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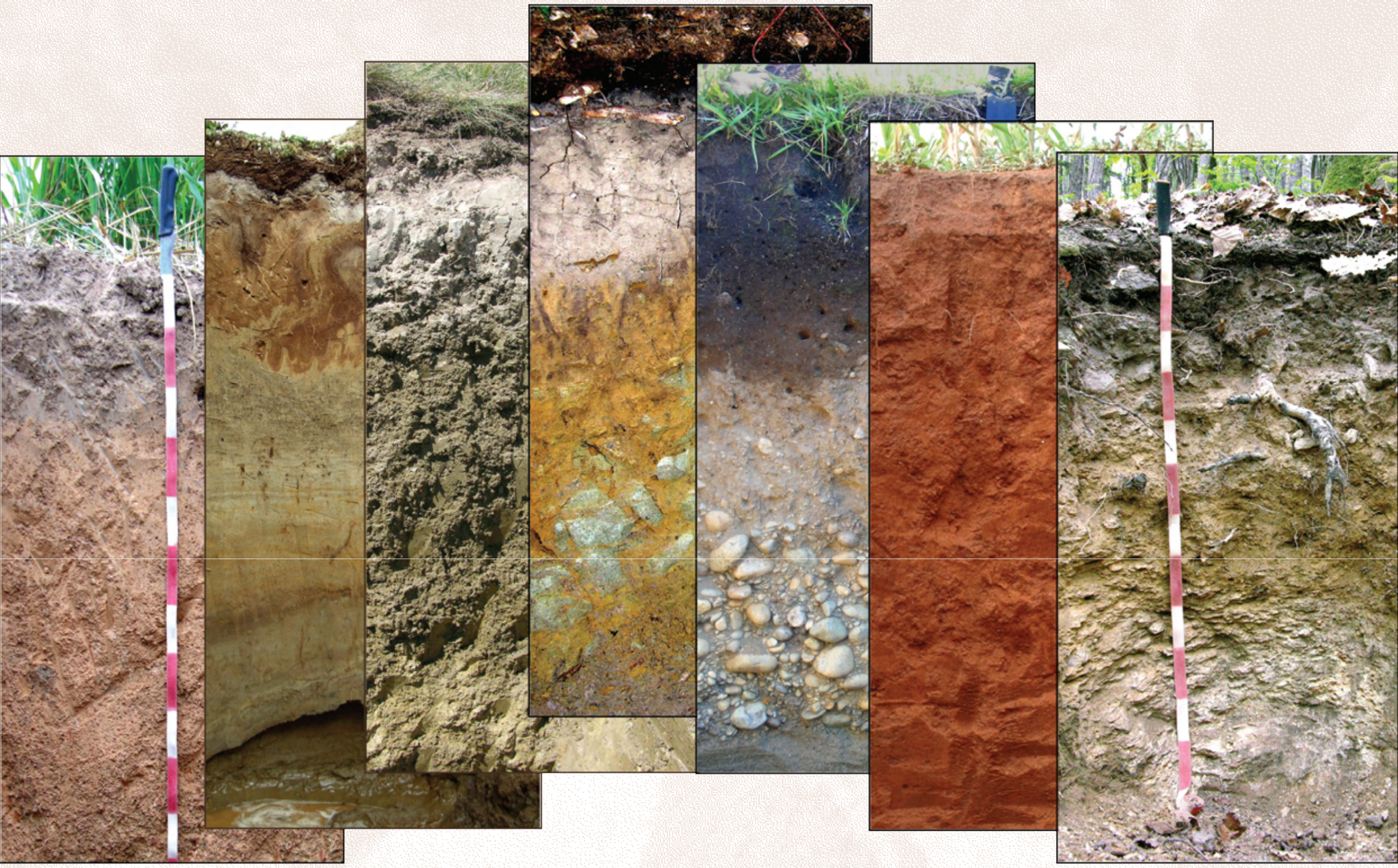
World reference base for soil resources 2006

A framework for international classification, correlation and communication



International Union of Soil Sciences

ISRIC World Soil Information

FAO FIAT PANIS

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2006 edition

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Foreword

The first official version of the World Reference Base for Soil Resources (WRB) was released at the 16th World Congress of Soil Science at Montpellier in 1998. At the same event, it was also endorsed and adopted as the system for soil correlation and international communication of the International Union of Soil Sciences (IUSS).

After eight years of intensive worldwide testing and data collection, the current state-of-the-art of the WRB is presented. This publication reflects the valuable work of the authors of the earlier drafts and the first version of the WRB, as well as the experiences and contributions of many soil scientists who participated in the work of the IUSS Working Group on the WRB.

Globalization and global environmental issues necessitate harmonization and correlation of technical languages, such as the one used in soil science. It is hoped that this publication will contribute to the understanding of soil science in the public debate and in the scientific community.

The publication has been made possible by the sustained efforts of a large group of expert authors, and the cooperation and logistic support of the IUSS, the International Soil Reference and Information Centre (ISRIC) and the Food and Agriculture Organization of the United Nations (FAO).

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This edition has been edited by Erika Michéli (Szent István University, Hungary), Peter Schad (Technische Universität München, Germany) and Otto Spaargaren (ISRIC – World Soil Information, Netherlands). Particular mention should go to Richard Arnold (United States of America), Hans-Peter Blume (Germany) and Rudi Dudal (Belgium). They were involved from the inception of the International Reference Base, more than 25 years ago, and have provided invaluable institutional memory for the objectives and approach.

The Working Group wishes to express its gratitude to FAO for its support and for making possible the printing and distribution of this publication.

List of acronyms and abbreviations

Al	Aluminium
Ca	Calcium
$CaCO_3$	Calcium carbonate
CEC	Cation exchange capacity
COLE	Coefficient of linear extensibility
EC	Electrical conductivity
EC_e	Electrical conductivity of saturation extract
ECEC	Effective CEC
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
HCl	Hydrochloric acid
IRB	International Reference Base for Soil Classification
ISRIC	International Soil Reference and Information Centre
ISSS	International Society of Soil Science
IUSS	International Union of Soil Sciences
K	Potassium
KOH	Potassium hydroxide
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
NaOH	Sodium hydroxide
ODOE	Optical density of the oxalate extract
P	Phosphorus
RSG	Reference Soil Group
S	Sulphur
SAR	Sodium adsorption ratio
SiO_2	Silica
SUITMA	Soils in Urban, Industrial, Traffic and Mining Areas (special working group)
Ti	Titanium
TRB	Total reserve of bases
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USDA	United States Department of Agriculture
WRB	World Reference Base for Soil Resources
Zn	Zinc

Chapter 1
Background to the world reference base for soil resources

HISTORY

From its beginnings to the first edition in 1998

In the early 1980s, countries became increasingly interdependent for their supplies of food and agricultural products. Problems of land degradation, disparity of production potentials and of population-carrying capacities became international concerns that required harmonized soil information. Against this background, the Food and Agriculture Organization of the United Nations (FAO) felt that a framework should be created through which existing soil classification systems could be correlated and harmonized. Concurrently, it would serve as an international means of communication and for exchange of experience. The elaboration of such a framework required a more active involvement of the entire soils community.

At the initiative of FAO, the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP), and the International Society of Soil Science (ISSS), a group of soil scientists representing a broad range of soil institutions met in Sofia, Bulgaria, in 1980 and 1981 to enhance international involvement in a follow-up to the Soil Map of the World (FAO–UNESCO, 1971–1981). The meeting was hosted by the Poushkarov Institute of Soil Science and Yield Programming. The meeting decided to launch a programme to develop an International Reference Base for Soil Classification (IRB) with the aim to reach agreement on the major soil groupings to be recognized at a global scale, as well as on the criteria to define and separate them. It was expected that such an agreement would facilitate the exchange of information and experience, provide a common scientific language, strengthen the applications of soil science, and enhance communication with other disciplines. The group met in 1981 for a second time at Sofia and laid down the general principles of a joint programme towards the development of an IRB.

