to be upheld.

1. The period from 1944 to 1954

Initial concepts

During the first period, the study of soils was based on a concept of pedogenesis characterized by verticality of processes, the autochthonous nature of soils and contemporary environmental factors.

— *Verticality of processes* : During this period, soil was simply defined by its profile down to the underlying, unaltered parent rock. The only processes taken into consideration for the differentiation of horizons were vertical transport movements with, at least at the beginning, an important role being accorded to accumulations occurring through upward movements. This approach resulted in an inadequate understanding of the true regimes of soil moisture circulation.

— *Autochthonous nature of soils* : Soils were considered to be derived from the weathering of underlying rock. This resulted at a very early stage in studies on weathering processes and on the relations between soils and geological formations. It should be recalled that operational priorities at that time led to the study of these alterations within the still poorly understood formations of the African granite-gneiss basement complex, rather than in sedimentary substrata. A somewhat later preoccupation was the influence on soils of residual eruptive rocks and of their primary minerals.

— *Contemporary environmental factors* : Profiles were looked upon as the result of the contemporary conditions of the environment, principally of the climate. This explains the importance accorded, at least initially, to the principle of zonality as regards processes and indeed as regards the soils themselves.

The pedological method

During this period pedologists studied only profiles therefore, and the relationships between their horizons, thus restricting the amount of descriptive data. In addition, the terms used were often poorly defined and very open to individual interpretation. Pedologists nevertheless tried to determine as best they could the nature of the underlying rocks. They tried finally to collate the known environmental data and more particularly those on climate with those analytical and morphological results that were available, taking into consideration the then accepted theories.

Reasons and motives

Several interacting causes explain this approach :

— First, recognition must be made of the conditions under which the inventory and study of soils were undertaken, conditions imposed by the large areas to be covered. Mapping scales oscillated to all intents and purposes between two extremes : survey along routes consisting of discontinuous observations with a small scale map as the product, and systematic surveys at a large or very large scale, usually undertaken for agricultural purposes. The importance accorded to the principle of zonality, which facilitated the extrapolation of results, can be readily appreciated.

— Its is necessary to mention also the relative practical difficulties in reaching and observing illuvial horizons at depth, and the lack of relevant laboratory techniques. For example, in relation to clay movement, criteria were lacking for distinguishing, with any degree of certainty, between illuvial layers, formations resulting from in situ transformation and even, in certain cases, alluvial strata. This did not, however, prevent certains explanations being advanced which introduced the role of leaching.

— The pedological features of tropical environments were poorly known and understood. They were described habitually by reference to those of temperate environments, and it was quite difficult to disengage from this custom. Certain constituents, such as iron compounds capable of giving readily identifiable and resistant products, were more rapidly interpreted than others.

— Due to inadequate analysis of illuvial horizons, special attention was given to eluvial horizons, particularly in arid regions. These latter horizons were easier to reach and to study, and their suitability for agriculture could more easily be determined. This explains in part the relatively privileged place invariably accorded to leaching processes in the French classification.

First results

In spite of these difficulties and imperfections, the results obtained during the course of this period are important, to the extent even of markedly influencing methods still used at the present time. The major categories of soils were recognized and defined : in particular, Isohumic Soils of the steppes, soils Tropical Ferruginous Soils and Ferrallitic Soils. The principal factors of their evolution — weathering, leaching, organic matter — were determined. The mass of data obtained led to the elaboration of a classification of tropical soils which, in spite of numerous adaptations and refinements, is strongly reflected in our pedological presentation and nomenclature today.

The results obtained during this period were also very interesting from the agronomic point of view. The crucial edaphic requirements of a number of crops were determined, such as groundnuts, cocoa, coffee, cotton, irrigated rice, bananas, pineapples, etc. The first soil suitability and crop potential maps were made in such diverse regions as Madagascar, Chad (Bongor area), Mali (middle Niger delta) and Congo Brazzaville (Niari valley). Some of these gave rise to the first tentative attempts at soil mapping, notably in Madagascar and Congo Brazzaville.

