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PROJECT OF SOIL CLASSIFICATION

(PROJET DE CLASSIFICATION DES SOLS)

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PROJECT OF SOIL CLASSIFICATION
(PROJET DE CLASSIFICATION DES SOLS)

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FOREWORD

This publication "Project of Soil Classification" is issued in ISRIC's series of Technical Papers. Such papers are intended for dissemination of information on technical aspects of soil research, and range from standardization of procedures and terminology to case studies.

An earlier paper in the series is ISRIC's well-known "Field Extract of Soil Taxonomy" (Technical Paper 4), and the present paper may be considered as a sequel. It contains the English translation of the main text, as well as a selection from the appendices of the French language document on a possible new soil classification system for international use (O.R.S.T.O.M., Paris, 1979). The format of the Soil Taxonomy field extract has been retained, enabling to use the both texts side-by-side in the field.

The two Technical Papers as well as the propagation of the Legend Volume of FAO/Unesco's Soil Map of the World, find their place in ISRIC's programme of furthering the study and correlation of soil classification systems that have an international reach. The release of this English text may give renewed impetus to the elaboration of an International Reference Base for soil classification (IRB), under the auspices of ISSS, UNEP, FAO and Unesco.

ISRIC gratefully acknowledges O.R.S.T.O.M.'s permission to produce this English version of their working document. It also wishes to acknowledge the stimulating role of Prof.Dr. A. van Wambeke of Cornell University and of Dr. H. Eswaran of the USDA Soil Management Support Services. It is through their good services that the first draft translation was provided to ISRIC by the Science Education Administration of Agriculture and the National Science Foundation, Washington D.C., USA.

Wageningen, July 1984
Dr. W.G. Sombroek
Director ISRIC

1. INTRODUCTION

Thanks to the founders of pedology (V. Dokuchaev and his successors Sibirtsev, Prasolov, Glinka)[1], the fact that soil is the product of the effect of the environment on rocks, is established.

A "natural body" thus results, being well specified and characterized by its morphology, its physical, chemical and biological properties, which differentiate it from the parent rock. This natural body varies with the climatic conditions, vegetation, topography which adjusts drainage with time, and the effects of human activities.

A. PRINCIPLES OF SOIL FORMATION

ZONALITY LAWS

Russian pedologists derived a general law from these principles. This law is the "zonality law" according to which, one or several characteristic soils correspond to each bioclimatic zone. Later on, this law was split in a "horizontal" or "latitudinal zonality" law, in terms of which soils vary regularly with latitude, and a "vertical" zonality law. The latter law applies more specially to the mountain zones where analogous variations, but not at all identical to those found in the latitude, are observed.

Actually, horizontal zonality arises from an observation of the distribution of soils on a single parent material, widespread in Europe (also in North America). These are materials of glacier origin which were deposited and subsequently redistributed during the Quaternary.

The "normal" (or zonal) conditions were associated with a frequently loamy granulometry, a plane or a slightly undulate topography and a deep watertable. This was valid as well in Eastern Europe as in USA. Moreover, these materials were deposited during the relatively short period (on the geological scale) of the recent Quaternary. The result is that the only variables to be really taken into account were the present climatic conditions, most often responsible for the vegetative cover, in such a way that soils were rapidly associated with the bioclimatic conditions. However, it was soon observed that besides these "normal" or (zonal) conditions, other conditions also existed, mainly, the effects of steep slopes, of poor drainage conditions and of different parent rocks. The corresponding soils were considered as "intrazonal". Finally, properties of extreme youngness (for reasons of topographical, climatic order or of particular parent rock) help define "azonal" soils.

FORMATION FACTORS

Hence, the pedogenesis conditions were narrowly related to the soils themselves. The soils were not classified according to their proper characteristics but to their formation processes determining the soil characteristics. Therefore, one has only to analyze these factors,

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[1] These bases are found in the main books of pedology in Russian language, also in articles or textbooks (translated in English) by Gerasimov, Joffe, Vilenskiy and in other books.

especially the bioclimatic factors, to know the kind of soils. The classification of soils found then support on the study of the soil genesis. It was considered referring to the causal process:

Factors $\longrightarrow$ Processes $\longrightarrow$ Soil Characteristics.

It is surprising to observe that in the ancient and even in the modern systems, the reference to factors was done in particularly imprecise conditions. Even the reference to climate was over-simplified. It is not rare to find expressions, nonaccompanied with definitions, like *warm climate, moderately humid climate,* etc. This does not account for the great variety of climates encountered throughout the world.

Besides, the more thorough knowledge of the world soils leads to the evidence that the so-called "normal" formation conditions, concern limited zones only. Elsewhere, the topographical conditions and the parent rocks frequently vary very greatly as well as, especially, the time of pedogenesis. This time - often very short - starting from already weathered material, may be also immeasurably long. Whole geological periods may be involved instead of a few thousand years. During these periods, the same bioclimatic conditions have lasted withouth variation or even have changed several times. The soils which we see today are not necessarily related to all present conditions, but may be as well related to a distant past, on which one begins only to become correctly informed.

FORMATION PROCESSES

In order to palliate the above-mentioned difficulties, some pedologists[1] considered the processes, when they could not connect correctly the soils and the formation factors. The involved processes include the accumulation of organic matter, salinization, hydromorphy, silicification, alkalization, rubefaction, "lessivage" and many other ones. In most cases, these concepts are useful to understand what happens in nature, without providing a precise knowledge of their content. Experimentation of these concepts is rarely possible, since several parameters have to be controlled. Thus, it is quite rare that all natural conditions be reproduced in the laboratory. Therefore, in this domain, it is very difficult to get real certainties.

The lessivage process appears to be relatively simple to many West-European and American pedologists, for whom lessivage is the transfer into the profile (and/or outside of it) of fine particles which leave a horizon to accumulate into another. This operation, of commonplace appearance, was difficultly allowed (if still so) by some Soviet pedologists who considered the whole operation as an alteration of the clay minerals followed by a migration of matter in the ionic or the complex form, followed by the recombination[2] of these elements in a reception horizon. But, even when it is assumed that an agreement is obtained on the process, its definition is not an easy job.

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[1] Aubert, 1954; Aubert and Duchaufour, 1956; C.P.C.S. 1967.

[2] See for example, Fridland, 1958; Rode, 1964.

Other processes have to be considered as well as dissolution, hydrolysis, chelation, oxido-reduction, etc.. While the general principles are well-known and determined by laws (like those of Goldberg-Waage or Nernst), the exact way in which they apply to soils is far from being suitably elucidated. The way in which the different metals and silica migrate in soils, the way and the reasons of combinations leading to clay minerals, to hydroxides and to salts are as much questions of renewed actuality, receiving only general answers, while consequently, many necessary precisions are still lacking. The references to the processes are often variable and lead to interpretations which change according to observers. Besides, they are often expressed in vague terms, insufficiently based on concrete data. In this case as well, the limits of the effects of the processes are rarely given and the choice is finally left to the pedologist who is motivated by his personal opinions[1]. Moreover, soils were submitted in many cases, to several successive processes, of which only the final result is known. Thus, it is erroneous to explain the genesis by a single process alone.

B. SYSTEMS OF OBJECTIVE CLASSIFICATIONS

EVOLUTION OF OBJECTIVE CLASSIFICATIONS

The encountered difficulties regarding factors and the processes of soil formation were hard to overcome by many scientists. They lead to concentrate on effects instead of causes. The precursors in this domain are undoubtedly Huguet Del Villar and De Sigmond[2] who, as early as 1932, gave a classification of soils based on constituents. Later on, analogous positions were adopted by Leeper[3] who, in 1954, felt the necessity of a "revolution", and by USDA[4]. As early as 1951, this organization started a complete remodelling of the American classification of soils, leading since 1960 to the 7th Approximation which preceded the present "Soil Taxonomy". In Australia[5] appeared the Factual Key of Northcote, then the Constitutional Classification of Fieldes in New Zealand[6], etc., while FAO-UNESCO[7] gave a list of soil units, on a binomial basis, defined (with few exceptions) by intrinsic criteria of the soils, mostly taken from the 7th Approximation.

Meanwhile, many European countries remained faithful to the former genetic systems. However, Mrs. Conea[8] of Rumania made an attempt of classification in which appear diagnostic horizons, close to those of Soil Taxonomy or of the FAO-UNESCO list. In Zaire (previous Congo), Sys et al.[9] gave a classification in which mineral constituents appear at the highest possible level.

Although the obtained results were quite different, sometimes even disappointing, the starting point of the classification is always the same. The soil is considered as an object, i.e. according to its proper characteristics,

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[1] Strongly condemned by G. Smith, 1962, 1965.

[2] Huguet Del Villar, 1932, De Sigmond, 1938.

[3] Leeper, 1954.

[4] USDA: 7th Approximation, 1960; Soil Taxonomy, 1975.

[5] Northcote, 1960-1962.

[6] Fieldes, 1968.

[7] FAO-UNESCO, 1974.

[8] Conea, 1974.

[9] Sys et al. 1960.

independent of preconceived ideas. The results were quite different, since the followed aims were different. In most cases, it was, in the first place, necessary to classify the soils of a particular geographical zone of a country of limited area and not the totality of the soils of the globe (even for Soil Taxonomy). Some authors consider that the system is aimed to the satisfaction of the needs of given users[1]. Therefore, Soil Taxonomy, while being based on objective and scientific data, has in the first place a pragmatic purpose. This limits the scientific range, for example, by declaring that the pedon only concerns the zone involved by the roots and that, anyway, it cannot exceed 2 meters.

However, the premises were often excellent. Simonson[2] recommended the reference to the morphology and to the constituents of the soils. American pedologists opened the way by refining the definitions of the horizons and the description of the profiles. Fieldes[3] pushed very far the analysis of mineral constituents. A reference volume, the pedon[4] was proposed to contain all constituents and all necessary properties for the characterization of a soil unit.

New languages were created, either by using juxtaposed syllables, or by using binomials, similarly to names of genera and of species in botany, or by using real formulae, combining letters and numbers.

DISADVANTAGES OF THE EXISTING SYSTEMS

None of the existing systems can be considered as having completely solved the problems posed by the classification of soils. It seems that this is due to the reference which is too restricted to a given geographical region and to the particular orientation given to the systems (genetic or pragmatic).

An excessive importance was attributed to the morphology of soils and also to the soils of the temperate zone. Thus, Russian authors confer a greater importance to the chernozem and the podzol, while North American authors give their preference to the mollic epipedon and the argillic horizon. Besides, it may be sorry that the Russians attribute an exaggerated importance to the bioclimatic conditions and that in Soil Taxonomy, a too strong stress is laid on the climatic, moisture and thermic regimes[5].

On the other hand, the mineral and organic constituents of soils were assigned a very modest role, although these constituents were long ago recognized as primordial criteria of the formation processes of the soils and of their properties.

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[1] G. Smith, 1962.
[2] Simonson, 1962.
[3] Fieldes, 1968.
[4] Simonson and Gardiner, 1960; Johnson, 1963.
[5] Proposed at different levels, from the order to the family.

The classification should be *coherent*. The entries into the different categories should be always done in the same way. Soils of a given country or of a particular geographical zone or the effect of a particular process should not be especially favored. The retained units have to be defined in the same manner, without attributing a higher importance to a parent rock or to a topographical position, by incorporating soils of all ages. The retained criteria for each unit shall be defined in the most objective way. This means that whenever possible, codes or measurements[1] shall be used. As a result, it is desirable that the soil be connected, not with its formation factors or processes, which are used or interpreted differently by the various pedological schools, but rather with the visible, tangible and measurable results, due to the effect of both factors and processes. This, therefore, leads to giving a particular importance to the soils inherent criteria: to the constituents, to the morphology and to the physicochemical characteristics. It seems that this is the only way of avoding the personal interpretations which often distinguished the use of classifications.

SPECIFITY OF THE CHARACTERISTICS

One of the greatest difficulties of any classification is the identification of the individuals, at each level of the classification. This includes the precise definition of the specific characteristics of each unit. The presence of all of them proves that one is actually dealing with the particular unit concerned. The absence of one of these specific characteristics and the presence of another mean that the considered soil automatically belongs to another unit[2].

A particularly great effort should be undertaken in order to decide on the limits of a unit. If this purpose is attained, the main objective is also attained, the latter being to avoid that many classifications lead to different names or ranks when applied to the same soil. This necessitates a precise definition of the criteria but may lead to a certain amount of arbitrary rigidity. This rigidity may be corrected by successive approximations.

SETTING OF THE CLASSIFICATION

In order to set up the classification, field and laboratory data are to be used.

In the field, all necessary observations on the pedon are conducted as well as on the soil cover which it helps to characterize. The pedon is decomposed in a certain number of horizons where definite characteristics are observed and described according to standardized determination methods[3]. A suitable number of horizons, not too small, has to be obtained and used to reconstruct the pedon.

The mineral and organic constituents are identified and quantitatively determined in the laboratory when the process is necessary and possibly carried out. Their

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[1] Dijkerman, 1974. This does not mean that all difficulties will suddenly disappear. But it is supposed that an objective approach helps to solve a number of difficulties.

[2] For example, in Soil Taxonomy, see the definition of the mollic epipedon.

[3] Characteristics like structure, consistence and porosity are difficult to codify but they are always important for the identification of horizons and of soils.

structural organization is examined by the microscope. Measurements are also conducted on certain properties like pH, cation exchange capacity, degree of base saturation and granulometry, all being necessary properties for a sufficiently accurate characterization of the horizons.

When all these data are collected, a place may be assigned for each soil in the classification system. A careful choice should be done for each soil; this care allows to avoid a priori interpretations and to solve the problem of the limits, rarely satisfactorily approached in genetic classifications.

Finally, the examination of the soil itself and of its characteristics at a given moment should be completed by finding and analyzing complementary data withouth which our knowledge is incomplete. This should finally lead to two objectives: genesis and use.

GENESIS

The first objective is to provide the explanation of the soil *genesis* (or pedogenesis). This necessitates, not only a knowledge of the present environment of the soil, but also that one tries to rediscover the biogeographical events of the past: climates, vegetations, position and modifications of parent rocks, modifications undergone by the relief, time during which other conditions have prevailed. Briefly, one has to try to reconstitute the history of the pedogenesis medium within the available limits in order to get a better understanding of how the past was able to influence the present. One should also consider the relations between the soil and its neighbours and examine the landscape in which the soil exists and determine the soil-landscape group to which the soil belongs.

USE

The second objective is the proposal of different *use* possibilities of the soil. This necessitates the search of supplementary data of the soil itself, as for example, hydrodynamic data, the number and nature of stones contained in the soil, the variations of different properties[1], the slope, the vegetative cover, the effect of soil utilization by man, the dynamics of soil evolution in the landscape. One should also know the actual climatic data and determine the risks of dryness and of frost and know the seasonary or annual insolation, index and analyze data (whenever they exist) relative to agronomical tests, already conducted on the studied soils. Only after obtaining all these data, a certain number of assumptions can be emitted and proposals for the utilization of soils can be formulated.

D. CONCLUSIONS

Such dealing with the question results into a classification of soils having the merit of being an objective element of their knowledge. It is thus independent of any particular scientific theory as it is derived only from observations, determinations or measurements, which anyone can do or repeat. The personal influence is reduced to a minimum. Thus, our project of soil classification should allow the obtainment of a system which is:

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[1] As for example, the exact thickness of horizons.

comprehensive: because it acknowledges all criteria.
natural : because the soil subject is defined by criteria having natural limits and not by an artificial selection of the criteria.
coherent : because the system is based on hierarchical criteria and treated on a particular taxonomical scheme.
universal : because the system is valid for all times and all countries.

This leaves a free hand for the two domains where the research worker's or of the practician's personality can have a determining effect: the explanation of the soil genesis or of the choice of a mode of utilization. Thus, the primordial objective is the following: classify well so as to be universal, allow a better understanding and a better utilization. Briefly, an extrapolation of knowlege is achieved.

2. OBJECT OF CLASSIFICATION

From the very beginning of the soils' classification, the factors and formation processes of the soils were alternatively privileged. In the USSR and in other European countries, this alternation is actually followed. For Joffe[1], for example, the notion of soil and that of processes are undissociable. For the many reasons given in the introduction, the attempt is not to neglect the factors and processes but only to account for the results of their effect, i.e. the soil as it is accessible to the observer.

PROFILE

The term *profile* has been used for a very long time. For Marbut[2] it is the most suitable entity for the study of the soil. It was generally subdivided in two parts: the *solum*[3] which comprises the horizons resulting from the pedological differentiation itself, surmounting a rather badly defined part which can be compared with the *parent material* which will be defined later[4]. The Soviet authors[5] speak of *soil itself* and of a *weathering crust*. This notion of profile does not always appear as the best[6] since it implies a two-dimensional body whereas three are clearly necessary to characterize a structure or the arrangement of the rooting zone. Therefore, the notion of pedon, proposed by the American pedologists since 1960[7], appears quite suitable.

PEDON

The *Pedon* is "*the smallest volume of soil to be recognized and sampled in order to represent the nature and arrangement of its horizons and the variability of its properties which will be contained in the samples*"[8]. The problem of the soil depth seems difficult to solve. Some authors propose 1.5 meter while Soil Taxonomy[8] gives 2 meters. Boulaine[9] adopts the term pedon and defines it as "*the necessary and sufficient elementary volume to define at a given moment the whole structural characteristics and constituents of the soil. The lower depth is the geological structure, unaffected by the dynamics of the living matter*".

The notion of pedon seems to be entirely valid in both definitions. It is particularly valid in the Boulaine definition which refers to the morphology and constituents, *at a given time*, which should be that of the observation.

However, the lower depth limit is difficult to define. In current practice[10], it is difficult to go beyond two meters, especially in the intertropical zone. Big road works or railway trenches involve only a very small area of the territory which has to be mapped. Besides, the

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[1] Joffe, 1948.
[2] Marbut, 1928.
[3] USDA, 1951.
[4] Chap. 4.
[5] Gerassimov, 1968.
[6] Jones, 1959.
[7] USDA, 1960.
[8] USDA, 1975.
[9] Boulaine, 1969.
[10] Particularly during soil survey.

ditches of more than two meters are very expensive. For this reason, this depth has to be considered as a sufficient one during the working out of the groups and the subgroups. Nevertheless, one has to account for the whole profile whenever the possibility arises.

The profile ends with the parent rock or the parent material and not with an arbitrarily chosen level. The limit of the proposed biological effects[1] to describe and define the profile is very vague and cannot be taken into consideration. While all soils are influenced by effects of biological origin, the abiotic weathering is certainly important in the intertropical zone and it is not easy to differentiate between the biological and the abiotic effects.

Consequently, even if all characteristics provided by USDA are not retained here, particularly the one concerning depth, it is assumed that pedon is the best term to designate the needed unitary volume. In order to solve the practical problems posed during cartography, three pedon subdivisions are proposed (p. 19 and following).

POLYPEDON

The soil individual is the smallest unit *which is possibly cartographed* and which may help in the classification. It is formed of one or several contiguous pedons and limited by different pedons or nonsoil. This notion of polypedon is to be compared with the *genon*[1], while the *pedogenon*[2] is a landscape unit capable of including one or several chains of soils.

CHAIN OF SOILS

The notion of soil chain goes back to the studies of Milne[3], in East Africa. It implies that on a slope, the different observed soils are genetically related to each other, some constituents of the lower parts being formed with elements coming from upstream. In soil chains, a given succession of soils may be observed, as already demonstrated by different authors[4,5].

Some soil surveyors have proposed to take chains or sequences of soils as basic units for the classification of soils as well as for cartography. But such units are not necessarily those of the classification. These units may be founded on the combination of several members of the classification. They may also involve the use of data concerning vegetation or topography. Phytosociology has also adopted units which are not those of the flora. But it is not possible for a phytosociologist to ignore the flora and the classification of plants.

CONCLUSIONS

The object for classification in the present attempt is the pedon, representative of a polypedon the smaller cartographic unit. This pedon is the elementary volume containing all the soil properties, its constituents and

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[1] Boulaine, 1969.

[2] Lamouroux, 1967.

[3] Milne, 1935.

[4] Bocquier, 1973; Boulet, 1974; Ruellan, 1971.

[5] But, it must be understood that it is possible to have succeeding soils on a slope without transport of matter, realizing sequence of geomorphological, climatic or lithological nature.

morphology, and extending to the parent rock. Thus, a natural body is defined, limited in space at a given known moment. This natural body helps to determine the different subdivisions of the considered system.

It is quite possible to analyze at different scales the components of the different subdivisions of the system and to push this analysis as far as it seems necessary. It is also possible to regroup the pedons according to the observed sequences on slopes in the catchment basins or still, in whole regions. The geomorphological and/or geographical significance of the units which were thus associated are particularly interesting. But, a reference for the identification of the elementary components is a different problem from that of the classification of soils.

3. CHARACTERIZATION OF THE SOILS

3.1 INTRODUCTION

The characterization of soils and their classification require the analysis and the taking into account of two fundamental data:
- the mineral and organic constituents,
- the morphology of soils through the horizons.

During the soil formation, the horizons gradually develop from the minerals inherited from the parent rock and/or as fast as the secondary minerals and organic constituents are formed. This morphology-constituents order may help in building the classification, because it is difficult to deal with the constituents and the morphology at the same time, even if it is certain that the soil is an entity.

CONSTITUENTS

During the last thirty years, considerable progress was realized in the field of the identification of mineral constituents[1]. In addition to the traditional chemical methods (but which did not loose their interest in many cases), several other methods are added, which allow the identification and the localization of mineral species. Now, microscopy, using natural or polarised light, enables an examination of microstructures. Thermal analysis, X-ray diffraction, absorption in the infrared band, electron microscopy, the use of microscanners, and of Mössbauer spectrometry gradually enter in the current or occasional laboratory techniques. The elementary analysis has also progressed through new techniques, often automatic, like coulometry, colorimetry, atomic absorption, arc or flame spectrography.

All these techniques, using increasingly cheaper material, allow fast determinations which are often quantitative.

With regards to the organic constituents, appreciable progress was realized, but not to the extent reached by the mineral constituents. In the first case, it is possible to identify the mineral species for which exact formulae can be assumed, or at least, structures related to well-defined behaviors. In the second case, fractions, obtained by the treatment of humus horizons are currently isolated by using chemical reagents and conventional techniques. Considerable efforts remain to be done in this domain in order to obtain the standardization of the extraction techniques and a characterization, analogous to that of many mineral constituents. In this respect, Mac Carthy[2] has enunciated: "Although these materials drew the attention of scientists during about two hundred years, a relatively small progress was accomplished in the elucidation of their chemical nature...". Until now, only fractions for which the characteristics and the behaviors can be grasped are obtained. The knowledge of molecular weights, of functions and of the exact structure seem to be rather afar.

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[1] Data concerning the nature, genesis and the evolution of the mineral constituents of soils which will be mentioned in the following pages are due to the studies of G. Millot and his collaborators, of S. Caillere and S. Henin, of G. Pedro and to those of many other mineralogists.

[2] Mac Carthy, 1976.

In the present state of knowledge, it is possible to identify some mineral constituents and to classify them. In order to recognize the clay minerals, hydroxides or oxides, or salts, it is not at all necessary to propound hypotheses concerning the conditions of their formation and on the prevailing conditions during their genesis. The observed proper characteristics, especially the measurable characteristics are quite enough. With regards to the organic constituents, knowledge is much less advanced and only a more summary identification is possible.

MORPHOLOGY

It is not easy to obtain immediately a global morphological characterization of the whole pedon. Therefore, it is necessary to decompose the pedon in a given number of horizons which allow the identification of the whole pedon.

The characterization of horizons compels that of the reliable measurable and observable criteria, and not that of the factors and processes which lead to their formation. For this purpose, a choice should be made among the possible criteria (which are too many) for those which are the most easily accessible to measurement and observation and also for those which enable an easy distinction between the horizons.

The chosen criteria allow to identify and to name the horizons. The obtainment of these characteristics is the main purpose of this classification.

This research of the characterization of the horizons was done in different trials of classification. In this study, many references will be made to Soil Taxonomy[1], where the definition of the diagnostic horizons was the object of advanced studies. Reference will be also made to trials of characterization done by Fitzpatrick[2] and by Chatelin and Martin[3].

3.2 SOIL CONSTITUENTS

A. MINERAL CONSTITUENTS

The mineral constituents in the soils may have three origins: inheritance, transformation and synthesis. In most cases, the attempted distinction is judged as true. But, it is not excluded that different origins may be possible for a same constituent (for example, hematite may be inherited from a volcanic product and as well, synthesized in the soil).

INHERITANCE

Certain constituent minerals of the rocks are not (or scarcely) modified by the weathering processes. These minerals are not dissolved and are not subject to hydrolysis. They are not affected by the changes of the redox potential or modified by the organic chelating agents. The most important is certainly *quartz*[4], abundant in a number of acidic rocks. Among the nonaltered or slightly

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[1] USDA, 1976.

[2] Fitzpatrick, 1971.

[3] Chatelin and Martin, 1972.

[4] It is useful to recall that the solubility of quartz is very low (3 to 6 ppm); however, it may play an important role in the mineral syntheses (Fauck, 1973; Claisse, 1972).

altered minerals in the soils, magnetite, ilmenite, rutile, apatite, zircon, metamorphism silcates can be mentioned among others.

Slightly soluble minerals may exist in soils, e.g. calcite or dolomite, which are directly yielded by the underlying rock. This may be the case of different unstable silicates (such as feldspars, micas, chlorites, pyroxenes, amphiboles...). In both cases, this presence of minerals, weatherable by dissolution or by hydrolysis, should be considered as a sign of youthfulness[1] or at least, of a slight evolution, still going on.

Some clay minerals may be also considered as inherited minerals. In certain soils, derived from calcareous rocks, or from clayey sediments, only the process of dissolution of calcium carbonates is concerned. The clay minerals which accompany calcium carbonates in the rock are delivered to the soil to which they become incorporated without undergoing immediate modifications. This is the case of some rendzinas. It is also the case of soils derived from loess, and different materials of transported origin.

TRANSFORMATION

A number of primary or secondary phyllitic minerals suffer minor modifications such as the displacement of some metals, of interfoliar cations, charge modifications, etc., without a fundamental perturbation of the foliate. This is the case of the passage from biotite to the trioctahedral vermiculite and from vermiculite to montmorillonite. These transformations, called *degradations*, are often done through interstratified minerals. They correspond to moderate alteration conditions and are frequent in soils of the temperate zone. But, they may be observed elsewhere. *Aggradations* also exist where the initial minerals fixmetal ions or hydroxylated ions. Vermiculites and smectites are liable to fix inbetween the foliates "packages" of hydroxides. These discontinuous supplementary masses impart to the minerals a higher basal spacing with a chlorite behavior which may be also suppressed by treatment with an appropriate reagent (caustic soda, sodium fluoride solution, etc.).

SYNTHESIS

In many cases, there is a fundamental difference between the structure of the primary and that of the secondary minerals. For example, feldspars have a tridimensional structure bearing no relation with the phyllitic structure of the minerals produced during weathering. This leads to assume that the complete destruction of the first is necessary before the building up of the second, with a part of the elements (Si, Al, or Fe, Mg or K), while others are eliminated. A spectrum of new constituents is thus gradually created. Although the synthesis seems to have a modest role in the temperate zone, on the contrary, it predominates in the intertropical zone. The constituents which are thereby synthesized belong to the following categories: salts, zeolites, clay minerals, oxides and hydroxides.

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[1] Deposition by winds, waters or glaciers, of fresh minerals at the upper part of the profile.

SALTS

All very soluble salts existing in soils are brought through solution and transferred in the ionic form[1] (sodium chloride, sodium sulfate, sodium carbonate, etc.). The solutions are provided by sea water, by the continental waters circulating in the depth, or near to the surface through sediments, even those very weakly salty. These solutions concentrate near to the surface or in its proximity. When the concentration exceeds the limit of salt solubility, according to temperature and the other present salts, precipitation takes place. This precipitation may happen in the form of a discrete and diffuse deposit at different soil levels; crystals may be seen in the slits or between the aggregates. In other cases, individual masses, capable of getting generalized in saline crusts near to the surface, may be obtained.

Moderately soluble salts, like *gypsum*, arise from solutions which were charged with ions while seeping through sediments rich in gypsum, or still, during the weathering of basic volcanic rocks. The concentration of these gypsum containing solutions increase in presence of salts without common ions (like sodium chloride). When concentrations attain or exceed the gypsum solubility, gypsum precipitates in the soil in the form of isolated crystals of small weight (sometimes in rose form) or in almost continuous layers.

The *calcite* solubility is much lower than that of the previous salts but it is appreciably increased by the presence of carbonic gas. Carbonate is then converted into calcium bicarbonate and HCO_3^- and Ca^{2+} ions are transferred by water. But calcite of rocks is not the only calcium source. The weathering of the plagioclases, of some amphiboles, pyroxenes or garnets, yields also bicarbonate and calcium ions which are transferred by the solution. A temperature rise is enough to produce a loss of water and/or carbonic gas and the precipitation of calcium carbonate. The latter may assume discrete forms (very fine crystals, invisible to the naked eye, or pseudomyceliums), or on the contrary, discontinuous masses, whether indurated or not (nodules, concretions) or even in the form of continuous masses (hardenings, crusts).

ZEOLITES

These minerals, whose structure recalls that of feldspar, are only recently known in soils. They are encountered in very alkaline soils. They result from the weathering of basic rocks. They have been identified in Zaire, California, Italy. The hydrolysis of primary silicates yields bases, silica and aluminium, which recombine to give zeolites like *analcime*, *philipsite*, etc..

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[1] Soils directly derived from a saline sediment rich in sodium or potassium chloride may be considered, like those existing in different geological layers; nevertheless, the case is rare and limited to some open sky salt ores and to the levelling of diapirs of the Triass.

FIBROUS CLAY MINERALS[1]

These minerals are formed by the joining of laths analogous to those of amphiboles, and separated by voids. They are mostly magnesian or alumino-magnesian, seldom ferruginous. For a long time, it was believed that these minerals were produced only in a logoonary supersalted medium. It is by now known that they are also formed in soils in arid or semi-arid continental conditions, in association with secondary saline accumulations[2] and where pH is distinctly alkaline (9 or higher)[3].

PHYLLITIC CLAY MINERALS 2/1/1 OR 2/1

These minerals may have different origins, inheritance from rocks, transformation or synthesis. In several cases, the origin is not determined.

Chlorites and *pseudochlorites*. The ferrous and magnesium minerals are normal components of some metamorphic rocks. But, it is also known that trioctahedral chlorites are the weathering products of various ferromagnesians and that chlorites or aluminous pseudochlorites are more and more frequently identified in soils.

These minerals are identified by using X-ray diffraction. The basal spacing is 14 Å and is not changed by heating to 500°C or by treatment with polyalcohols. When pseudochlorites are treated by alkaline or complexing reagents in order to eliminate the interlayered hydroxide packages, they lose their chlorite property to assume that of a smectite or that of a vermiculite.

Illites. These minerals give a 2/1 layer near to that of micas. But the charge is 0.6 because of substitutions of Si^{4+} by Al^{3+} in the tetrahedral layer. Replacements of Al^{3+} by Fe^{3+} may also take place in the octahedral layer. The charge deficiency is mainly compensated by K^+ ions which are located in the hexagonal cavities of the layers and impart to them a certain rigidity.

Illites are observed in various soils of the temperate zone, as well as of the intertropical one. They may result from size reductions and from the degradation of micas, or by synthesis from elements of other minerals.

The basal spacing is 10 Å. It is not modified by heating at 500°C, neither by treatment with polyalcohols. The cation exchange capacity is close to 30 meq/100 g.

Vermiculites have a 2/1 layer where the charge is 0.5 to 0.7. Substitutions of Si^{4+} by Al^{3+} take place in the tetrahedral layer. Magnesium, iron, aluminium may be present in the octahedral layer. The charge deficiencies are abundant and are compensated by the cations, especially hydrated magnesium. Vermiculites are frequent in soils of the temperate zones and are more seldom encountered in those of the intertropical zone.