In 1982, the 12th Congress of the ISSS, in New Delhi, India, endorsed and adopted this programme. The work was conducted by a newly created IRB working group, chaired by E. Schlichting with R. Dudal serving as secretary. At the 13th Congress of the ISSS, in Hamburg, Germany, in 1986, the IRB programme was entrusted to Commission V, with A. Ruellan as chair and R. Dudal as secretary. These charges were continued through the 14th Congress of the ISSS, in Kyoto, Japan, in 1990.

In 1992, the IRB was renamed the World Reference Base for Soil Resources (WRB). Hence, a WRB working group was established at the 15th Congress of the ISSS, in Acapulco, Mexico, in 1994, with J. Deckers, F. Nachtergaele and O. Spaargaren as chair, vice-chair and secretary, respectively, through the 16th Congress of the ISSS, in Montpellier, France, in 1998. At the 17th World Congress of Soil Science, in Bangkok, Thailand, in 2002, the leadership for the WRB programme was entrusted to E. Michéli, P. Schad and O. Spaargaren as chair, vice-chair and secretary, respectively.

At a meeting of the IRB Working Group in Montpellier in 1992, it was decided that the revised FAO–UNESCO legend would form the basis for the further development of the IRB and that efforts were to be merged. It would be the task of the IRB to apply its general principles to the further refinement of the FAO–UNESCO units and to provide them with the necessary depth and validation.

Progress in the preparation of the WRB was reported to the 15th Congress of the ISSS at Acapulco in 1994 (FAO, 1994). Numerous contributions were received from soil scientists; the WRB was discussed and tested in meetings and excursions at Leuven, Belgium (1995), Kiel, Germany (1995), Moscow, Russian Federation (1996), South Africa (1996), Argentina (1997) and Vienna, Austria (1997). The first official text of the WRB was presented at the 16th World Congress of Soil Science in Montpellier in 1998 in three volumes:

1. World Reference Base for Soil Resources. An introduction.
2. World Reference Base for Soil Resources. Atlas.
3. World Reference Base for Soil Resources.

The WRB text was then adopted by the ISSS Council as the officially recommended terminology to name and classify soils. By general agreement, it was then decided that the text would remain unchanged for at least eight years, but that it would be tested extensively during this period and a revision proposed at the 18th World Congress of Soil Science in 2006.

From the first edition in 1998 to the second edition in 2006

In the period 1998–2006, the WRB became the official reference soil nomenclature and soil classification for the European Commission and was adopted by the West and Central African Soil Science Association as the preferred tool to harmonize and exchange soil information in the region. The main text was translated in 13 languages (Chinese, French, German, Hungarian, Italian, Japanese, Latvian, Lithuanian, Polish, Rumanian, Russian, Spanish and Vietnamese) and adopted as a higher level of the national soil classification system in a number of countries (e.g. Italy, Mexico, Norway, Poland and Viet Nam). The text was further illustrated by lecture notes and a CD-ROM on the major soils of the world (FAO, 2001a and 2001b) and a World Soil Resources Map at a scale 1:25 000 000 by the Joint Research Centre, FAO and the International Soil Reference and Information Centre (ISRIC) in 2002. A Web site was established (http://www.fao.org/landandwater/agll/wrb/default.stm) and a newsletter was distributed to hundreds of soil scientists. Specific attention was paid to land-use and soil management issues for tropical and dryland soils using WRB information (FAO, 2003 and 2005). Numerous articles appeared in peer-reviewed soil science journals and books, suggesting improvements to the system. Two conferences were held together with field trips: in 2001 in Velence (Hungary, organized by the Szent István University in Gödöllö); and in 2004 in Petrozavodsk (Russian Federation, organized by the Institute of Biology, Karelian Research Centre). At the same time, a number of field excursions were organized to test and refine the WRB approach in the field: Burkina Faso and Côte d'Ivoire (1998); Viet Nam and China (1998); Italy (1999); Georgia (2000); Ghana and Burkina Faso (2001); Hungary (2001); South Africa and Namibia (2003); Poland (2004); Italy (2004); Russian Federation (2004); Mexico (2005); Kenya and the United Republic of Tanzania (2005); and Ghana (2005).

Summer schools, coordinated by E. Michéli (Hungary), were organized under the auspices of the EU Joint Research Centre in Ispra, Italy (2003 and 2004), and in Gödöllö, Hungary (2005), to teach the system to soil science students and practitioners. In the same period, the European Commission issued the Soil Atlas of Europe based on the WRB (European Soil Bureau Network/European Commission, 2005). A major effort was undertaken to harmonize nomenclature with the soil taxonomy of the United States Department of Agriculture (USDA) and other major national soil classification systems. Some national classifications took up elements of the WRB, e.g. the Chinese soil taxonomy (CRGCST, 2001), the Czech soil classification (Němeček *et al.*, 2001), the Lithuanian soil classification (Buivydaité *et al.*, 2001), and the Russian soil classification system (Shishov *et al.*, 2001). A WRB e-mail forum was organized in 2005 to enable finalization of suggestions for each Soil Reference Soil Group. Independently, special working groups of the International Union of Soil Sciences (IUSS) (formerly the ISSS), such as the ones on Cryosols and on Soils in Urban, Industrial, Traffic and Mining Areas (SUITMA) proposed changes to the system, some of which have been adopted in the present text.

The second edition of the WRB has undergone a major revision. Technosols and Stagnosols have been introduced, leading to 32 Reference Soil Groups (RSGs) instead of 30. The Technosols are soils with a certain amount of artefacts, a constructed geomembrane or technic hard rock. The Stagnosols unify the former Epistagnic subunits of many other RSGs. Some re-arrangement has taken place in the order of the key, with Anthrosols, Solonetz, Nitisols and Arenosols moving upwards. The definitions of many diagnostic soil horizons, soil properties, and materials have been adjusted. The qualifiers are now subdivided into prefix and suffix ones. Prefix qualifiers comprise those that are typically associated with the RSG (in order of their importance) and the intergrades to other RSGs (in order of the key). All other qualifiers are listed as suffix qualifiers.

BASIC PRINCIPLES

The general principles on which the WRB is based were laid down during the early Sofia meetings in 1980 and 1981, and further elaborated upon by the working groups entrusted with its development. These general principles can be summarized as follows:

- The classification of soils is based on soil properties defined in terms of diagnostic horizons, properties and materials, which to the greatest extent possible should be measurable and observable in the field.
- The selection of diagnostic characteristics takes into account their relationship with soil forming processes. It is recognized that an understanding of soil-forming processes contributes to a better characterization of soils but that they should not, as such, be used as differentiating criteria.
- To the extent possible at a high level of generalization, diagnostic features are selected that are of significance for soil management.
- Climate parameters are not applied in the classification of soils. It is fully realized that they should be used for interpretation purposes, in dynamic combination with soil properties, but they should not form part of soil definitions.
- The WRB is a comprehensive classification system that enables people to accommodate their national classification system. It comprises two tiers of categorical detail:
  - the ***Reference Base***, limited to the first level only and having 32 RSGs;
  - the ***WRB Classification System***, consisting of combinations of a set of prefix and suffix qualifiers that are uniquely defined and added to the name of the RSG, allowing very precise characterization and classification of individual soil profiles.
- Many RSGs in the WRB are representative of major soil regions so as to provide a comprehensive overview of the world's soil cover.
- The Reference Base is not meant to substitute for national soil classification systems but rather to serve as a common denominator for communication at an international level. This implies that lower-level categories, possibly a third category of the WRB, could accommodate local diversity at country level. Concurrently, the lower levels emphasize soil features that are important for land use and management.
- The Revised Legend of the FAO/UNESCO Soil Map of the World (FAO, 1988) has been used as a basis for the development of the WRB in order to take advantage of international soil correlation that has already been conducted through this project and elsewhere.