Values and limitations

Nevertheless, it was possible at a very early stage, about 1950, to see the limitations of this first approach as regards soil mapping and soil survey interpretation. It was found impossible, for example, to interpret soil dynamics by experimentation. The initial approaches were often revealed to be incapable of providing the explanation for soil properties. It became essential to include the time factor in soil classifications, and the possible variations in time of some factors of soil formation, essentially climate and vegetation. It also became necessary to recognize lateral gains ans losses of material. This quickly gave rise to the catenary concept which was, however, too often limited to a cartographic presentation. These findings required not only that horizons be observed in a more detailed and objective way, but also that study be made of variations in profiles across landscapes. The result was an identification of various new research avenues which were investigated during the period that followed.

2. The period from 1954 to 1966

This second period can be characterized by two principal approaches which corresponded, on the on hand, to the more or less systematic development of medium scale soil cartography and, on the other, to the development of laboratory techniques and resources. This resulted in a more complete field coverage and a more intensive characterization of soils, which in turn exposed the limitations of the principles that were previously held and enforced their adaptation. The lateral connexions between soils compelled recognition, and the interpretation of these relationships was sought in oblique (or diagonal or diahedral) movements of materials. Nevertheless, water balance experiments and related trials showed that simple lateral bulk transfers were inadequate to explain these relationships. Thus it became necessary to introduce a historical perspective. This involved recognition of the intervention of paleoclimatic discontinuous sequences. There were, though, major difficulties in arriving at the total picture : polygenesis, biological evolutionary pulsations, etc. A path was opened by the study of relationships between soil and relief forms.

Needs in soil studies

As a consequence of previous results, interest was directed to understanding soils from the land management viewpoint, a tendency reflected by the receipt of numerous requests, and to developing techniques in applied pedology. A better structuring of teams working in the field was achieved, as well as improvements in laboratories. New techniques were developed. Solutions were found to problems set by the large areas that needed to be surveyed (interpretation of aerial photography) and by the necessity for quantitative characterization of soils (more relevant and, above all, more rapid analytical methods).

Differences between ecological zones

It is necessary here to make a distinction between arid zones and humid zones. In arid zones the necessity for extensive but diversified agriculture (livestock keeping, food and industrial crops, utilization of forested areas), within a sensitive environment very prone to erosion, called for much systematic mapping in the north of Cameroon, in Upper Volta, Niger, Chad, Senegal, etc. These surveys were made possible by the relative ease of travel and observation in the landscapes of these areas, which comprise more or less open savannas and pseudo-steppes. In an area of apparently monotonous appearance, because of low relief and the common presence of cuirasses, any sharp differentiations are quickly noticed and their relationships to the landscape unravelled.

In the humid zone, agriculture is localized and intensive. Soil surveys requested concerned either large-scale mapping or fertility studies. The systematic inventory of the zone remains an offshoot of work mostly done at engineering construction sites-deforestation, cuts for new roads and railways, etc. Such surveys are generally undertaken in a way that is poorly adapted to investigating soils that are in any event often little differentiated. Any differentiations are at right angles to contour lines, whereas communication lines which follow the courses of major rivers, or run along valleys, only traverse the lower parts of slopes.

These differences of access in the field have induced a contrast, still very marked at the present time, between our knowledge of soils in seasonally dry climates an those, particularly Ferrallitic Soils, in more humid regions.

Advent of results

This period was also one in which perceptible progress was made as regards understanding erosion phenomena and the very real problems posed by the conservation of soil under mechanized cultivation. The high values given by measures of run-off and of surface transport by water in Casamance (Senegal) and Guinea were not without influence on the importance subsequently accorded to reworking and surface transport mechanisms in soil evolution and in the development of impoverished, reworked and colluvial horizons, stone lines, etc.