The basal spacing is 12-14 Å. On heating to 500°C, it is reduced to 10 Å, but treatment with polyalcohols has no effect. The cation exchange capacity is higher than 100 meq/100g.

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[1] For a complete study of the clay minerals, refer to the books of Grim, 1953; Cailliere and Henin, 1964; Millot, 1964; Pedro, 1965.

[2] Ruellan, Millot, Paquet, 1969; Lamouroux, 1972; Eswaran et al., 1974.

[3] Quantin, 1976.

Smectites have a 2/1 layer and a charge of 0.2 to 0.6. Two categories of minerals may be distinguished according to the localization of the substitutions. When they only take place in the tetrahedral layers (Si^{4+} by Al^{3+}), with an aluminous octahedral layer, a ferro-aluminous layer, or a ferruginous layer, we get beidellite, ferriferous beidellite or nontronite. If the substitutions mainly occur in the octahedral layers (Al^{3+} or Fe^{3+} by Mg^{2+}), we then have montmorillonite or ferriferous montmorillonite. Saponites present a mixed structure. These clay minerals are encountered in soils of the temperate and intertropical areas. They can result from degradation or aggradation.

The basal spacing is 12-14 Å. On heating to 500°C, it reduces to 10 Å. Treatment with polyalcohols increases it to 16-18 Å. The cation exchange capacity varies from 50 to 120 meq/100g.

1/1 PHYLLITIC CLAY MINERALS

These minerals include two categories: *serpentinites* which contain magnesium alone in their octahedral layer and *kandites* which contain aluminium alone in this layer.

The magnesian minerals have a layer where all octahedral sites are occupied by magnesium. They almost always derive from the weathering of ultrabasic rocks, such as peridotites for example, which are rich in magnesian minerals, olivine or enstatite. Serpentinites involve several varieties like antigorite, lizardite, chrysotile. Their basal spacing is 7 Å.

Aluminous minerals have an octahedral sheet where two sites out of three are occupied by aluminium while the third is empty. An important distinction may be made between kandites, according to the presence of water between the layers (halloysites) or its absence (kaolinites). The base exchange capacity is higher for the first minerals than for the second ones, being higher than 30 meq and lower than 10 meq/100g, respectively.

Halloysites are minerals which are very often associated with the weathering of rocks of volcanic origin and are also abundantly observed in soils derived from calcareous parent rocks. Their basal spacing is 10 Å. On heating to 100°C, it is reduced to 7.3 Å. Metahalloysites are dehydrated tubular forms with 7.3 Å spacings.

Kaolinites are very widespread in soils of the intertropical zone. Their basal spacing is 7 to 7.2 Å. On heating to 500°C, the lattice is entirely disturbed and no peaks are observed.

AMORPHOUS ALUMINA SILICATES

Some minerals in relation with the weathering of volcanic glass, are known under the name of *allophanes*. They contain variable ratios of silica, alumina and water. Their base exchange capacity varies much with pH. A simple test was proposed by Fieldes and Perrott[1] to identify these silicates in situ. The inner structure of these substances is still debated but of no regular patterns to yield a definite X-ray diffraction spectrum. The allophanes are always tightly associated with organic matter.

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[1] Fieldes and Perrott, 1966.

Imogolite is a fibrous mineral observed by electron microscopy[1]. In X-ray diffractions, humps are observed at 12-18, 7.8-8 and 5.5 A.

The cation exchange capacity varies much with pH[2]. The changes between pH 3.5 and 7 may reach 100 meq/100g.

OXIDES AND HYDROXIDES

Ferruginous minerals. Two oxides[3] are formed in soils:

α-Fe_2O_3, *hematite*, of red color, nonmagnetic, very widespread in soils of regions with a long dry season.

γ-Fe_2O_3, *maghemite*, of dark color, magnetic, rather scarce.

Two hydroxides also exist:

α-Fe OOH, *goethite*, yellow-orange color, widespread, especially in soils of regions with humid climate.

γ-Fe OOH, *lepidocrocite*, also of yellow-orange color, scarce, but identified in hydromorphic soils, andosols, podzols. Only hematite and goethite are commonplace constituents of soils[4].

Amorphous ferruginous products, called *stilpnosiderite* are known, but of no determined formula.

Aluminous minerals. Only hydroxides are found in the soil (when oxides are found, they are inherited from certain schists). *Gibbsite*, $Al(OH)_3$ is frequently found in many soils of the intertropical zone. It is also known in some soils of the temperate zone. *Boehmite*, γ-AlOOH is less abundant and often found in the cuirasses also associated with limestones, etc. The α-AlOOH diaspore is practically unknown in soils.

Among the dioxides, those of silicon, titanium and manganese can be cited.

Silica may be synthesized in soils in the form of secondary quartz, for example in some soils derived from peridotites and especially in accumulations in arid zones (silcretes). Silica may also appear in the form of opal, which may be considered as a hydrated cryptocrystalline form. Siliceous products of plant origin also exist as shown by the diatomaceous test and by the phytolites.

Titanium and *manganese* are most often observed in the form of TiO_2 and MnO_2, more or less well crystallized and hydrated.

Finally, we have to report the presence in a few soils (often in the form.of oxides) of metals such as nickel, chromium, cobalt, vanadium... .

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[1] Yoshinaga and Aomine, 1962.

[2] Aomine and Jackson, 1959.

[3] Magnetite, Fe_3O_4 is a slightly weatherable spinel in certain basic rocks and not a product of pedogenesis.

[4] To these minerals was recently added *ferrihydrite* $Fe_5(OH)_8 \cdot 4H_2O$ of rusty color, akin to amorphous products, also frequent in podzols and in certain hydromorphic soils.

B. ORGANIC CONSTITUENTS

The knowledge of the organic constituents of the soil did not progress to the same extent as that of the mineral ones. In fact, the isolation and identification of natural compounds corresponding to a given formula or elementary composition, is not yet achieved. This is due to the complexity of animal and plant organic matter and to the complexity of transformations affecting them in the soil, as well as the number of products covered by the term "*humus*". Until now, artificial fractionations of organic matter were done by using chemical solvents or reagents (caustic soda, phosphoric acid, pyrophosphates...), known to often modify the fractions in question.

Two methods can be used:

a) *Total determination*. This method is known since long, very fast and very rough. It allows to obtain the total carbon and nitrogen content and the ratio C/N which gives a very plain idea of the degree of evolution of the organic material. In addition to these determinations, there are also the pH, the degree of saturation, the color, the thickness of the humus horizon. All these data may be expressed by exact values, easily reproducible with minimum error. They allow a fast and simple characterization of the soil organic horizons. Because of their objective character, they were incorporated in many classifications.

b) *Fractionation tests*. They were long ago applied in the USSR, and in France, mainly in the Biological Pedological Center of Nancy (Duchaufour and his collaborators).

Duchaufour[1] indicated that "the fractionation methods in use are often approximate and difficult to explain". Observations of the same kind were frequently formulated, particularly by Ponomareva[2] or by Mac Carthy[3]. The latter author has thus expressed the need of international common efforts to bring the necessary harmony in the extraction techniques and the definition of the obtained products. In fact, it seems that different solutions are used for the treatment of organic material and that the adjustment of the modifications taking place during the operation is difficult.

The main fractions will be given below, as they were described by Duchaufour[4].

Fulvic acids (FA) and *humic acids* (HA) are extracted by a solution of sodium pyrophosphate or of diluted sodium hydroxide. Fulvic acids are not precipitated by acids (such as N H_2SO_4) while humic acids are precipitated by acids. Two humic acid types are distinguished:

Brown humic acids are slightly condensed, relatively labile. During paper electrophoresis, they migrate towards the anode (Jaquin)[5].

Grey humic acids, more strongly condensed, bound to the clay, do not migrate, or very slightly, during paper electrophoresis. They resist strongly to biodegradation factors.

The nonextracted fraction is that of *humin* which represents from 50 to 70% of the total organic matter. Various authors[6] distinguished many kinds of humins:

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[1] The main part of the following definitions is taken from the most recent textbook of Duchaufour, 1977.

[2] Ponomareva, 1964, 1969.

[3] Mac Carthy, 1976.

[4] Duchaufour, 1977.

[5] Jaquin, 1964.

[6] Duchaufour, 1973; Perraud, 1971.

Inherited or residual humin (H_3) is still very close to the fresh organic matter. It forms slightly stable bonds with the clay. It may be separated by the effect of ultrasonics and by densimetry.

Insolubilization humin arises from the irreversible precipitation and insolubilization of the soluble forerunner substances. They are separated in two fractions: fraction H_1 extracted with caustic soda after treatments (HCl-HF, dithionite); the other fraction H_2 is not extracted.

Microbian humin, results from the microbian neoformation in a very active medium (polysaccharides, polyuronides, aminosugars).

Developed humin (by maturation): humin with aromatic nucleus, very strongly polycondensed, poor in functional groups and resistant to normal extraction reagents.

In spite of the difficulties reported by Duchaufour, these different fractions are extracted from the humus horizons of soils and can be used for characterization. In literature, we often find the term fulvic acid, gray and brown humic acids and humin. But do they correspond to the above-given definitions? Very rare trials of fractionation of humin were conducted.

Consequently, in the present state of knowledge, the reference to these humic fractions encounters two difficulties:

- The first is related to the extraction method, characterization and finally, the exact definition of each fraction which is particularly interesting. It is quite desirable that the methodological standardization recommended by Mac Carthy[1] be carried out.
- The second concerns the lack of data. These fractions were studied in different countries or laboratories (e.g. USSR, France, Canada, Germany). But it is certain that determinations lack in many countries and in many soils[2]. The examination of the humified matter is not yet systematic as for the mineral constituents. It will be so when the first difficulty is overcome.

Consequently, much work is still to be carried out by workers in the field of soil organic chemistry to make up for the lag which separates the identification and characterization of the mineral and those of organic constituents. Meanwhile, it seems preferable to stick to the carbon percentage, the thickness, the color and the degree of saturation of the humus horizon. However as soon as they are conveniently known, the nature of organic matter constituents must be taken into account.

3.3 THE PEDON

MAIN SUBDIVISIONS

The pedon extends vertically till the parent rock or the parent material[3].

The pedon is composed of stratified horizons whose formation and structure are explained by processes of strictly pedogenetic nature. These horizons contribute to the identification of soils. Therefore, they may be used as criteria in the fulfillment of the classification.

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[1] Mac Carthy, 1976.

[2] Different determinations were done in Africa by Duchaufour and Dommergues, 1963; Perraud, 1971; Thomann, 1963, 1964, etc.. It seems that this is not the case in other parts of the intertropical world.

[3] Cf. page 20-22 of this text.

The horizons are defined by all their macro- and micromorphological characteristics and also by their physical and chemical ones. But not all these elements are used for the classification. One or more or the specific characteristics which allow to distinguish a horizon or a soil from another horizon or another soil have to be found.

In this project, no reference will be purposely made to the terminology A B C D which is too narrow to characterize and identify all horizons, even when supplementary indices and letters are added[1]. In fact, these letters have a particular genetic implication which supposes that we know perfectly the processes of formation of the horizons. When this certainty is absent, we prefer to classify the horizons according to their characteristics rather than to hypotheses expressed on their genesis.

The pedon may be subdivided in four different parts which may not be simultaneously present: *organic, humus, differentiated mineral, parent material,* finally ending with the parent rock.

THE ORGANIC PART involves an accumulation of organic matter, clearly distinguishable from the humified or differentiated mineral parts and situated in the upper part of the pedon. This organic matter may or may not be transformed (matters of plant or animal origin are no more recognized) and partially incorporated in the mineral material. The contents in organic carbon are high (these contents are given later on). The organic matter plays the main role in the horizon. To the horizons of this part of the pedon belong the *organons*.

THE HUMUS PART. The organic matter is transformed and exists in lower amounts in comparison with the previous horizons and with the mineral constituents to which the organic matter is integrated. The darker color of this part of the profile (black, gray, brown) is due to this humified matter. The one or several horizons of this part are the *humons*.

THE MINERAL DIFFERENTIATED PART is distinguished from the humus part by its color, often more vivid because of a lesser organic carbon content and which corresponds to the color of the mineral constituents. It is also distinguished from the parent material by its characteristic pedological structure resulting from one or more processes of soil formation. Some horizons may still assume high contents of humified organic matter. The distinction between humus horizons and mineral horizons is then relative. The horizons of this mineral part of the profile are made up of *mineralons*. The whole set of humus and differentiated mineral parts form the *solum*[2].

In some pedons no mineralons are present at all. The solum is then only composed of one or several organons or humons. The adjective *ameristic* (not subdivided) is proposed to denote such a solum, by opposition to a differentiated or complex solum where several mineralons can exist.

THE PARENT MATERIAL is the loose material of the lower part of the pedon, subjacent to the solum and mainly mineral. It often arises from the underlying rock by simple mechanical division and/or a chemical and biochemical weathering not resulting into deep modification

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[1] But the correspondance may be easily done.

[2] Soil Survey Manual, USDA, 1951. In some cases, intact boulders (of basalt or limestone) may be included in the solum.

of the structure of the parent rock (under the effect of pedoplasmation[1]. Two or several superposed parent materials may exist. The distinction between these materials and the other parts of the pedon is essential.

a) The parent material is easily distinguished from the humons by lower amounts of organic matter and by the absence of important structural transformations due to the biological activity.
b) The distinction between the parent material and the mineralons is sometimes difficult. This is especially the case of very advanced weathering or of soils derived from "*pedolites*"[2]. In this case, the constituents of the parent material and of the mineralons are about the same. The distinction between both is possible only on the basis of a structural modification (pedoplasmation) due to pedogenesis.
c) In comparison with a sedimentary rock, the parent material is easily recognized by the appreciable state of division of the materials, accompanied by penetration of roots or by transformation of minerals or by redistribution of salts.
d) The superimposition of properties, proper to other pedogenetic processes like the accumulation (of iron and aluminium sesquioxides, clays, amorphous silica, carbonates and sulfates of calcium and magnesium, or more soluble salts), eventually followed by a low cementation or by weak hydromorphy (spots or marmorization) should not be sufficient to obliterate the original rock structure, otherwise the horizons are mineralons.
e) It is not always sure whether the solum is derived from the underlying material or from an analogous material. This is the case of deposits (loess or volcanic ashes) which do not always manifest a clear contrast with the underlying material when transformed into soils.

Two categories of parent materials can be distinguished. Some of these materials are formed and derived from the rock below: *alterite*; the others were formed elsewhere and were redeposited by waters or wind: *pedolite*[3].

- *Alterite*. The structure and the nature of the parent rock are quite recognizable. Alterite is due to physical breakdown and/or to chemical weathering of the parent rock. No displacement of the altered mass takes place with respect to the parent rock situated below. It may be said that the structure[4] of the rock is maintained.
- *Pedolite* is a mixture of soil and rock constituents, having undergone a rather long transportation by waters, ice or wind. Pedolite did not undergo any modification by *diagenesis*[5] (neither compaction, cementation, recrystallization, nor metasomatosis) which may affect the sedimentary rocks. It lost the original structure but kept both secondary and primary minerals. The fluviatile alluvium and loess are the most remarkable representatives.

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[1] Flach, Cady and Nettleton, 1968.
[2] Cf. following pages.
[3] Gerasimov, 1971 "The geological products of destruction and redeposition of modern and ancient soils, to a certain extent, presenting properties acquired in the process of soil formation".
[4] Millot and Bonifas, 1955.
[5] Cf. Jung, pages 52 to 55, 1963.

THE PARENT ROCK is the rock underlying the soil, and from which it is often derived. When no apparent relation exists between the rock and the soil situated above it we speak of a *bed-rock*. It is interesting to distinguish two categories of parent rocks.

Primarolithes do not contain pedological mineral constituents like salts, oxides and hydroxides or clay minerals but only constituents of eruptive or metamorphic rocks formed in the depth. They are unstable in surface conditions and liable to provide pedological constituents by transformation or by synthesis.

Sedimentolithes[1] contain, alone or mixed, analogous constituents to those formed in soils, but having undergone diagenesis to a variable extent. However, by dissolution and weathering they are liable to deliver mineral constituents to the soils, such as the clay minerals, oxides, hydroxides from which they inherit.

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[1] Such as sandstones, limestones, marls and so on.

Table 1. Main subdivision of the Pedon

Pedon	Solum	Organic part	Organons	A_{oo} or A_o
		Humus part	Humons	A_1
		Differentiated mineral part	Mineralons	
	Parent material	Non or slightly differentiated mineral part	Alterite Pedolite	C
Petron	Parent rock or bed-rock	Primarolithe Sedimentolithe		D

4. HORIZONS

4.1 NOMENCLATURE OF HORIZONS

The proposed names to designate the horizons are inspired from the numerous ones given in the literature[1]. Many of them were created when the existing ones were found unsuitable. For each of these names, a simple and precise definition was proposed.

Most often, these horizons assume a name ending by the suffix *-on*, like andon..., ferbisialliton..., oxydon... etc., followed by several adjectives or preceded by a prefix.

The following list is not considered as exhaustive. There is a need to adopt or to create new names when necessity arises. Also, it will be always possible to add adjectives which help to qualify the horizons. In this domain, the required aim is to achieve precision without prejudice to euphony.

A given number of ciphered criteria appear in the characterization of horizons. These are very often those of Soil Taxonomy or of the 1974 FAO-Unesco legend. By now, these criteria appear to be the best. Naturally, such criteria are open to revision and can be modified during the compulsion of the classification.

The following definitions of horizons are only valid in the case of simple pedons, i.e. in the absence of a cover of volcanic ash, alluvion, or colluvion. The case of complex profiles will be treated in connection with each separate class.

4.2 ORGANIC HORIZONS

The organic horizons or *organons* are surface horizons characterized by the accumulation of organic matter. Their fine fraction contains more than 30% of total organic matter if there is more than 30% of clay, or more than 20% of total organic matter if there is no clay[2]. For the intermediate clay contents, the corresponding organic matter contents are calculated. In the calculation of the total organic matter, tree trunks, branches and other ligneous fragments, which are considered as inert are excluded. Only the debris of leaves, nonligneous stems and roots are taken into consideration.

Four types of organons are distinguished[3]:

1 - FIBRIC ORGANON. This organon contains more than 50% (by volume) of fibrous organic matter. A fiber is a fragment of plant tissue which is sufficiently big to be retained by a sieve of mesh 100 (ϕ = 0.15 mm). This fiber should have a recognizable cellular structure. The material is dispersed in a solution of sodium hexametaphosphate before sieving. Fragments of a bigger size than 2 cm should be possibly crushed between the fingers, otherwise they should be considered as a coarse fraction.

The apparent bulk density is generally very low (0.1). The saturation water content is very high (850 to 3000% in comparison with the sample dried at 105°C).

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[1] For example, Chatelin and Martin, 1972; Fitzpatrick, 1971; USDA, 1976; FAO-Unesco, 1975.

[2] For example, case of very sandy soils.

[3] For further details, refer to Soil Taxonomy, p. 59 to 62 from which the main definitions were taken.

2 - FOLIC ORGANON. This organon contains more than 50% (by volume) of foliated or stratified organic debris. These organic matters derive mainly from small sized and recognizable leaves, twigs or branches. The physical characteristics are analogous to those of the fibric organon.

3 - HEMIC ORGANON. This organon contains from 10 to 50% of fibrous or foliaceous organic matter. The organon has intermediary characteristics between the fibric and folic organons on one side, and the sapric organons on the other side. When the organic matter is rubbed, it crumbles easily. The apparent bulk density varies from 0.07 to 0.18. The saturation water content varies between 450% and 850% (with respect to the sampled dried at 105°C).

4 - SAPRIC ORGANON. This organon contains less than 10% of organic matter of recognizable original form. The apparent density is higher than 0.2. The saturation water content is less than 450% (with respect to the sample dried at 105°C).

According to the thickness, the following organons are distinguished:

- the *pachic* organon, when the thickness is more than 18 cm.
- the *leptic* organon, when the thickness is less than 18 cm.

According to the pH, the following organons are distinguished:

- the *eutric* organon, when the pH is ≥ 5.5.
- the *dystric* organon, when the pH is ≤ 5.5.

Supplementary precisions may be introduced in the determination of the degree of saturation (cf. 40).

Tentative correspondance between the organons and other organic horizons. a) Poorly drained soils; b) Well drained soils.

a - *Oligotrophic Peat*
  Organon (fibric, folic, hemic or sapric); pachic or leptic; dystric.
  - *Mesotrophic Peat*
  Organon (fibric, folic, hemic or sapric); pachic or leptic; eutric.

b - *Mor* (cf. CPCS, 1967, Duchaufour, 1977)
  Folic-hemic-sapric complex organon; (generally) leptic; dystric.

4.3 HUMUS HORIZONS

The humus horizons or *humons* are surface horizons or directly situated under organons and containing more organic matter than the underlying horizons. The organic matter is humus (the initial organic material is not recognizable); it is incorporated[1] and bound to the mineral material. Humon is recognized by its color, by a higher organic matter content than that of the underlying horizon and by a different structure. This change in the structure, and the situation in the profile, are particularly important and allow to relate certain horizons containing organic matter with the mineralons (this is the case of the cheluvions of podzols, of certain argilons of different classes). The mineral material bound to humus may be formed of primary or secondary minerals.

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[1] *Juxtaposition* of the organic and mineral materials may be observed with the naked eye or with a lens. They are easily separated by fanning or dense liquids. The *incorporation* is accompanied with a bond between the mineral and organic phases and this bond cannot be broken without an alteration of one of the phases.

Two kinds of humons are distinguished: the *sombron* and the *pallidon*, to which are added *epimineralon* and *epilithalteron.*

a. SOMBRON

Sombron is a humon containing from 1 to 30% of organic matter if the horizon is clayey, and from 1 to 18% if it is sandy. For the sandy clay soils, the content is calculated in proportion of the constituents. It is called *melanic* when the moist chroma is ≤ 1.5 and the dry value ≤ 2.5.

The sombron is called *normal* when the moist chroma is comprised between 1.5 and 3.5 and the moist value < 4 and the dry value < 6.

The sombron is called *pachic* if the thickness is higher than or equal to 18 cm, *leptic* if the thickness is less than 18 cm.

The sombron is *hyperpachic* if there is more than 1% of carbon over more than 100 cm.

The sombron is called *eutric* or *dystric* according to whether the saturation degree is higher than or less than 50%.

b. PALLIDON

The pallidon is a horizon which contains more than 0.5% of organic matter.

The color is lighter than that of the sombron (higher chroma and value: moist chroma ≥ 4, dry value ≥ 6).

The pallidon is called *pachic* when the thickness is more than 18 cm; *leptic* when it is less than 18 cm.

It is called *eutric* or *dystric* according to whether the saturation degree is higher or less than 50%.

c. EPIMINERALON[1], EPILITHALTERON[2]

The surface horizons which do not have enough organic matter to be qualified as sombron or pallidon, and/or which do not have a sufficiently distinct color to be distinguished as a mineralon are *epimineralons*, or as an alteron are *epilithalterons*.

To the terms sombron or pallidon, such adjectives as allophanic[3], andic, bisiallitic... can be applied to express the presence of characteristic mineral constituents. These adjectives are used when the pedon does not show any mineralon (ameristic solum).

Tentative correspondence between sombrons and some humus horizons (cf. CPCS, 1967; Duchaufour, 1977).

Calcic Mull - pachic or leptic saturated sombron.

Calcareous Mull - pachic or leptic pereutric sombron.

Eutrophic Mull - pachic or leptic eutric sombron.

Acidic Mull (and moder) - pachic or leptic dystric sombron.

Tropical Mull - pachic or leptic, dystric or perdystric pallidon or sombron.

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[1] Cf. p. 26.

[2] Cf. p. 43.

[3] These terms are defined later on.

4.4 MINERAL HORIZONS

4.4.1 PRINCIPLES OF DENOMINATION

The mineral horizons or mineralons form the part of the solum which is situated immediately below the organons or humons. In the absence of a humon, the upper part of the mineralon which contains a small quantity or organic matter is called *epimineralon*. When it is not visibly distinguished from the mineralon with certainty, then the only factors to be taken into consideration are the slightly higher content in organic matter, the position in the pedon and eventually, the structure modification.

All mineralons are grouped in large entities according to their mineralogical constitution and especially, to the nature of their secondary minerals. These entities are not horizons as long as their organization is not defined.

mineralon = constituents + organization
(nouns) (adjectives)

These minerals may be the product of weathering "in situ" due to pedogenesis. But they may be also inherited from a former weathering and set in the parent material; they may also result from synthesis in a sedimentary rock.

The choice and the classification of these mineral sets are not arbitrary. They result from the distribution of the minerals in the supergene alterations and in the soils and account for the natural conditions of their formation. These conditions are also considered as specific of the different natural entities which they contribute to define.

Moreover, these minerals have particular properties which condition the organization, the physical and chemical properties of the soils[1] to which they belong and which determine their behavior.

The nature of the specific constituents which define each set is expressed by a particular noun. Twelve diagnostic groups have been retained and named by a noun which recalls the nature of the constituents: *halon, thion, sulfon, gypson, carboxyton, andon, bisialliton, ferbisialliton* (or *fersialliton*), *monosialliton, fermonosialliton* (or *ferralliton*), *oxydon* and *cheluvion*. It is possible to determine the nature of the predominant constituent by adding a particular prefix to the name of the material, e.g.:

Kaoliferraliton or *ferrioxydon*

But the real definition of a horizon is done by the addition of the particular arrangement of its constituents. Thus, one (or several) adjectives are added to the name of each mineral entity. These adjectives are used for the determination of the nature of the horizon, in order to account for its particular differentiation, e.g.:

Orthic or *argillanic* or *carboxic bisialliton*
Gravelly or *gleyic* or *indurated ferralliton*

Complementary data on the macrostructure and on the absorbing complex may be introduced by using other adjectives, e.g.:

Aluminic orthic ferralliton
Natric columnar bisialliton

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[1] Among these, the bulk density, water content, cation exchange capacity, color, etc..

In the following section, the nouns used for materials and the adjectives used for the designation of the horizons are given.

4.4.2 MINERAL BODIES, MAIN NOUNS CORRESPONDING TO A PARTICULAR CONSTITUTION OF THE MATERIAL AND DIAGNOSTIC OF A CLASS OR A SUBCLASS

HALON[1] corresponds to a material of the following criteria:
Constituents: correspond to more soluble salts than gypsum such as: sodium chloride, magnesium chloride, potassium chloride, calcium chloride; sodium sulfate, magnesium sulfate; sodium carbonate and bicarbonate. This list is not exhaustive and may involve mixed salts like carnallite, polyhalite, etc.
Characterization: The conductivity of the saturated paste extract should be higher than 8 ms at 25°C.

THION[1] corresponds to a material containing products where sulfur is in the reduced state and corresponding to the following criteria:
Constituents: corresponds to sulfides or polysulfides of metals like iron and/or elementary sulfur (more than 0.75% sulfur in the sulfide or in native sulfur state).
Characterization: in the field, pH is often close to neutrality. It gets very quickly acidified by exposure of the specimen to air and pH decreases to 3.5, except when the material contains calcium carbonate.

SULFON[1] corresponds to a material containing acidic products where sulfur is in the oxidized state and corresponds to the following criteria:
Constituents: particular ferric sulfates (Fe^{3+} and alkaline sulfates: *jarosites*) and free sulfuric acid.
Characterization: Identification of jarosites by the constituing ions and by the color formed of yellow mottles (hue $\geq$ 2.5Y; chroma $\geq$ 6; pH $\leq$ 3.5.

GYPSON[1] corresponds to a material which has the following criteria:
Constituents: contains calcium sulfate, generally as gypsum.
Characterization: the secondary calcium sulfate content should, on the average, be more than 15%.

Secondary calcium sulfate is recognized:
- macroscopically, by accumulation forms such as, pseudomyceliums, masses, nodules, crusts, etc.;
- microscopically, by accumulation of calcium sulfate (gypsanes) around voids, sand grains, roots and in the plasma mass.

CARBOXITON[1] corresponds to a material of the following criteria:
Constituents: secondary calcium and/or magnesium carbonates (exceptionally, there may be appreciable contents in barium or strontium).

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[1] The corresponding adjectives to these nouns are halic, sulfurized, acidosulfated, gypsic, carboxic, respectively.

Characterization: the contents in secondary carbonates should, on the average, be higher than 15%. The secondary lime is recognized:
- macroscopically, by accumulation forms such as pseudomyceliums, masses, nodules, crusts, etc.;
- microscopically, by accumulation of lime (calcitanes) around voids, sand grains, roots and in the plasma mass.

ANDON[1] corresponds to a material having the following criteria:
Constituents: Andon is made up especially with amorphous secondary[2] and/or cryptocrystalline and very hydrated minerals. These are mainly silicates (allophanes, imogolite, hisingerite), silica (opal), very fine iron and aluminium hydroxides (goethite, lepidocrocite, maghemite, magnetite, gibbsite, boehmite). These constituents form stable organomineral complexes with humic acids[3].
Characterization:
Main geochemical characteristics:
a) The proportion of cryptocrystalline or amorphous secondary silicates, in the total amount of phyllosilicates, should be at least 50%.
b) The proportion of the very finely soluble amorphous or cryptocrystalline substances, relatively to the fraction, smaller than 2 µ, should be at least 50%.

The estimation of these amorphous constituents for which analytical methods are proposed in the appendices, is still delicate and insufficiently checked. It may be replaced and/or completed by a given number of field or laboratory tests whose specificity is not absolute; but the results of several of these tests together should facilitate the identification.

In the field

Morphology: variable, but very often dark color of the horizons, of apparent loamy texture, slightly developed structure, very friable consistence, slightly or not adhesive, slightly plastic (the other morphological characteristics are developed further on; the identification of the amorphous materials in a tactile way is essential, as they should not be confused with the clayey products).

In the laboratory[4]
- X-ray diffraction: the diagram of the fine fraction does not give any clear peak of crystalline products apart from those of primary minerals.
- Differential thermal analysis: the thermal diagram shows an important endothermal peak at 150-160°; this peak is not characteristic in presence of halloysite or smectites.
- The cation exchange capacity depends strongly on the pH.

  • The measured cation exchange capacity (CEC) at pH 4 and pH 9 of the fine earth fraction, shows a relative variation (with respect to the measurement at pH 9.0) of at least 40%:

$$\frac{\Delta\ \text{CEC}}{\text{CEC (pH 9)}} \times 100 > 40$$

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[1] The corresponding adjective to this noun is allophanic.
[2] X-ray diffraction gives no characteristic peaks, but humps.
[3] Cf. Hetier, 1975; Moinerau, 1977.
[4] Cf. the note of G. Smith of 1978 "Priliminary proposal for reclassification of andepts and some andic subgroups".

- The ratio $\frac{\text{variable charge}}{\text{CEC pH 8.2}}$ is > 0.7

where CEC at pH 8.2 is measured with a barium chloride solution buffered with triethanolamine and the variable charge is the difference between CEC at pH 8.2 - (exchangeable bases + exchangeable Al).

The measurements of CEC on the total soil should be done without drying, without destruction of organic matter and without extraction of the hydroxides.

- The measuremant of CEC, carried out on the < 2 µ fraction is most often higher than 50 meq/100 g, sometimes higher than 100 meq/100g.