- The first edition of the WRB, published in 1998, comprised 30 RSGs; the second edition, published in 2006, has 32 RSGs.
- Definitions and descriptions of soil units reflect variations in soil characteristics both vertically and laterally so as to account for spatial linkages within the landscape.
- The term *Reference Base* is connotative of the common denominator function that the WRB assumes. Its units have sufficient width to stimulate harmonization and correlation of existing national systems.
- In addition to serving as a link between existing classification systems, the WRB also serves as a consistent communication tool for compiling global soil databases and for the inventory and monitoring of the world's soil resources.
- The nomenclature used to distinguish soil groups retains terms that have been used traditionally or that can be introduced easily in current language. They are defined precisely in order to avoid the confusion that occurs where names are used with different connotations.

Although the basic framework of the FAO Legend (with its two categorical levels and guidelines for developing classes at a third level) was adopted, it has been decided to merge the lower levels. Each RSG of the WRB is provided with a listing of possible prefix and suffix qualifiers in a priority sequence, from which the user can construct the second-level units. The broad principles that govern the WRB class differentiation are:

- At the higher categorical level, classes are differentiated mainly according to the primary pedogenetic process that has produced the characteristic soil features, except where *special soil parent materials* are of overriding importance.
- At the second level, soil units are differentiated according to any secondary soil-forming process that has affected the primary soil features significantly. In certain cases, soil characteristics that have a significant effect on use may be taken into account.

It is recognized that a number of RSGs may occur under different climate conditions. However, it was decided not to introduce separations on account of climate characteristics so that the classification of soils is not subordinated to the availability of climate data.

ARCHITECTURE

Currently, the WRB comprises two tiers of categorical detail:

1. **Tier 1: The RSGs**, comprising 32 RSGs;
2. **Tier 2: The combination of RSGs with qualifiers**, detailing the properties of the RSGs by adding a set of uniquely defined qualifiers.

Key to the Reference Soil Groups

The Key to the RSGs in the WRB stems from the Legend of the Soil Map of the World. The history behind the Key to the Major Soil Units of the Legend of the Soil Map of the World reveals that it is mainly based on functionality; the Key was conceived to derive the correct classification as efficiently as possible. The sequence of the Major Soil Units was such that the central concept of the major soils would come out almost automatically by specifying briefly a limited number of diagnostic horizons, properties or materials.

Table 1 provides an overview and logic for the sequence of the RSGs in the WRB Key. The RSGs are allocated to sets on the basis of *dominant identifiers*, i.e. the soil-forming factors or processes that most clearly condition the soil formation. The sequencing of the groups is done according to the following principles:

1. First, organic soils key out to separate them from mineral soils (*Histosols*).

2. The second major distinction in the WRB is to recognize *human activity* as a soil-forming factor, hence the position of the *Anthrosols* and *Technosols* after the *Histosols*; it also appears logical to key out the newly-introduced Technosols close to the beginning of the Key, for the following reasons:
   - one can almost immediately key out soils that should not be touched (toxic soils that should be handled by experts);
   - a homogeneous group of soils in *strange materials* is obtained;
   - politicians and decision-makers who consult the Key will immediately encounter these problematic soils.
3. Next are the soils with a severe limitation to rooting *(Cryosols* and *Leptosols)*.
4. Then comes a group of RSGs that are or have been strongly influenced by water: *Vertisols*, *Fluvisols*, *Solonetz*, *Solonchaks*, and *Gleysols*.
5. The following set of soil groups are the RSGs in which iron (Fe) and/or aluminium (Al) chemistry plays a major role in their formation: *Andosols*, *Podzols*, *Plinthosols*, *Nitisols* and *Ferralsols*.

TABLE 1
Rationalized Key to the WRB Reference Soil Groups

1. Soils with thick organic layers:	Histosols
2. Soils with strong human influence	
Soils with long and intensive agricultural use:	Anthrosols
Soils containing many artefacts:	Technosols
3. Soils with limited rooting due to shallow permafrost or stoniness	
Ice-affected soils:	Cryosols
Shallow or extremely gravelly soils:	Leptosols
4. Soils influenced by water	
Alternating wet-dry conditions, rich in swelling clays:	Vertisols
Floodplains, tidal marshes:	Fluvisols
Alkaline soils:	Solonetz
Salt enrichment upon evaporation:	Solonchaks
Groundwater affected soils:	Gleysols
5. Soils set by Fe/Al chemistry	
Allophanes or Al-humus complexes:	Andosols
Cheluviation and chilluviation:	Podzols
Accumulation of Fe under hydromorphic conditions:	Plinthosols
Low-activity clay, P fixation, strongly structured:	Nitisols
Dominance of kaolinite and sesquioxides:	Ferralsols
6. Soils with stagnating water	
Abrupt textural discontinuity:	Planosols
Structural or moderate textural discontinuity:	Stagnosols
7. Accumulation of organic matter, high base status	
Typically mollic:	Chernozems
Transition to drier climate:	Kastanozems
Transition to more humid climate:	Phaeozems
8. Accumulation of less soluble salts or non-saline substances	
Gypsum:	Gypsisols
Silica:	Durisols
Calcium carbonate:	Calcisols
9. Soils with a clay-enriched subsoil	
Albeluvic tonguing:	Albeluvisols
Low base status, high-activity clay:	Alisols
Low base status, low-activity clay:	Acrisols
High base status, high-activity clay:	Luvisols
High base status, low-activity clay:	Lixisols
10. Relatively young soils or soils with little or no profile development	
With an acidic dark topsoil:	Umbrisols
Sandy soils:	Arenosols
Moderately developed soils:	Cambisols
Soils with no significant profile development:	Regosols

6. Next comes a set of soils with perched water: *Planosols* and *Stagnosols*.
7. The next grouping comprises soils that occur predominantly in steppe regions and have humus-rich topsoils and a high base saturation: *Chernozems*, *Kastanozems* and *Phaeozems*.
8. The next set comprises soils from the drier regions with accumulation of gypsum *(Gypsisols)*, silica *(Durisols)* or calcium carbonate *(Calcisols)*.
9. Then comes a set of soils with a clay-rich subsoil: *Albeluvisols*, *Alisols*, *Acrisols*, *Luvisols* and *Lixisols*.
10. Finally, relatively young soils or soils with very little or no profile development, or very homogenous sands, are grouped together: *Umbrisols*, *Arenosols*, *Cambisols* and *Regosols*.

The qualifier level

In the WRB, a distinction is made between typically associated qualifiers, intergrades and other qualifiers. ***Typically associated*** qualifiers are referred to in the Key to the particular RSGs, e.g. Hydragric or Plaggic for the Anthrosols. ***Intergrade*** qualifiers are those that reflect important diagnostic criteria of another RSG. The WRB Key will, in that case, dictate the choice of the RSG and the intergrade qualifier will provide the bridge to the other RSG. ***Other qualifiers*** are those not typically associated with an RSG and that do not link to other RSGs, e.g. Geric or Posic for Ferralsols. This group reflects characteristics such as colour, base status, and other chemical and physical properties provided that they are not used as a typically associated qualifier in that particular group.

Principles and use of the qualifiers in the WRB

A two-tier system is used for the qualifier level, comprising:

- **Prefix qualifiers:** *typically associated qualifiers* and *intergrade qualifiers*; the sequence of the intergrade qualifiers follows that of the RSGs in the WRB Key, with the exception of Arenosols; this intergrade is ranked with the textural suffix qualifiers (see below). Haplic closes the prefix qualifier list indicating that neither typically associated nor intergrade qualifiers apply.
- **Suffix qualifiers:** *other qualifiers*, sequenced as follows: (1) qualifiers related to diagnostic horizons, properties or materials; (2) qualifiers related to chemical characteristics; (3) qualifiers related to physical characteristics; (4) qualifiers related to mineralogical characteristics; (5) qualifiers related to surface characteristics; (6) qualifiers related to textural characteristics, including coarse fragments; (7) qualifiers related to colour; and (8) remaining qualifiers.
- Table 2 provides an example of the listing of prefix and suffix qualifiers.