At the same time, considerable progress was made as regards methods and techniques, which continued to be more finely adapted and made more specific.

Field observations proliferated and the concept of catenas became more widely accepted. This tended to become one of the basic tenets in studies that were undertaken. In a parallel and complementary way, soil descriptions took on a more detailed, more objective and more quantitative character. This development was helped by knowledge obtained from elsewhere, especially the United States Soil Survey.

In the laboratories, new physio-chemical facilities were installed. These became more widespread and more varied, and their use became routine. They complemented the new methods for mineralogical analysis of soils, particularly of clay minerals.

Information gained

Interpretation in this period was thus based on more reliable and more complete field and laboratory information. Greater understanding of geochemical patterns had, moreover, become available in related disciplines, with respect to rock weathering for example. The ideas put forward were dominated by the lateral movement of materials. Soil distributions that were observed appeared to result from either reworking and superficial movements of constituents or internal movements of soluble elements (for example iron) or of crystalline material (various fine particles including clay minerals). Interactions between these phenomena and processes frequently occur and make them all the more difficult to analyse.

Account was also taken of the time factor, but in a variety of ways. In certain cases, soil differenciations were explained by the successive acquisition of characteristics according to variations through time of the pedogenetic factors (polygenetic approach). In other cases, recourse was made, to a greater or lesser extent, to the cyclical theories of geologists, in which pedogenetic phases (biochemical processes) are deemed to alternate with morphogenetic phases (mechanical processes dominant). The biorhexistasic theory, regarding pulsations and interruptions in the development of life forms, is based in part on this premise. Many difficulties remained due to the unknownable precise history and sequences of processes, only the end results of which are observed by us. The effects of successive changes in ancient environmental conditions on the preservation or transformation of several kinds of soil were investigated in this period. Explanations rested particularly on the nature and arrangement of inherited material in the soil. It should be noted in this regard that in a given landscape, the dominant soil properties (and sometimes all the characteristics retained) reflect long-lasting, strongly imprinted past conditions of the soil-forming factors. Those pedological characteristics deriving from more arid and/or cooler climates, and those corresponding to past periods of shorter duration, are for the most part subsequently obliterated when more intense processes ensue. Likewise, old pedological features can be obliterated by orogenetic activity such as erosion of the regolith through a lowering of the base level, subsidence, sedimentation, deposition of volcanic ash, etc. The preponderance, or lack, of certain soils in some areas, can also be explained by reference to tectonic phenomena.

New insights

Many results were obtained during this second period. They led to a better characterization of already defined soil units and also to recognition of new ones, such as the montmorillonitic soils (e. g. Vertisols, Eutrophic Brown Soils), Solodized Solonetz, soils having free lime in the profile, Fersiallitic Soils, gypseous soils, etc.

The influence of internal drainage on the neosynthesis of soil constituents was clarified during this period, and the important ideas of leaching environments and closed-system landscapes. Demonstration that certain parent rocks have a pedological origin illustrated the importance of past events on present-day soil differentiation and allowed certain conclusions gained from our studies to be applied to temperate to zone soils. Finally the advance in medium-scale systematic mapping, the basis for regional planning, facilitated the production of numerous small scale (1/1,000,000) soil maps. Comparison and review of the spatial distribution of soil introduced a fruitful source of biogeographical information.

From an agronomic standpoint, exercices in mapping crop potential became more rationalized and standardized the processes of soil evolution under dry and irrigated crops were studied, and certain mechanisms were, clarified. Measures for soil conservation and for control of water erosion were presented and advised upon, and conditions of development and regeneration of various forest species (in Morocco and Ivory Coast) were clarified.