- The difference between pH (H_2O) and pH (KCl) is most often less than 1 (0.1 to 0.5).
- The specific area of the < 2 µ fraction and of the total soil is very high and varies between 200 and 700 m^2/g. But it is evident that the vitric soils have only a low specific surface.
- Sodium fluoride test. The pH of a suspension of 1 g of fine earth in 50 ml of 1 N solution of sodium fluoride exceeds 9.4 within 2 minutes. This test may be very easily used in the field with a phenolphthalein reagent paper. But one should know the limits to the test (presence of certain salts, cheluvions, fine gibbsite, negative effect of some humons, etc.).
- Bulk density. The measurement is conducted on undried air specimens and maintained at a moisture content of 1/3 bar. The bulk density of fine earth should be less than 0.9; however, the vitric andosols have a bulk density higher than 0.9. It should be remembered that some fermonosialsols have a bulk density lower than 0.9.
- Dehydration. The water content in a specimen at pH 3 may reach high values (100 to 300%). Dehydration is not completely reversible[1]. The water retention loss at pH 3 of a specimen kept at its natural humidity and of the same air dried soil is measured and the loss is found to be higher than 40%, on a humid soil basis.

BISIALLITON[2] corresponds to a material having the following criteria:
Constituents: Bisialliton is characterized by the presence of fibrous clay minerals (attapulgite, sepiolite, chrysotile), 2/1/1 phyllitic (chlorites), 2/1 (smectite, vermiculites, illites); associated with 1/1 clay minerals, in variable proportions.
Characterization:

1. Main geochemical characteristics:

a) The proportion of bisiallitic minerals in the total amount of clay should be at least 10%.
b) The proportion of free iron sesquioxides of the < 2 mm soil should be less than 3%[3]. Generally speaking, the limit of 3% is suggested to separate, on one hand, the ferbisialsols and fermonosialsols, and the bisialsols and the monosialsols on the other hand. In the particular case of soils containing certain 2/1 ferriferous clay minerals, sensitive to the dissolution reagent often used, it seems desirable to account also for the ratio free iron/total iron (expressed as oxides). The value of this ratio should be the object of subsequent discussions.

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[1] Colmet-Daage et al., 1967.
[2] The corresponding adjective to this noun is bisiallitic.
[3] Tentative figure.

2. The identification of the above-mentioned constituents can be made by one or more of the following methods:

- By X-ray diffraction, characteristic peaks of the above-mentioned clay minerals are observed at 10, 10.5, 12, 14 Å; those of the 1/1 clay minerals may also appear. The peaks of the iron and aluminium oxides and hydroxides are absent or very small.
- The molecular ratio SiO_2/Al_2O_3, determined on the clay fraction is ≥ 2.2.
- The cation exchange capacity, related to 100 g of clay is *higher than* 16 meq.
- The free iron sesquioxides in fine earth are extracted by an appropriate technique (Deb, de Endredy) and are less than 3%.

FERBISIALLITON (or FERSIALLITON)[1] corresponds to a material having the following criteria:
Constituents: Ferbisialliton is characterized by the presence of fibrous clay minerals (attapulgite, sepiolite, chrysotile); phyllitic 2/1/1 (chlorites), 2/1 (smectites, vermiculites, illites); oxides or/and crystalline or amorphous iron hydroxides associated in variable proportions with 1/1 clay minerals.
Characterization:

1. Main geochemical characteristics:
a) The proportion of bisiallitic clay minerals in the total amount of clay minerals should be at least 10%.
b) The proportion of free iron sesquioxides should be at least 3% of the fine earth.

2. The identification of the above-mentioned constituents may be done by one or more of the following techniques:

- By X-ray diffraction, the characteristic peaks of the clay minerals are observed at 10, 10.5, 12, 14 Å; those of the 1/1 clay minerals may also appear. The peaks of iron oxides or hydroxides may be present; they may be masked in case of abundance of amorphous products.
- The molecular SiO_2/Al_2O_3 ratio, determined on the clay fraction is ≥ 2.2.
- The cation exchange capacity, related to 100 g of clay is higher than 16 meq.
- The free iron sesquioxides contents determined in the fine earth fraction are higher than or equal to 3%.

MONOSIALLITON[1] corresponds to a material having the following criteria:
Constituents: Monosialliton is mainly formed of 1/1 clay minerals (kaolinite, halloysite, metahalloysite) and eventually, of aluminium hydroxides. Fibrous clay, 2/1/1 phyllitic minerals do not exist or very scarcely. Also, no iron, titanium or manganese oxides do exist, in appreciable amounts.
Characterization:

1. Main geochemical characteristics:
a) The proportion of the bisiallitic clay minerals with respect to the whole clay fraction should be less than 10%.

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[1] The corresponding adjectives to these nouns are ferbisiallitic or fersiallitic and monosiallitic, respectively.

b) The proportion of free aluminium hydroxides should correspond to a ratio of free aluminium/total aluminium less than 30%.
c) The proportion of free iron sesquioxides in the fine earth fraction should be less than 3%.
d) The sum of total free oxides (Al, Fe, Ti, Mn,...) should be less than 50% of the weight of dried soil at 105°C.
e) The contents of weatherable minerals (other than quartz, muscovite, magnetite) should be less than 10% in the 20 to 200 µ fraction.

2. The identification and the estimation of the abovementioned constituents can be realized by one of the following techniques:
a) By X-ray diffraction, the characteristic peaks of kaolinite, halloysite, metahalloysite, gibbsite, or boehmite are observed. Those of hematite, goethite or lepidocrocite are not observed.
b) The presence of these minerals may be ascertained by examination of the endothermic and exothermic peaks of the diagrams of differential thermal analysis.
c) The silica/alumina ratio, determined on the clay fraction, is *less* than 2.2.
d) The cation exchange capacity, related to 100 g of clay, is *less* than 16 meq for kaolinitic soils, than 25 meq for halloysitic soils.
e) The content of free iron sesquioxides, determined on the fine earth fraction, is *less* than 3%.

FERMONOSIALLITON (or FERRALLITON) corresponds to a material having the following criteria:
Constituents: Ferralliton is composed of 1/1 clay minerals (kaolinite, metahalloysite, halloysite), iron oxides and/or hydroxides, aluminium hydroxides; different oxides or hydroxides of titanium, manganese, chromium, nickel, cobalt....
Characterization:

1. Main characteristics:
a) The proportion of bisiallitic clay minerals in the clay fraction should not exceed 10%.
b) The proportion of free iron sesquioxides in the fine earth fraction should be higher than or equal to 3%.
c) The sum of total free sesquioxides, in relation to the soil weight, dried at 105°C, should be less than 50%.
d) The ratio of aluminium in free hydroxides to total aluminium should be in the proportion free aluminium/total aluminium ≤ 30%.
e) The content of weatherable minerals (other than quartz, muscovite and magnetite) should be less than or equal to 10% in the 20-200 µ fraction.

2. The previous identification is carried out by the following techniques:
a) By X-ray diffraction, the characteristic peaks of kaolinite, metahalloysite, halloysite, gibbsite, boehmite, goethite, hematite, etc. are observed.
b) The presence of these minerals can be ascertained by examination of the endothermic and exothermic peaks of differential thermal analysis diagrams.
c) The Silica/alumina ratio, determined on the clay fraction, is *less* than 2.2.
d) The cation exchange capacity, related to 100 g of clay, is *less* than 16 meq for kaolinitic soils and *less* than 25 meq for halloysitic soils.
e) The content of free iron sesquioxides, determined on the fine earth fraction, is *higher* than or *equal* to 3%.

OXIDON corresponds to a material of the following criteria:
Constituents: Oxidon is mainly formed of oxides, and hydroxides of iron, titanium, manganese, chromium, cobalt, nickel, ... either as a mixture or with one mostly predominating element among them (most often, iron or aluminium). Clay minerals are absent or very slightly present.
Characterization:

1. Main geochemical characteristics:
a) The total free metallic oxides should exceed 50% of the soil weight, dried at 105°C.
b) The content in (1/1) clay minerals should not exceed 10%, which corresponds to about 4.7% of combined silica.
c) The content of weatherable primary minerals cannot be higher than 10% in the fraction 20-200 µ.

2. The identification of the constituents may be done by the following techniques:
a) X-ray diffraction. The characteristic peaks of the different oxides or hydroxides are observed.
b) Differential thermal analysis. The previous characteristics can be ascertained by the endothermic or exothermic peaks of the differential thermal analysis diagrams.
c) The centesimal chemical analysis allows the obtainment of the soil composition and the evaluation of the different oxides. The silica/alumina ratio should be *less* than 2.2; according to the amount of aluminium, the ratio may be very low or very near to 2.2.
d) The cation exchange capacity, related to 100 g of clay, should be *less* than 5 meq; ECEC (exchangeable bases + aluminium) should be less than 2.5 meq; Δ pH ($KCl-H_2O$) should be higher than -0.5.

CHELUVION[1] corresponds to a material having the following criteria:
Constituents: Cheluvion is characterized by the presence of organic matter, iron and/or aluminium in the form of an organomineral complex.
Characterization: The identification of cheluvion is done after extraction of the material by a reagent of sodium pyrophosphate (I) and sodium dithionite to which sodium citrate (II) is added.[2]

When there is more than 0.1% of extractable iron by reagent (I), then $\frac{Al + Fe}{Clay} \% \geq 0.2$

If there is less than 0.1% of extractable iron by reagent (II), then C + Al/Clay % ≥ 0.2.

Complexed iron and aluminium by organic matter should be in such proportions with respect to free iron and aluminium so that Fe + Al extr. by (I)/Fe + Al extr. by (II) ≥ 0.5.

The cheluvion content in organic matter is higher than that of the above or below horizons. Sand grains are covered with crackled coatings. Small black granules of organic matter may exist. The C/N ratio of cheluvion is generally higher than 14.

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[1] This term is derived from "cheluviation" of Swindale and Jackson, 1956, and also used by Pedro, 1964, 1966. Many of the following characteristics are close to those of the spodic horizon of Soil Taxonomy.

[2] Reagent I extracts complexed iron and aluminium; Reagent II extracts free iron and aluminium oxides.

In the pedon, cheluvion is normally situated under an eluvial horizon, most often under an albic horizon. In case of erosion, it may appear on the surface. In case of ploughing, the eluvial horizon may lack.

4.4.3 COMPLEMENTARY DENOMINATIONS USED TO CHARACTERIZE THE PREVIOUS MATERIALS AND RELATED TO THE CONSTITUENTS

The denomination is that of an adjective (or of a radical derived from this adjective) and set before the name of the material.

- *Kaolinitic* (radical *kaoli-*) applies to the noun ferralliton when more than 50% of clay minerals are represented by kaolinite.
  E.g. *Kaolinitic ferralliton* or *Kaoliferralliton*
- *Halloysitic* (radical *halloysi-*) applies to the noun ferralliton or monosialliton when more than 50% of the 1/1 clay minerals are represented by halloysite.
  E.g. *Halloysitic ferraliton* or *Halloysiferralliton*
- *Chloritic* (radical *chlori-*) applies to the noun bisialliton or ferbisialliton when more than 50% of clay minerals are represented by chlorite.
  E.g. *Chloritic bisialliton* or *chlori-bisialliton*
- *Smectitic* (radical *smecti-*) applies to the noun bisialliton or ferbisialliton when more than 50% of the clay minerals are represented by montmorillonite or nontronite.
  E.g. *Smectic bisialliton* or *smectibisialliton*
- *Vermiculitic* (radical *vermiculi-*) applies to the noun bisialliton or ferbisialliton when more than 50% of the clay minerals are represented by vermiculite.
  E.g. *Vermiculitic ferbisialliton* or *vermiculi-ferbisialliton*
- *Illitic* (radical *illi-*) applies to the bisialliton or ferbisialliton nouns, when more than 50% of the clay minerals are represented by illite.
- *Mixed* applies to the bisialliton or ferbisialliton nouns when several 2/1 and 1/1 clay minerals are present in a mixture and that none exceeds 50%. Kaolinite should exceed 10%.
  E.g. *Mixed bisialliton*
- *Gibbsitic* (radical *gibbsi-*) applies to a ferralliton or a monosialliton when more than 30% of alumina is in the form of gibbsite. The ratio free Al_2O_3/total Al_2O_3 is comprised between 30 and 80%.
  E.g. *Gibbsitic ferralliton* or *Gibbsiferraliton*
- *Boehmitic* (radical *boehmi-*) applies to a ferralliton or a monosialliton when more than 30% of alumina is in the form of boehmite and when the ratio free Al_2O_3/total Al_2O_3 is comprised between 30 and 80%.
  E.g. *Boehmitic ferralliton* or *Boehmiferralliton*
- *Hematitic* (radical *hemati-*) applies to a ferbisialliton or a fermonosialliton when more than half of the free iron oxides are in the form of hematite.
  E.g. *Hematitic ferbisialliton* or *Hematiferbisialliton*
- *Goethitic* (radical *goethi-*) applies to a ferbisialliton or a fermonosialliton when more than half of the free oxides is in the form of goethite.
  E.g. *Goethitic ferbisialliton* or *Goethiferbisialliton*
- *Ferritic* (radical *ferri-*) applies to an oxydon when more than half of the free oxides is in the form of iron oxides.
  E.g. *Ferritic oxydon* or *Ferrioxydon*
- *Allitic* (radical *alli-*) applies to an oxydon when more than half of the free oxides is in the form of alumina oxides.
  E.g. *Allitic oxydon* or *Allioxydon*

4.4.4 ADJECTIVES USED FOR THE DESIGNATION OF HUMONS AND MINERALONS AND FOR THE DETERMINATION OF THE NAME OF THE HORIZON FOR THE PURPOSE OF THE DETERMINATION OF ONE OF THE UNITS OF THE CLASSIFICATION: SUBCLASS, GREAT GROUP, GROUP OR SUBGROUP

While the noun concerns the constitution, the adjective applies to the morphology and/or to some physico-chemical characteristics. For example:

Indurated ferralliton; Gravelly ferbisialliton; Vitric andon.

The *haplic*[1] horizon is the least differentiated horizon. It is defined by a group of criteria which are liable to vary within limits which will be defined later. When a certain threshold is exceeded (to be determined), this horizon is left for another one. The haplic horizon presents the simplest mineral criteria bound to a noun which characterizes the horizon.

The haplic horizon is defined through the criteria which it effectively possesses and also by the absence of some other criteria. The presence of the second criteria involves the replacement of the haplic adjective by another.

The haplic horizon is defined by using the following characteristics:

- Colors[2]. They are very variable but uniform; black, yellow, brown, red. They are stated in a special page[3].
- Structures. Their number is high. The following structures are excluded: massive, vertic, columnar, lithopolygonal, particulate.
- Textures. They are very variable. However, the sum silt + clay should be higher than or equal to 15%.
- Consistencies. They are variable, but should be placed in the following spectrum:
  - in the dry state: between "fragile" and "hard"
  - in the humid state: between "friable" and "firm"

If the characteristics of the horizon correspond to the above-mentioned ones, it is called haplic. If one or several changes take place, the haplic adjective is replaced by another. The list of the adjectives is given below. It is not final and may be completed.

- Less than 15% and more than 5% (clay + silt): *arenic.*
- Less than 5% (clay + silt): *psammic.*
- 85% or more of rock fragments: *lithic.*
- 5% or more of coarse materials: *gravelly, stony.*
- 2% or more of color spots and different from that of the whole horizon: *mottled.*
- Positive reaction to sodium fluoride[4]: *andic.*
- Secondary salts in insufficient amount in comparison with the necessary values for the saline horizons: *hypohalic, hyposulfurized, hypoacidosulfated, hypogypsic, hypocarboxic.*
- 10% or more of weatherable primary minerals in the fraction 20-200 µ: *penevolved.*
- A gradient of elements less than 2 µ at the inside of the horizon or of the profile: *argillanic, bulgic, impoverished*; the textural gradient should be higher than 1.4.

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[1] From the greek "haplos": simple.

[2] Munsell Color Charts.

[3] Cf. pp. 42.

[4] The sodium fluoride test is positive, not only in presence of allophanes, but also in the case of certain soils rich in hydroxides and of some podzols.

- A particular structure: *particulate, massive, vertic, gelic, lithopolygonal, columnar.*
- A very hard or very firm consistence: *compact, indurated, placic.*

Characteristics related to the *organic constituents.*

- *Organic*: is said of a horizon which presents the characteristics of an organon (content in organic matter); the thickness is insufficient to comply for an organosol or a primarosol, but it is higher than 2.5 cm.

The adjectives *fibric, folic, hemic, sapric* may be applied to humons if it were possible to recognize organic debris in them (organic debris as defined on p. 22-23).

Characteristics due or bound to the *mineral constituents.*

- *Hypohalic, hyposulfurized, hypoacidosulfated, hypogypsic, hypocarboxic*: apply to a horizon which contains soluble salts, sulfides, iron sulfates, gypsum, secondary lime in *insufficient* amounts for a halon, thion, gypson, sulfon or carboxiton.

If the maximum amount is thus determined, the minimum amount cannot be determined right now and should be the object of a subsequent study.

For the time being, it is proposed for:

- *Hypohalic*: a conductivity of the saturated paste extract, comprised between 4 and 8 ms.
- *Hyposulfurized*: gets slowly acidified by exposure of the specimen to air; positive detection of sulfides by lead acetate paper.
- *Hypoacidosulfated*: no characteristic yellow color; pH no lower than 3.5; positive reaction to barium chloride.
- *Hypogypsic*: less than 15% of calcium sulfate; positive reaction to barium chloride.
- *Hypocarboxic*: less than 15% of calcium carbonate and/or magnesium, distinct reaction with hydrochloric acid.
- *Ferric*: applies to a horizon of a bisiallitic or a monosiallitic soil which locally contains, at least on a depth of 2.5 cm, a friable accumulation of iron oxides or hydroxides.
- *Silicic*: applies to a compact or a gravelly horizon the cement of which is composed of silica. A silicic horizon does not disintegrate in water or in weak acidic solutions, but does in a hot alkaline solution.
- *Allophanic*: applies to a horizon which contains such a quantity of cryptocrystalline products (associated with humus) that the clay minerals cannot be observed in the field. The sodium fluoride test is positive, the bulk density is less than 0.9 and the consistence is very friable.
- *Andic*: applies to a horizon which contains *at the same time* cryptocrystalline silicates and *clay minerals*, easily identified by touching and by X-ray diffraction[1].
- *Penevolved*: applies to a bisialliton, ferbisialliton, monosialliton, fermonosialliton which contain weatherable minerals in appreciable amounts.
  a) in the case of a bisialliton or a ferbisialliton, the horizon contains 10% and more of weatherable primary minerals in the 20-200 µ fraction.
  b) in the case of a monosialliton or a fermonosialliton, the horizon contains: more than traces and less than 10% or 2/1 clay minerals with relation to the total content in clay and/or 10% and more of weatherable primary minerals in the 20-200 µ fraction.

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[1] The sodium fluoride test is positive but cannot be used alone because it is not specific. The bulk density should be < 1.0.

If the horizon contains more than 10% of 2/1 or 2/1/1 clay or fibrous minerals, with relation to the total clay content, it should be considered as a bisialliton or a ferbisialliton.

Micas and chlorites are counted among the weatherable minerals if they are present in the parent rock or in the sand and silt fractions.

Characteristics due to the *parent rock* or to the *parent material*.

- *With lime* (or *calcareous*): is said of any horizon which contains fragments of calcareous rock.
  If the contents are less than 15%, this wording is enough.
  If the contents are comprised between 15 and 85%, the adjective *calcolithic* will be used.
  If the contents are higher than 85%, the adjective *lithocalcareous* will be used.
- *With dolomite*: is said of any horizon which contains fragments of dolomite. This expression is enough if the contents are less than 15%.
  If the contents are comprised between 15 and 85%, the adjective *dolomilithic* will be used.
  If the contents are higher than 85%, the adjective *lithodolomitic* will be used.

  In the same way, it may be said of the other rocks: with *basalt*, *basaltolithic*, *lithobasaltic*, etc.
- *Arenic*: is said of a horizon which contains between 5 and 15% of clay + silt.
- *Psammic*: is said of a horizon which contains less than 5% of clay + silt.
  It is suggested that *quartzipsammic* should denote that the horizon is composed of quartzic minerals or as slightly weatherable as quartz and that *vitropsammic* should denote that the horizon is mainly composed of pyroclastic volcanic materials (the acquisition of andic properties is very rapid, even when the pyroclastic material appears to be very slightly weathered.
- *Stony*: is said of a horizon which contains 5-85% of rock fragments or of slightly weatherable minerals (concerning quartz), of *higher* dimensions than 7.5 cm of diameter; debris of indurated horizon; masses, nodules, concretions of variable nature which can be determined.
- *Gravelly*: is said of a horizon which contains more than 5% of gravel fragments of *smaller* dimension than 7.5 cm; these gravels may be rock fragments, difficultly weatherable minerals, indurated horizon fragments (fine gravel), or masses, nodules and concretions of variable nature which can be determined.
- *Silty*: is said of a material when the silt content is higher than 40% with at least 50% of sands or less than 30% of clay.

Characteristics related to the *structure*.

A great number of fragmentary structures like blocky, subangular blocky, granular, etc. are associated with the haplic horizon. On the other hand, the following structures confer to the horizon a particular name.

- *Massive*: is said of a continuous horizon, coherent, non-porous, without any pronounced dissociation faces. Fragmentation is artificial and breaks the horizon into splinters of variable size.

- *Vertic*: is said of a clay horizon which, in the dry state, presents deep wide cracks, slickensides, and wedge shaped aggregates[1].
- *Prismatic*: is said of a horizon of a structure showing plane faces with angular edges of vertical orientation, thus producing prismatic forms.
- *Columnar*: is said of a clay horizon which shows prisms or columns with a rounded[2] top.
- *Lithopolygonal*: is said of a horizon or a group of horizons when the loose material regularly alternates with vertical stony walls. The intersection of these walls with the surface delineates polygons ranging between some decimeters to a few meters of diameter.
- *Particulate* (or *psammoclodic*): is said of a noncoherent or loose structure in which sands predominate. These sands are not connected with any kind of cement (like organic matter, clay, oxides, etc.).
- *Turbic* (or *gelic*): is said of a horizon (or a group of horizons) in which the horizontal arrangement of the materials has been irregularly perturbated (generally by the frost).
- *Shiny*: applies to a well defined structured soil (from fine to medium blocky) in which all ped faces are shiny. The breaking down of an aggregate produces smaller but still shiny fragments. This shiny state is lost on drying.
- *Aliatic*: is said of a ferralliton, characterized by a porous massive macrostructure of weak cohesion *and* by a fine microstructure (aliatic). *"Po de café"* or "latosolic" in Brazil.
- *Mealy* (or *fluffy*): is said of a structure of very friable microaggregates, with a very weak cohesion, and high microporosity.

Characteristics related to a *gradient of fine elements* at the inside of a pedon or of a toposequence.

- *Argillanic*: is said of a horizon characterized by the presence of clay coatings (argillans or ferri- or mangani- argillans) on the structural elements. These argillans should be visible in the field and on thin section, 50 cm at least of the first 125 cm, regardless of the nature of the subhorizon. The structure should be medium subangular blocky in a humid soil.
- The coatings form a thin layer, visible with the naked eye or with a lens, on some of the aggregates' faces and in the pores along the cracks. They do not appear on the whole surfaces when the aggregates are broken.
- At a microscopic scale, the argillans are characterized in the polarized light by their orientation, parallel to the walls coated by these argillans. There is the possibility of a multi-layer formation, of a particular color and of a strong birefringence compared with the matrix.
- Quantitatively, argillans should represent 5% at least of the observed area.

  The accumulation bulge is not indispensable but possible.

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[1] The presence of smectite is very frequent, but not necessarily so; the gilgai microrelief is not general.

[2] The presence of high exchangeable sodium is frequent but not necessarily so.

- *Bulgic*[1]: is said of a horizon which contains less than 5% of argillans and situated below an eluvial horizon of 15 cm thickness at least. This eluvial horizon should be the poorer in clay of the upper part of the pedon. The bulgic horizon is comprised between horizons, less rich in clays (clay bulge). It should fulfil the following conditions:
  1. If these 15 cm contain less than 20% clay, the increase in the clay content should be at least 7% in absolute value (for example, from 20 to 27%) on more than 8 cm.
  2. If these 15 cm have more than 20% clay, there should be a textural gradient of 1.4 or more.
- *Impoverished*: is said of, a) a horizon (or of a group of horizons) which does not surmount an argillanic or bulgic horizon, but which contains increasing clay contents, from the upper to the lower part of the pedon; b) a pedon where the textural gradient is higher than 1.4 if the clay content exceeds 35% in the first 15 cm.
- *Eluvial*: is said of a horizon which lost fine elements and which is placed above an argillanic or bulgic horizon.

ADJECTIVES applying to the transition of *an eluvial horizon* to the *underlying horizon*.

These transition may be progressive, as in the previously described cases; it may also be sudden: *planic* and *glossic*.

- *Planic*: is said of the contact between an eluvial horizon and the subjacent horizon when the clay content satisfies the following conditions:
  a) When there is less than 20% clay in the surface, the increase should be the *double* (*or more*) on a distance of at least 8 cm.
  b) If there is more than 20% clay in the surface, the increase should be higher than 20% on 8 cm at least and the clay content of the underlying horizon should be the double of that of the upper horizon (at least in a part of the horizon).
- *Glossic*: is said of an irregular contact between an eluvial horizon and an argillanic, bulgic, cheluvic horizon, with formation of pockets of at least 5 cm width and more long than wide. The pockets occupy more than 15 cm of the upper part of the above-mentioned horizons.

Characteristics ascribed to the *water influence* on a horizon.

- *Perhydric*: is said of a horizon having a water retention capacity of more than 100% at pF = 3, with respect to the dried specimen at 105°C. A high percentage of this water is irreversibly lost by dehydration in air and Δ $pF_3/pF_{4.2}$ is higher than 70%. Generally, the horizon is in the *thioxotropic* state: when a clod is pressed between the fingers, it suddenly acquires a liquid consistence.
- *Mottled*: is said of a horizon showing mottles (or marmorizations) of different colors than that of the whole horizon: red, yellow, brown. This indicates a heterogeneous distribution of iron and/or manganese hydroxides throughout the clay matrix. The following terms may be further specified:
- *Reticulate*: is said of a horizon in which the mottles of a different color (from that of the horizon) are distributed in a pattern of variable mesh.

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[1] Bulgic, from bulge.

- *Gley*[1]: is said of a horizon of continuous grey, bluish or greenish color, indicating the presence of ferruginous products in a reduced form. A small number of mottles is possible (occupying less than 5% of the exposed surface of the horizon).
- *Hemigley*[1]: is said of a similar horizon (to the previous one), but in which the yellow, brown or red mottles occupy 5% or more of the exposed surface of the horizon. In both cases, the simultaneous presence of ferruginous products in the ferric and in the ferrous states is observed.

Characteristics due to the accumulation of *silica, salts* or *sesquioxides* and to their induration.

The considered constituents are very variable, salts: sodium chlorides and carbonates; calcium carbonates or sulfates; silica; titanium and manganese oxides; iron sesquioxides; iron or aluminium hydroxides; sometimes, cobalt, chromium, nickel oxides, etc.. These constituents may involve secondary or primary minerals, as well as rock debris.

- *Compact*: is said of a horizon which in the dry state presents a heavier consistence than "hard" or "non-fragile"; in the humid state, it crumbles between the fingers and has a macroporosity less than 5%.
- *Indurated*: is said of a continuous horizon which breaks only under a hammer or a blast bar.
- *Nodular*: is said of a horizon in which the accumulations are not concentric.
- *Concretionary*: is said of a horizon in which the accumulation appears in a concentric form.
- *Encrusted*: is said of a horizon in which the accumulation appears in a discontinuous form and is irregularly hardened.
- *Foliaceous*: is said of a horizon in which the accumulation is a thin layer (less than 2.5 cm thickness). This layer is soft, more or less continuous and reticulate. This term may apply to lime, iron or manganese sesquioxides, silica and to clay. This horizon may contain organic matter. When this horizon is hard, it becomes similar to the *placic* horizon of Soil Taxonomy.
- *Tufaceous*: is said of a horizon in which the accumulation appears in a variable consistence (fragile to hard), but which may easily become fragmentary or powdery[2].
- *Diffuse*: is said of a horizon in which the accumulation is almost homogeneous and nonvisible.
- *Pseudomycelium*: is said of a horizon in which the accumulation is filiform, braided, arborescent, dendriform or ramified at the surface of the aggregates.

We should recall the adjectives related to the presence of secondary salts in a horizon:

- *Halic*: is said of a horizon in which the measured electrical conductivity on the saturated paste extract is higher than 8 ms; if it is higher than 15 ms, the adjective *hyperhalic* is used; if it is comprised between 4 and 8 ms, the adjective *hypohalic* is used.

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[1] Gley or hemigley horizons are used in the distinction of hydromorphic groups with gley or with hemigley, if the gley or the hemigley appear in the first 30 cm under the humon. If this condition is not fulfilled, they are used in the distinction of hydromorphic subgroups.

[2] Cf. "Soft powdery lime" from the units of Soil Taxonomy or from the FAO-Unesco legend.

- *Sulfurized*: is said of a horizon containing more than 0.75% sulfur in the sulfide state or as natural sulfur and in which the pH drops rapidly below 3.5 upon exposure to the air. When these characteristics are not observed, but only a positive reaction for sulfides with lead acetate paper and a slow acidification, we propose the adjective *hyposulfurized*.
- *Acidosulfated*: is said of a horizon containing jarosites and free sulfuric acid: yellow[1] mottles with a hue ≥ 2.5Y and a chroma ≥ 6 and a pH ≤ 3.5. When these color characteristics are not all met and when pH > 3.5 and the reaction with barium chloride is positive, we propose the adjective *hypoacidosulfated*.
- *Gypsic*: is said of a horizon which contains 15% or more of secondary calcium sulfate. When the calcium sulfate contents are higher than 50%, we propose the adjective *hypergypsic*. When the calcium sulfate contents are less than 15% with a positive reaction with barium chloride, we propose the adjective *hypogypsic*.
- *Carboxic*: is said of a horizon which contains 15% or more of calcium and/or secondary magnesium carbonate. When the carbonate contents are higher than 50%, we propose the adjective *hypercarboxic*. When the contents are less than 15% carbonate, but with a distinct reaction with the acid, the adjective *hypocarboxic* is used.

Characteristics due to *ions* fixed on the absorbing complex. (N.B.: Other characteristics may be found but they are mentioned in another place.)

- *Eutric*: is said of a horizon having a saturation degree equal to or higher than 50%; *hypereutric* (or *pereutric*) applies to a higher saturation than 90%; *saturated* applies to a hypereutric horizon where an excess salt is present (like sodium chloride, calcium sulfate or calcium carbonate).
- *Dystric*: is said of a horizon of a saturation degree, less than 50%; *hyperdystric* (or *perdystric*) when the saturation degree is less than 10%.
- *Natric*: is said of a horizon where the exchangeable sodium contents are such that Na/T x 100 > 15%, where SAR is higher than 13 and the electric conductivity (EC) is less than 20 ms.
- *Aluminated*: is said of a horizon in which the contents in exchangeable aluminium (extracted by normal potassium chloride) are measurable. The following terms are proposed:
- *Aluminic*: $\frac{Al}{Al+S} \times 100 = 10$ to 50.
- *Hyperaluminic:* $\frac{Al}{Al+S} \times 100 = 50$ to 100.
- *Magnesic*: is said of a horizon in which the ratio Ca/Mg is < 1.
- *Calco-magnesic*: is said of a horizon whose absorbing complex is dominated by calcium and magnesium ions and which is not natric, neither aluminated, nor magnesic (the indication of this characteristic may be omitted).
- *Hyperacidic*: is said of a horizon in which pH (water) is less than or equal to 4.9.
- *Acidic*: is said of a horizon in which pH (water) is higher than 4.9 and less than or equal to 6.6.
- *Neutral*: is said of a horizon in which pH (water) is higher than 6.6 and less than or equal to 7.3.
- *Basic*: is said of a horizon in which pH (water) is higher than 7.3 and less than or equal to 8.7.

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[1] "Straw colored".

- *Alkaline*: is said of a horizon in which pH (water) is higher than 8.7.
- *Calcaric*: is said of a horizon which produces effervescence with acids and contains diffuse calcium carbonate of primary or secondary origin.