Prefix qualifier names are always put before the RSG; **suffix qualifier** names are always placed between brackets following the RSG name. Combinations of qualifiers that indicate a similar status or duplicate each other are not permitted, such as combinations of Thionic and Dystric, Calcaric and Eutric, or Rhodic and Chromic.

TABLE 2
Prefix and suffix qualifiers in the WRB – case of Cryosols

Prefix qualifiers	Suffix qualifiers
Glacic	Gypsiric
Turbic	Calcaric
Folic	Ornithic*
Histic	Dystric
Technic	Eutric
Hyperskeletic	Reductaquic*
Leptic	Oxyaquic
Natric	Thixotropic
Salic	Aridic
Vitric	Skeletic
Spodic	Arenic
Mollic	Siltic
Calcic	Clayic*
Umbric	Drainic*
Cambic	Novic*
Haplic	

* = newly introduced qualifiers
Examples:
1. Histic Turbic Cryosol (Reductaquic, Dystric).
2. Haplic Cryosol (Aridic, Skeletic).

Specifiers such as Epi-, Endo-, Hyper-, Hypo-, Thapto-, Bathy-, Para-, Proto-, Cumuli- and Ortho- are used to indicate a certain expression of the qualifier.

When classifying a soil profile, all applying qualifiers of the listing must be recorded. For mapping purposes, the scale will determine the number of qualifiers used. In that case, prefix qualifiers have priority over the suffix qualifiers.

The qualifier listing for each RSG accommodates most cases. Where not listed qualifiers are needed, the cases should be documented and reported to the WRB Working Group.

The geographical dimension of WRB qualifiers – match to mapping scale

The WRB was not designed originally for mapping soils but its roots are in the Legend of the Soil Map of the World. Before the WRB came into existence, the FAO Legend was used for soil mapping at various scales, and rather successfully (e.g. soil mapping in Bangladesh, Botswana, Ethiopia, the European Union, Kenya, and the United Republic of Tanzania). Whether desirable or not, people are using the WRB as a tool for soil mapping (e.g. 1:1 000 000 scale Soil Map of Europe; 1:250 000 Soil Map of the Central Highlands of Viet Nam).

A basic principle in soil mapping is that the soil surveyor designs the legend of the map so as to best suit the purpose of the survey. If the WRB is designed to support small-scale mapping of the global soil landscapes, it would be advantageous to have a structure that lends itself to support such overview maps. Hence, the discussion on the qualifier listings should not be held in isolation of the overview maps of the soils of the world or the continents in the WRB. Therefore, it is suggested that the WRB qualifiers be linked to small-scale soil maps as follows:

- prefix qualifiers for mapping between $1/5*10^6$ and $1/10^6$ scale;
- suffix qualifiers for mapping between $1/10^6$ and $1/250*10^3$ scale.

For larger mapping scales, it is suggested that, in addition, national or local soil classification systems be used. They are designed to accommodate local soil variability, which can never be accounted for in a world reference base.

THE OBJECT CLASSIFIED IN THE WRB

Like many common words, the word soil has several meanings. In its traditional meaning, soil is the natural medium for the growth of plants, whether or not it has discernible soil horizons (Soil Survey Staff, 1999). In the 1998 WRB, soil was defined as:

"… a continuous natural body which has three spatial and one temporal dimension. The three main features governing soil are:

- It is formed by **mineral and organic constituents** and includes solid, liquid and gaseous phases.
- The constituents are organized in **structures**, specific for the pedological medium. These structures form the morphological aspect of the soil cover, equivalent to the anatomy of a living being. They result from the history of the soil cover and from its actual dynamics and properties. Study of the structures of the soil cover facilitates perception of the physical, chemical and biological properties; it permits understanding the past and present of the soil, and predicting its future.
- The soil is in **constant evolution**, thus giving the soil its fourth dimension, time."

Although there are good arguments to limit soil survey and mapping to identifiable stable soil areas with a certain thickness, the WRB has taken the more comprehensive approach to name any object forming part of the ***epiderm of the earth*** (Nachtergaele, 2005). This approach has a number of advantages, notably that it allows tackling environmental problems in a systematic and holistic way and avoids sterile discussions on a universally agreed definition of soil and its required thickness and stability. Therefore, the object classified in the WRB is: any material within 2 m from the Earth s surface that is in contact with the atmosphere, with the exclusion of living organisms, areas with continuous ice not covered by other material, and water bodies deeper than 2 m[1].

The definition includes continuous rock, paved urban soils, soils of industrial areas, cave soils as well as subaqueous soils. Soils under continuous rock, except those that occur in caves, are generally not considered for classification. In special cases, the WRB may be used to classify soils under rock, e.g. for palaeopedological reconstruction of the environment.

The lateral dimension of the object classified should be large enough to represent the nature of any horizon and variability that may be present. The minimum horizontal area may range from 1 to 10 m^2 depending on the variability of the soil cover.

RULES FOR CLASSIFICATION

Classification consists of three steps.

Step one

The expression, thickness and depth of layers are checked against the requirements of WRB diagnostic horizons, properties and materials, which are defined in terms of morphology and/or analytical criteria (Chapter 2). Where a layer fulfils the criteria of more than one diagnostic horizon, property or material, they are regarded as overlapping or coinciding.

Step two

The described combination of diagnostic horizons, properties and materials is compared with the WRB Key (Chapter 3) in order to find the RSG, which is the first level of WRB classification. The user should go through the Key systematically, starting at the beginning and excluding one by one all RSGs for which the specified requirements are not met. The soil belongs to the first RSG for which it meets all specified requirements.

Step three

For the second level of WRB classification, qualifiers are used. The qualifiers are listed in the Key with each RSG as prefix and suffix qualifiers. **Prefix qualifiers** comprise those that are **typically associated** to the RSG **and** the **intergrades** to other RSGs. All other qualifiers are listed as suffix qualifiers. For classification at the second level, all applying qualifiers have to be added to the name of the RSG. Redundant qualifiers (the characteristics of which are included in a previously set qualifier) are not added.

Specifiers can be used to indicate the degree of expression of qualifiers. Buried layers can be indicated by the Thapto- specifier, which can be used with any qualifier, listed in Chapter 5.

Where a soil is buried under new material, the following rules apply:

1. The overlying new material and the buried soil are classified as one soil if both together qualify as Histosol, Technosol, Cryosol, Leptosol, Vertisol, Fluvisol, Gleysol, Andosol, Planosol, Stagnosol or Arenosol.
2. Otherwise, the new material is classified at the first level if the new material is 50 cm or more thick or if the new material, if it stood alone, fits the requirements of a RSG other than a Regosol.
3. In all other cases, the buried soil is classified at the first level.

[1] In tidal areas, the depth of 2 m is to be applied at low tide.

4. If the overlying soil is classified at the first level, the buried soil is recognized with the Thapto- specifier and -ic added to the RSG name of the buried soil. The whole is placed in brackets after the name of the overlying soil, e.g. Technic Umbrisol (Greyic) (Thapto-Podzolic). If the buried soil is classified at the first level, the overlying material is indicated with the Novic qualifier.

It is recommended that the *Guidelines for Soil Description* (FAO, 2006) be used to describe the soil and its features. It is useful to list the occurrence and depth of diagnostic horizons, properties and materials identified.

The field classification provides a preliminary assessment using all observable or easily measurable properties and features of the soil and associated terrain. The final classification is made when analytical data are available. It is recommended that *Procedures for Soil Analysis* (Van Reeuwijk, 2006) is followed in determining chemical and physical characteristics. A summary of these is included in Annex 1.

Example of WRB soil classification

A soil has a ferralic horizon; texture in the upper part of the ferralic horizon changes from sandy loam to sandy clay within 15 cm. The pH is between 5.5 and 6, indicating moderate to high base saturation. The B horizon is dark red; below 50 cm, mottling occurs. The field classification of this soil is: **Lixic Ferralsol (Ferric, Rhodic)**. If subsequent laboratory analysis reveals that the cation exchange capacity (CEC) of the ferralic horizon is less than 4 $cmol_c$ kg^{-1} clay, the soil finally classifies as **Lixic Vetic Ferralsol (Ferric, Rhodic)**.