Classification of soils

The classification of tropical soils was subject to radical change, both in its structure and its content. A new class was formed to group together tropical black clay soils, that of Vertisols, in line with the same unit of the United States Department of Agriculture (U. S. D. A.) Seventh Approximation. Other classes were modified, such as the Isohumic Soils (previously called Steppic), for wich subclasses were recognized for soils of subtropical arid regions and for soils of semi-arid tropical regions. Tropical Eutrophic Brown Soils were included with the class of Brownish Soils (Sols Brunifiés). Above all, the old class of soils with hydroxides and with rapidly mineralised organic matter was split into two classes namely Ferrallitic Soils and Sesquioxide-rich Soils.

The higher levels of the Ferrallitic Soils class were entirely restructured. Certain criteria dissappeared (e. g. obligatory presence of gibbsite) while others were subject to modification (silica-sesquioxide ratio equal to or less than 2). Subclasses were differentiated according to their degree of base saturation. New soil groups were proposed : impoverished soils (loss of clay from the A horizon without corresponding accumulation in the B horizon), reworked soils (with layers of coarse materials), immature soils (out of phase with normal evolution through truncation of the surface horizon, for example, or superficial additions).

Sesquioxide-rich Soils included Tropical Ferruginous Soils, with temporarily impeded drainage of their illuvial B horizons and the possibility of iron immobilisation as concretions or cuirasses, and also Fersiallitic Soils, which included — among others — Terra Rossa or Red Mediterranean Soils.

The Hydromorphic Soils class was reorganized according to the different types of soils moisture regimes.

In spite of these changes, the new soils classification was not entirely satisfactory. It took practically no account of either internal movements or lateral surface movements. The historical factor was not integrated into a dynamic picture sufficiently synthetic and all-embracing.

The position as regards interpretation of the new classificatory criteria was somewhat uneven, not to say at times divergent, depending on localities and intensities of survey. These difficulties dominated the first part of the following period.

3. The period from 1966 to the present day

Diversification of scientific findings

The present period corresponds to a phase of detailed study of the distribution of soils within relatively simples landscapes. After the preceding period of intensive, systematic mapping, which is moreover still continuing in certain geographic zones (humid tropical forest zones, Mediterranean areas), it became necessary to assess the results obtained, to compare data, and to analyse and recognize the limits of these data. During this period, pedologists have found a breathing space for this type of activity, which has also been made possible by a refocusing of interest on several general themes, which facilitated exchange and confrontation of ideas. This period is also witnessing production of general synthetic publications and of higher doctoral theses. We are reaping multiple benefits that have accrued from the composite results of previous endeavours in many fields.

— The first of these is the morphological and analytical characterization of soils. Such inventories continue to grow and to gain in refinement. The search for a common terminology and language is manifested in the drafting and editing of glossaries for the description of horizons and of profile environments, with a view to data processing activities. A soil date bank has been set up, and interpretation programmes have been produced and transcribed.

— There has been progress likewise in understanding the spatial distribution of soil units. Information available from mapping facilitates recognition of soil relationships at various scales and of various kinds - toposequences regional patterns, climatic correlations, etc.

— At the same basic data in the geochemical field, and with respect to circulation in porous media, have become sufficiently precise to enable sound interpretative frameworks, to be set up.

— Finally, at the technical level, the possibilities for chemical, mineralogical and physical analyses have continued to develop and diversify, from quantitative as well as qualitative points of view. Methods include X-ray florescence, quantometry and infra-red spectrography.

Progress in techniques

Methods have also continued to evolve in the field of observation techniques. In particular, new possibilities for applying the microscope, whether optical or electron, to research on soils have enabled more intensive studies, at still larger magnifications to be undertaken. The results obtained have offered the possibility of explaining spatial arrangements in terms of time successions and have enabled distinctions to be made between sedimentary and pedological structures.

In the field, and complementing standard approaches, studies are focused more specifically on the following aspects. First the lateral differentiation between profiles along catenas is being investigated at progressively shorter distances. Discontinuities in the soil continuum are being studied and greater precision is being given to the boundaries between soil units. Secondly, present-day processes are being observed directly in the field. Foci for study include the antagonistic effects of wetting and drying, their consequences on soil structure, the percolation of water and removal of material in solution or suspension, the dynamics of sulphur, and so on.