Characteristics related to *water presence* in a pedon or a horizon.

- *Available water volume*. It is defined by the difference between water retained by the soil at pH 3 minus water retained by the soil at pF 4.2.
  Available water volume:
  5 to 10% - Low
  10 to 14% - Medium
  14 to 20% - High
- *Drainage*. Two notions should be distinguished.
  The first characterizes the effective presence of water in the soil; this presence is due more to topographical than to pure pedological conditions. This is the *external drainage*.
  Very good : The soil water content is seldom above the field capacity.
  Good : The water content does not exceed the field capacity except for short periods. None of the horizons is modified but the parent material may undergo modifications.
  Rather good: The water content exceeds the field capacity during an appreciable period of the year. Mottles appear in the mineralons.
  Poor : The soil is saturated during a long period of the year.
  Very poor : Presence of a watertable at less than 36 cm, during almost the whole year.
  The second notion concerns the water transmitting properties of a pedon or of a horizon which has just been moisted (by rain or by irrigation). The *internal* drainage is then involved. The percolation rate is estimated by an appropriate technique (Münz).
  Percolation rate:
  Rapid > 100 mm/hour
  Medium 20 to 100
  Slow < 20

Characteristics related to the presence of *stones* or of *rocks* on the soil surface or inside the soil.

- *Rockiness*: concerns the presence of rocks at the soil surface susceptibly hindering the use of agricultural machines.
- *Slightly rocky*: some outcrops, enough to interfere with tillage. Spacing of outcrops should be 100 to 30 meters. They should cover from 2 to 10% of the surface.
- *Moderately rocky*: sufficiently rocky to impede tillage thus leaving a soil, favorable for grazing or for growing hay crops. Outcrops are separated by 10 to 30 meters and cover 10 to 25% of the surface.
- *Very rocky*: every use of agricultural implement is excluded, with the exception of light tools. Soil may be pastured or left in woods. The outcrops are separated by 3 to 10 meters and cover 25 to 50% of the surface.
- *Extremely rocky*: no use of agricultural implements is possible; the soil has to be left for extensive pasturing or wood. The outcrops are separated by less than 3 meters and cover 50 to 90% of the surface.
- *Rock outcrops*: When more than 90% of the surface is occupied by rock.

- *Stoniness*: applies to the presence of stones[1] inside the pedon.
- *Slightly stony*: presence of few stones, not hindering soil cultivation.
- *Moderately stony*: presence of stones in sufficient quantities to hinder soil cultivation.
- *Strongly stony*: presence of stones hindering cultivation. A removal of stones is necessary.
- *Very strongly stony*: presence of stones hindering cultivation. An intensified removal of stones is necessary.
- *Excessively stony*: there are too many stones to enable any type of cultivation.

Characterization of the *slopes*.

The slope is expressed in % and applies to the slope on which the pedon is observed:

Flat	0	to	0.5%
Very smooth slope	0.5	to	2 %
Smooth slope	2	to	5 %
Moderate slope	5	to	9 %
Steep slope	9	to	15 %
Very steep slope	15	to	30 %
Abrupt	30	to	60 %

Designation of *colors*: it is done according to the Munsell Soil Color Charts.

The following terms are used:

- *Black* or *melanic*: applies to any color when the moist chroma is less than or equal to 1.5 and the value is less than or equal to 2.5.
- *Dark*: this name applies to the humus horizons which are called "sombrons", and correspond to any color when the moist chroma is less than 3.5 and the moist value is less than or equal to 4 and the dry value is less than or equal to 6.
- *Grey*: color appearing on all plates and corresponding to a chroma less than 2 and to a value higher than 3.
- *Red*: color appearing on plate 5YR and on redder plates (on plate 5YR, the moist value is less than or equal to 5, the moist chroma is less than or equal to 4), but which do not correspond to the definition of black.
- *Brown*: color appearing on plate 5YR (moist value is higher than 5; moist chroma is higher than 4), as well as on plates 7.5YR, 10YR, 2.5YR when the word brown appears in the designation as a noun and when the chroma is higher than 2.
- *Yellow*: color appearing on plates 7.5YR, 10YR, 2.5Y, 5Y when the words yellow and olive appear in the designation as nouns and when the chroma is higher than or equal to 2.

4.5 THE PARENT MATERIAL

This material corresponds both to pedolite and alterite, being subdivided into a given number of units[2] or *ALTERONS* which are regrouped in three main categories: *lithalterons*, *isaltherons* and *mixed alterons*.

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[1] Coarse fragments ranging from 2 to 20 cm.

[2] FAO-Unesco, 1974 considered that the parent material did not lead to the formation of horizons. In this text, it is considered that the weathering cannot be dissociated from the process of soil formation.

LITHALTERON - A lithalteron results from the division of a rock with little or no chemical weathering. On the observed domain[1], there should be less than 15% of weathered materials. Different lithalterons may be distinguished such as:

- *A loose lithalteron* which may be: arenic (forming a sand); silty (forming fine products of 2 to 50 μ); clayey (forming finer products than 2 μ).
- *A hard lithalteron* when the alteron is formed of blocks and stones, separated by silts.

ISALTERON - This alteron results from a chemical transformation, without modification of the initial volume of the rock (from which derives the name *"isovolume"* weathering). On the observed domain, there should be more than 85% of weathered materials. Besides, pedoplasmation should not be responsible for the transformation of more than 15% of this domain. When the ratio of the transformed domain by pedoplasmation increases, we are in presence of a mixed alteron, even of a mineralon.

Characteristics of the isalteron:

- *Isochromous*: of homogeneous color.
- *Mottled*: with mottles of variable colors and forms.
- *Reticulate*: with colored mottles in a pattern.
- *Spheroidal*: heterogeneous weathering in spherical thin layers around the rock balls, but still hard (for example, basalt or granite).
- *Lamellar*: heterogeneous alteration, in thin layers (schists, marls, certain limestones).

When a moderate distribution of the secondary products is observed and the rock structure is not obliterated, we may add: carboxic, gypsic, halic, silicic, ferric, etc..

MIXED ALTERON - An alteron which contains, in addition to the weathering products, slightly weathered or unweathered rock fragments; or it is an alteron which is starting to be modified by pedological differentiation.

a) Transition towards the parent rock; an intergrade between a lithalteron and an isalteron: we speak of an *ambialteron*, if the observed domain contains from 15 to 85% of the parent rock fragments.

b) Transition towards the mineralons or humons.

- The *mineralo-alteron* is an intergrade between the alteron and mineralon. Over 0 to 85% of the observed domain, modifications are observed, being due to pedogenetic processes other than the accumulation of humified organic matter.
- The *humo-alteron* is an intergrade between an alteron and a humon. The alteron contains more than 0.5% of organic matter and the structure of the rock is transformed.
- The *epialteron* is a surface horizon, situated at the top of an alteron, but which is differentiated:
  a- by a low content (less than 0.5%) of organic matter;
  b- by a slightly higher organic matter content than (more than 0.1) the alteron.

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[1] Observed domain: a surface on a profile.

CONCLUSIONS

All soil forming processes end with the formation of the soil constituents, both organic and mineral, and also with the arrangement of these constituents and the differentiation in horizons.

These constituents and horizons were defined in the previous pages by the application of measurement methods and appropriate observations unaffected by the personality of the pedologist. These measurements and observations are used in the constitution of the classification itself.

5. PRINCIPLES AND ELEMENTS OF THE CLASSIFICATION (TAXA)

5.1 INTRODUCTION

Before describing the following system, the objectives and the principles of the classification are given.

a) The classification should satisfy two distinct objectives. The one may be called scientific and the other utilitary.

The first objective concerns the identification of the soil through its proper characteristics in a universal language which allows the comparison with other soils and their arrangement in the classification. These data are of three kinds: the constituents, the organization of the horizons and the physical and chemical properties.

The second objective concerns the determination of the particular characteristics of the soil and those of its environment which allow to direct its utilization and to determine some conditions of its genesis and of its evolution.

The separation between these two objectives is indispensable. The first one concerns the survey of the fundamental characteristics of a soil which should be known in order to be identified and distinguished among other soils and also for their subsequent use. The second one is much more apt to change and depends more on the considered utilization mode for the soil. The agricultural, pastoral or forester utilization are the most important. But the needs of the different possible cultivations are far from being the same and from being known with accuracy. The method of the soil treatment for a given utilization, especially in the intertropical zone, are only gradually discovered, after many unsuccessful trials.

But other methods of using a soil also exist, as for example, by constructing communication ways, public and private buildings, burying liquid or gas pipes, settling of parks, etc.. The required data are so variable that an advance list cannot be propounded. The two types of characteristics may overlap, since the first ones have also their interest in the soil management. But the second characteristics depend on the utility choice and are only known in proportion to the progress of knowledge.

b) The classification should have a *structure* and a *coherence* allowing its easy use, and consequently, its memorization. Therefore, it appears useful that the diagnostic criteria of the same order appear always at the same level[1]. In a system of local or regional significance, it is possible to combine soils and the characteristics which are believed to be important or primordial. In a system, meant to be universal, this practice is not desirable. One should determine the useful level for a given criterion and stick to it. This should allow to introduce every novelty in the system and implies that a hierarchy of criteria be established and that the way in which future extensions will be effectuated, can be anticipated, even summarily.

c) A *hierarchy* is necessary because it is not possible to provide all the criteria at the same time, even if they were considered of identical importance. This is the case of the constituents and of the arrangement of the

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[1] This is not realized in the case of a pragmatic classification, like Soil Taxonomy.

soil in horizons, which are the most evident criteria to take into account in the classification. It seems preferable, for different reasons, to give the priority to the constituents.

1. This is not new and exists since long in many classifications. It is noticed that in the C.P.C.S. system, the French pedologists have placed the mineral constituents in the first rank of criteria for the identification of the andosols, the hydroxide-containing soils, the ferrallitic soils and the halomorphous soils. The true morphological characteristics appear only in the groups and the subgroups. In Soil Taxonomy, the American classifiers do the same with the organic and mineral constituents, for the oxisols, the spodosols and the histosols[1].

The differences with the present work is that this step is systematically followed, in the first level of the classification. In fact, if it were normal that a particular importance be attributed to kaolinite and to hydroxides, an identical importance should be attributed to the 2/1, 2/1/1 clay minerals (smectites, illites, vermiculites, chlorites...).

2. During pedogenesis, the constituents (organic matter, clay minerals, sesquioxides) are formed first. This may not clearly appear in some soils of the temperate zones, but it is an evidence in the intertropical zone where the alterite is often exceedingly thick with respect to the solum. Most often, the solum is only developed when the parent material (alterite or pedolite) exists. But, it is agreed that the weathering processes continue during the differentiation and the evolution of the horizons.

3. The soil constituents are responsible for a great number of characteristics. The first and the oldest characteristic used by pedologists is color, due to organic matter, clay minerals, sesquioxides and to salts.

– Constituents also determine (to a high extent) the structure, consistence and cementation, properties which are not always sharply defined in the characterization of a soil.

4. The constituents are a reflection of the formation factors of the soil. They are in fact the product of the effect of bioclimatic factors on a parent rock and are influenced by drainage. They undergo a slow and continuous modification with time. However, with exception of the most soluble salts and the organic matter, they present a particular stability. For this reason, a certain discrepancy is often observed between the present conditions of the environment and the constituents-morphology couple.

5. In addition, and this translates a new situation which did not prevail at the time of the setting up of most classifications, it is possible to identify with certainty[2] the mineral constituents of the soil by using the new techniques which were lately generalized (particularly, X-ray diffraction). A quantitative determination of some constituents is even possible.

Moreover, another identification which may be qualified as an indirect identification may be added to the direct one by using particular properties of certain

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[1] And suggest to do the same for the "andisols".

[2] During a long time, only rough chemical methods were available. Even if they were enthusiastically used by Lacroix, De Sigmond or Harison etc., they only gave very incomplete information.

constituents (high specific area of the amorphous products, swelling of the 2/1 clay minerals, bulk density, water content...).

For the above-given reasons, it was therefore felt logical to classify soils by starting with the nature of the constituents followed by the morphology of their horizons. Then, and in the third place, some physical and chemical characteristics appear, accounting for the behavior of the soils. In the fourth place, other characteristics are taken into consideration, in order to give indications on the orientation to be given to its utilization and which are useful for the explanation of the soils' genesis.

But, it is certain that the first three sets of criteria should be taken into account to define the soil correctly at a given moment. Thus, the soil finds its identity and the natural units make their appearance. So, the new units which are to be discovered should be included in the soil definition without particular difficulties.

5.2 LEVEL I - CONSTITUENTS

The constituents are used for the fundamental divisions, the classes, they are also used within the classes, for the subclasses. These constituents are arranged in the following way:

- Primary minerals, slightly or nontransformed, weatherable or not.
- Raw organic material.
- Salts of different solubilities and properties.
    - . Soluble salts, e.g.: halite, sulfides.
    - . Moderately soluble salts, e.g.: gypsum.
    - . Slightly soluble salts, e.g.: calcium, and/or magnesium carbonate, jarosites.
- Allophanes + organic matter complexes[1].
- Clay minerals or phyllites in 2/1/1 or 2/1 lattices.
    - . without free iron sesquioxides[2].
    - . with free iron sesquioxides.
- 1/1 phyllitic clay minerals.
    - . without free iron sesquioxides.
    - . with free iron sesquioxides.
- Free metallic oxides and hydroxides.
- Iron and aluminium organic matter complexes.

The above-mentioned constituents are arranged in function of the main soil forming processes and their appearance in soils.

We start with the unweathered primary minerals. The raw organic material was placed at a very close level. Then, the classes were arranged according to the groups of diagnostic constituents, in an order of increasing resistance to weathering: First, the salts and the allophanes, the 2/1/1 and 2/1 clay minerals, then the 1/1 clay minerals. An important distinction, based on content, was established between the soils which contain free iron oxides and those which do not contain these oxides or minute quantities of them. Then come the oxides and finally, the metal-organic complexes. These complexes are the last in the arrangement because it was assumed that

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[1] Alumino-silicic gels, allophanes, hisingerite, imogolite.

[2] They include not only sesquioxides, but also hydroxides, oxihydroxides where iron is not included in silicate structures.

a podzol could possibly form from any of the groups of the previous constituents. Moreover, it is considered that this sequum is difficultly reversible except for the salts of some clay minerals and sesquioxides in poor drainage conditions.

THE MAIN CLASSES

1. The *Primarosols* dominantly contain primary minerals and fragmented or nonfragmented rocks. No chemical weathering exists. Lithalterons are observed, but not isalterons, and no mineralons. A certain accumulation of organic matter is possible but the quantity of a secondary mineral materials should be limited to or less than 15% of the fine earth.

2. The *Organosols* result from a strong accumulation of organic matter, slightly or nontransformed, lying on any substrate, with or without free water.

3. The *Selsols* contain a large quantity of salts[1]. The subdivisions in this class are based on the nature of these salts.

4. The *Andosols* contain cryptocrystalline secondary silicates which impart particular properties to the soils. Most often, they are derived from pyroclastic volcanic rocks.

5. The *Bisialsols* contain clay minerals or phyllites in 2/1/1 or 2/1 lattices with a small quantity of free iron sesquioxides.

6. The *Ferbisialsols* contain clay minerals or phyllites, in 2/1/1 or 2/1 lattices, associated with free iron sesquioxides.

7. The *Monosialsols* contain predominant 1/1 clay minerals with a small quantity of free iron sesquioxides.

8. The *Fermonosialsols* contain predominant 1/1 clay minerals but with much free iron sesquioxides.

9. The *Oxydisols* are characterized by the outweighing presence of oxides or hydroxides of different metals, with small amounts of clay minerals.

10. The *Podzols* result from the acido-complexolytic weathering of clay minerals and of iron and aluminium sesquioxides which are removed from the upper part of the pedon, whereas complexes of organic matter with iron and aluminium appear lower in the pedon. The eluvial horizon is not always conspicuous.

SUBCLASSES

They are determined by the variations in the nature of the constituents of a class. These variations may appear at two levels:

a) Differences amongst the mineral or organic constituents whose properties and/or conditions of genesis are quite different, helping in the definition of a class. Then we speak of a *"great subclass"*.

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[1] One should remember that the word "salt" is given here its broadest meaning and applies to constituents of very different solubility.

b) The presence of constituents usually used for the definition of another class. Then we speak of "*subclass*"; in this case, real intergrades are involved.

The case where two or several sets of properties are present at different levels in the same pedon will be examined in part II, for each class.

A - *The great subclasses.* In the case of selsols, for example, the great subclasses result from the predominant presence of a given category of salts.

- Halisols: predominant presence of alkaline soluble salts: chlorides, sulfates, carbonates.
- Thiosols: predominant presence of sulfides or sulfur.
- Sulfosols: predominant presence of alkaline-iron sulfates[1] and free sulfuric acid.
- Gypsisols: predominant presence of calcium sulfate.
- Carboxysols: predominant presence of calcium and/or magnesium carbonate.

Inside a class characterized by the presence of several constituents, it may be useful (whenever it is possible) to determine the nature of one of these constituents, especially when its presence affects the soil's properties. For example, it is interesting to distinguish in the ferbisialsols between the *goethi-ferbisialsols* and the *hemato-ferbisialsols*. In the *fermonosialsols*, the distinction is made between the *kaoli-fermonosialsols* and the *halloysi-fermonosialsols*. In the oxydisols, the distinction is made between the *ferri-oxydisols* and the *alli-oxydisols*.

B - *Subclasses.* The presence in the same pedon of several sets of constituents may occur in some classes. For example:

When salts are present in the pedon in the required position and quantities, the soils are classified as selsols, regardless of the nature of the other constituents.

But, in several cases, the thickness of the saline horizon, the insufficient amount of salts, the position of the saline horizon in the pedon, do not allow a classification in the selsols class. In case of a calcium carbonates accumulation in a ferbisialsol, we speak of a:

- carboxy-ferbisialsol or of a
- carboxic ferbisialsol.

For example, when we write: hemato-ferbisialsol, we give complementary precisions on the subclass.

Apart from the case of salts, the presence of several diagnostic constituents in the same pedon is not frequent. In most cases, a bisialsol, a ferbisialsol, a fermonosialsol, enclose the constituents of the class in the solum and in the alterite or the pedolite. When this is not the case, it is the relative amount and the position in the pedon which decide of the choice of the class.

5.3 LEVEL II - MORPHOLOGY

At the morphology level, we try to account for all observed horizons from the soil surface to the parent rock. Humons, mineralons and alterons are successively observed when they are accessible. But, it is known that in the intertropical zone, the alterons may not be

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[1] Jarosites.

visible with the ordinary means of inspection. Thus, for the soil classification, three observation levels are favored.

1. From 0 to 60 cm - This level corresponds to the most frequently tilled part of the soil for agricultural purposes. It is called: *Suprasol.*
2. From 60 to 200 cm - This level corresponds to the deep part of the soil which is most often accessible to observation by the ordinary means of surveying[1]. It is called: *Infrasol.*
3. Beyond 200 cm - This level corresponds to the deep part of the soil which is only accessible through exceptional circumstances. It is called: *Bathysol.*

During a soil survey, it is possible to limit oneself to a depth of 2 meters. As far as the level of groups and subgroups is concerned the retained morphological characters for the classification should be observable in the infrasol. On the other hand, for a complete study and identification of the soil, it is indispensable to consider the bathysol.

The pedon is observed from top to bottom. The order of interference is successively: organons (if they exist), humons, mineralons, parent materials and/or parent rocks.

- The humons are used for the identification of the *Great groups.*
- The mineralons are used for the identification of the *Groups* and *Subgroups.*
- The parent materials and the parent rocks are used for the definition of the *Families.*

GREAT GROUPS

The great groups shall be defined by the characteristics of humons. Two great categories exist: the sombron and the pallidon which are defined by their organic carbon content and their color, completed by the thickness (hyperpachic, pachic or leptic) and the degree of saturation (eutric or dystric). A great number of great groups is thus available.

They may be explicitly written, but they are more simply written in an abbreviated form.

- Great group with a pachic eutric or pachieutric sombron or still we may write pachieusombric great group.
- Great group with a dystric leptic or leptodystric pallidon or leptodyspallidic great group.

When the humon lacks, the great group is founded on an *epimineralon* (for example: eutric epiferbisialliton or dystric epiferrioxydon).

GROUPS

The groups are established according to the present mineralons in the solum, or at least in the infrasol.

For each class and subclass, there is an *ameristic* group, corresponding to the absence of a mineralon. In this case, the humon lies directly on an alteron or on the parent rock.

For each class or subclass, there is also an *orthic* group which has only a haplic mineralon[2].

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[1] The limit of 2 meters is the one adopted by Soil Taxonomy but in a different sense.

[2] And, possibly another horizon which does not interfere at group level. To it corresponds a *modal* subgroup.

But, other different mineralons are frequently observed in a profile: Each group will be named according to a main horizon in the pedon (which recalls a process of particular differentiation). For example:

- The *argillanic* and *bulgic* groups corresponds to the presence of an argillanic or bulgic horizon; the *hydromorphic* group corresponds to a gley or hemigley horizon; the *indurated* group corresponds to an indurated horizon.

When a pedon contains several horizons developing differential characteristics in the same mineralon, the name of the group will be determined by using a single main mineralon. This choice will be the same for each class and will result from the position of the mineralon in the pedon and from the importance attributed to it in the differentiation of the pedon.

For example, one has to decide the relative importance of an argillanic mineralon and a gley mineralon in order to chose between the argillanic and hydromorphic groups. The horizons which are not used for the establishment of the group will be accounted for at subgroup level.

When the soil is very thick and not all horizons are reached, the groups will be forcibly established by taking into account the accessible horizons in the infrasol (for example, case of the fermonosialsols).

SUBGROUPS

The SUBGROUPS are established as follows:

a) By accounting for the horizons *other* than those used for the establishment of the groups. For example, a soil of the orthic or argillanic group which presents under the haplic mineralon a hemigley horizon is attached to the hydromorphic subgroup.

b) The subgroups are also formed by using adjectives which are not used for establishing groups, like *"arenic"*, *"ferric"*, *"andic"*, etc..

For example, in the bulgic group, an arenic or arenoferric subgroup may exist.

The adjective *modal* applies to the designation of a subgroup when none of the previous designations is suitable. It may apply to soils of the same group which are differentiated only by color.

For example:

- Orthic group; red modal subgroup
- Bulgic group; yellow and red modal subgroup
- Argillanic group; brown modal subgroup.

c) The subgroups are formed by adjectives used in the formation of the groups, when the anticipated characteristics for the groups are not assembled.

For example:

We have a "gravelly" group if there is more than 50% of elements of less than 7.5 cm in diameter occurring over a thickness of more than 50 cm in the infrasol.

If these conditions are not fulfilled, we have only a gravelly subgroup (from 5 to 50% of elements of less than 7.5 cm diameter and a thickness of less than 50 cm).

If a gley or hemigley horizon is not within 30 cm from the humon, it is considered as a hydromorphic subgroup.

FAMILIES

The FAMILIES are established by taking into account the parent material and eventually, when the latter is lacking, the parent rock associated with the soil.

The type of parent material is indicated in specifying that it is an alterite or a pedolite. For example:

- isochromous isalterite from basalt
- mottled isalteron from gneiss
- loessic silty pedolite
- alluvial sandy pedolite

5.4 LEVEL III - PHYSICAL AND CHEMICAL CHARACTERISTICS

At this level, we try to account for more variable characteristics than the previous ones and of edaphic nature. But they also allow to go deeper in the knowledge of soils. Three subdivisions were provided.

The GENUS is intended to allow the characterization of the absorbing complex, by yielding precisions on the degree of saturation[1], pH and eventually, on the particular ions fixed on the complex, such as sodium, magnesium and aluminium. At this level too, information is yielded (if data allow it) on the toxicity (Mn, Al, B, etc.) and on eventual deficiencies, in addition to the contents of total or available phosphoric acid.

These data shall be provided for the diagnostic mineralon and will complete those of the humon.

The TYPE allows to give precisions on some physical characteristics.

The *Texture* is provided for the first 18 centimeters. We shall mention if this texture is maintained without change in the pedon, or if it undergoes variations. The designation of the texture is done by referring to a triangle (in appendix).

The *available water volume* is also given according to data on page 41.

The VARIETY mainly accounts for the thickness of both the pedons and the horizons.

- . The pedon is *thin* if the thickness is less than 18 cm.
- . The pedon is *rather thin* if the thickness is comprised between 18 and 60 cm.
- . The pedon is *rather thick* if the thickness is comprised between 60 and 200 cm.
- . The pedon is *thick* if the thickness is more than 200 cm.

The variety changes: if the thickness variations of the horizons in the suprasol are more than 10 cm.

If, in the infrasol (from 60 to 200 cm), the thickness variations of the horizons are more than 20 cm.

If, in the bathysol (> 200 cm), the thickness variations of the horizons are more than 50 cm.

The SERIES[2] will not be considered as a taxonomic unit but rather as a homogeneous cartographic unit; all pedons of a series show the same arrangement of horizons, the same composition, color, structure, consistence (this data is already provided by levels I and II), but also the same thickness of the horizons, the same pH (data provided by level III).

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[1] Cf. p. 113.

[2] In no case, the considered series in this text is equivalent to the soil series concept of Soil Taxonomy of USDA.

A change of genus, type or variety involves automatically a change of series. The series carries a geographical name in relation with the place where the series was defined.

At levels I, II and III, it is believed that most necessary data for a pedon characterization are available, by using known criteria *for all soils*.

If other criteria appear to be systematically necessary for all soils and horizons, it is always possible to decide to open a new heading and to indicate the hierarchical level on which the new heading has to be placed.

The number of units like great group, group, subgroup, etc. is neither determined nor limited in advance. We are not restricted to one list which is always difficult to modify later on. A new unit is created according to the previously mentioned rules.

The name given to the soil will be forcibly variable according to the degree of required precision. Evidently, the name will be rather long if no essential information is to be omitted[1]. However, on referring to Soil Taxonomy, we find that the soil is not really characterized before having attained the level of the family and that at this stage, the name is already rather long.

5.5 LEVEL IV - DATA RELATIVE TO THE POSSIBILITIES OF SOIL UTILIZATION

This data is relative to two kinds of characteristics. The first, the phases, concern the soils themselves and result from the complementary characteristics which are related to the utilization. The second kinds, or variants, concern the environment.

These two sets of data have a direct impact on the proposals, liable to be emitted on the soil's utilization.

PHASES

- *Rockiness*. This data concerns the presence and abundance of rocks on the surface (cf. p. 41).
- *Stoniness*. This data concerns the presence and the abundance of stones inside the pedon (cf. p. 42).
- *Drainage*. Two ways for drainage: external and internal.

  The *external* drainage concerns the effective presence of water in a pedon at a given moment; it is a geographical characteristic.

  The *internal* drainage is a true soil characteristic and concerns the case that the soil transmits downward flowing excess water. These characteristics are given in detail on page 41.
- The *soil moisture regime* of the soil characterizes the external drainage conditions in the soil over the whole year.
- The *temperature regime* of the soil characterizes the temperature of the soil during the year. It is proposed to follow in this domain the modes of characterization of Soil Taxonomy (pp. 51 to 63). If the necessary measurements are lacking in the control section, it is suggested to deduce them from monthly data of rainfall and temperatures of the nearest stations.
- The *slope*, expressed in percentage is given for the watershed on which the soil is examined (cf. p. 42).

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[1] A subsequent study could be the examination and the proposal of an abridged nomenclature.

VARIANTS

- The *climatic model.* It concerns the type of climate in the zone of the studied pedon. It is expressed in a standardized system (Köppen, Thornthwaite, Gaussen... or other) which allow distance correlations. Data on the soil insolation, the snowing time, the frost hazard, etc. are added if available.
- The *vegetation* which occupies the soil under study. The vegetation type is expressed through the terms of a code.
  . The *land utilization type.*
  . The *geomorphological model* of the place where the soil is observed will be given through the terms of a code.
  . The *results of pastoral* and *agricultural experimentation* when they do exist.

5.6 EXPRESSION OF THE RESULTS

The soil is examined in detail in the field. Not only this leads to a description of the soil, but the examination of its environment allows also to determine its geographical extension. A temporary name, based on a local particularity (city or village, river, mountain, etc.) is attributed to the soil in order to remember it later.
No definite classification can be proposed in this stage because the main elements of the soil are not all known.

A complete sampling of the different horizons which will then be recognized takes place. The gathered specimens will be the object of usual determinations such as mechanical analysis, study of the absorbing complex, determination of free iron and of salts if they be present. A given number of specimens will be prepared in view of the identification of the mineral constituents. This identification will be carried out systematically if the zone has never been studied before. If the zone is already known, only a small number of specimens undergo the mineralogical analysis.

When the complete results of all undertaken analyses, associated with the morphological observations, are available, then a final name can be attributed to the soil.

At this stage, it is possible to consider two modes for expressing the results. The first may be called the synthetic profile, the second corresponds to the classification itself.

SYNTHETIC PROFILE. The synthetic profile corresponds to the expression of the two, sometimes of the three, first levels of the classification. They correspond to the description of the three main parts of the pedon, if these were accessible, or to the presentation of the infrasol alone.

The main three parts of the pedon are separated by //. Inside each part, the different horizons are separated by /. Each horizon is designated by the nouns corresponding to the basic characteristic followed by one or several adjectives, the temporary list of which was previously given. Thus, it is possible either to reach the subgroup or the family.

The following examples are taken from appendix II where all morphological or analytical data can be found.

1. Orthic ferrallitic soil derived from ankaratrite.
   Leptic dystric pallidon // Red haplic ferralliton // Ankaratrite isalteron.

2. Leached ferrallitic soil derived from migmatite. Pachic eutric pallidon // Yellow argillanic ferralliton// Red argillanic ferralliton // Migmatite isalteron.

3. Leached melanic planic bisialsol derived from loam. Pachic eutric melanon // Planic contact // Black argilanic bisialliton // Loam.

4. Perhydric andosol derived from volcanic ash. Hyperpachic sombron // Perhydrid andon // Volcanic ash.

CLASSIFICATION

It is possible to stop at the previous stage which allows a synthetic aspect by providing data of composition (involved in the names ferralliton, bisialliton or andon) and the morphological data. But, it is always desirable to provide the maximum scientific information on the pedon under examination. The first three levels should be necessarily provided. A relative flexibility is permissible in the fourth part of the name of the soil, in order to avoid the expressions becoming larger than desired.
Examples:

1. Class	Fermonosiallitic
Subclass	Gibbsitic
Great group	Leptodyspallid
Group	Orthic
Subgroup	Modal red
Family	Ankaratrite isalterite
Genus	Acidic dystric
Type	Clayey

2. Class	Fermonosiallitic
Subclass	Kaolinitic
Great group	Pachieupallid
Group	Argillanic
Subgroup	Yellow and red
Family	Migmatite isalterite
Genus	Acidic eutric
Type	Sandy clay

3. Class	Bisialsol
Subclass	Mixed
Great group	Pachieumelanic
Group	Planic
Subgroup	Dark brown, hypocarboxic
Family	Calcareous, silty clay pedolite
Genus	Neutral, saturated
Type	Silty clay

4. Class	Andosol
Subclass	Aluminous allophane
Great group	Hyperpachidyssombric
Group	Perhydric
Subgroup	Reddish brown modal
Genus	Acidic dystric
Type	Sandy clay

Supplementary data are added to the previous ones, the new ones being liable to orient the utilization and the soil pioneering.

1. Phases	Moderately deep; nonrocky; nonstony; ustic; isothermic; good internal and external drainage.
Variants	Malagasy pluvioptimoaridic climate; frost; 4 months of dryness; planted afforestation; very weak slope.