Chapter 2
Diagnostic horizons, properties and materials

Diagnostic horizons and *properties* are characterized by a combination of attributes that reflect widespread, common results of the processes of soil formation (Bridges, 1997) or indicate specific conditions of soil formation. Their features can be observed or measured, either in the field or in the laboratory, and require a minimum or maximum expression to qualify as diagnostic. In addition, diagnostic horizons require a certain thickness, thus forming a recognizable layer in the soil.

Diagnostic materials are materials that influence pedogenetic processes significantly.

DIAGNOSTIC HORIZONS

Albic horizon

General description

The albic horizon (from Latin *albus*, white) is a light-coloured subsurface horizon from which clay and free iron oxides have been removed, or in which the oxides have been segregated to the extent that the colour of the horizon is determined by the colour of the sand and silt particles rather than by coatings on these particles. It generally has a weakly expressed soil structure or lacks structural development altogether. The upper and lower boundaries are normally abrupt or clear. The morphology of the boundaries is variable and sometimes associated with *albeluvic tonguing*. Albic horizons usually have coarser textures than the overlying or underlying horizons. However, with respect to an underlying *spodic* horizon, this difference may only be slight. Many albic horizons are associated with wetness and contain evidence of *reducing conditions*.

Diagnostic criteria

An albic horizon has:

1. a Munsell colour (dry) with ***either***:
   a. a value of 7 or 8 and a chroma of 3 or less; ***or***
   b. a value of 5 or 6 and a chroma of 2 or less; ***and***
2. a Munsell colour (moist) with ***either***:
   a. a value of 6, 7 or 8 and a chroma of 4 or less; ***or***
   b. a value of 5 and a chroma of 3 or less; ***or***
   c. a value of 4 and a chroma of 2 or less[1]. A chroma of 3 is permitted if the parent materials have a hue of 5 YR or redder, and the chroma is due to the colour of uncoated silt or sand grains; ***and***
3. a thickness of 1 cm or more.

Field identification

Identification in the field depends on soil colours. In addition, a ×10 hand-lens may be used to ascertain that sand and silt grains are free of coatings.

[1] Colour requirements have been changed slightly with respect to those defined by FAO–UNESCO–ISRIC (FAO, 1988) and Soil Survey Staff (1999) in order to accommodate albic horizons with a considerable shift in chroma when wetted. Such albic horizons occur frequently in, for example, southern Africa.

Additional characteristics
The presence of coatings around sand and silt grains can be determined using an optical microscope for analysing thin sections. Uncoated grains usually show a very thin rim at their surface. Coatings may be of an organic nature, consist of iron oxides, or both, and are dark coloured under translucent light. Iron coatings become reddish in colour under reflected light, while organic coatings remain brownish-black.

Relationships with some other diagnostic horizons
Albic horizons are normally overlain by humus-enriched surface layers but may be at the surface as a result of erosion or artificial removal of the surface layer. They can be considered an extreme type of eluvial horizon, and usually occur in association with illuvial horizons such as an *argic*, *natric* or *spodic* horizon, which they overlie. In sandy materials, albic horizons can reach considerable thickness, up to several metres, especially in humid tropical regions, and associated diagnostic horizons may be hard to establish.

Anthraquic horizon

General description
An anthraquic horizon (from Greek *anthropos*, human, and Latin *aqua*, water) is a human-induced surface horizon that comprises a *puddled layer* and a *plough pan.*

Diagnostic criteria
An anthraquic horizon is a surface horizon and has:
1. a puddled layer with both:
   a. a Munsell hue of 7.5 YR or yellower, or GY, B or BG hues; value (moist) of 4 or less; chroma (moist) of 2 or less[1]; ***and***
   b. sorted soil aggregates and vesicular pores; ***and***
2. a plough pan underlying the puddled layer with all of the following:
   a. a platy structure; ***and***
   b. a bulk density higher by 20 percent or more (relative) than that of the puddled layer; ***and***
   c. yellowish-brown, brown or reddish-brown iron–manganese mottles or coatings; ***and***
3. a thickness of 20 cm or more.

Field identification
An anthraquic horizon shows evidence of reduction and oxidation owing to flooding for part of the year. When not flooded, it is very dispersible and has a loose packing of sorted small aggregates. The plough pan is compact, with platy structure and very slow infiltration. It has yellowish-brown, brown or reddish-brown rust mottles along cracks and root holes.

Anthric horizon

General description
An anthric horizon (from Greek *anthropos*, human) is a moderately thick, dark-coloured surface horizon that is the result of long-term cultivation (ploughing, liming, fertilization, etc.).

Diagnostic criteria
An anthric horizon[2] is a mineral surface horizon and:
1. meets all colour, structure and organic matter requirements of a *mollic* or *umbric* horizon; ***and***

[1] Colour requirements taken from the Chinese soil taxonomy (CRGCST, 2001).
[2] Modified after Krogh and Greve (1999).

2. shows evidence of human disturbance by having one or more of the following:
   a. an abrupt lower boundary at ploughing depth, a plough pan; ***or***
   b. lumps of applied lime; ***or***
   c. mixing of soil layers by cultivation; ***or***
   d. 1.5 g kg^{-1} or more P_2O_5 soluble in 1-percent citric acid; ***and***
3. has less than 5 percent (by volume) of animal pores, coprolites or other traces of soil animal activity below tillage depth; ***and***
4. has a thickness of 20 cm or more.

Field identification
Anthric horizons are associated with old arable lands that have been cultivated for centuries. Signs of mixing or cultivation, evidence of liming (e.g. remnants of applied lime chunks) and their dark colour are the main criteria for recognition.

Relationships with other horizons
Anthric horizons can resemble or overlap with *mollic* or *umbric* horizons. Anthric horizons may have developed from *umbric* horizons through human intervention. As they have been limed for a considerable period of time, their base saturation is high. This sets them apart from *umbric* horizons. The usually low biological activity below tillage depth is uncommon in soils with *mollic* horizons.

Argic horizon
General description
The argic horizon (from Latin *argilla*, white clay) is a subsurface horizon with distinct higher clay content than the overlying horizon. The textural differentiation may be caused by:
- an illuvial accumulation of clay;
- predominant pedogenetic formation of clay in the subsoil;
- destruction of clay in the surface horizon;
- selective surface erosion of clay;
- upward movement of coarser particles due to swelling and shrinking;
- biological activity;
- a combination of two or more of these different processes.

Sedimentation of surface materials that are coarser than the subsurface horizon may enhance a pedogenetic textural differentiation. However, a mere lithological discontinuity, such as may occur in alluvial deposits, does not qualify as an argic horizon.

Soils with argic horizons often have a specific set of morphological, physico-chemical and mineralogical properties other than a mere clay increase. These properties allow various types of argic horizons to be distinguished and their pathways of development to be traced (Sombroek, 1986).