Lessons

Studies in soil geography have introduced two complementary ideas :

— the role of lateral differenciation in the distribution of soils within a landscape ;

— the analogies between this distribution and the zoning of the principal mapping units of tropical soils.

These studies have clarified the genetic and historical relationships between the different types of soils which are associated in certain landscapes. A genetic continuity can thus exist between upslope eluvial soils and downslope accumulation soils. As a corollary, the latter can succeed the former in time as well as in space.

Tropical landscapes thus represent « biogeodynamic » systems which contain within themselves the mechanisms of their continuing development. In one study in Chad, for example, this has been shown to be determined by a lateral and ascending type of pedogenesis. It seems probable that many comparable systems exist in other parts of the world. This means that, if external factors remain constant, the distribution of soil within a landscapes is a function only of age, that is to say the length of time of the systems's development. This is precisely the situation observed in certain recent systems (10,000 years old) in Chad which have been only very slightly disturbed by climatic and tectonic variations.

On the other hand, in ancient systems this type of distribution is liable to be modifield through a whole series of mechanisms. A change in external factors can accelerate or retard the biogeodynamic evolution of the system. Ancient pedological formations can participate to a greater or lesser extent in new development and can complicate differentiations (of cuirasses in particular). Catastrophic events (tectonics, climatic changes) can modify and even obliterate the traces of the ancient system.

In contrast a juvenile soil shows only the beginnings of vertical differenciation. It is strongly influenced by the nature of its parent material (Andosols and Eutrophic Brown Soils, for example). The systems in this case are not sufficiently developed to be discernible.

Pedological systems

These results agree with the regional data obtained during the second period of activity and complete the historical concept in soil geography. If the results of these detailed studies are collated with the whole mass of information obtained in small-scale synthetic soil mapping, analogies are revealed between the systematic distribution of various soil units at the scale of a catchment or landscape (local distribution) and the distribution of these same soil units at the scale of latitudinal and altitudinal successions in the relevant bioclimatic belts (zonal distribution). The order of succession is comparable, although relative area proportions of soils in the succession vary according to the climatic gradient. In tropical semi-arid areas, accumulation soils (Vertisols, Planosols and so on) are dominant. Passing towards increasingly humid areas, leached upslope soils begin to obtrude (Ferruginous Tropical Soils). On lower slopes accumulation soils are little by little replaced by Pseudogley Hydromorphic Soils, often with cuirasse or iron concretions. Even wetter areas, the domain of Ferrallitic Soils, are characterized by the dominance of eluvial profiles. Drastic leaching completely removes much material, the more soluble constituents often passing right to the coast where they are deposited (in some places helping to form mangrove swamps). In rare cases, Ferrallitic Soils may even disappear, leaving only quartz sands with podzolic differentiation. Bioclimatic zonality might therefore involve the successive dominance of each of the major soil units of a given general evolutionary system.

From the biogeodynamic standpoint, soils are no longer considered as the product of various environmental factors, to which their formation was classically attributed. Rather, soils are included in the totality of environmental features, with all of which they have close interdependent relationships. They are at the same time consequences and components of the environment. With its other constituents they form an ecosystem or biogeocenosis. In dry tropical regions with young topography soil differentiation reveals marked contrasts and provides favourable conditions for study. It is here that interpretations of biogeodynamic events can best be applied, and the approach can be interestingly demonstrated. In addition to the understanding of pedogenesis, this type of research contributes to our knowledge of the evolution of landscapes and the morphological, hydrological and hydrogeological consequences of that evolution. On the other hand, such research also serves to introduce into fundamental disciplines such as geology data on the origins of the diversification of the soil mantle. It prepares the way therefore for an experimental, and subsequently theoretical, approach.