2. Phases	Rather thick; nonrocky; nonstony; udic; isohyperthermic; good internal and external drainage.
Variants	Hot subtropical climate; rare frost; dryness for 1 or 2 months; extensive grazing; weak slope.
3. Phases	Rather thick; nonrocky; nonstony; udic; external good drainage; internal (estimated) medium drainage.
Variants	Moderate subtropical climate; some frosts; no severe drought; extensive grazing; smooth slope.
4. Phases	Rather thick; nonrocky; nonstony; perudic isohyperthermic; good external and internal drainage.
Variants	Perhumid; tropical climate; evergreen rain forest; moderate slope.

5.7 CONCLUSIONS

The previous proposals lead to the following remarks:

1 - There is no final list of the classification subdivisions. At any required level, additions are possible, when judged necessary. The new subdivision is then justified by attributing a name to it.

2 - It may be supposed that the list of classes will not increase substantially since it gives place to all important families of the soil constituents. The situation is not the same with regards to the subclasses which may be increased if it were necessary to state more accurately a particular type of constituent (subsequently, at the level of organic constituents for example).

3 - The list of great groups seems liable to include all types of humus horizons.

4 - The groups, determined by a mineralon of major importance in the determination of the morphology, received a single name, as, for example, orthic, argillanic, indurated. This leaves the other mineralons which may exist in the same pedon in the category of subgroups, as reticulate, hydromorphic, etc..

5 - The number of possible subgroups cannot and should not be definitely determined. Therefore, it is illusive to try to set up a rigid frame since the subgroups are in fact planned to account for the solum characteristics, unexpressed by the units situated above them.

6 - The same applies to level III which deals with the physical and chemical characteristics, for which the variety is great at the absorbing complex level.

With these three levels, it appears that most fundamental characteristics of the constituents, the morphology and the physicochemical characteristics are given. If any important characterization element not yet indexed appears necessary and if it were possibly determined everywhere, it can be always introduced at the required level.

At level IV, data relative to the actual environment are anticipated. It is judged that their knowledge is necessary and should be added to the knowledge of the first three levels when the utilization of the soils is required. Their list is not exhaustive and may be modified when the necessity arises.

No synthetic language, analogous to that laid down by syllables for Soil Taxonomy, was proposed. Later on a coded system has to be planned (in numbers and in letters) in order to account for the units which may then be used by data banks.

Finally, a last operation remains to be done, i.e. the appraisal of the genesis and of the present and future evolution of the soil. It is necessary to know all what was previously determined on the soil; but this is not enough. Now, the pedologist should try to ascend the past and reconstitute the soil history. He should use all the accumulated knowledge on the soils of the studied region and to account for the accumulated attainments during years in the study of the world soils. Cause and effect relationships arising from a wide geographical knowledge may be proposed between soils and their present characteristics and the conditions of the environment. These relations may be considered as a result of the comparison of the studied soil-environment complex with other complexes of the same kind or different.

Then, it is possible that proposals may be simultaneously formulated on the environment in close relation with the soil formation, on the mechanisms allowing to explain the processes which have contributed in providing the soil with its constituents, its morphology and its physical and chemical characteristics which it possesses at the moment of the study.

6. SOIL CLASSIFICATION

Soils are classified by using the characteristics which they present.

- Level I (classes and subclasses) is determined by using the constituents and the constituents sets.
- Level II (great groups to families) is determined by using morphological characteristics of the organons, humons and mineralons.
- Level III (genus to series) is determined by using physical and chemical characteristics of the horizons.
- Level IV (phases and variants) is determined by using particular characteristics of the pedon and data of the environment.

In the absence of organons and mineralons, and if the soil content in secondary mineral products is less than 15%, it is classified in the *Primarosols*.

- If the solum presents an organon of sufficient thickness and content in organic matter, the soil is classified in the *Organosols*.
- If the soil has only a humon, without any mineralon, and contains at least 15% of secondary minerals, the soil is placed in one of the other 8 classes. The nature of the mineral or the organomineral constituents orientates the choice of the class.
- If the solum presents a single or several mineralons belonging to the same mineral entity, the latter determines the class.
- If the solum presents two mineralons (or more) belonging to two different mineral or organomineral sets, the choice of the class will be determined by one of the mineralons in function of its thickness and its position in the pedon.

Table 2 allows to achieve the required choice.

6.1 PRIMAROSOLS

* DEFINITION - Primarosols are soils which do not show (or very slightly) pedological differentiation. The constituents of the parent rock did not, or very slightly, undergo weathering. A slight accumulation of organic matter may exist.

The pedon may contain:

- an organon which (if it ever exists) has a maximum thickness of 18 cm (and a minimum of 2.5 cm), otherwise we proceed to organosols.
- and/or a humon.

They must contain less than 15% of secondary minerals, otherwise another class is involved (clay minerals, sesquioxides, salts or allophanes).

* CONSTITUENTS -

Organic constituents

The organic matter may be present in variable quantities. It is slightly incorporated in the mineral material.

Mineral constituents

The physical breaking up is predominant, the chemical weathering is very weak or absent. Rocks, rock fragments and weatherable or nonweatherable primary minerals are abundant. These materials (rocks or minerals) may arise from a rock "in situ" but may be brought by waters and winds. Primary minerals may be difficult to weather, for example quartz.

Table 2 Key to the classes as based on presence and nature of constituents of soil horizons

Possibility for the soil to be a: Soil horizon present	Primarosol	Organosol	Selsol	Andosol Bisialsol Monosialsol	Ferbisialsol Fermonosialsol	Oxydisol Podzol
Organon alone	If organon < 18 cm	If organon ≥ 18 cm	No	No	No	No
Organon + other horizon(s)						
solum < 60 cm	No	If organon ≥ 18 cm and 3/4 of the solum	If organon < 3/4 of the pedon	No	No	No
solum ≥ 60 cm		If organon ≥ 45 cm	If organon < 45 cm	No	No	No
Humon alone	No	No	If humon is saline	If humon is allophanic bisiallitic monosiallitic	If humon is ferbisiallitic fermonosiallitic	If humon is oxydic cheluvic
One or two diagnostic mineralons belonging to the same entity	No	No (except above possibility)	If mineralon is saline	If mineralon is andon bisialliton monosialliton	If mineralon is ferbisialliton fermonosialliton	If mineralon is oxydon cheluvion
Two diagnostic mineralons belonging to the different entities						
1. Presence of a saline mineralon (≥ 15 cm) in the suprasol	No	No	Possible	No	No	No
2. Presence of induron within 60 cm	No	No	No	No	Possible	Possible
3. Absence of the saline mineralon						
a) solum < 60 cm	No	No	The thickest mineralon is diagnostic.			
b) solum ≥ 60 cm	No	No	The thickest mineralon is diagnostic, except the case when the upper mineralon is ≥ 60 cm; in this case, it is always diagnostic.			

The sum of the secondary minerals in the humon or the organon cannot exceed 15%. The presence of salts in the alterite is possible.

* MORPHOLOGY OF PRIMAROSOLS

Organons. When they exist, they lie directly on the alterite or the parent rock. They should have a maximum thickness of 18 cm.

Humons. They should contain less than 15% of secondary mineral products. The following characteristics may be retained:

a - Color - No particular color, often grey.
b - Structure - Fragmentary, slightly developed, particulate.
c - Texture - Variable.
d - Consistence - In the dry state: fragile.
In the humid state: loose, very friable.
e - Porosity - From porous to very porous.
f - Reaction with sodium fluoride: negative.
g - Could be halic, gypsic, carboxic.

Mineralons: absent.

Alterons
Epilithalterons: frequent.
Lithalterons : hard or loose (arenic, silty or clayey).
Could be halic, gypsic, carboxic, reticulate.

Parent materials: hard or loose.

SUBDIVISIONS OF THE CLASS OF THE PRIMAROSOLS

Two subclasses, based on the presence or absence of organic matter are the mineral primarosols and organic primarosols.

Subclass 1 - Mineral Primarosols

General characters of the morphology.
- Neither organon nor humon, but,
  - Epilithalteron.
  - Lithalteron: stony or in blocks, arenic or non fragmented rocky surface, or pedolite (silty or clayey) loose and stratified.

Other divisions:
No great groups nor groups.
Possibility of subgroups, families, genera.

Subclass 2 - Organic Primarosols

General characters of the morphology.
- Organon of less than 18 cm thickness[1] [2] and/or
- Arenic or psammic humon[2].
- Stony lithalteron or in blocks, or arenic.
- Rock.

Other subdivisions:
Great groups, subgroups, families, genera.

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[1] Above this thickness, we pass on to an organosol.
[2] In these horizons, the quantity of secondary mineral products does not exceed 15%.

6.2 ORGANOSOLS

* DEFINITION - The organosols are characterized by the presence of organic matter to which they owe their main properties.

They should have an organon in the upper part of the pedon.

a) If there is no mineralon, the thickness of the organon should be equal to or higher than 18 cm, otherwise we remain in the primarosols.

b) In case of having a mineralon:

1 - If the pedon is less than 60 cm, the organon should be 3/4 at least of the pedon.

2 - If the pedon is more than 60 cm, the thickness of the organon should be equal to 45 cm or more.

If these conditons are not fulfilled, the soil has to be placed in another class.

* CONSTITUENTS -

Organic constituents

The organic matter derives from trees or shrubs or herbaceous plants (grass, rushes, reeds, mosses, etc.).

It simultaneously contains nontransformed matter, recognizable with the naked eye and on touching, and transformed matter, of unidentified origin. Fibrous organic materials, foliated (stacked), or nonrecognizable materials may be distinguished.

The organic matter content is more than or equal to 50% by volume (or 30% by weight of the sample dried at 105°C). The bulk density should be less than 0.1. The water content should be higher than 800% with respect to the sample dried at 105°C.

The C/N ratio should be higher than 10.

Mineral constituents

These constituents are not in the least specific.

* MORPHOLOGY OF ORGANOSOLS

Organons

a - Color - always dark, from black to red.
b - Structure - fibrous, foliated or sapric.
c - Porosity - very high.
d - Reaction with sodium fluoride: negative.

Mineralons

When they exist, they are of different kinds: bisialliton, ferralliton, etc.

Various kinds of *Alterite* or *Pedolite*: sandy, sandy-clay or clayey.

The *parent rock* may be sedimentolithe (shell rich sand, marl, diatomite...).

SUBDIVISIONS OF THE CLASS OF THE ORGANOSOLS

Four subclasses are proposed[1], based on the characteristics of the organic matter.

Subclass 1 - Fibric organosols

They contain more than 50% (by volume) of fibrous organic matter.

Subclass 2 - Folic organosols

They contain more than 50% (by volume) of foliated or stacked organic matter.

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[1] Cf. Soil Taxonomy.

Subclass 3 - Hemic organosols

They contain from 10 to 50% of fibrous or foliaceous organic matter.

Subclass 4 - Sapric organosols

They contain less than 10% of recognizable organic matter.

Other subdivisions: No great groups.
Groups: when a mineralon is present.
Subgroups: according to the possibility of having a halic, thionic, gypsic or carboxic organon.
Families: according to the nature of the material or of the subjacent parent rock for organons.

6.3 SELSOLS

* DEFINITION - Selsols are characterized by the presence of *salts*, of variable solubility, which impart to soils their main properties.

- If an organon exists.
  a) If the solum has a thickness of 60 cm or less, the organon should represent less than 3/4 of the solum.
  b) If the solum has more than 60 cm thickness, the organon should have less than 45 cm thickness.
  If the previous conditions are not fulfilled, the soil has to be classified among the *organosols*.
- If the solum has only a humon, directly in contact with an alteron, a pedolite or the parent rock, this humon should be saline[1].
- If the solum has only one mineralon, bound to a humon and/or an organon, this mineralon should be saline[1] and situated at the top of the pedon, under the humon or the organon. This saline horizon should be at least 15 cm thick and situated in the first 60 centimeters of the pedon (suprasol).
  If the solum thickness is less than or equal to 60 centimeters, the soil is a selsol if the thickness of the saline horizon is more than or equal to ¼ of that of the solum.

The selsols are subdivided in five great subclasses, according to the nature of the salts, in the following order:

thiosols,	sulfosols,	halisols,	gypsisols,	carboxisols
1	2	3	4	5

a) The thiosols correspond to the reduced forms and the sulfosols to the oxidized forms.
b) In case of the simultaneous presence of several diagnostic saline horizons, it is assumed that the importance of soils with regards to both pedogenesis and utilization is in the above-given order.

Consequently, in case of the simultaneous presence of salts from subclass 1 and other subclasses, the determining subclass will be always 1.

- For example, in case of the simultaneous presence of sulfides and halite, one has to do with the subclass of the halic thiosols or halithiosols.
- When there is the simultaneous presence of gypsum and calcium carbonate soils are ascribed to the subclass of carboxic gypsisols or carboxigypsisols.

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[1] Remember that the word "saline" is a general term applying to all salts, whatever their solubility.

c) When a certain type of saline constituents is present in the suprasol and another in the infrasol (in sufficient amounts to have a saline horizon in both cases), the determining constituent of the subclass is the one present in the suprasol; while the one present in the infrasol determines a group.
d) When a second type of saline constituents is present in the pedon (in the suprasol or in the infrasol), but in smaller quantities than expected to form a saline horizon, the presence of this second group of constituents is effective at the level of subgroups, with the help of a proper adjective.

6.3.1 THIOSOLS

* DEFINITION - The thiosols form a subclass of the selsols, characterized by a thion, situated at less than 60 cm from the surface.

* CONSTITUENTS - The diagnostic mineral constituents are the following:

- elementary sulfur and/or iron sulfide or polysulfides with a sulfur content exceeding 0.75%.
  The pH becomes rapidly more acidic by exposure to air.

* MORPHOLOGY OF THIOSOLS

Organons and *humons*

Different organons, sombrons and pallidons (rare) are known, being eutric or dystric.

Mineralons

The diagnostic mineralons of the subclass are:
The *haplic thion* which contains the diagnostic constituents and shows the following characteristics, none of which alone is enough for the identification.

a - Color - Uniform or mottled.
b - Structure - Variable, but with the exception of prismatic, vertic, or columnar.
c - Texture - Variable, but with the exception of arenic or psammic.
d - Consistence - In the dry state: fragile to slightly fragile.
In the humid state: friable to firm.
In the soaked state: fluid.
e - Less than 5% of coarse materials.
f - Absence of andic characteristics.
g - Absence of characteristics of argillanic or bulgic horizons.
h - Absence of other salts than those defining the thion.

The other thions are derived from the haplic thion by modification of one of the above-given characteristics.

Thion:	Modification of
arenic	c
compact	d
gravelly or stony	e
vertic, prismatic, columnar	b
argillanic or bulgic	g
carboxic, gypsic or halic	h

Diagnostic mineralons of other subclasses: halon, gypson, carboxyton.

Diagnostic mineralons of other classes: bisialliton, ferbisialliton, monosialliton, fermonosialliton.

Alterons: usually pedolite.

SUBDIVISIONS OF THE GREAT SUBCLASS OF THE THIONIC SELSOLS OR THIOSOLS

Subclasses (other than those with a single thion).
- Halic thiosol or halithiosol: the characteristics of the halon appear in the suprasol.
- Gypsic thiosol or gypsithiosol: the characteristics of the gypson appear in the suprasol.
- Carboxic thiosol: the characteristics of the carboxiton appear in the suprasol.

Great groups
Organic, sombric or pallidic, dystric or eutric.

Groups
The following groups are possible and arranged in such a way that the presence of the characteristic horizon corresponding to the group outweighs all preceding groups.

. Ameristic - The solum does not present a thion; the thionic humon lies directly on an alterite, a pedolite or on a parent rock.

. Orthic - The solum presents a humon and a haplic thion and none of the following mineralons above it in the suprasol.

. Gravelly or stony - The solum should present a gravelly or stony horizon beginning the suprasol. It should have at least 50 cm thickness and at least 50% of the weight as gravels or stones.

. Argillanic or bulgic - The solum presents an argillanic or a bulgic horizon beginning in the suprasol.

. Halic - The presence of halic characteristics appears somewhere in the infrasol.

. Gypsic - The presence of gypsic characteristics appears somewhere in the infrasol.

. Carboxic - The presence of carboxic characteristics appears somewhere in the infrasol.

Subgroups
Gravelly and stony may be considered as subgroups where these characteristics appear below the suprasol.
- Arenic, vertic, prismatic, columnar, hypohalic, hypogypsic, hypocarboxic, when the corresponding characteristics are observed in the suprasol.

6.3.2 SULFOSOLS

* DEFINITION - The sulfosols form a such class of selsols characterized by a sulfon situated in the first 60 centimeters of the pedon.

* CONSTITUENTS - The diagnostic mineral constituents are: ferric and alkaline sulfates (jarosites), free sulfur (with a higher content or equal to 0.75%).
- Sulfuric acid, shown by a pH less than 3.5.

* MORPHOLOGY OF SULFOSOLS

Organons and *Humons*
Organons, sombrons and pallidons are known, being eutric, dystric or saturated.

Mineralons

The diagnostic mineralons of the subclass are:
The *haplic sulfon* contains diagnostic constituents and presents the following characteristics, none of which alone is sufficient for the identification.

a - Color - Grey, mottled with red, brown and especially yellowish (straw colored).
b - Structure - Variable, with the exception of the prismatic, columnar, vertic.
c - Texture - Variable, with the exception of the arenic or more sandy.
d - Consistence - In the dry state: fragile to hard. In the humid state: friable to firm. Soaked: fluid to firm ("butter consistence").
e - Less than 5% of coarse material.
f - Absence of andic characteristics.
g - Absence of characteristics of the leached horizon (argillanic or bulgic).
h - Absence of salts, other than those defining the sulfon.

The other sulfons are derived from the haplic sulfon by a modification of one of the above-mentioned characteristics.

		Modification of
Sulfon:	arenic	c
	gravelly, stony	e
	vertic, prismatic, columnar	b
	argillanic, bulgic	g
	sulfurized, halic, gypsic, carboxic	h

Diagnostic mineralons of other subclasses of the selsols: halon, thion, gypson, carboxiton.

Diagnostic mineralons of other classes: bisialliton, ferbisialliton, monosialliton, fermonosialliton.

Alterons: usually pedolite.

SUBDIVISIONS OF THE GREAT SUBCLASS OF THE SULFONIC SELSOLS OR SULFOSOLS

Subclass (other than the subclass with sulfon alone)

- Halic sulfosols or halisulfosols: the halon characteristics appear in the suprasol.
- Gypsic sulfosols or gypsisulfosols: the characteristics of the carboxiton appear in the suprasol.

Great groups

Organic, sombric or pallidic; dystric or eutric.

Groups

The following groups are possible, arranged in such a way that the presence of the characteristic horizon, corresponding to the group overweighs all preceding groups:

. Ameristic - The solum does not show a sulfon. The sulfonic humon lies directly on an alterite, a pedolite or on a parent rock.

. Orthic - The solum presents a humon and a haplic sulfon and none of the following mineralons is present above it in the suprasol.

. Gravelly or stony - The solum should present a gravelly or stony horizon in the suprasol. It should have at least 50 cm thickness and present at least 50% by weight of gravels and stones.

. Argillanic or bulgic - The solum presents an argillanic or bulgic horizon starting in the suprasol.

. Thionic, halic, gypsic, carboxic - The presence of halic, gypsic, carboxic characteristics are manifest in the suprasol; of thionic characteristics in the infrasol.

Subgroups

At the level of the subgroup, one may consider: gravelly, stony, when these horizons appear in the infrasol.

- arenic, prismatic, columnar, vertic.
- sulfurized, hypohalic, hypogypsic, hypocarboxic when the corresponding characteristics are observed in the suprasol and/or the infrasol.

6.3.3 HALISOLS

* DEFINITION - The halisols form a great subclass of the selsols, characterized by a halon present in all seasons and situated at less than 60 cm from the surface.

* CONSTITUENTS - The diagnostic mineral constituents are the following: sodium chloride, sulfate, carbonate and/or bicarbonate, magnesium sulfate, and chloride, calcium chloride.

The conductivity of the saturated paste extract should be higher than or equal to 8 ms at 25°C.

No particular criteria concerning the clay minerals or the sesquioxides are used. There is no specific organic constituents.

* MORPHOLOGY OF HALISOLS

Humons

Several sombrons or pallidons are known; several great groups are possible: they all are eutric or saturated.

Mineralons - Diagnostic mineralons of the class.

The *haplic halon* contains the diagnostic constituents and presents the following characteristics none of which alone is enough for the identification.

a - Color - Variable, but uniform.
b - Structure - Fragmentary; exclude: massive, columnar, prismatic, vertic.
c - Texture - Variable, with the exception of arenic or psammic.
d - Consistence - In the dry state: friable to hard.
In the humid state: friable to firm.
e - Less than 5% of coarse materials.
f - Less than 2% of colored mottles.
g - Absence of andic characteristics.
h - Absence of characteristics of the argillanic or bulgic horizon.
i - Absence of other salts than those defining the halon.

The other halons are derived from the haplic halon by modification of one of the above characteristics:

	Modification of
Halon: arenic	c
massive	b
compact	d
gravelly	e
encrusted	d
with gley	f
with hemigley	f
vertic	b
argillanic or bulgic	h
carboxic, gypsic	i

Diagnostic mineralons of:
- *other subclasses*: gypson, carboxyton, thion, sulfon.
- *other classes*: bisialliton, ferbisialliton, mono- and fermonosialliton.

Alterons: generally pedolite.

SUBDIVISIONS OF THE GREAT SUBCLASS OF THE HALIC SELSOLS OR HALISOLS

Whenever it is possible, the nature of the salts is determined so as to know whether they are chlorides, sulfates, bicarbonates and if the predominant cation is sodium, magnesium or calcium. For example, halisols with sodium chloride, or chlorosulfated sodico-magnesian halisols, or calcium chloride halisols.

The *subclasses* are (other than the subclass with a single halon):
- gypsic halisols or gypsihalisols. The characteristics of the gypson appear in the suprasol.
- carboxic halisols or carboxihalisols. The characteristics of the carboxiton appear in the suprasol.

Great groups

Sombrons, pallidons, epimineralons are known; with predominance of pallidons. They are all eutric or saturated.

Groups

The following groups are possible, arranged in such a way that the presence of a characteristic horizon corresponding to the group overweighs all the preceding groups.

- . Ameristic - The solum does not show a halon. The halic humon lies directly on the alteron or on a parent rock.
- . Orthic - The solum has a humon *and* a haplic halon.
- . Massive - The solum has a compact halon in the suprasol, with a thickness of at least 50 cm.
- . Hydromorphic - The solum has a gley or a hemigley in the first 30 centimeters under the humon.
- . Gravelly or stony - The solum should present a gravelly horizon in the suprasol. It should have at least 50 cm thickness and more than 50% of the weight in gravels (or stones).
- . Argillanic or bulgic - The solum presents an argillanic or bulgic horizon in the suprasol.
- . Planic - The solum presents an eluvial horizon and an argillanic or bulgic horizon in the infrasol.
- . Encrusted - The solum presents an encrusted halon in the suprasol.
- . Thionic, acidosulfated, gypsic, carboxic - The solum presents a thion, sulfon, gypson or carboxiton in the infrasol.

Subgroups

Gravelly and stony subgroups may be considered when these horizons are present in the infrasols:
- arenic, prismatic, columnar, vertic.
- sulfurized, acidosulfated, hypogypsic, hypocarboxic when the corresponding characteristics are observed in the suprasol and/or the infrasol.

6.3.4 GYPSISOLS

* DEFINITION - The gypsisols form a great subclass, characterized by a gypson situated at less than 60 cm from the surface (in the suprasol).

* CONSTITUENTS - The diagnostic mineral constituent is gypsum (to which the anhydrite may be added). The calcium sulfate content should be higher than 15% somewhere in the suprasol. There is no particular criterion concerning the clay minerals or the sesquioxides. There is no specific organic constituent.

* MORPHOLOGY OF GYPSISOLS

Organons and *Humons*

Different organons and humons, eutric or saturated are possible.

Mineralons. The diagnostic mineralons of the class are:

The *haplic gypson* contains the diagnostic constituents and presents a set of characteristics, none of which is sufficient for the identification.

The accumulation of calcium sulfate is diffuse or with pseudomycelium.

a - Color - Variable but uniform.
b - Structure - Are excluded: massive, columnar, prismatic, vertic.
c - Texture - Any, with the exception of the arenic or psammic.
d - Consistence - In the dry state: friable to hard.
In the humid state: friable to firm.
e - Less than 5% of coarse materials.
f - Less than 2% of mottles of a different color than that of the horizon.
g - Absence of andic characteristics.
h - Absence of characteristics of the argillanic or bulgic horizon.
i - Absence of other salts than those which define the gypson.

The other gypsons are derived from the haplic gypson by modification of one of the above-given characteristics.

Gypson:	Modification of
arenic	c
massive	b
compact	e
nodular	e
concretionary	e
foliaceous	e and d
tufaceous	e and d
encrusted	e and d
indurated	d
with gley	f
with hemigley	f
vertic	b
argillanic	h
bulgic	h
halic	i
carboxic	i
thionic	i
acidosulfated	i

Diagnostic mineralons of other subclasses of the class of selsols: thion, sulfon, halon, carboxiton.

Diagnostic mineralons of other classes: bisialliton, ferbisialliton, monosialliton, fermonosialliton.

Alterons

- Lithalteron, loose to hard.
- Mixed alteron.

SUBDIVISIONS OF THE GREAT SUBCLASS OF THE GYPSIC SELSOLS OR GYPSISOLS

The *subclasses* are (besides that with gypson alone).

- Carboxic gypsisols or carboxigypsisols. The characteristics of the carboxiton appear in the suprasol.

Groups

The following groups are possible. They are arranged in such a way that the presence of a characteristic horizon corresponding to the group overweighs all preceding groups.

- . Ameristic - The solum shows no gypson: the gypsic humon lies directly on an alteron or on a parent rock.
- . Orthic - The solum presents a humon and the haplic gypson and none of the following mineralons above it in the suprasol.
- . Hydromorphic - The solum presents a horizon with gley or hemigley in the first 30 centimeters under the humon.
- . Gravelly or stony - The solum should present a gravelly or stony horizon in the suprasol. It should have at least 50 cm thickness and present 50% at least of the weight as gravel and/or stone.
- . Argillanic or bulgic - The solum presents an argillanic or bulgic horizon starting in the suprasol.
- . Encrusted, foliaceous, tufaceous - The solum presents an encrusted, foliaceous or tufaceous gypson in the suprasol.
- . Indurated - The solum presents an indurated gypson (or even a gravelly or stony horizon) not allowing the penetration of roots through the suprasol.
- . Thionic, acidosulfated, halic, carboxic - The solum presents a thion, sulfon, halon or carboxiton in the infrasol.

Subgroups

At the level of the subgroup, one may consider: gravelly, stony, encrusted, foliaceous, tufaceous, indurated, when these horizons appear below the suprasol.

Other subgroups: hydromorphic, arenic, prismatic, columnar, vertic.

- Acidosulfated, sulfurized, hypohalic, hypocarboxic, when the corresponding characteristics are observed in the suprasol and/or the infrasol.

6.3.5 CARBOXISOLS

* DEFINITION - Carboxisols form a great subclass, characterized by a carboxiton, situated at less than 60 cm from the surface (in the suprasol).

* CONSTITUENTS - The diagnostic mineral constituents are the following: calcium carbonate (calcite or aragonite), dolomite, giobertite of secondary origin. The carbonate content should be higher than 15%, somewhere in the suprasol. There is no particular criterion concerning the clay minerals or the sesquioxides. There is no specific organic constituent.

* MORPHOLOGY OF CARBOXISOLS

Organons and *Humons*

Different organons, sombrons and pallidons, especially eutric or saturated are known.

Mineralons. The diagnostic mineralons of the class are:

The *haplic carboxiton* contains the diagnostic constituents and presents such characteristics, none of which alone is sufficient for the identification. The accumulation of carbonates is diffuse or with pseudomyceliums, the carboxiton is carboxic.

a - Color - Variable but uniform.
b - Structure - Fragmentary, exclude the massive, columnar, prismatic, vertic.
c - Texture - Variable, but with the exception of arenic.
d - Consistence - In the dry state: friable to hard. In the humid state: friable to firm.
e - Less than 5% of coarse material.
f - Less than 2% of colored mottles other than that of the horizon.
g - Absence of andic characteristics.
h - Absence of characteristics of argillanic or bulgic horizon.
i - Absence of other salts than those which define the carboxiton.

The other carboxitons are derived from the haplic carboxiton by modification of one of the above-given characteristic.

		Modification of
Carboxiton:	arenic	c
	massive	b
	compact	d
	nodular	e
	foliaceous	e and d
	tufaceous	e and d
	encrusted	e and d
	indurated	d
	with gley	f
	with hemigley	f
	vertic	b
	argillanic, bulgic	h
	acidosulfated, thionic, gypsic, halic	i

Diagnostic mineralons of other subclasses: gypson, halon, thion, sulfon.

Diagnostic mineralons of other classes: bisialliton, ferbisialliton, mono- and fermonosialliton.

Alterons

- Loose or hard lithalterons.
- Mixed alterons.
- Pedolites.

SUBDIVISIONS OF THE GREAT SUBCLASS OF CARBOXIC SELSOLS OR CARBOXISOLS

Groups

The following groups are possible. They are arranged in such a way that the presence of a characteristic horizon corresponding to the group overweighs all the preceding groups.

. Ameristic - The solum has no carboxiton. The carboxic humon lies directly on the alteron or on the parent rock.

. Orthic - The solum has a humon *and* a haplic carboxiton.

. Hydromorphic - The solum has a horizon with gley or hemigley in the first 30 centimeters under the humon.

- . Gravelly or stony - The solum should have a gravelly or stony horizon in the suprasol. It should have at least 50 cm thickness and at least 50% of the weight in calcareous gravel and stones.
- . Argillanic or bulgic - The solum has an argillanic or bulgic horizon starting in the suprasol.
- . Encrusted, foliaceous, tufaceous, nodular - The solum has an encrusted, foliaceous, tufaceous or nodular carboxiton in the suprasol.
- . Indurated - The solum has an indurated carboxiton in the suprasol.
- . Sulfonic, halic, gypsic - The solum has a sulfon, halon, gypson in the subsoil.

Subgroups

As *subgroups*, we may consider: gravelly, stony, tufaceous, encrusted, indurated, below the suprasol.

- Hydromorphic, gravelly, stony, arenic, acidosulfated, hypohalic, hypogypsic, when the corresponding characteristics are observed in the suprasol and/or the infrasol.

6.4 ANDOSOLS

* DEFINITION - The Andosols are characterized by the presence of "amorphous" mineral materials of allophane type, very narrowly associated with humic materials and to which the andosols owe their main properties.

In the upper part of the pedon, an allophanic humon and in the upper part of the mineralons, an andon, is found.

Above the humon, there may be an organon which should not represent more than three fourth of the solum if the latter is less than 60 cm thick, and not more than 45 cm if the solum is at least 60 cm thick. If the pedon has only a humon directly in contact with the alterite or the parent rock, it should be an allophanic humon.

The distinction between the primarosol on ashes or volcanic lapillis and a vitric andosol is done on the basis of the positive reaction with the sodium fluoride test, or of marks of weathering (such as color or structure) in the parent material and a bulk density lower than 0.9.

Also, a diagnostic mineralon of another class like the selsol, bisialsol, ferbisialsol, fermonosialsol, etc. may exist in the pedon. But, in this case, the andon should predominate in the suprasol, as specified in table 2.

The age of the soil is often less than 10,000 years. Andosols are generally derived from pyroclastic volcanic materials.

* CONSTITUENTS - The mineral constituents are the following:

- Amorphous or cryptocrystalline mineral materials or allophanes, to which imogolite may be also added.
- They may also contain 1/1 clay minerals (especially halloysite) or some 2/1 clay minerals (chlorites, illites or smectites).
- Iron hydroxides, most often amorphous in cryptocrystalline and sometimes iron oxides (inherited) like hematite, magnetite, maghemite, ilmenite. Very often crystallized aluminium hydroxides (gibbsite) or amorphous aluminium hydroxides.