Diagnostic criteria
An argic horizon:
1. has a texture of loamy sand or finer and 8 percent or more clay in the fine earth fraction; ***and***
2. one or both of the following:
   a. has, if an overlying coarser textured horizon is present that is not ploughed and not separated from the argic horizon by a *lithological discontinuity*, more total clay than this overlying horizon such that:
      i. if the overlying horizon has less than 15 percent clay in the fine earth fraction, the argic horizon must contain at least 3 percent more clay; ***or***

ii. if the overlying horizon has 15 percent or more but less than 40 percent clay in the fine earth fraction, the ratio of clay in the argic horizon to that of the overlying horizon must be 1.2 or more; ***or***

iii. if the overlying horizon has 40 percent or more total clay in the fine earth fraction, the argic horizon must contain at least 8 percent more clay; ***or***

b. has evidence of clay illuviation in one or more of the following forms:

i. oriented clay bridging the sand grains; ***or***

ii. clay films lining pores; ***or***

iii. clay films on both vertical and horizontal surfaces of soil aggregates; ***or***

iv. in thin section, oriented clay bodies that constitute 1 percent or more of the section; ***or***

v. a coefficient of linear extensibility (COLE) of 0.04 or higher, and a ratio of fine clay[1] to total clay in the argic horizon greater by 1.2 times or more than the ratio in the overlying coarser textured horizon; ***and***

3. has, if an overlying coarser textured horizon is present that is not ploughed and not separated from the argic horizon by a *lithological discontinuity*, an increase in clay content within a vertical distance of one of the following:
   a. 30 cm, if there is evidence of clay illuviation; ***or***
   b. 15 cm; ***and***
4. does not form part of a *natric* horizon; ***and***
5. has a thickness of one-tenth or more of the sum of the thicknesses of all overlying horizons, if present, and one of the following:
   a. 7.5 cm or more, if it is not entirely composed of lamellae (that are 0.5 cm or more thick) and the texture is finer than loamy sand; ***or***
   b. 15 cm or more (combined thickness, if composed entirely of lamellae that are 0.5 cm or more thick).

Field identification

Textural differentiation is the main feature for recognition of argic horizons. The illuvial nature may be established using an ×10 hand-lens if clay skins occur on ped surfaces, in fissures, in pores and in channels – illuvial argic horizon should show clay skins on at least 5 percent of both horizontal and vertical ped faces and in the pores.

Clay skins are often difficult to detect in shrink–swell soils. The presence of clay skins in protected positions, e.g. in pores, meets the requirements for an illuvial argic horizon.

Additional characteristics

The illuvial character of an argic horizon can best be established using thin sections. Diagnostic *illuvial* argic horizons must show areas with oriented clays that constitute on average at least 1 percent of the entire cross-section. Other tests involved are particle-size distribution analysis, to determine the increase in clay content over a specified depth, and the fine clay/total clay analysis. In illuvial argic horizons, the fine clay to total clay ratio is larger than in the overlying horizons, caused by preferential eluviation of fine clay particles.

If the soil shows a *lithological discontinuity* over or within the argic horizon, or if the surface horizon has been removed by erosion, or if only a plough layer overlies the argic horizon, the illuvial nature must be clearly established.

Relationships with some other diagnostic horizons

Argic horizons are normally associated with and situated below eluvial horizons, i.e. horizons from which clay and Fe have been removed. Although initially formed as a

[1] Fine clay: < 0.2 µm equivalent diameter.

subsurface horizon, argic horizons may occur at the surface as a result of erosion or removal of the overlying horizons.

Some clay-increase horizons may have the set of properties that characterize the *ferralic* horizon, i.e. a low CEC and effective CEC (ECEC), a low content of water-dispersible clay and a low content of weatherable minerals, all over a depth of 50 cm. In such cases, a *ferralic* horizon has preference over an argic horizon for classification purposes. However, an argic horizon prevails if it overlies a *ferralic* horizon and it has, in its upper part over a depth of 30 cm, 10 percent or more water-dispersible clay, unless the soil material has *geric* properties or more than 1.4 percent organic carbon.

Argic horizons lack the sodium saturation characteristics of the *natric* horizon.

Argic horizons in cool and moist, freely drained soils of high plateaus and mountains in tropical and subtropical regions may occur in association with *sombric* horizons.

Calcic horizon

General description

The calcic horizon (from Latin *calx*, lime) is a horizon in which secondary calcium carbonate ($CaCO_3$) has accumulated in a diffuse form (calcium carbonate present only in the form of fine particles of less than 1 mm, dispersed in the matrix) or as discontinuous concentrations (pseudomycelia, cutans, soft and hard nodules, or veins).

The accumulation may be in the parent material or in subsurface horizons, but it can also occur in surface horizons. If the accumulation of soft carbonates becomes such that all or most of the pedological and/or lithological structures disappear and continuous concentrations of calcium carbonate prevail, a hypercalcic qualifier is used.

Diagnostic criteria

A calcic horizon has:

1. a calcium carbonate equivalent in the fine earth fraction of 15 percent or more; ***and***
2. 5 percent or more (by volume) *secondary carbonates or* a calcium carbonate equivalent of 5 percent or more higher (absolute, by mass) than that of an underlying layer; ***and***
3. a thickness of 15 cm or more.

Field identification

Calcium carbonate can be identified in the field using a 10-percent hydrochloric acid (HCl) solution. The degree of effervescence (audible only, visible as individual bubbles, or foam-like) is an indication of the amount of lime present. This test is important if only diffuse distributions are present. When foam develops after adding 1 *M* HCl, it indicates a calcium carbonate equivalent near or more than 15 percent.

Other indications for the presence of a calcic horizon are:

- white, pinkish to reddish, or grey colours (if not overlapping horizons rich in organic carbon);
- a low porosity (interaggregate porosity is usually less than that in the horizon immediately above and, possibly, also less than in the horizon directly underneath).

Calcium carbonate content may decrease with depth, but this is difficult to establish in some places, particularly where the calcic horizon occurs in the deeper subsoil. Therefore, accumulation of secondary lime is sufficient to diagnose a calcic horizon.

Additional characteristics

Determination of the amount of calcium carbonate (by mass) and the changes within the soil profile of the calcium carbonate content are the main analytical criteria for establishing the presence of a calcic horizon. Determination of the pH (H_2O) enables distinction between accumulations with a basic (*calcic*) character (pH 8.0–8.7) due to the dominance of $CaCO_3$, and those with an ultrabasic (*non-calcic*) character (pH > 8.7) because of the presence of $MgCO_3$ or Na_2CO_3.

In addition, microscopical analysis of thin sections may reveal the presence of dissolution forms in horizons above or below a calcic horizon, evidence of silicate epigenesis (calcite pseudomorphs after quartz), or the presence of other calcium carbonate accumulation structures, while clay mineralogical analyses of calcic horizons often show clays characteristic of confined environments, such as smectite, palygorskite and sepiolite.

Relationships with some other diagnostic horizons

When calcic horizons become indurated, transition takes place to the *petrocalcic* horizon, the expression of which may be massive or platy.

In dry regions and in the presence of sulphate-bearing soil or groundwater solutions, calcic horizons occur associated with *gypsic* horizons. Calcic and *gypsic* horizons typically (but not everywhere) occupy different positions in the soil profile because of the difference in solubility of calcium carbonate and gypsum, and they can normally be distinguished clearly from each other by the difference in morphology. Gypsum crystals tend to be needle-shaped, often visible to the naked eye, whereas pedogenetic calcium carbonate crystals are much finer in size.

Cambic horizon

General description

The cambic horizon (from Italian *cambiare*, to change) is a subsurface horizon showing evidence of alteration relative to the underlying horizons.

Diagnostic criteria

A cambic horizon:

1. has a texture in the fine earth fraction of very fine sand, loamy very fine sand[1], or finer; ***and***
2. has soil structure ***or*** absence of rock structure[2] in half or more of the volume of the fine earth; ***and***
3. shows evidence of alteration in one or more of the following:
   a. higher Munsell chroma (moist), higher value (moist), redder hue, or higher clay content than the underlying or an overlying layer; ***or***
   b. evidence of removal of carbonates[3] or gypsum; ***or***
   c. presence of soil structure ***and*** absence of rock structure in the entire fine earth, if carbonates and gypsum are absent in the parent material and in the dust that falls on the soil; ***and***
4. does not form part of a plough layer, does not consist of *organic* material and does not form part of an *anthraquic, argic, calcic, duric, ferralic, fragic, gypsic, hortic, hydragric, irragric, mollic, natric, nitic, petrocalcic, petroduric, petrogypsic, petroplinthic, pisolithic, plaggic, plinthic, salic, sombric, spodic, umbric, terric* or *vertic* horizon; **and**
5. has a thickness of 15 cm or more.