Limits of the latest research

In other regions the application of the principles of biogeodynamics still appears to be rather problematical. In particular it seems that there are several risks attendant if too strict an application to the humid tropics is attempted. Here the evolutionary periods to be considered are often much longer in duration. Thus a 10,000 year period in an arid zone might be contrasted with several million years on an ancient humid zone landscape which is nonetheless still active and which has no intact equivalent in arid areas. One is thus led to recognize in ferrallitic environments two forms of pedogenesis, which have not as yet been reconciled :

— An old pedogenesis of very deep soils, in the top few metres of which one can observe evolution under the influence of present-day factors (climate, vegetation) although below that depth the features of the soil are congealed as a legacy of the distant past: such relatively unvarying and barren ancient subsoils can still be found today in certains situations. The final result is virtually complete removal of many constituents.

— A recent pedogenesis of relatively shallow soils, which are much more diversified and which often differentiate very rapidly, through impoverishment, hydromorphic phenomena, induration, etc. According to the relief, the processes involved can be essentially ones of net removal or of removal plus addition. The latter compare with the situation in arid zones.

— A complex form of pedogenesis occurs in all cases where there is interfingering between or a mixture of old and new profile features.

In arid regions where there is a water deficit, lateral differentiations are unimportant. They are mainly restricted to shallow depths and are principally vertical. It is the same with recent materials that are particularly liable to weather rapidly, such as volcanic ash which forms Andosols. One is thus obliged to return to a more classical pedological approach whenever one of the external environmental factors takes precedence over internal pedogenetic factors.

New directions

In order to clarify some of these points current mechanisms of soil evolution are being investigated. Focusing on carefully selected, simple landscapes relatively undisturbed by man, these studies have as their aim elucidation of the basic mechanisms influencing the first stages of the differentiation of soils. This work involves observation, direct measurements of the circulation of solutions (direction, distance, velocity) and measurements of the transfer of substances for which these mechanisms are responsible (method, intensity, speed of the reactions involved).

In agronomy the principal new lines of research concern land management. More holistic solutions, complementing and incorporating previously gained knowledge are being formulated. Responses adapted to advances in land use practices are being sought by processind and interpretation of data on soil and land. This is a rapidly expanding field of activity, about which it is difficult as yet to pronounce judgement.

Problem of soil classification

The ORSTOM classification of soils has not been modified but its specifications have been reappraised in the field. It has been found difficult to distinguish between the principal subclasses of Ferrallittic Soils. The concept of reworking has been applied with varying degrees of success and has been discussed. But even more than its content, it is the very principle of the classification that has been called into question. The aim of our classification is to provide, at one and the sametime, an unequivocal means of identification, and the support for our tenets. Is this a reasonable possibility ? The search for greater objectivity, a better framework for our approach and an increasingly representative tally of results are the main considerations which now shape our work. It is necessary to reconcile the idea of a landscape unit with that of a soil profile. This is a fundamental problem for the classification, which at present deals only with vertical soil differentiations and their interpretation. In addition, the morphological criteria adopted are for the most part visually contrasted enough to be distinguished, in theory, without ambiguity. But is this approach compatible with greater realism in our research ?

Our studies are revolving around these preoccupations. We are following up many different lines at once, including the collection of all manner of data relating to mineral and organic constituents of soils, horizons, profiles, landscapes and regions. A certain priority is, however, given to micromorphological and geochemical investigations, and to those concerning transfers of matter in porous media. At the same time, increasing importance is being accorded to soil structure and fabric studies and to a better characterization of soil constituents.

The 10th Congress of the International Society of Soil Science in Moscow provides an opportune occasion to bring the results and trends of our research face to face other movements and theories which pervade and enrich the contemporary pedological scene. We trust that this review, and the questions and problems that it presented, will enable our concepts to be better understood by our colleagues from other countries. It should also enable our ideas to be more exactly placed in the global context of soil science.

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