- Among the salts, only calcium carbonates are observed, but very seldom.

Organic constituents. The organic matter is often abundant (According to occurrences, the humic acids overweigh the fulvic acids or the contrary). Fulvic acids form stable complexes with aluminium.

* MORPHOLOGY OF ANDOSOLS

A) *Organons.* Andosols with organon are known.

B) *Humons.* Dystric or eutric sombrons and pallidons are known.

The dystric humons may be considered as the most frequent; but the eutric equivalents are by now well known. The humons are seldom gravelly; they are often sandy (lapillis and ashes). The allophanic humons may exist alone. In this case, they are used to characterize the class. Structure is mealy and bulk density lower than 0.9.

C) *Mineralons.*

Haplic andon. It contains the mineral constituents, characteristic of the class. The morphological characteristics are the following:

a) Color - Brown, dark brown or reddish brown colors are the most frequent (plates 5YR, 7.5YR, 10YR). Yellow (plates 7.5YR, 10YR, 2.5YR) is rare; red (plate 5YR) is rare but possible.

b) Structure - The structure is often massive and microporous; sometimes fine to very fine fragmentary. The splinters are often angular and of variable size.

c) Texture - Silt is often very abundant (more than clay). The percentage of sands should be less than 60%. The variations in the profile are small. No illuvial accumulation, no cutans and no shining faces.

d) Consistence - In the dry state: very fragile; under the pressure of fingers, a fragment resists weakly before bursting.

- In the humid state: friable but more coherent.
- In the soaked state: smeary consistence, nonplastic, nonsticky.

e) Porosity - Porous to very porous (total porosity of 70 60 80%), bulk density lower than or equal to 0.9.

f) Must not show the characteristics of a carboxic horizon or of a gypsic horizon.

g) Must not show the characteristics of a silicic horizon.

h) Must not show the characteristics of the compact horizon, with duripan, placic, indurated.

i) Must not show the characteristics of the perhydric horizon.

The other following andons may be observed: vitric, carboxic, with duripan, placic, perhydric.

* ALTERONS - The true alteron is rare. An ambialteron is often observed.

* PARENT ROCKS - Practically, these are mainly the broken up volcanic rocks (pyroclastic and rich in microlites) from which the andosols originate. Ashes and lapillis, acidic to basic and strongly divided, are the most frequent parent rocks.

SUBDIVISIONS OF THE CLASS OF ANDOSOLS

Two *great subclasses* are proposed:
Vitric great subclass. The soils contain great quantities of parent material (ashes, lapillis, pumice, etc.) and few weathering products. They may be defined:

- either by a water content measured on the humid soil, under a pressure of 15 bars, less than 20% of the fine earth (expressed by weight);
- or by a content of over 60% unweathered material and bulk density higher than 0.9.

Allophanic great subclass. The water content of the fine earth under 15 bars pressure is more than 20% and/or the content of weatherable materials is less than 60%.

Allophanic great subclass is divided in two subclasses: a) with siliceous allophane; b) with aluminous allophane.

a) Subclass with siliceous allophane

The silica/alumina ratio, determined on the fraction < 2µ is higher than or equal to 2.5. The constituents are allophanes, 1/1 clay minerals and 2/1 clay minerals. The bulk density ranges from 0.7 to 0.9.

b) Subclass with aluminous allophane

The silica/alumina ratio, determined on the fraction < 2µ is less than 1.5. The constituents are: allophanes, imogolite, halloysites and gibbsite. The bulk density is 0.2 to 0.7.

Great groups

Different great groups are known. However, the Pachidys-sombric great group is the most frequent.

Groups

. Ameristic - The solum has only an allophanic humon lying on an alteron or on a parent rock.

. Orthic - The solum has only a haplic andon below the humon.

. Perhydric - The solum has a perhydric horizon in the suprasol.

. Compact - The solum has a compact horizon in the suprasol.

. Duric - The solum has a duric horizon[1] in the suprasol.

. Multiple - The suprasol should present two or more of superposed solums.

. Hydromorphic - The suprasol should present a gley or hemigley.

In the vitric great subclass, there is no orthic group as defined before. The main group is arenic group where the textures are coarse with a sand content higher than 50%. But the soils of this subclass should not have a negative NaF test, otherwise we proceed to the primarosols.

Subgroups

The modal subgroup of the orthic group is obtained on determining the color of the mineralon. Other subgroups are possible like:

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[1] This horizon is cemented by silica or clay, or due to a thermal effect.

. Placic - The solum has a placic horizon in the subsoil.

. Carboxic - The solum has a carboxic horizon in the subsoil.

. Perhydric, compact, duric hydromorphe - The solum has a perhydric horizon, compact or duric, below 60 cm.

6.5 BISIALSOLS

* DEFINITION - The bisialsols are characterized by the presence of 2/1/1 or 2/1 clay minerals and by less than 3% free iron oxides, which imparts to the soils their main characteristics.

- In presence of an organon:
  a) If the solum has 60 cm thickness or less, the organon should represent less than 3/4 of the solum.
  b) If the solum has more than 60 cm thickness, the organon should have less than 45 cm thickness.
  If the previous conditions are not fulfilled, the soil has to be classified in the organosols.
- If the pedon has only a humon, directly in contact with an alteron or with the parent rock, this humon should be bisiallitic.
- If the solum has only one mineralon, a humon and eventually an organon, this mineralon should be a bisialliton, situated at the top of the pedon under the humon. In the absence of humons, the bisialliton is called epibisialliton.

Several bisiallitons may be present in the same solum.

- If the solum has one or several diagnostic mineralons, other than bisialliton, we should account for the position and the relative importance of these mineralons in the solum.
  A) If one of these mineralons is *saline*, it would not be present in the first 60 centimeters, otherwise the soil is classified in the selsols.
  B) When one of these mineralons is not saline:
  a - When the solum thickness is *less* than or equal to 60 cm, the thickest mineralon is the diagnostic mineralon.
  b - When the solum thickness is *more* than 60 cm, the thickest mineralon is the diagnostic mineralon, except when the upper mineralon has a greater thickness than 60 cm.

If these conditions are not fulfilled, the other mineralons become determining factors.

* CONSTITUENTS - The diagnostic mineral constituents are the following:

- The 2/1/1 and/or 2/1 clay minerals should represent 10% or more of the clay fraction.

The free iron sesquioxides should represent less than 3% of the fine earth.

Together with the previous constituents, 1/1 clay minerals, secondary silica, salts and allophane may be found.

No specific organic constituents of the class are observed.

* MORPHOLOGY OF BISIALSOLS

Humons

All different sombrons and pallidons are known. Some sombrons may be melanic. Some humons may contain calcium carbonate or calcium sulfate.

Mineralons. Diagnostic mineralons of the class.

The *haplic bisialliton* contains the diagnostic constituents and shows the following characteristics, none of which is sufficient for the identification and allows to define the modal subgroup of the orthic group.

a - Color - Yellow or brown. No grey, olive or red.
b - Structure - Fragmentary of small dimension, the angular forms are frequent. The particulate, massive, columnar and vertic structures are excluded.
c - Texture - All textures, except those with less than 15% clay + silt.
d - Consistence - In the dry state: friable to hard. In the humid state: loose to firm.
e - Less than 5% of coarse material (gravels or stones).
f - Less than 2% of color mottles, different from that of the horizon.
g - Absence of characteristics of the andic horizon.
h - Absence of characteristics of the argillanic or bulgic horizon.
i - Absence of secondary salts or of silica.
j - Less than 15% of parent rock fragments.
k - Less than 15% of alterite.
l - Less than 10% of weatherable primary minerals between 0.02 and 2 mm.

The other bisiallitons are derived from the haplic bisialliton by modification of the above-mentioned characteristics.

		Modification of
Bisialliton:	arenic	c
	andic	g
	argillanic	h
	bulgic	h
	carboxic	i
	columnar	b
	compact	b and d
	gravel	e
	gypsic	i
	with gley	f
	with hemigley	f
	halic	i
	stony	e
	lithic	j
	reticulate	a
	silicic	i
	vertic	b
	calcaric	i
	penevolved	e

Diagnostic mineralons of other classes: halon, gypson, carboxiton, thion, sulfon.

Nondiagnostic mineralon: albon.

Alterons. May completely lack:
- very different lithalterons;
- isalterons;
- mixed alterons.

SUBDIVISIONS OF THE CLASS OF BISIALSOLS

Great subclasses. Theoretically, they may be numerous and determined according to the criteria, given in p. 29-30. However, only two great subclasses are retained:
- Smectic, dominated (more than 50%) by smectites (montmorillonites, beidellites);
- Mixed, where several 2/1 clay minerals are present in a mixture, none exceeding 50%.

Subclasses. They are from the presence of a diagnostic horizon of another class in the suprasol, like:

halon	halibisialsol
gypson	gypsibisialsol
carboxiton	carboxibisialsol

Great groups. All great groups are possible.

Groups

The following groups may be considered. They are arranged in such a way that the presence of a characteristic horizon corresponding to the group overweighs all preceding horizons.

. Ameristic - No bisialliton appears. The humon lies directly on an alteron or on the parent rock.

. Orthic - The solum has a humon and a haplic bisialliton.

. Lithopolygonal - The solum presents a lithopolygonal bisialliton.

. Gelic - The solum presents one or several horizons perturbated by frost.

. Compact - The solum presents a compact bisialliton in the suprasol and is 50 cm thick at least.

. Hydromorphic - The solum presents a gley or hemigley horizon in the first 30 cm under the humon.

. Reticulate - The solum presents a reticulate bisialliton in the first 30 cm under the humon.

. Vertic - A vertic bisialliton should appear in the suprasol.

. Gravelly stony - The solum should present a gravelly horizon in the suprasol; it should be 50 cm thick at least and have more than 50% of the weight in gravels or stones.

. Argillanic or bulgic - The solum presents an argillanic or bulgic bisialliton in the suprasol.

. Planic - The solum presents a planic contact between an eluviated horizon and an argillanic or bulgic bisialliton in the suprasol.

. Glossic - The solum presents a glossic contact between an eluviated horizon (albic) and an argillanic or bulgic bisialliton, in the suprasol.

. Columnar - The solum presents a columnar bisialliton in the suprasol.

Subgroups

They are specified by the addition of subordinate horizons to the horizons which determine the group, insufficiently thick or appearing below the suprasol.

In addition to the modal subgroup, the following subgroups may be obtained: impoverished, gravelly, reticulate, andic, arenic, hypohalic, hypogypsic, hypocarboxic, calcaric, hydromorphic, vertic, etc..

Subdivisions in the *subclass* of carboxibisialsols. (They may be the same in other subclasses.) The great groups are determined in the usual way.

The groups are determined according to the characteristics of the bisialliton, and the subgroups, according to the characteristics of the carboxiton.

6.6 FERBISIALSOLS

* DEFINITION - The ferbisialsols are characterized by the presence of 2/1/1 or 2/1 clay minerals and of more than 3% free iron sesquioxides which confer to the soils their main characteristics (2/1 or 2/1/1 clay minerals must be more than 10% of the clay minerals).

- In presence of an organon:
  a) If the solum has a thickness of 60 cm or less, the organon must represent less than 3/4 of the solum.
  b) If the solum has more than 60 cm thickness, the organon must be less than 45 cm thick.
  If these conditions a) or b) are not fulfilled, the soil has to be classified in the organosols.
- If the solum has only a *humon*, directly in contact with an alteron or the parent rock, this humon should be ferbisiallitic.
- If the solum has only a single mineralon and a humon, and eventually an organon, this mineralon must be a ferbisialliton situated under the humon (and/or the organon). In the absence of the humon (or organon) the ferbisialliton is called *epiferbisialliton*.
- If the solum presents one or several diagnostic mineralons other than ferbisialliton, we should account for the position and the relative importance of these mineralons in the solum.
  A) If one of these mineralons is *saline*, it should not be present in the first 60 cm, otherwise the soil has to be classified in the selsols.
  B) If one of these mineralons is other than saline:
  a - When the solum thickness is *less* than or equal to 60 cm, the thickest mineralon is the diagnostic mineralon.
  b - When the thickness of the solum is *more* than 60 cm, the thickest mineralon is diagnostic, except when the uppermost mineralon is thicker than 60 cm.
  If these conditions are not fulfilled, the other mineralons become determining.

* CONSTITUENTS - The diagnostic mineral constituents are the following:

- The 2/1/1 or 2/1 clay minerals should represent *more than 10%* of the clay fraction. The free iron sesquioxides should represent *3% or more* of the fine earth.
- In addition to the previous constituents, 1/1 clay minerals, titanium and manganese oxides and hydroxides, secondary silica and salts may be found.

No specific organic constituents of the class do exist.

* MORPHOLOGY OF FERBISIALSOLS

Humons

All different sombrons and pallidons are known. In order to characterize the humons, adjectives used to characterize the mineralons are used.

Mineralons. Diagnostic mineralons of the class.

The *haplic ferbisialliton* contains the diagnostic minerals of the class and presents the following characteristics, none of which is alone sufficient for the identification.

a - Color	- Red, yellow or brown. No grey and no olive.
b - Structure	- Fragmentary of small size. The angular forms are frequent. The particulate, compact massive, columnar and vertic structures are excluded.

c - Texture - All texture except those with less than 15% clay + silt.
d - Consistence - In the dry state: friable to hard. In the humid state: friable to firm.
e - Less than 5% of coarse materials.
f - Less than 2% of color mottles different from that of the horizon.
g - Absence of characteristics of the andic horizon.
h - Absence of characteristics of the argillanic or the bulgic horizon.
i - Less than 10% of weatherable primary minerals in the 0.02-2 mm fraction.
j - Absence of salts or of secondary silica.
k - Less than 15% of fragments of parent rock.
l - Less than 15% of alterite.

The other ferbisiallitons are derived from the haplic ferbisialliton by modification of one of the above-mentioned characteristics.

		Modification of
Ferbisialliton:	arenic	c
	andic	g
	argillanic	h
	bulgic	h
	carboxic	j
	columnar	b
	compact	b and d
	gravelly	e
	stony	e
	gypsic	j
	with gley	a
	with hemigley	a
	halic	j
	indurated	d and e
	lithic	k
	penevolved	i
	reticulate	a
	silicic	j
	vertic	b

Diagnostic mineralons of other classes: Halon, gypson, carboxiton, thion, sulfon, oxidon.

Non diagnostic mineralon: albon.

SUBDIVISIONS OF THE SUBCLASS OF FERBISIALSOLS

Subclasses. They are established according to the nature of the constituents.

Great subclasses: Hemati (or Rhodo) ferbisialsols.
Goethi (or Xanthi) ferbisialsols.
Subclasses : Carboxi- gypsi- or haliferbisialsols.

Great groups. Most of the great groups are known.

Groups.

The following groups are arranged in such a way that the presence of a characteristic horizon corresponding to the group overweighs all the preceding horizons.

- Ameristic - The solum has no ferbisialliton. The ferbisiallitic humon lies directly on the parent material or on the parent rock.
- Orthic - The solum has a humon and a haplic ferbisialliton.
- Lithopolygonal - The solum has a lithopolygonal ferbisialliton.
- Gelic - The solum has one or several horizons, perturbated by frost in the suprasol.

. Compact - The solum has a compact ferbisialliton in the suprasol, of at least 50 cm thickness.

. Hydromorphic - The solum has a gley or hemigley horizon in the first 30 cm under the humon.

. Reticulate - The solum has a reticulate ferbisialliton in the first 30 cm under the humon.

. Vertic - The solum must have a vertic ferbisialliton in the suprasol.

. Gravelly stony - The solum must present a gravelly or stony horizon in the suprasol. It must be at least 50 cm thick and have more than 50% of the weight as gravels or stones.

. Argillanic or bulgic - The solum shows an argillanic or bulgic ferbisialliton in the suprasol.

. Planic - The solum presents a planic contact between an eluviated horizon and an argillanic or bulgic ferbisialliton in the suprasol.

. Glossic - The solum presents a glossic contact between an eluviated horizon (albic) and an argillanic or bulgic ferbisialliton in the suprasol.

. Columnar - The solum presents a columnar ferbisialliton in the suprasol.

. Indurated - The solum presents an indurated ferbisialliton (or a gravelly or stony horizon) not allowing the passage of roots through the suprasol.

The *subgroups* are determined from the mineralons not taken into account during the formation of the groups. These mineralons are of insufficient thickness or appear only in the infrasol.

6.7 MONOSIALSOLS

* DEFINITION - Monosialsols are characterized by the presence of 1/1 phyllitic clay minerals and by less than 3% of free iron oxides, which confers to the soils their main characteristics.

- In the presence of an *organon*:
  a) If the solum is 60 cm thick or less, the organon must represent less than 3/4 of the solum.
  b) If the solum is more than 60 cm thick, the organon must be less than 45 cm thick.
  If the preceding conditions are not fulfilled, the soil is to be classified among the organosols.
- If the solum has only a humon, directly in contact with an alteron or with the parent rock, this humon must be monosiallitic.
- If the solum presents only a mineralon, bound to a humon and/or an organon, this mineralon must be a monosialliton, and situated under the humon (and/or the organon). In the absence of a humon, and/or the organon, the monosialliton is called *epimonosialliton*.
  Several monosiallitons may exist in the same solum.
- If the solum presents one or several diagnostic mineralons, other than monosialliton, we should account for the position and relative importance of these mineralons in the solum.
  a) When the solum thickness is *less than* or *equal* to 60 cm, the thickest mineralon is the diagnostic mineralon.

b) When the solum thickness is *more than* 60 cm, the thickest mineralon is diagnostic, except when the uppermost mineralon is thicker than 60 cm.
If these conditions are not fulfilled, the other mineralons become determinant and the class changes.

* CONSTITUENTS - The diagnostic mineral constituents are the following:

- 1/1 clay minerals and eventually aluminium hydroxides.
- The 2/1/1 or 2/1 clay minerals should not represent more than 10% of the clay fraction.
- The iron sesquioxides represent less than 3% of fine earth.
- The aluminium hydroxides represent less than 50% of fine earth.

The salts and secondary silica and the allophanic products are rare but possible. There are no specific organic constituents of the class.

* MORPHOLOGY OF MONOSIALSOLS

Humons

The different humons are possible. The pallidons and dystric sombrons appear to be the most common.

Mineralons. Diagnostic mineralons of the class.

The *haplic monosialliton* contains the diagnostic constituents and presents the following characteristics, none of which alone is enough for the identification.

a - Color - Yellow or pale yellow of plates 5Y, 2.5Y, 10YR; with a dry value higher than 6. No red nor grey.
b - Structure - Fragmentary of small sizes. The particulate, massive compact, columnar and vertic forms are excluded.
c - Texture - All textures are possible, except those with less than 15% clay + silt.
d - Consistence - In the dry state: friable to hard.
In the humid state: loose to firm.
e - Less than 5% of coarse materials.
f - Less than 2% of color mottles different from that of the horizon.
g - Absence of characteristics of the andic horizon.
h - Absence of characteristics of the argillanic or bulgic horizon.
i - Must not present more than 10% of weatherable minerals in the 0.02 a 2 mm fraction.
j - Less than 15% of fragments of parent rocks.
k - Less than 15% alterite.
l - Absence of salts or of secondary silica.

The other monosiallitons are derived from the haplic monosialliton by modification of the above-mentioned characters.

		All characteristics except
Monosialliton:	arenic	c
	andic	g
	argillanic	h
	bulgic	h
	carboxic	l
	columnar	b
	compact	b and d
	gravelly, stony	e
	gypsic	l
	with gley	f
	with hemigley	f

	All characteristics except
halic	l
lithic	j
reticulate	f
silicic	l
vertic	b
penevolved	i

Diagnostic mineralons of other classes: oxidons.
Nondiagnostic mineralons: albon.

Alterons may completely lack:
- Isalterons;
- Ambialterons;
- Hemialterons.

Parent rocks should contain low amounts of iron.

SUBDIVISION IN THE CLASS OF MONOSIALSOLS

Subclasses

The great subclasses are established according to the nature of the class constituents. When these are determined by using the chemical criteria alone, the subclass cannot be determined.

The following great subclasses are proposed:
- Kaolinitic : contain 50% or more or kaolinitic minerals in the fraction < 2μ.
- Halloysitic : contains 50% or more of halloysitic minerals in the fraction < 2μ.
- Gibbsitic : contains between 30 and 60% gibbsite in the fraction < 2μ.

Great groups

Are often dyspallid, but other humons are possible.

Groups

The following groups are proposed, arranged in such a way that the presence of a characteristic horizon corresponding to the group overweighs all preceding horizons.

. Ameristic - Does not present any monosialliton - The monosiallitic humon lies on the parent material or on the parent rock.

. Orthic - The solum presents a humon and a haplic monosialliton in the suprasol.

. Compact - The solum presents a compact monosialliton at least 50 cm thick in the suprasol.

. Hydromorphic - The solum presents a gley or hemigley horizon in the first 30 cm under the humon.

. Reticulate - The solum presents a reticulate monosialliton in the first 30 cm under the humon.

. Gravelly or stony - The solum presents a 50 cm thick gravelly or stony horizon and should have more than 50% of its weight in gravels or stones, in the suprasol.

. Argillanic or bulgic - The solum presents an argillanic or bulgic monosialliton in the suprasol.

. Planic - The solum presents a planic contact between an eluviated horizon and an argillanic or bulgic monosialliton in the suprasol.

. Glossic - The solum presents a glossic contact between an eluviated horizon (albic) and an argillanic or bulgic monosialliton in the suprasol.

. Indurated - The solum presents an indurated monosialliton not allowing the passage of roots through the suprasol.

Subgroups

The subgroups are formed by using horizons not having the required characteristics to form a group or which are situated below group forming horizons or which are situated below the suprasol.

Among the observed subgroups, the silicic, ferric, impoverished, hydromorphic, reticulate and compact subgroups are cited.

6.8 FERMONOSIALSOLS

* DEFINITION - The fermonosialsols[1] are characterized by the presence of 1/1 clay minerals, of iron oxides or hydroxides and/or aluminium hydroxides, which confer to the soils their main characteristics. Besides, in order to get a fermonosialsol:

- In case of having an *organon*, the following should be fulfilled:
  a) If the solum is 60 cm or less, the organon represents less than 3/4 of the solum.
  b) If the solum is more than 60 cm thick, the organon should be less than 45 cm thick.

  If the previous conditions are not fulfilled, the soil has to be classified among the organosols.
- If the solum presents only a *humon*, directly in contact with an alteron or with the parent rock, this humon is fermonosiallitic.
- If the solum presents a single mineralon, bound to a humon and/or an organon, this mineralon is a fermonosialliton situated at the top of the pedon under the humon and/or the organon. In the absence of humons and/or organons, the mineralon is an *epifermonosialliton*.

  Several fermonosiallitons may exist in the same solum.
- If the solum presents one or several diagnostic mineralons, other than the fermonosialliton, one should account for the position and the relative importance of these mineralons in the solum.
  a) When the solum is less than or equal to 60 cm thick, the thickest mineralon is the diagnostic mineralon.
  b) When the solum is thicker than 60 cm, the thickest mineralon is the diagnostic mineralon, except if the upper mineralon is thicker than 60 cm.

  If these conditions are not fulfilled, the other mineralons become determining and a class change takes place.

* CONSTITUENTS - The diagnostic *mineral constituents* are:

- The 1/1 clay minerals (kaolinite, metahalloysite, halloysite).
- Iron and aluminium hydroxides, iron oxides.

  Variable quantities of titanium, manganese oxides may also be found.

The fermonosialsols do not contain:

- 50% or more of total free oxides[2] (or else they merge into the oxidisols).

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[1] Equivalents of ferrallitic soils (pro parte) of the CPCS classification; not of all the FAO-Unesco ferralsols. The corresponding mineralon will be also named *ferraliton* for simplicity.

[2] All the hydroxides are calculated in oxides and in % of soil dried at 105°C.

- 10% or more of 2/1/1 or 2/1 clay minerals in the clay fraction (or else they merge into the bisialsols or ferbisialsols).
- Less than 3% of free iron oxides in the total soil (or else they merge into the monosialsols).
- Amorphous mineral products in sufficient quantities for the soil to be described as "allophanic"; however, it may be described as "andic".

  The presence of salts or of secondary silica is rare but should not be excluded. No organic constituents, specific of the class, do exist.

* MORPHOLOGY OF FERMONOSIALSOLS

Humons

The different sombrons and pallidons are known, although the dystric pallidons are the most widespread. These horizons may contain indurated elements (nodules, concretions, fine gravel, rock or mineral fragments).

Diagnostic mineralons of the class:
The *haplic fermonosialliton* contains the diagnostic constituents and presents the following characteristics, none of which is sufficient for the identification.

a - Color - Red, yellow or brown. Absence of grey or olive.
b - Structure - The fragmentary structures, from fine to medium are the most frequent, with a low degree of development. The massive, columnar and vertic structures are excluded.
c - Texture - All textures, except those with less than 15% of clay + silt.
d - Consistence - In the dry state: loose to fragile. In the humid state: friable to firm.
e - Less than 5% of coarse material.
f - Less than 2% of color mottles different from that of the horizon.
g - Absence of characteristics of the andic horizon.
h - Absence of characteristics of the argillanic or bulgic horizon.
i - Absence of salts or of secondary silica.
k - Less than 10% of weatherable minerals in the 0.02 to 2 mm fraction.
l - Less than 10% of 2/1 clay minerals in the fraction < 2µ.
m - Less than 15% of parent rock fragments.
n - Less than 15% of alterite.

The other fermonosiallitons are derived from the haplic fermonosialliton by modification of the above-given characteristics.

Fermonosialliton : or Ferraliton	exception of:
arenic	c
andic	g
argillanic	h
bulgic	h
carboxic	i
columnar	b
compact	b and d
gravelly or stony	e
with gley	f
with hemigley	f
halic	i
indurated	d
gypsic	i
lithic	m
penevolved	k
reticulate	f
silicic	i
vertic	b

Diagnostic mineralons of other classes: oxidon.
Nondiagnostic mineralons: albon.

Alterons may completely lack:
- Lithalteron;
- Isalteron;
- Mixed alteron.

SUBDIVISIONS IN THE CLASS OF FERMONOSIALSOLS (FERRALLITICS)

Subclasses. They are established according to the nature of the particular constituents of the class. When the class is determined by using chemical criteria alone, the subclass cannot be determined accurately.

The following subclasses are proposed:
Kaolinitic
Halloysitic
Gibbsitic

Great groups

All great groups are known. The dyspallid groups is the most frequent.

Groups

- Ameristic - Presents no ferralliton. The humon is ferrallitic and lies directly on the parent material or on the parent rock.
- Orthic - Presents the haplic ferralliton and none of the following mineralons above it in the suprasol.
- Compact - Presents a compact ferralliton in the suprasol with at least 50 cm thickness.
- Hydromorphic - The solum presents a gley or hemigley horizon, at least in the 30 first cm under the humon.
- Reticulate - The solum presents a reticulate ferralliton, immediately under the humon or in the first 30 cm under the humon.
- Gravelly or stony - The solum presents a gravelly or stony horizon in the suprasol; it should be at least 50 cm thick, and contain at least 50% of gravels and/or stones, but possibly be penetrated by the roots.
- Argillanic or bulgic - The solum presents an argillanic or bulgic ferralliton in the suprasol.
- Planic - The suprasol presents a planic contact between an eluviated horizon and an argillanic or bulgic ferraliton.
- Indurated - The solum presents an indurated ferralliton in the suprasol not allowing the passage of the roots.

The *subgroups* are formed by using the mineralons which were not taken into account for the establishment of the groups, or which are insufficiently thick. We should remember that certain characteristics like impoverished, aliatic, shiny, penevolved appear only in the subgroup.

6.9 OXIDISOLS

* DEFINITION - Oxidisols are soils which are dominated by metallic oxides or hydroxides and in which the clay minerals play a minor role.

In the upper part of the solum, these soils should have an oxidic humon and an oxidon.

Above the humons, no organon of more than 50 cm should exist. Salts of any kind are unknown.

* CONSTITUENTS -

Mineral constituents

- The crystallized or amorphous oxides or hydroxides of Fe, Al, Ti, Mn, Co, Cr, Ni, V, in the form of oxides, should represent at least 50% of the soil; the primary minerals, hard to weather, should be subtracted from the total.
- They may contain less than 10%[1] clay minerals.
- Amorphous materials are not present in sufficient amounts to justify the adjective "allophanic" for the soil; however, it could be described as "andic".

Organic constituents

The quantity of organic matter may vary from very little to very abundant. Presently, no precise data are available on the constitution of this organic matter.

* MORPHOLOGY OF OXIDISOLS

Humons

The following horizons are known: Sombron and Pallidon. The adjective "dystric" and "eutric" are certainly less significant than in the previous classes.

Mineralons

The *haplic oxidon* contains the specific constituents of the class and the following morphological characteristics.

a - Color - Red, yellow or brown. No grey.
b - Structure - Often aliatic; fragmentary with blunted aggregates, angular forms are rare.
c - Texture - Often very fine; with a high content of elements < 2μ.
d - Consistence - In the dry state: fragile to hard. In the humid state: very friable to firm.
e - Porosity - Very porous.
f - Less than 5% of coarse elements.
g - Less than 2% of color mottles other than that of the horizon.
h - No argillanic or bulgic characteristics.
i - No positive reaction with sodium fluoride.
j - No secondary salts.
k - Less than 10% of weatherable primary minerals in the 0.02 to 2 mm fraction.
l - No characteristics of the compact horizon.
m - Less than 15% of parent rock fragments.

The other following oxidons may be observed: argillanic, hydromorphic (with hemigley or gley), stony, gravelly, indurated, compact, reticulate, shiny.

* ALTERONS - When the soil is derived from an ultrabasic rock, the alterons may totally lack. If not so, the following alterons may be obtained:

Isalteron
Ambialteron
Hemialteron

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[1] Tentative figure.

* PARENT ROCKS - All parent rocks are theoretically possible. The most frequent are the ultrabasic rocks, poor in aluminium.

SUBDIVISIONS OF THE CLASS OF OXIDISOLS

Great subclasses. They are founded on the nature of the mineral constituents. The following subclasses are proposed:

Ferritic when Fe_2O_3% exceeds 30%
Allitic when Al_2O_3% exceeds 30%

The terms ferrito-allitic or allito-ferritic are proposed to indicate that the first oxide is more abundant than the second one.

When the contents (to be determined) in accessory metals (such as Mn, Ti, Cr, Co, Ni, V, etc.) become high, it may be interesting to indicate the fact with a supplementary adjective, for example:

Allitititanic Ferritinickelic

Great groups. The great groups pallidic and sombric are known.

Groups

- Ameristic - The solum does not present a mineralon. The humon is oxidic and lies directly on the parent material, or on the parent rock.
- Orthic - The solum presents the haplic oxidon and no other mineralon above it in the suprasol.
- Compact - The solum presents a compact oxidon in the suprasol and the latter should be at least 50 cm thick.
- Hydromorphic - The solum presents a gley or hemigley horizon at least in the first 30 cm under the humon.
- Reticulate - The solum presents a reticulate oxidon immediately under the humon or in the first 30 cm under the humon.
- Gravelly or stony - The solum presents a gravelly or stony horizon in the suprasol and should be at least 50 cm and contain at least 50% of gravels and/or stones, but can be penetrated by the roots.
- Indurated - The solum presents an indurated oxidon in the suprasol not allowing the passage of roots.

Subgroups

For the formation of subgroups, we consider those which were not used for the formation of groups. Aliatic, shiny, penevolved, empoverished, etc. subgroups may be also obtained.

6.10 PODZOLS

* DEFINITION - Podzols are characterized by:
a) The removal of clay minerals, of iron and aluminium sesquioxides from the upper part of the pedon. This removal may, or may not, be accompanied with the formation of an albon.
b) The formation of complexes between organic matter, iron and aluminium, which involves the appearance of a *cheluvion*.