[1] *Very fine sand* and *loamy very fine sand*: 50 percent or more of the fraction between 63 and 125 µm.

[2] The term rock structure also applies to unconsolidated sediments in which stratification s still visible.

[3] A cambic horizon always has less carbonate than an underlying horizon with calcium carbonate accumulation. However, not all primary carbonates have to be leached from a horizon in order for it to qualify as a cambic horizon. If all coarse fragments in the underlying horizon are completely coated with lime, some of these fragments in the cambic horizon are partly free of coatings. If the coarse fragments in the horizon showing calcium carbonate accumulation are coated only on the underside, those in the cambic horizon are free of coatings.

Relationships with some other diagnostic horizons

The cambic horizon can be considered the predecessor of many other diagnostic horizons. All these horizons have specific properties, such as illuvial or residual accumulations, removal of substances other than carbonates or gypsum, accumulation of soluble components, or development of specific soil structure, that are not recognized in the cambic horizon.

Cambic horizons in cool and moist, freely drained soils of high plateaus and mountains in tropical and subtropical regions may occur in association with *sombric* horizons.

Cryic horizon

General description

The cryic horizon (from Greek *kryos*, cold, ice) is a perennially frozen soil horizon in *mineral* or *organic* materials.

Diagnostic criteria

A cryic horizon has:

1. continuously for two or more consecutive years one of the following:
   a. massive ice, cementation by ice or readily visible ice crystals; ***or***
   b. a soil temperature of 0 °C or less and insufficient water to form readily visible ice crystals; ***and***
2. a thickness of 5 cm or more.

Field identification

Cryic horizons occur in areas with permafrost[1] and show evidence of perennial ice segregation, often associated with evidence of cryogenic processes (mixed soil material, disrupted soil horizons, involutions, organic intrusions, frost heave, separation of coarse from fine soil materials, cracks, patterned surface features, such as earth hummocks, frost mounds, stone circles, stripes, nets and polygons) above the cryic horizon or at the soil surface.

Soils that contain saline water do not freeze at 0 °C. In order to develop a cryic horizon, such soils must be cold enough to freeze.

To identify features of cryoturbation, sorting or thermal contraction, a soil profile should intersect different elements of patterned ground, if any, or be wider than 2 m.

Engineers distinguish between *warm* and *cold* permafrost. *Warm* permafrost has a temperature higher than -2 °C and has to be considered unstable. *Cold* permafrost has a temperature of -2 °C or lower and can be used more safely for construction purposes provided the temperature remains under control.

Relationships with some other diagnostic horizons

Cryic horizons may bear characteristics of *histic*, *andic* or *spodic* horizons, and may occur in association with *salic*, *calcic*, *mollic* or *umbric* horizons. In cold arid regions, *yermic* horizons may be found in association with cryic horizons.

Duric horizon

General description

The duric horizon (from Latin *durus*, hard) is a subsurface horizon showing weakly cemented to indurated nodules or concretions cemented by silica (SiO_2), presumably in the form of opal and microcrystalline forms of silica (*durinodes*). Durinodes often have

[1] Permafrost: layer of soil or rock, at some depth beneath the surface, in which the temperature has been continuously below 0 °C for at least some years. It exists where summer heating fails to reach the base of the layer of frozen ground. Arctic Climatology and Meteorology Glossary, National Snow and Ice Data Center, Boulder, USA (*http://nsidc.org*).

carbonate coatings that have to be removed with HCl before slaking the durinodes with potassium hydroxide (KOH).

Diagnostic criteria
A duric horizon has:

1. 10 percent or more (by volume) of weakly cemented to indurated, silica-enriched nodules (durinodes) or fragments of a broken-up *petroduric* horizon that show all of the following:
   a. when air-dry, less than 50 percent slake in 1 *M* HCl even after prolonged soaking, but 50 percent or more slake in concentrated KOH, concentrated NaOH or in alternating acid and alkali; ***and***
   b. are firm or very firm and brittle when wet, both before and after treatment with acid; ***and***
   c. have a diameter of 1 cm or more; ***and***
2. a thickness of 10 cm or more.

Additional characteristics
Dry durinodes do not slake appreciably in water, but prolonged soaking can result in the breaking-off of very thin platelets and in some slaking. In cross-section, most durinodes are roughly concentric, and concentric stringers of opal may be visible under a hand-lens.

Relationships with some other diagnostic horizons
In arid regions, duric horizons occur associated with *gypsic*, *petrogypsic*, *calcic* and *petrocalcic* horizons. In more humid climates, the duric horizon may grade into *fragic* horizons.

Ferralic horizon

General description
The ferralic horizon (from Latin *ferrum*, iron, and *alumen*, alum) is a subsurface horizon resulting from long and intense weathering in which the clay fraction is dominated by low-activity clays and the silt and sand fractions by highly resistant minerals, such as (hydr)oxides of Fe, Al, Mn and titanium (Ti).

Diagnostic criteria
A ferralic horizon:

1. has a sandy loam or finer particle size and less than 80 percent (by volume) gravel, stones, pisoplinthic nodules or petroplinthic gravel; ***and***
2. has a CEC (by 1 *M* NH_4OAc) of less than 16 $cmol_c\ kg^{-1}$ clay[1] and an ECEC (sum of exchangeable bases plus exchangeable acidity in 1 *M* KCl) of less than 12 $cmol_c\ kg^{-1}$ clay; ***and***
3. has less than 10 percent water-dispersible clay, unless it has one or both of the following:
   a. *geric* properties; ***or***
   b. 1.4 percent or more organic carbon; ***and***
4. has less than 10 percent (by grain count) weatherable minerals[2] in the 0.05–0.2 mm fraction; ***and***

[1] See Annex 1.
[2] Examples of minerals that are included in the meaning of *weatherable minerals* are all 2:1 phyllosilicates, chlorite, sepiolites, palygorskite, allophane, 1:1 trioctahedral phyllosilicates (serpentines), feldspars, feldspathoids, ferromagnesian minerals, glass, zeolites, dolomite and apatite. The intent of the term *weatherable minerals* is to include those minerals that are unstable in humid climates compared with other minerals, such as quartz and 1:1 lattice clays, but that are more resistant to weathering than calcite (Soil Survey Staff 2003).

5. does not have *andic* or *vitric* properties; ***and***
6. has a thickness of 30 cm or more.

Field identification

Ferralic horizons are associated with old and stable landforms. The macrostructure seems to be moderate to weak at first sight but typical ferralic horizons have a strong microaggregation. The consistence is usually friable; the disrupted, dry soil material flows like flour between the fingers. Lumps of ferralic horizons are usually relatively light in mass because of the low bulk density; many ferralic horizons give a hollow sound when tapped, indicating high porosity.

Illuviation and stress features such as clay skins and pressure faces are generally lacking. Boundaries of a ferralic horizon are normally diffuse and little differentiation in colour or particle-size distribution within the horizon can be detected. Texture is sandy loam or finer in the fine earth fraction; gravel, stones, pisoplinthic nodules or petroplinthic gravel comprise less than 80 percent (by volume).

Additional characteristics

As an alternative to the weatherable minerals requirement, a total reserve of bases (TRB = exchangeable plus mineral calcium [Ca], magnesium [Mg], potassium [K] and sodium [Na]) of less than 25 $cmol_c$ kg^{-1} soil may be indicative.

Relationships with some other diagnostic horizons

Ferralic horizons may meet the clay increase requirements that characterize the *argic* horizon. If the upper 30 cm of the horizon showing a clay increase contains 10 percent or more water-dispersible clay, an *argic* horizon has preference over a ferralic horizon for classification purposes, unless the soil material has *geric* properties or more than 1.4 percent organic carbon.

Acid ammonium oxalate (pH 3) extractable Fe, Al and silicon (Al_{ox}, Fe_{ox}, Si_{ox}) in ferralic horizons are very low, which sets them apart from the *nitic* horizons and layers with *andic* or *vitric* properties. *Nitic* horizons have a significant amount of active iron oxides: more than 0.2 percent acid oxalate (pH 3) extractable Fe from the fine earth fraction which, in addition, is more than 5 percent of the citrate-dithionite extractable Fe. *Vitric* properties require an $Al_{ox} + ½Fe_{ox}$ content of at least 0.4 percent, and *andic* properties at least 2 percent.