- In presence of an *organon*:
  a) If the solum is 60 cm thick or less, the organon should represent less than 3/4 of the solum, otherwise, we have an organosol.
  b) If the solum is 60 cm thick or more, the organon should have less than 45 cm thickness, otherwise, we have an organosol.
  c) In the case of podzols, the organon is frequently leptic and complex; it may lack completely (especially in the intertropical zone).

  There are no podzols which have only a single humon (and an albon) without a cheluvion.

  Generally, an albon inserts between the organic and humus horizons and the cheluvion. It may lack. Therefore, the following successions may be obtained:
  organon - humon - albon - cheluvion
  humon - albon - cheluvion
  organon - humon - cheluvion
  humon - cheluvion

  When a podzol develops from a soil that can be identified by a diagnostic mineralon like bisialliton, fermonosialliton,
  - if the whole solum of the podzol is more than 60 cm thick, the podzol overweighs the underlying soil on the class level;
  - if the whole solum of the podzol is less than 60 cm thick, the other soil is privileged.

* CONSTITUENTS - The diagnostic constituents of the cheluvion are complexes of organic matter, iron and aluminium.

The standards of identification of these constituents are given in p. 32.

The abundant presence of fulvic acids conditions, the formation of the organo-mineral complexes and the phenomenon of cheluviation.

The products of the cheluvion, rich in aluminium, react positively to the Fieldes and Perrott test (alkalinity exchange with NaF).

* MORPHOLOGY OF THE PODZOLS

The *Organons* may be pachic, but they are often leptic, dystric and complex (mor). They may lack.

The *Humons* may be pallidic or sombric, often dystric or hyperdystric.

Diagnostic mineralon of the class.

The *haplic cheluvion* contains the diagnostic constituents and presents the following characteristics:

a - Color - It is generally dark, grey or brown.
b - Structure - It is granular, particulate, slightly developed.
c - Texture - Coarse textures are the rule.
d - Consistence - In the dry state: loose to fragile.
In the humid state: friable.

The other possible cheluvions are: duric, indurated, placic.

Nondiagnostic mineralon: albon. This albon may be loose or indurated (by secondary silica).

The *alterons* are almost always arenic.

SUBDIVISIONS IN THE CLASS OF PODZOLS

Subclasses. They are established according to the nature of the constituents of the cheluvion.

- Ferrohumopodzols: have a cheluvion of brown color. Neither iron nor the organic matter appear to predominate (to be specified).
- Ferropodzols: have a cheluvion of red to brown-red color (to be specified).
- Humopodzols: have a cheluvion of brown to brown-red color (to be specified).

Great groups are established according to the organons and the humons.

Groups

. Orthic - Presents a haplic cheluvion.

. Duric - The cheluvion breaks in the hand.

. Indurated - The cheluvion breaks under the hammer.

. Placic - The cheluvion is thin, hard and wavy (cf. p. 39).

Subgroups

. Hydromorphic - Presents a gley or hemigley horizon in the suprasol.

. Compact - Presents a compact albon.

. Albic - Presents an albon between the organic and humic horizons and the cheluvion.

. Silicic - The albon is indurated by secondary silica.

7. COMPARISON WITH OTHER CLASSIFICATIONS

The French classification and Soil Taxonomy will be successively examined, the soil units of FAO-Unesco being discussed in relation to the latter classification.

French Classification of C.P.C.S. (1967)

Great differences are observed. Particular reference will be made to the structure of the systems and to the place occupied by some important soils.

For the designation of the classification units, the same nouns are retained (classes, subclasses, groups, subgroups, etc.) although their content is not necessarily the same.

a - With regards to classes, the products of weathering of the primary materials were only accounted for, provided they are materialized by groups of particular and specific constituents.

b - With regards to the subclasses, the notion of the pedoclimate was abandoned on account of the difficulty of its specification. It was replaced by differences in the organic and mineral constituents.

c - The groups and subgroups of the CPCS system which translate the process of differentiation of the pedon have been retained and developed by addition of the great group reserved for the humus horizons.

d - The family helps in the identification of the parent material.

e - Supplementary units were proposed in order to take into account the characteristics of the absorbing complex, the granulometry of the surface horizon, etc..

f - Complementary characteristics of the soil and of its present environment were proposed in order to contribute to the determination of the possibilities of its utilization and of its genesis.

The content of classes was much modified.

1. Raw mineral soils. The main part of this class is found in the primarosols. However, these primarosols assume soils containing organic matter. Their main limit is the presence or the absence of secondary minerals.
2. The weakly developed soils do not subsist as a class. They are divided in other classes in function of the mineral content of the humons, since the mineralons lack.
3. The vertisols do not subsist as a class. Since their main characteristics are morphological, they appear in the level of the vertic groups in the bisialsols or the ferbisialsols. However, they may be grouped at the level of a smectic subclass (with swelling clay minerals).
4. The andosols correspond to a class.
5. The calci-magnesic soils do not subsist as a class. The subclasses of the carbonated, saturated and gypsic soils are divided in the bisialsols or ferbisialsols or selsols. Rendzinas are found in an ameristic group of the bisialsols; the brown calcareous or calcic soils belong to the bisialsols.
6. The class of the isohumic soils does not subsist as a class. The thick and saturated humus horizons can be observed in different classes like the bisialsols, the ferbisialsols, the andosols, seldom in the others. They are found throughout the great pachi-eusombric or pachi-eupallid groups.
7. The class of brunified soils is mainly found in the bisialsols through great lepto-eu or dys-sombric or pallid groups, except the ferruginized soils which fall in the ferbisialsols.
8. The class of the podzolized soils is almost completely found in the podzols, up to the degree that a cheluvion is present. In case of the absence of this

diagnostic horizon, the soils are distributed in other classes (for example, a given number of podzolic soils).

9. The class of soils with iron sesquioxides involves two subclasses: the tropical ferruginous soils will be split in monosialsols or bisialsols on one side, or in ferbisialsols or fermonosialsols on another side according to their iron content; the fersiallitic soils are found in the ferbisialsols.

10. The ferrallitic soils become fermonosialsols if their iron content is high enough.

11. The hydromorphic soils do not exist as a class, but are most often distributed as groups. If the organic matter contents are very high, they fall in the organosols.

12. The class of the salsodic soils is split up. If the salts contents are sufficient, a part is found in the halisols. The presence of sodium on the absorbing complex is indicated in the genera; a particular structure is indicated in the groups.

It was found useful to create new classes or subclasses to account for the secondary accumulation of calcium sulfate or carbonate, for particular sulfates or sulfides, for the almost exclusive accumulation of metallic sesquioxides (Fe, Al, Ti, ...).

Soil Taxonomy of USDA (1975)

On one hand, certain steps of Soil Taxonomy have been followed in the proposed system. The pedon was particularly retained as elementary volume in spite of the difficulty shown by the problem of depth. As in Soil Taxonomy, an effort was undertaken for a better definition of the horizons by measurements or standardized observations.

But, on another hand, the epipedons were not retained. Only the observed horizons were accounted for.

While Soil Taxonomy is, to begin with, destined to users of all kinds, the new system is, first, a scientific construction, proposed for pedologists.

While Soil Taxonomy is in the first place an American system, subsequently extended to the rest of the world, a general system was at once sought after to cover the whole world. No soil of any region is privileged. As a result, the structure of the two systems is quite different.

While the diagnostic criteria of the orders in Soil Taxonomy are heterogeneous (and based on a mollic epipedon, a clay horizon, constituents, a moisture regime, a structure, etc.), the nature of the constituents are privileged in the proposed system. Only the entisols, the histosols, the spodosols are very near to the primarosols, the organosols and the podzols.

The suborders generally apply to moisture regimes (*aqui-, ust-, ud-, xer-, tor-*) to climatic regimes (*trop-, bor-*) or to constituents (*and-, psamm-*). In the proposed systems, all reference to the climatic or moisture regimes is left to level IV, while only the varieties of the constituents are used.

The great groups use a diagnostic property which may be a temperature (*cryo*fluvent) or a moisture (*xer*ochrept) regimes or a characteristic of the pedon (*hapl*argid, *rhod*udalf), a physicochemical characteristic (*natr*ustalf), a constituent (*gibbsi*humox). In the proposed system, the great groups, groups, subgroups arise only from the micromorphology.

The family associates such different characteristics as granulometry, the nature of the clay minerals, the thermal regime, whereas in the proposed system, each of these characteristics appears at a specific level.

Consequently, although it was felt necessary to determine exactly all the horizons and soil characteristics as done by the Soil Taxonomy, the apportionment of these characteristics was done quite differently.

Soil Units of FAO-UNESCO

Although the aim of FAO-Unesco is not the setting up of a soil classification, the retained units and their characteristics are often very close to those of Soil Taxonomy. Particularly, with regards to luvisols, acrisols, ferralsols, podzols, vertisols, etc. the corresponding soils of Soil Taxonomy (alfisols, ultisols, oxisols, spodosols, vertisols) are very close.

Some units of the FAO-Unesco list are particular, because they do not exist as such neither in Soil Taxonomy nor in the French system.

The *nitosols* are soils with "an argillic horizon with such a clay distribution that the clay percentage does not diminish by more than 20% with respect to its maximum in the first 150 centimeters". These soils correspond to the great "pale" groups of Soil Taxonomy. In the proposed system, they correspond to argillanic or bulgic groups.

The *planosols* which correspond to a particularly sharp change of granulometry are expressed in the proposed system by a planic group which may appear in several classes.

The "*podzoluvisols*" may be considered as represented by the glossic group which may also be present in different classes.

The "*xerosols*" and "*yermosols*", characterized by a weak humus horizon and an arid moisture regime do not have true equivalents at a high level. They are distributed at the great groups level with epimineralons in different classes.

The "*gleysols*" which assume hydromorphic characteristics at less than 50 centimeters depth are allocated in different classes at the hydromorphic group level.

Regardless of the used classification type, it is almost always possible to propose a place for each soil in the considered system. In the insertions given with the appendices, the correspondence between the different systems was proposed.

8. GENERAL CONCLUSIONS

The authors of the above-given system propose few general observations which, for them, seem to be important.

1. The classification is no more a simple and immediate operation. Times have evolved when, after examination of a profile, a name was immediately attributed to it. The classification has become a *complex operation* which needs not only a good morphological description, but also the possession of several varied analytical data.

In some countries, a clear distinction is made between the survey, the establishment of limits, and the compilation of field data, and the classification, determination of the name to be given to the soil after a study of all field and laboratory data. The final decision should be taken, if possible by a party, after returning to the field when in possession of the whole data.

The classification of the soils is then a true *research operation.*

2. The given classification was required to be:

Universal - No one among the authors had a personal experience of the boreal or polar soils. On this point then, the classification is incomplete. Some members of the group had varied experience of the different regions of the globe. This quasi-world-wide experience of the participants was particularly important since the object of the work was to provide a classification, applicable to all soils.

Natural - Whenever the characteristics are measurable according to techniques accessible to everyone, or determined in the same way by everyone, they may be introduced in the classification. The system is then particularly open at any moment.

Coherent - All assumed characteristics in the system are always so at the same level. It appeared that the homogeneity which was expected to result from this was particularly important.

3. The *criteria*, retained and *hierarchically* given, are those believed to be really issued from *soil forming factors* and *processes*.

Criteria concerning the constituents were presented in the order which appeared to be the most important and to account for the increasing stability of the produced secondary minerals. The subsequently presented criteria were those related to the morphological arrangement of the pedon, successively the humus horizons, the mineral horizons, the parent material. Then followed data of physicochemical or physical nature. The characteristics considered as accessory or labile, or outsiders to the soils, were given afterwards. All data may be useful for the valuation. But since the latter is changing and speculative, it is left for the user to choose wat seems important to him in the domain of his interest.

Genesis was not explicitly mentioned in this text, since it was assumed that the cause to effect relations which may be invoked can be determined in different ways. However, the order in which the succession of the classes was given is not devoid of genetic motivations. With all the data available for classifying, he may try to reconstitute the soil genesis.

4. What *kind of classification* was the outcome of the past few years of thinking over?

Is it a *classification* or a *taxonomy*? This point is not very important and dictionaries do not differentiate very well between these two synonyms. But the first thing is that it is a reference system.

very well between these two synonyms. But the first thing is that it is a reference system.

Is it *ascending* or *descending*? It should be both at the same time. The progress made by pedology, as autonomous science, the wide-range of geographical knowledge of the world soils allows a certain generalization and the presentation of, to begin with, a descendant scheme which accounts for the considerable knowledge, already acquired. But, it is evident that this scheme should be continuously checked and adjusted by using any new element. This is what actually happens in other branches[1] of science.

5. The avaialble *vocabulary* in pedology is still very lacking, even when certain new terms proposed by other researchers or organisms are used. It is not desirable to annex a term and attribute a different meaning to it. For example, when it was necessary to name a thick dark humus horizon, and with a high degree of saturation, it was impossible to adopt the term "mollic" because it was judged that this horizon does not fulfil all the conditions of the eight criteria associated with the word[2]. So, the term "sombron" was created.

A given number of names was thus created through construction, since it was impossible to adopt existing terms. For each of these names, a definition was proposed. At the same time, it was required that the name be as *euphonic* as possible; this was not always succeeded. Any new name which may be proposed is then welcomed, especially if it presents a better euphony. Of course, it has to correspond to the same definition.

6. The *accuracy* in the language is also required. Each term (noun or adjective) is accompanied with a quantitative or a qualitative definition. The given definitions are those which appeared to be the best to the working team. The fixation of the limits was already considered as one of the most important operations of the classification. But of course, none of the proposed values is definitely rigid and may always be open to revisions. All justified improvements are welcome and appreciated.

Repetitions may appear in many places. For the time being, no particular effort is made to suppress them. They temporarily help to clarify the notions which appear as important.

7. When everything is taken into consideration, the system - as already worked out - is simultaneously a *language* and a *reference system*: It allows to identify the soils as observed in the field and analyses; it allows to designate the soil and to go deeper in its knowledge.

The manipulation of the new names, often very long (but not so long as those of Soil Taxonomy) is still a rather tedious operation. The search of eventual simplifications of a coded language should be undertaken.

Much work remains to be done in order to improve the definitions and the precision, to refine the vocabulary and to progress in the chosen way.

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[1] "While in the history of the subject, knowledge has proceeded from local to the general, later generations of students are taught the generalization and interpret these locally". L.C. King, 1976.

[2] In Soil Taxonomy.

8. The *pedological process*. The proposed classification of soils in this text is a synthetic language intending to enable pedologists to name a soil by using the available characteristics, the list of which is provided. A consensus should be attained, regardless of the pedologist and *regardless of his 'ideas' on the respective values of the factors and the processes of soil formation*. The used characteristics are in fact accessible to everyone, through observation and measurement; the means of their determination are not, in the least, open for discussion. Therefore, it is judged that the objective classification becomes at this stage *a real tool of work* which enables the pedologist to proceed with his studies in the following directions: research, cartography and valuation.

The *research work* aims at the establishment of relations between the pedons and the polypedons on one side and the constituents and their arrangements which account for the factors and the processes of soil formation, on the other side. At this stage of the study, the soils' systems will be evidenced and could subsequently lead (when a great number is known) to *a particular classification of dynamic units*.

At this stage also, research work can be undertaken in order to study *the history of soils* and to try to retrace the past processes and to relate them with the present ones.

The *cartography of soils* may also rely on the classification and push further, according to the considered objective, the knowledge of the characteristics of soils and their environment.

On accounting for the results obtained in these different directions, it is possible to formulate proposals for the *utilization of soils*.

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APPENDICES

Three appendices complete the previous text: a selection of pedons, the principles of the chosen analytical methods, and an index of the old and newly used terms.

1. The PEDONS. Four pedons, considered as characteristic among many others, are given hereafter, in an abridged form, as it is not possible to present all the existing ones.

Data are provided on: 1) the environment; 2) the morphology; 3) the micromorphology (when available); 4) analytical data on the humon and characteristic mineralon; 5) synthetic data on the profile; and 6) the position in different classification systems and the proposed one, of the soil.

With regards to the morphology, a simplified presentation is offered by always giving the color, the texture and the stucture. The considered name for the horizon (or group of horizons) is also given.

With regards to the micromorphology, it is particularly important for the determination of the argillanic group. Unfortunately, it is not always available.

The same is true with regards to the necessary analytical data (particularly free iron oxides) which are not always provided. But, in most cases, it is possible to decide in spite of certain lacks.

In the proposed classification system, the name reaches the variety. For certain pedons, we can go further, particularly at level IV for which we often have data on the water and thermal regimes.

Besides, many proposed pedons were selected among those which have been examined during international meetings and conferences. These pedons are accompanied with descriptions and analytical data, officially provided by the organizers of the trips. The used vocabulary is that found in the official guide books. The name (or the names) which appears on the descriptive card is that (or those) of the person (or persons) who examined the pedons and provided the corresponding picture.

2. PRINCIPLES OF THE ANALYTICAL OR EXAMINATION METHODS.

An abridged presentation of these methods appears in the second appendix. Since they are very often known to the readers or easy to find in books or articles cited as references, it was not found necessary to given them in detail. Choices still remain to be made for certain techniques particularly, because an applied technique is not necessarily good for all soils. Finally, no decisions with respect to the texture triangles were taken.

3. INDEX of used terms. The given document involves a great number of neologisms. A certain number of old terms was defined and respecified. They should be easily found by using the Index.

APPENDIX I - A SELECTION OF FOUR PEDONS

App. I.1 A PEDON OF THE CLASS OF FERMONOSIALSOLS

I. ENVIRONMENT

Origin: Study of soils derived from volcanic rocks in Madagascar, 1957. Mem IRSM VIII. P. Ségalen (FX 34).
Location: Ampahimanga near Arivonimamo (Central Madagascar).
Topography: Flat, northern terminal of Ankaratra lava flows.
Parent-rock or parent material: Ankaratrite (very basic).
Climate:
P_t 1200 mm; January 500 mm; 5 months dryness
T_m 18°C; January 20°C; July 13°C.
Vegetation: Forestations of Eucalyptus (+ Helychrysum sp).
Present occupation by: *Phillipia sp.*; *ctenium concinum*, *Aristida sp.*

II. MORPHOLOGY

Depth (cm)	Description	Horizon
0- 25	Dark red; clayey; coarse to very coarse; moderately structured blocky; friable	Leptic dystric pallidon
25-160	Dark red; clayey; moderately to weakly structured subangular blocky; friable	Red haplic ferralliton
160-	Grey alterite of ankaratrite	Isalterite

III. MICROMORPHOLOGY

IV. ANALYTICAL DATA

1) Surface horizon

Org. Matter		Granulometry			pH		BS
%	C/N	Cl	Si	Sa	H_2O	KCl	%
4-7	12-14	30	40	30	6.0	-	-

2) Mineralon

Org. Matter		Granulometry			>2	pH	
%	C/N	Cl	Si	Sa	mm	H_2O	KCl
-	-	30	40	30	-	6.0	-

Exch. Cations (meq/100 g)						BS	ESP
Ca	Mg	K	Na	Al	CEC	%	%
<1	<1	0.1	tr	-	6-8	<50	-

P_2O_5 (%)		Fe_2O_3 (%)		$SiO_2/$
tot.	avail.	free	tot.	Al_2O_3
-	-	-	20	0.7

Salts: $Al(OH)_3$ 43%

Mineral constituents: kaolinite, gibbsite, hematite.

V. SYNTHETIC DATA

The granulometry of this soil is particularly difficult to determine with the usual dispersing agents. An ultrasonic determination gives 65 to 70% for the two surface horizons. In spite of the red coloration, the organic matter contents are (abnormally) high.

VI. CLASSIFICATION

CPCS			Ferrallitic moderately unsaturated in B, typic, red
USDA			Haplustox
FAO			Rhodic ferralsol
PCS*	I.	C	Fermonosialsol
		SC	Gibbsitic
	II.	GG	Leptodyspallide
		G	Orthic
		SG	Red modal
		F	Isalterite of ankaratrite
	III.	Ge	Acid, dystric
		Ty	Clayey
		V	Rather thick

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* Project de Classification des Sols

App. I.2 A PEDON OF THE CLASS OF FERMONOSIALSOLS

I. ENVIRONMENT

Origin: Fieldtrip of 1977 Brazil Soil Classification Workshop. A. Perraud - P. Ségalen.
Location: Rio de Janeiro, RJ, BR-2.
Topography: Undulating, summit of a hill.
Parent-rock or parent material: Migmatite.
Climate:
P_t 1280 mm; January 193 mm; July 34 mm
T_m 23.2°C; January 26.5°C; July 19.8°C
Vegetation: Semi-deciduous tropical forest.
Present utilization: Goyava trees, mango trees, orange trees.

II. MORPHOLOGY

Depth (cm)	Description	Horizon
0- 40	7.5YR 3/2 to 4/2H dark brown sandy clay; coarse to fine, weakly developed subangular blocky, some clay coatings	Pachic eutric pallidon
40- 80	7.5YR 4/4 brown; sandy clay, fine to medium, moderately to strongly developed subangular blocky; continuous and strong clay coatings; hard, friable, plastic	Yellow argillanic ferralliton
80-260	2.5YR 4/6H red; sandy clay; fine to medium, strongly developed subangular blocky; continuous and strong clay coatings	Red argillanic ferralliton
260 or more		Isalterite of migmatite

III. MICROMORPHOLOGY

IV. ANALYTICAL DATA

1) <u>Surface horizon</u>

Org. Matter		Granulometry			pH		BS
%	C/N	Cl	Si	Sa	H_2O	KCl	%
1.8	9	27	12	61	6.7	5.8	83

2) <u>Mineralon</u> (80-100 cm)

Org. Matter		Granulometry			>2	pH	
%	C/N	Cl	Si	Sa	mm	H_2O	KCl
D.5	7	62	8	30	10	6.5	5.6

Exch. Cations (meq/100 g)						BS	ESP
Ca	Mg	K	Na	Al	CEC	%	%
2.5	1.0	0.02	0.07	D	4.9	73	-

P_2O_5 (%)		Fe_2O_3 (%)		$SiO_2/$
tot.	avail.	free	tot.	Al_2O_3
-	4	-	7.8	2.0

Salts: -

Mineral constituents: kaolinite, goethite.

V. SYNTHETIC DATA

Moderate accumulation of organic matter.
Clear differentiation of the color and of the texture.

VI. CLASSIFICATION

Brazil			Red yellow, podzolic, eutrophic equivalent; moderate A, loam/clay; semi-deciduous forest; wavy
USDA			Oxic paleustalf
FAO			Eutric nitosol
PCS	I.	C	Fermonosialsol
		SC	Kaolinitic
	II.	GG	Pachieupallid
		G	Argillanic
		SG	Yellow red modal
		F	Alterite of migmatite
	III.	Ge	Acid, eutric
		Ty	Sandy clay
		V	Thick

App. 1.3 A PEDON OF THE CLASS OF BISIALSOLS

I. ENVIRONMENT

Origin: Fieldtrip in Uruguay, 1973, P. Ségalen.
Location: Trinidad, Uruguay.
Topography: Undulated, slope 5%.
Parent-rock or parent material: "Lodolite" on crystalline rock.
Climate: Paso de Los Toros: subtropical
P_t 1064 mm; Jan. 120 mm; July 38 mm
T_m 18.1°C; Jan. 25.2°C; July 11.8°C
Present utilization: pastures.

II. MORPHOLOGY

Depth (cm)	Description	Horizon
0- 34	10YR 2.4/2 very dark brown to 10YR 2.4/1; loamy; subangular blocky; weakly structured	Eutric pachic melanon
34- 45	Grey to rusty mottles	mottled bisialliton
45	Planic contact	
45- 76	10YR 2/1 black to 10YR 3.3/1 dark grey; clay; thin continuous clay coatings, small concretions; large, moderately blocky structured	Black argillanic bisialliton
76- 96 or more	7.5YR 4/2 brown to dark brown, clayey; large, coarsely structured blocky; with calcium carbonate → moderate effervescence.	Brown hypocarboxic bisialliton

III. MICROMORPHOLOGY

IV. ANALYTICAL DATA

1) Surface horizon

Org. Matter		Granulometry			pH		BS
%	C/N	Cl	Si	Sa	H_2O	KCl	%
6.1	12.8	28	48	26	5.5	-	72

2) Mineralon

Org. Matter		Granulometry			>2	pH	
%	C/N	Cl	Si	Sa	mm	H_2O	KCl
0.5	12.0	53	30	17	-	7.9	6.8

Exch. Cations (meq/100 g)						BS	ESP
Ca	Mg	K	Na	Al	CEC	%	%
26	10	0.3	2.8	-	38.8	100	7

P_2O_5 (%)		Fe_2O_3 (%)		$SiO_2/$
tot.	avail.	free	tot.	Al_2O_3
-	-	-	-	-

Salts: -

Mineral constituents: smectite metahalloysite, illite.

V. SYNTHETIC DATA

Organic matter very high in the surface then decreases abruptly. Very strong clay differentiation with a planic contact. The dominant clay mineral is montmorillonite. The exchange capacity merges from 20 in the surface to 39 in the depth (55 cm).

VI. CLASSIFICATION

CPCS			Brunified lessivated soil
USDA			Argiudoll
FAO			Luvic phaeozem
PCS	I.		Mixed bisialsol
	II.	GG	Pachieusombric
		G	Planic
		SG	Hypocarboxic, dark brown
		F	Calcareous loamy clay pedolite
	III.	G	Neutral, saturated
		Ty	Sandy loamy clay
		V	Rather thick

App. 1.4 A PEDON OF THE CLASS OF ANDOSOLS

I. ENVIRONMENT

Origin: Soil Map of the New Hebrides, 1977, P. Quantin No. 455.
Location: Banks Islands. Mont Too-Lava
Topography: Summit of a cone.
Parent-rock or parent material: Ashes and volcanic tuffs.
Climate: Perhumid.
Vegetation: Nephelophilic forest, rich in ferns and epiphytes.
Present utilization: -

II. MORPHOLOGY

Depth (cm)	Description	Horizon
0- 10 and 10- 80	7.5YR 3/2 very dark brown to 5-7.5YR 3/4 dark reddish brown, contains much humus; loamy, fine to medium blocky, merging to very friable massive, nonsticky, nonplastic	Hyperpachic dystric sombron
80-120	5YR 4/4 brown red; loamy, massive, nonsticky; friable, strong micro-porosity, thixotropic	Reddish brown perhydric andon
120-200 or more	7.5YR 4/4 ocher brown, loamy, finely sandy; massive, friable, thixotropic	ditto

III. MICROMORPHOLOGY

IV. ANALYTICAL DATA

1) Surface horizon 0-10 cm

Org. Matter		Granulometry			pH		BS
%	C/N	Cl	Si	Sa	H O	KCl	%
24.5	10.3	22	19	34	4.9	-	16.8

2) Mineralon 80-110 cm

Org. Matter		Granulometry			2	pH	
%	C/N	Cl	Si	Sa	mm	H O	KCl
1.7	-	15	10	73	-	5.5	-

Exch. Cations (meq/100 g)						BS	ESP
Ca	Mg	K	Na	Al	CEC	%	%
.9	.4	0.04	0.08	-	25.1	6	-

P O (%)		Fe O (%)		SiO /
tot.	avail.	free	tot.	Al O
-	20	-	-	1.26

Salts: -

Mineral constituents: total amorphous materials 29.2

Bulk density: 0.3

Water content,	fresh soil	152%
	soil pF 3	133%
	soil pF 4.2	82.4%

V. SYNTHETIC DATA

Very strong and deep accumulation of organic matter.
Perhydric and thioxtropic andon, strongly desaturated.

VI. CLASSIFICATION

CPCS	Andosols of tropical countries, desaturated, humic		
USDA	Hydrandept		
FAO/ Unesco	Humic Andosol		
PCS	I.	C	Andosol
		SC	With aluminous allophane
	II.	GG	Hyperpachydyssombric
		G	Perhydric
		SG	Reddish brown modal
		F	On ashes
	III.	Ge	Acid, dystric,
		Ty	Sandy clay
		V	Rather thick

APPENDIX 2 - PRINCIPLES OF ANALYTICAL METHODS

The analytical techniques (only the principles of which are given below and which are desdribed in detail in the different books and articles while titles are given in the bibliography), are those that may be used in the characterization of soils, in view of their classification.

The following techniques are those recommended by the workshop. When two or more methods are in competition, they are described until a later choice is made.

The majority of these methods may be applied at the present time in a normally equipped pedology laboratory. In all cases any method which needs the use of a relatively expensive or difficultly obtained material, is doubled by other methods which need only easily obtained material means or procedures.

1) ALUMINIUM ON THE COMPLEX[1]

Calculate the ratio Al/Al+S x 100 where S is the sum of extracted exchangeable cations by using 1 N ammonium acetate at pH 7 (cf. No. 13) and Al is the value of exchangeable aluminium (cf. No. 2).

2) EXCHANGEABLE ALUMINIUM[2]

a) Extraction of exchangeable aluminium by a normal solution of potassium chloride. To 20 g of the soil, add 200 ml of solution divided into three equal portions (of about 70 ml).

b) Aluminium is determined in the filtrate by colorimetry.

3) TOTAL ALUMINIUM

After the soil attack with a triacid reagent (see under 9), a) Precipitate the hydroxides and oxides which contain Al_2O_3, Fe_2O_3, TiO_2, P_2O_5. In order to determine Al_2O_3, Fe, Ti and P are determined separately and the sum of the three oxides is subtracted from the total amount. b) Aluminium is determined by colorimetry, using eriochrome cyanine R, after reducing ferric iron to the ferrous state.

4) FREE ALUMINIUM/TOTAL ALUMINIUM

Total aluminium comprises the corresponding amount in the silicates and the hydroxides. The amount of silica corresponds to that of kaolinite; the difference gives the amount of free alumina. One should check the nature of the present silicates in order to do this calculation.

5) AMORPHOUS MATERIALS

These materials are mainly iron oxides and/or hydroxides, aluminium silicates, combined or free. The absence of a lattice structure and the small dimensions do not allow the obtainment of an X-ray diffraction pattern.

The presence of large quantities of these materials in certain soils, like the andosols, renders the mechanical analysis very difficult, deeply modifies certain properties like the cation exchange capacity (large capacities depending on pH), the water properties, the

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[1] Kamprath, 1970.

[2] ORSTOM, S.S.C.

bulk density, the specific surface area, etc.. Thus, they may be characterized by the conjunction of many of these properties.

Checking of amorphous materials: Silica and alumina are dissolved by a 2% warm caustic soda solution. Iron oxides are easily dissolved by the Tamm liquid with oxalic acid or with a pyrophosphate solution of Bascomb. One should remember that the effect of dithionite goes far beyond the amorphous materials and dissolves the crystalline oxides in addition to the amorphous oxides.

Semi-quantitative determination[1]. It uses a kinetic dissolution of the amorphous materials which allows to distinguish the amorphous materials from the crystalline materials.

The initial method of Segalen uses 8 N HCL and 2% caustic soda, alternatively applied. The operation is repeated 6 or 8 times. The curve representing the dissolved amount as a function of the number of extractions allows a simple determination of the searched contents in the case of soils like the ferbisialsols, fermonosialsols, etc.

Later on, it was observed that these reagents were too strong for certain constituents like halloysite and the fine oxides and hydroxides. Modifications were proposed by Lamouroux and Quantin[2] and by Quantin[3]. The acid concentration was reduced to 4 N or 2 N and the caustic soda supressed. Moreover, the analysis of the velocity curves, instead of the cumulative curves, was proposed by Lamouroux and Quantin[4].

The ammonium oxalate-oxalic acid solution is considered as capable of extracting amorphous iron oxides[5].

An andosol is supposed to contain at least 50% of the secondary amorphous materials.

6) OPTICAL ANALYSIS OF SANDS

Sands yielded by the mechanical analysis are prepared for an optical examination. First, two fractions are separated, a light and a heavy fraction, by using a high specific gravity liquid like bromoform (d = 2.9). The minerals are spread on a slide by using Canada Balsam for the microscopic examination (identification and counting) if they are transparant. For opaque minerals, X-ray examination is done.

7) DIFFERENTIAL THERMAL ANALYSIS

This technique allows the measurement of the difference of released or absorbed heat by a constituent and by the neutral product, heated at a constant rate. Thermoelectric couples are immersed in the substances and the difference in electrical potential is recorded; the shape of curves and the temperatures at which the peaks appear are examined and allow the identification of the substances.

It is almost always difficult to identify correctly several substances in a mixture, because the peaks overlap. However, this technique is particularly useful (among others) in the identification of aluminium hydroxides and allows to determine certain montmorillonites.

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[1] Segalen, 1968.
[2] Lamouroux and Quantin, 1974.
[3] Quantin, 1975.
[4] Lamouroux and Quantin, 1975.
[5] Schwertmann, 1973.

8) THERMOGRAVIMETRIC ANALYSIS

If the heated sample (in a furnace) is connected with a balance where equilibrium is automatically established, the variations of weight as a function of temperature are recorded. The losses in the weight of the hydroxides of the clay minerals are then quantitatively determined.

9) ELEMENTAL ANALYSIS (attack with a triacid reagent)

This attack allows to separate the secondary products of the soil from the primary residue (mainly quartz) by using a mixture of $NHO_3 \div HCl \div H_2SO_4 = 3 \div 5 \div 2$ (vol. of conc. acid).

Two successive attacks are made in a beaker in a fuming hood until white fumes appear. The residue is filtrated and washed. The solution contains Al, Fe, Ti, Mn and the bases.

On a filter, the unattacked residue and silica of the solicates are received. Silica is then dissolved by a warm caustic soda solution and collected in an evaporating dish where it is neutralized (rendered insoluble again), filtrated and weighed after calcination at 1000°C.

- Direct determination may be done by colorimetry for Fe, Al, Ti, P and by atomic absorption for Mn.
- For the determination of bases, the hydroxides are precipitated by a hexamethylene tetramine solution at pH 6.5. The excess reagent is destroyed by aqua regia and the determination of the cations Ca^{2+}, Mg^{2+} is done by atomic absorption, and of Na^+ and K^+ cations, by flame photometry.
- The obtained values for all the elements are used for the determination of the centesimal composition of the sample. Particularly the values of silica, iron and aluminium oxides are used for the calculation of the molecular ratios or of the elemental composition.
- This technique may be applied to any granulometric fraction of the soil or to the > 2 mm fraction in case of concretions or cuirass.
- In case of a calcareous soil, it is recommended to start destroying the carbonates with 1 N HCl; filtrate, calcinate the filter and then undertake the attack as previously described. The filtrate of the limestone attack is added to that of the triacid.

10) ORGANIC CARBON

Many methods are available for the measurement of organic carbon in soils.

- Coulometry. The combustion of organic matter in a furnace in a stream of oxygen produces CO_2 which is determined by a coulometer. It is necessary to operate in the absence of limestone.
- Oxidation with potassium dichromate:
  Without heating, by the Walkley and Black[1] technique;
  With heating, by the Anne[2] technique.
  Determination is achieved by volumetry for the excess of added dichromate by using Mohr salts; by colorimetry of the formed chromic ions. Multiply carbon content by 1.724 in order to obtain the amount of organic matter.

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[1] Walkley and Black, 1934.
[2] Anne, 1945.

11) CARBON/NITROGEN (ratio)

The ratio is centesimal. The carbon content is divided by that of nitrogen. The normally found values in soils are near to 10.

12) EXCHANGEABLE CATIONS

- On a filter, was the soil with a 1 N ammonium acetate solution at pH 7. For a calcareous soil, take 10 g and percolate 250 ml of the solution; for a noncalcareous soil, 20 g of soil are used and 150 ml of solution.
- Dry up and use aqua regia to destroy all organic residue and the excess of ammonium acetate.
- Determine the cations separately:
  - Ca^{2+} and Mg^{2+} by complexometry or by atomic absorption.
  - Na^{+} and K^{+} by flame photometry.
- The value S is obtained by adding Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}, determined in meq/100 g soil.

13) CATION EXCHANGE CAPACITY (CEC)

This value is particularly important for the characterization of soils (or of soil fractions). It is controversed and the methods for its obtainment are variable.

a) Use 1 N ammonium acetate at pH 7 (cf. No. 12). Soil is saturated with ammonium ions by the acetate solution. The excess salt is removed by washing with alcohol.

The NH_4 soil is treated with a potassium salt which displaces ammonium, the latter is determined by volumetry after steam destillation.

This technique, the most criticized, is easy to use and the results, obtained on all soils of the world are available in literature. It is recommended by USDA[1].

b) Use 1 N calcium chloride at pH 7 (buffered with triethanolamine and nitric acid)[2].

- Soil is washed on a filter by a calcic solution.
- The excess reagent is removed by a N/50 nonbuffered $CaCl_2$ solution.
- Ca^{2+} is displaced by a potassium nitrate solution.
- Ca^{2+} and Cl^{-} are determined in the wash solution with potassium nitrate.
- The amount of calcium yielded by the chloride is calculated and subtracted from the total amount of calcium. The difference corresponds to CEC.

This technique is recommended by ORSTOM.

c) Use 0.5 N barium chloride, 0.2 N triethanolamine, buffered with HCl to pH 8.2.

On a filter, percolation of a soil sample with barium chloride.

Washing is done with water, then with a solution of 1 N magnesium nitrate.

Ba^{2+} is determined in the magnesium nitrate wash by flame photometry and the value of CEC is determined at pH 8.2

This determination is recommended to obtain the variable charges in addition to the permanent ones.

d) Effective exchange capacity ECEC.

In some countries, the exchange capacity is not measured, but it is obtained by adding the value S (sum of

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[1] Report No. 1

[2] Pelloux et al., 1971.

exchangeable bases), either to Al + H obtained by extraction by calcium acetate at pH 7, in which case ECEC = S + Al + H, or to the value of exchangeable Al, obtained by extraction by 1 N potassium chloride, in which case ECEC = S + Al (H is considered very small).

14) CLAY MINERALS

Two categories of problems are set by these minerals. These are the identification and the quantitative estimation.

The identification is the best done by X-ray diffraction. Each mineral species provides a spectrum which is expressed by a series of lines or peaks. Some are modified by chemical or thermal treatments. Their identification is no more problematic and the technique is a routine one. The data obtained by this technique are completed and checked by other techniques such as thermal and chemical analysis (elemental analysis and molecular ratios).

Other techniques may be also used like infra-red absorption, transmission electron microscopy and microdiffraction.

The quantitative analysis is still unsatisfactory and tedious. The determination of the peaks' heights of the X-ray diagrams allows to obtain rather approximate indications, if the ratios of the peaks' heights of the different minerals are compared with those obtained from mixtures of standard minerals using the same apparatus. Thus, it is possible to roughly determine the amounts present and to propose an approximate percentage. The chemical and thermal analyses may improve the results.

15) CALCIUM CARBONATE

Calcium carbonate of the soil may be primary (inherited from a rock) or secondary (formed during pedogenesis). Observation of the accumulation forms and, especially, the observation of the micromorphology, allow to decide of the origin of calcium carbonate. The determination of calcium carbonate may be done by several methods.

- *Bernard Calcimeter*. A volume of CO_2 obtained by the effect of HCl on a known weight of the soil is measured. The calcimeter is standardized with pure $CaCO_3$. One should account for the very slow attack of dolomite. The method is not recommended in case of presence of dolomite. A better method is then to measure the carbonate equivalent.
- *Carbonate Equivalent*. To a known weight of soil, add a given volume of an acid of a known strenght. The excess acid is determined allowing the determination of the amount of destroyed carbonate.
- *Coulometry*. Displacement of CO_2 with phosphoric acid and determination of the quantity of formed carbonic acid by using a coulometer.

16) CALCIUM SULFATE (gypsum and anhydrite)

A soil is treated with water in the maximal proportion of 1 g of soil for 50 ml water. To the filtrating solution, acetone is added to produce the precipitation of calcium sulfate. After centrifugation, redissolve the precipitate and measure the electrical conductivity of the solution. A standard curve is used[1].

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[1] Report No. 1.

17) PERMANENT CHARGE

It is considered as the charge obtained by 1 N ammonium acetate at pH 7, to which exchangeable Al is added (if Al is present).

Permanent charge = S + Al

18) VARIABLE CHARGE

It is considered as that charge which is obtained by subtracting the permanent charge from the value of CEC obtained by $BaCl_2$ - TEA at pH 8.2.

Variable charge = CEC ($BaCl_2$ - TEA 8.2) - (S + Al)

As for andosols, reference is often made to the Aomine and Jackson (1959) Δ value. Comparison is made between the obtained values of CEC at pH 3.5 (with an oxalic acid-ammonium oxalate mixture) and at pH 10.5 (with sodium bicarbonate). Quantin recommends to use a mixture of hydrochloric acid-ammonia and triethanolamine instead of sodium bicarbonate so as to operate at pH 9, easier to stabilize.

19) DEGREE OF SATURATION V

This degree is obtained by dividing the sum of bases S ($S = Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}$) in meq/100 g by CEC and multiplying by 100.

$$V\% = \frac{S}{CEC} \times 100$$

20) SOIL DENSITY

Apparent bulk density D_a

1. In the field, a known volume of the soil is removed by using a sharp-edged cylinder. After desiccation, the specimen is weighed.
2. A hole is made the volume of which is measured by using a fine membrane filled with water and sand. The weights of removed earth from this hole are determined.

Real density D_r

A pyknometer is used.

The bulk density is sometimes measured on the non-dried sample in air and at a corresponding humidity of 1/3 bar. This determination is particularly important for andosols.

21) X-RAY DIFFRACTION

In this technique, a clay sample fixed on a slide receives a beam of X-rays of a given wavelength produced by a cobalt (or copper) anticathode tube.

The diffracted rays are identified and recorded on a particular diagram. Application of Bragg's law allows the calculation of the d-spacing which separates the different planes of atoms of the constituents, and consequently, their identification[1].

This technique may be applied for the identification of the primary minerals (feldspars, amphiboles, pyroxenes, metamorphism silicates, etc.), released from rocks, as well as for the identification of secondary minerals produced during pedogenesis.

---

[1] Brown, 1961.

For the soil minerals (clay minerals or sesquioxides), a powder diagram or an oriented diagram is used on the fraction, smaller than 2 μ, which has already undergone different treatments.

This technique gives the best results for the identification of the constituents. It gives only a rather rough estimation of the present quantities.

GYPSUM: see calcium sulfate.

22) HUMUS

Different reagents are used for a complete removal of humus from the soil and to obtain fulvic and humic acids. The remaining fraction in the specimen is humin. 40 g of soil are successively treated with 200 ml portions of the following reagents.

1. *Phosphoric acid* (2 M, H_3PO_4, density 1.1) allows to separate the light organic matter from the free fulvic acids. It breaks the bonds between the organic and inorganic materials.
2. *Sodium pyrophosphate* (0.1 M $Na_4P_2O_7$) at pH 9.8 extracts the humic and fulvic acids. The extraction is repeated until a clear extract is obtained.
3. *Caustic soda* (0.1 N NaOH) extracts the remaining part of humic and fulvic acids.

Humic acids may be fractionated into grey and brown acids by paper electrophoresis.

The residue is collected and dried. It contains humin.

The different fractions are estimated by carbon determination by coulometry or oxidation with potassium dichromate.

23) SOIL IRON

This element is one of the most important ones of the soil[1]. It is determined by volumetry (Zimmermann - Rheinhardt method after reduction of Fe^{3+} in Fe^{2+} by stannous chloride); or by colorimetry with orthophenanthroline, after reduction with ascorbic adic.

Literature on the determination of this element is very rich and there is no need to summarize it.

A. Total iron

Attack of a known weight of the soil with concentrated hot HCl for 5 hours. Dilute, filter and determine.

B. Free iron

This name applies to soil iron oxides and hydroxides, with the exception of iron included in the structure of the primary minerals and of the clay minerals[2].

- Technique derived from the one recommended by DEB with sodium dithionite. The soil is treated in a centrifuge tube by sodium dithionite and 50 ml of a buffer solution of sodium citrate-sodium tartrate (pH 8.5). The extraction is repeated 3 times; the three solutions are mixed together and iron is determined.

  USDA[3] recommends similar techniques with other buffer solutions (particularly sodium citrate and bicarbonate).

---

[1] Segalen, 1964.
[2] Segalen, 1971.
[3] Report No. 1.

- Technique derived from that recommended by De Endredy. Apply a strong ultraviolet ray to a soil sample immersed in an ammonium-oxalic acid solution (at pH 3.5-3.7) (Tamm reagent). Generally, 2 to 3 hours are enough to dissolve all free iron. In presence of 2:1 clay minerals containing iron, the attack of the lattice is slower by this technique[1].

  Using this technique enables to get a kinetic extraction and to draw a cumulative curve from which free iron is deduced.

C. Cheluvion iron and aluminium

The extract with sodium pyrophosphate is used for the determination of iron, aluminium and the organic matter of podzol cheluvions. 200 ml of 0.1 M sodium pyrophosphate solution are added to 2 g of the soil. After mechanical agitation, filtration is followed by determination of Fe, Al, and C[2].

The extract with sodium pyrophosphate to which sodium dithionite is added is used for the extraction of iron and aluminium oxides which are no more bound to the chelating organic matter[3].

80 ml of the previous solution are added to 4 g of soil and 2 g of dithionite. Fe + Al obtained by this reagent are compared with Fe + Al obtained by the previous reagent.

JAROSITE: cf. Sulfates.

24) MECHANICAL ANALYSIS. THE PIPETTE METHOD

The following operations are successively undertaken:

- Treatment with hydrogen peroxide to destroy the organic matter.
- Dispersion in sodium hexametaphosphate or pyrophosphate.
- Mechanical agitation for 4 to 6 hours.
- Removal of aliquots for clay and silt.
- Washing, drying and sieving of the isolated sands after siphoning off the clay and the silt.

In case of pseudosands or pseudosilts, refractory to dispersion, undertake an ultrasonic treatment at 20 K Hertz during 10 to 15 minutes, with or without addition of a dispersing agent.

If the treatment with ultrasonics is still insufficient, the ferruginous cements may be dissolved with TAMM's reagent in the dark. The amounts of silica and of aluminium, released by this treatment[4], are then measured.

In case of andosols, the mechanical analysis should be done on the moist soil and the pH should be adjusted in order to obtain a better dispersion (some colloids are dispersed at an acid pH, between 3 and 4.5, others at an alkaline pH between 9 and 10.5), while dispersing by ultrasonic is also used.

Moreover, certain pretreatments should be avoided (hydrogen peroxide containing phosphoric acid) or dispersing agents like hexametaphosphate. It is sometimes recommended to try a direct dispersion of the soil before any pretreatment.

---

[1] Segalen, 1970.

[2] Bascomb, 1968.

[3] Franzmeier et al., 1965.

[4] Chauvel, 1977.

25) MICROMORPHOLOGY

This technique allows to examine the microstructure of the soil and to get useful information on the structure, the constituents and the arrangement of these constituents. It is especially useful for the determination of the origin of calcium carbonate or of gypsum, for example, and whether they are due to pedogenesis, or to other origins and to determine if there are any movements and deposition of clay and/or iron[1].

The application of this technique needs a workshop equipped for:

- Impregnation of the samples with a plastic material in order to "immobilize" the finest particles.
- Cutting blocks which are rather thick, to begin with.
- Polishing and thinning of the blocks to the desired thickness.

The thin sections are examined with a microscope using natural or polarized light.

The observation of the thin sections is always information rich. It allows to recognize and to identify certain minerals. Among others, it allows to distinguish the clay which did not undergo any movement and which is isotropic from the displaced clay forming coatings, links and fillings and which is birefringent. The identification of the latter clay type is particularly useful to distinguish the argillanic horizon.

26) TOTAL NITROGEN

Nitrogen is mineralized by the Kjeldhal technique in order to be transformed into inorganic nitrogen, by using sulfuric acid to whci a catalyst is added ($Se + K_2SO_4$).

- Determination of the released ammonium ion is done by volumetry after displacement of ammonium hydroxide by caustic soda and steam destillation.
- Determination may be also done by colorimetry of a blue product of the indophenol type, obtained by the reaction of phenol and sodium hypochlorite on the ammonium ion in presence of potassium nitroprussiate as catalyst.

27) OXIDIC METALS

These are Ni, Co, Cr, V, etc.. They exist as traces in the soil but in oxidisols their content may reach a high percentage. They may be tested and determined in a particular attack with strontium metaborate. In the obtained solution, the metals are determined with atomic absorption.

28) OXIDES AND HYDROXIDES

The identification is done with a physical technique (thermal analysis, X-ray diffraction) or a chemical technique (total or partial analysis).

The quantitative determination is very easy when the investigated product is separated since each metal is easily determined by one of the several methods presently available.

29) PENETROMETRY

The resistance of a soil or of a soil horizon to the penetration of a metallic rod driven in the soil by a known amount of energy is measured. The result may be expressed in the form of the necessary energy to go through a unit thickness[2].

---

[1] Brewer, 1964; Report No. 1.

[2] ACHRV, 1973.

30) PERMEABILITY (or filtration velocity)[1]

This property is measured by using the following technique:
Porchet method. A bore hole of known diameter is filled with water. The lowering of the water level as a function of time is measured.
Müntz method. At the soil surface, a constant water height is maintained (h = 3 cm). Infiltrating water is automatically replaced and the volume of filtrating water during 1 hour is measured.
Aspersion (Valetin) method. A plot of land of known area is sprinkled with water. The flow water is collected and the filtration is deduced.

These measurement techniques (penetrometry and permeability) help in characterizing the compact horizons.

A soil is impermeable if the water flow is less than 1 cm/hr; permeable for 1 to 10 cm/hr; very permeable for more than 10 cm/hr.

31) pH OF THE SOIL

20 g of soil are mixed with 50 ml of distilled water; agitation is followed by pH measurement by a glass electrode potentiometer.

After stabilization, the value pH-H_2O is recorded.

A known quantity of solid potassium chloride is then added to obtain a 1 N KCl solution. The suspension is agitated and the measurement is repeated to get pH/KCl. Calculate Δ pH = pH(KCl) - pH(H_2O).

The measurement of Δ pH is particularly instructive, for the identification of the andosols and the oxidisols, according to whether it is positive or negative.

32) POROSITY

This value is obtained by the measurement of the apparent and real bulk densities[1]:

$$P = 100\ (1 - \frac{D_a}{D_r})$$

or by suspending a clod to the bar of a balance and determining the total volume and the volume of the solid fraction by immersion in petroleum.

33) PHOSPHORUS (acid)

The total acid is obtained after the attack of the soil by concentrated boiling nitric acid for 5 hours.

Available phosphoric acid. The Olsen technique, modified by Dabin is recommended in this case.

The extraction is done by a solution of sodium carbonate and ammonium fluoride.

Phosphorus determination is done by colorimetry (molybdenum blue).

34) SALTS OF MEDIUM SOLUBILITY OR HIGHLY SOLUBLE

First, their extraction from the soil is done by the saturated paste technique[2]:
- 300 to 400 g of the soil is gradually mixed with water by using a smooth metallic spatula. Mixing is stopped on the formation of a shining film on the surface of the paste, or when it adheres no more to the spatula.

---

[1] ACHRV, 1973.
[2] Richards, 1954.

- The solution is then extracted by using a Buchner funnel connected with a suction pump. The following measurements are done on the obtained liquid.
  - pH (see above).
  - Electrical conductivity. A halic saline soil should have a conductivity equal to or higher than 8 ms (microsiemens).
  - Determination of the ions.

    1) Anions: chloride, by potentiometry with a silver electrode; sulfates by turbidimetry of barium sulfate; carbonate and bicarbonate by acidimetry.

    2) Cations: Ca^{2+} and Mg^{2+} by atomic absorption, Na^+ and K^+ by flame photometry.

The saline capacity may be roughly deduced from the conductivity.

Sum (anions and cations) in meq = EC x 10.

35) SiO_2/Al_2O_3 RATIO or K_1

This ratio is calculated by using the alumina and silica contents, obtained by the triacid attack on the chosen fraction.

$$\frac{SiO_2\%}{Al_2O_3\%} \times 1.7 = K_1$$

The choice of the value 2.2 to separate monosialsols and fermonosialsols from the bisialsols and ferbisialsols is justified by:

- The possible existence of iron containing 1:1 clay minerals.
- The presence of small amounts of 2:1 clay minerals or silica and increase the ratio.

The SiO_2/R_2O_3 ratio is calculated by using the SiO_2, Al_2O_3 and Fe_2O_3 contents.

$$\frac{SiO_2/60}{Al_2O_3/102 + Fe_2O_3/160} = K_2$$

The usefulness of this ratio in the identification of soils is not clear.

36) SODIUM (appraisal of)

The appraisal of sodium adsorbed on exchange complex can be done:

a) By the calculation of $\frac{\text{Na exch.}}{\text{CEC}} \times 100$, it is considered that there is a risk of sodification if the obtained values are higher than 15.

b) By the calculation of SAR or Sodium Absorption Ratio.

This ratio is calculated from the exchangeable ions in the following way[1]:

$$SAR = \frac{Na^+}{\sqrt{\dfrac{Ca^{2+} + Mg^{2+}}{2}}}$$

If the ratio exceeds 13, the risk of sodification exists.

37) (Test with) SODIUM FLUORIDE

1 g of fine earth is added to 50 ml of 1 N sodium fluoride solution. Within 2 minutes, the pH is measured and the soil is considered as allophanic if a pH 9.4 or more develops. For a lower value or if more slowly attained, the soil is considered as andic. In all cases,

---

[1] Richards, 1954.

this measurement denotes the presence of amorphous materials where Al is easily displaced[1].

While this test is very useful for the characterization of the andosols and the andic soils, one should not forget that cheluvions may also give positive reactions with this test.

In the field, a small mound of earth is placed on ashless filter paper, preimpregnated with phenolphthalein. A few drops of sodium fluoride solution are put on the mound to impregnate it. During the following minute, a violet color appears on the filter paper. This reaction is used for the precise determination of the allophanic or andic character.

38) FERRIC AND ALKALINE SULFATES (jarosites)

The extraction is done by using a warm solution of sodium carbonate[2].

The sulfates are estimated by turbidimetry of barium sulfate.

39) SULFIDES

A. *Soluble alkaline sulfides*

The extraction is done under a nitrogen atmosphere. A sample is treated with HCl and the formed H_2S is received in a solution of zinc acetate. The formed zinc sulfide is determined by iodometry[3].

B. *Insoluble sulfides and polysulfides*

Nascent hydrogen (HCl + Sn) is used for the reduction. Or, an oxidation in a furnace at 1000°C is done by using tungsten, iron and copper[4] oxides.

Sulfur in the formed gases is collected.

40) ELEMENTARY SULFUR

- Dissolve sulfur in acetone and transform it in copper sulfide CuS. Attack by HCl and determine H_2S by iodometry[5].
- Or, oxidize the sulfurized product by an oxidizing mixture in a nitrogen atmosphere. The sulfur dioxide obtained is determined by iodometry.

41) SPECIFIC SURFACE AREA

Form a monomolecular layer on the surface of a particle and measure the amount of fixed product to determine the surface.

The *Glycerol Method*. An anhydrous specimen is treated with a 2% glycerol solution. Heating is done in a furnace at 110°C, until a constant weight is reached[6].

Nitrogen Method (BET). On a cooled sample at -190°C, a current of nitrogen diluted in helium is passed. The amount of fixed nitrogen is measured by reheating the sample to release nitrogen[7].

The poorly crystallized or amorphous materials have a very high specific surface area of 200 to 700 m^2/g. The clay minerals and oxides have a smaller specific area, from 30 to 200 m^2/g.

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[1] Fieldes and Perrott, 1966.

[2] Vieillefon, 1974, Report No. 1, 1972.

[3] Vieillefon, 1974.

[4] Smittemberg et al., 1951.

[5] Report No. 1.

[6] Kinter and Diamond, 1958.

[7] Nelsen and Eggersten, 1958.

42) TEXTURE TRIANGLE

The texture triangle is constructed by using the data provided by the mechanical analysis (see above), for the clay, silt and sands, with the exception of water and organic matter contents (A + L + S = 100).

Several triangles of this kind exist, three of which are given next.

43) SOIL WATER

The soil water content at a given moment may be obtained:

a) After dehydration of a sample of a known weight in a furnace at 105°C.

b) By using the neutron scanner technique.

The determination of the moisture of a soil sample at different levels of the matrix potential is particularly important. The samples, presaturated with water, are placed on a semipermeable disc and submitted to variable pressures. This pressure is measured in units of g/cm^2, in which case the log value is taken, or it is determined in bars[1].

In France, two values are often used: these are, 16000 g/cm^2 (pF 4.2), corresponding to the wilting point and 320 g/cm^2 or 1/3 atmosphere (pF 2.5) which (in principle) corresponds to the field capacity. In USDA, the pressures are expressed in bars (15 and 1/3); they are very close to the previous pressures and the values are quite comparable.

Some values of water contents of soils after the application of a pressure of 15 bars are given below.

Nonvitric perhydrated andosols	150 to 300%
Nonvitric orthic andosols	30 to 150%
Vitric andosols	< 20%
Fermonosialsols with halloysite	10 to 80%
Bisialsols	40 to 80%

Rehydration of the soil

An andosol on which the water content at 15 bars is measured behaves in a different way according to whether the measurement of the water content was done after desiccation or on a sample having kept its natural moisture. The decrease is higher than 35%[2].

This Δ pF value denotes the irreversible dehydration. It may be given in absolute or in relative value with respect to the initial value of the moist soil.

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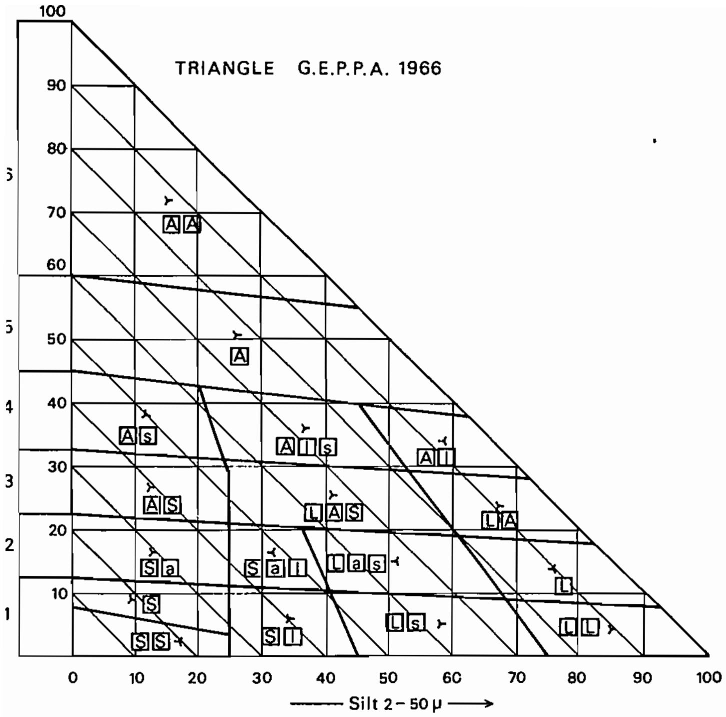
[1] ACHRV, 1972.

[2] Colmet-Daage et al., 1967; Quantin, 1976, 1978.


TRIANGLE G.E.P.P.A. 1966
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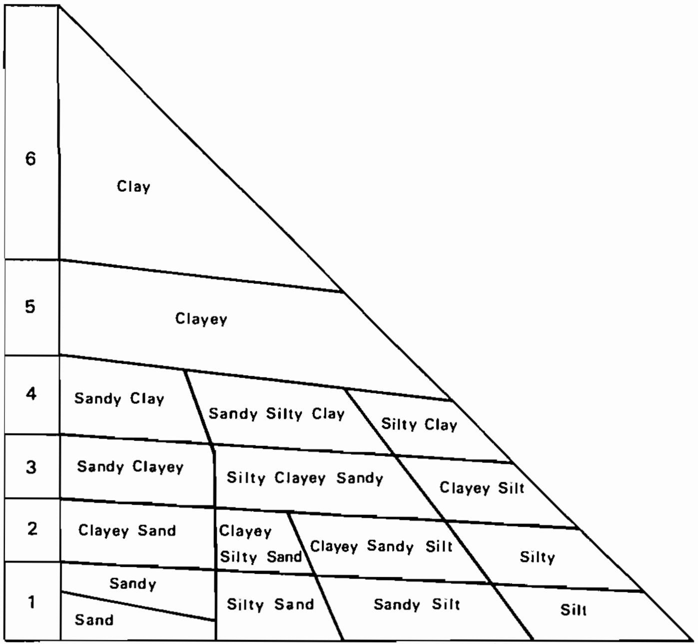
6
Clay
5
Clayey
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Sandy Clay
Sandy Silty Clay
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3
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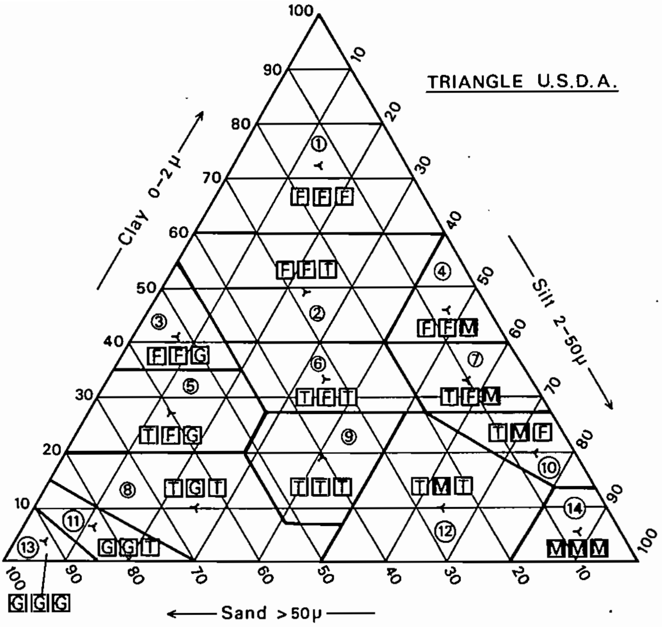

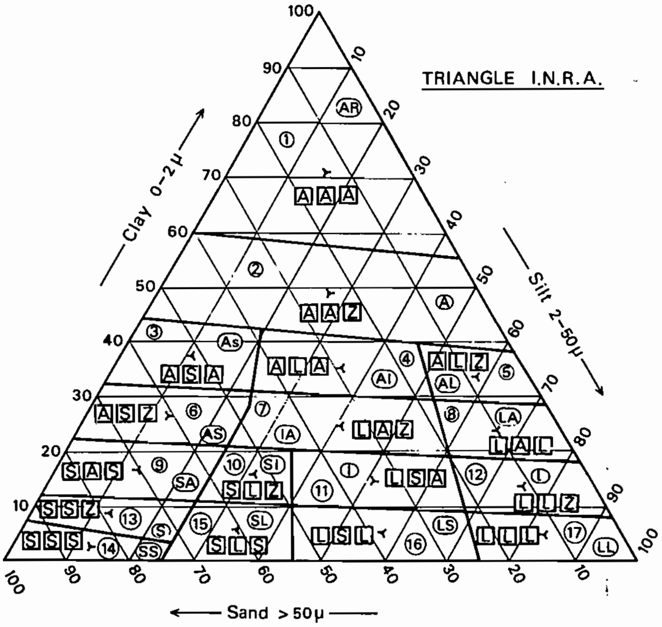

□□□ Code O.R.S.T.O.M.

○ Number

⬭ Abrev. I.N.R.A.

‹ Central texture

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