The interface with the *cambic* horizon is formed by the CEC/ECEC/weatherable mineral requirements. Some *cambic* horizons have a low CEC; however, the amount of weatherable minerals (or, alternatively, the TRB) is too high for a ferralic horizon. Such horizons represent an advanced stage of weathering and form the transition between the *cambic* and the ferralic horizon.

Ferralic horizons in cool and moist, freely drained soils of high plateaus and mountains in tropical and subtropical regions may occur in association with *sombric* horizons.

Ferric horizon

General description

The ferric horizon (from Latin *ferrum*, iron) is one in which segregation of Fe, or Fe and manganese (Mn), has taken place to such an extent that large mottles or discrete nodules have formed and the intermottle/internodular matrix is largely depleted of Fe. Generally, such segregation leads to poor aggregation of the soil particles in Fe-depleted zones and compaction of the horizon.

Diagnostic criteria

A ferric horizon has:

1. one or both of the following:
   a. 15 percent or more of the exposed area occupied by coarse mottles with a Munsell hue redder than 7.5 YR and a chroma of more than 5, moist; ***or***
   b. 5 percent or more of the volume consisting of discrete reddish to blackish nodules with a diameter of 2 mm or more, with at least the exteriors of the nodules being at least weakly cemented or indurated and the exteriors having redder hue or stronger chroma than the interiors; ***and***
2. less than 40 percent of the volume consisting of strongly cemented or indurated nodules and an absence of continuous, fractured or broken sheets; ***and***
3. less than 15 percent consisting of firm to weakly cemented nodules or mottles that change irreversibly to strongly cemented or indurated nodules or mottles on exposure to repeated wetting and drying with free access of oxygen; ***and***
4. a thickness of 15 cm or more.

Relationships with some other diagnostic horizons
If the amount of weakly-cemented nodules or mottles reaches 15 percent or more (by volume) and these harden irreversibly to hard nodules or a hardpan or to irregular aggregates on exposure to repeated wetting and drying with free access of oxygen, the horizon is considered to be a *plinthic* horizon. Therefore, ferric horizons may, in tropical or subtropical regions, grade laterally into *plinthic* horizons. If the amount of hard nodules reaches 40 percent or more, it is a *pisoplinthic* horizon.

Folic horizon
General description
The folic horizon (from Latin *folium*, leaf) is a surface horizon, or a subsurface horizon occurring at shallow depth, that consists of well-aerated *organic* material.

Diagnostic criteria
A folic horizon consists of *organic* material that:
a. is saturated with water for less than 30 consecutive days in most years; ***and***
b. has a thickness of 10 cm or more.

Relationships with some other diagnostic horizons
Histic horizons have similar characteristics to the *folic* horizon; however, these are saturated with water for one month or more in most years. Moreover, the composition of the *histic* horizon is generally different from that of the folic horizon as the vegetative cover is often different.

Fragic horizon
General description
The fragic horizon (from Latin *frangere*, to break) is a natural non-cemented subsurface horizon with pedality and a porosity pattern such that roots and percolating water penetrate the soil only along interped faces and streaks. The natural character excludes plough pans and surface traffic pans.

Diagnostic criteria
A fragic horizon:
1. shows evidence of alteration[1], at least on the faces of structural units; separations between these units, which allow roots to enter, have an average horizontal spacing of 10 cm or more; ***and***
2. contains less than 0.5 percent (by mass) organic carbon; ***and***

[1] As defined in the cambic horizon.

3. shows in 50 percent or more of the volume slaking or fracturing of air-dry clods, 5–10 cm in diameter, within 10 minutes when placed in water; ***and***
4. does not cement upon repeated wetting and drying; ***and***
5. has a penetration resistance at field capacity of 50 kPa or more in 90 percent or more of the volume; ***and***
6. does not show effervescence after adding a 10-percent HCl solution; ***and***
7. has a thickness of 15 cm or more.

Field identification

A fragic horizon has a prismatic and/or blocky structure. The inner parts of the prisms may have a relatively high total porosity (including pores larger than 200 mm) but, as a result of a dense outer rim, there is no continuity between the intraped pores and the interped pores and fissures. The result is a closed box system with 90 percent or more of the soil volume that cannot be explored by roots and is isolated from percolating water.

It is essential that the required soil volume be measured from both vertical and horizontal sections; horizontal sections often reveal polygonal structures. Three or four such polygons (or a cut up to 1 m^2) are sufficient to test the volumetric basis for the definition of the fragic horizon.

The ped interface can have the colour, mineralogical and chemical characteristics of an eluvial or *albic horizon*, or meet the requirements of *albeluvic tonguing*. In the presence of a fluctuating water table, this part of the soil is depleted of Fe and Mn. A concomitant Fe accumulation is observed at the level of the ped surface and Mn accumulations will occur further inside the peds (*stagnic colour pattern*).

Fragic horizons are commonly loamy, but loamy sand and clay textures are not excluded. In the latter case, the clay mineralogy is dominantly kaolinitic.

Dry clods are hard to extremely hard; moist clods are firm to extremely firm; moist consistence may be brittle. A ped or clod from a fragic horizon tends to rupture suddenly under pressure rather than to undergo slow deformation.

The fragic horizon has little active faunal activity except, occasionally, between the polygons.

Relationships with some other diagnostic horizons

A fragic horizon may underlie, although not necessarily directly, an *albic*, *cambic*, *spodic* or *argic* horizon, unless the soil has been truncated. It can overlap partly or completely with an *argic* horizon. Laterally, fragic horizons may grade into *(petro-) duric* horizons in dry regions. Moreover, fragic horizons can have *reducing conditions* and a *stagnic colour pattern*.

Fulvic horizon

General description

The fulvic horizon (from Latin *fulvus*, dark yellow) is a thick, dark-brown horizon at or near to the surface that is typically associated with short-range-order minerals (commonly allophane) or with organo-aluminium complexes. It has a low bulk density and contains highly humified organic matter that shows a lower ratio of humic acids to fulvic acids compared with the melanic horizon.

Diagnostic criteria

A fulvic horizon has:

1. *andic* properties; ***and***
2. one or both of the following:
   a. Munsell colour value or chroma (moist) of more than 2; ***or***

b. melanic index[1] of 1.70 or more; ***and***

3. a weighted average of 6 percent or more organic carbon, and 4 percent or more organic carbon in all parts; ***and***
4. a cumulative thickness of 30 cm or more with less than 10 cm non-fulvic material in between.

Field identification

When dark brown, the fulvic horizon is easily identifiable by its colour, thickness, as well as its typical, although not exclusive[2], association with pyroclastic deposits. Distinction between the blackish coloured *fulvic* and *melanic* horizons is made after determining the melanic index, which requires laboratory analyses.

Gypsic horizon

General description

The gypsic horizon (from Greek *gypsos*) is a commonly non-cemented horizon containing secondary accumulations of gypsum ($CaSO_4.2H_2O$) in various forms. If the accumulation of gypsum becomes such that all or most of the pedological and/or lithological structures disappear and continuous concentrations of gypsum prevail, a hypergypsic qualifier is used.

Diagnostic criteria

A gypsic horizon has:

1. 5 percent[3] or more gypsum and 1 percent or more (by volume) of visible secondary gypsum; ***and***
2. a product of thickness (in centimetres) times gypsum content (percentage) of 150 or more; ***and***
3. a thickness of 15 cm or more.

Field identification

Gypsum occurs as pseudomycelia, as coarse crystals, as nests, beards or coatings, as elongated groupings of fibrous crystals, or as powdery accumulations. The last form gives the gypsic horizon a massive structure. The distinction between compact powdery accumulations and the others is important in terms of soil capability.

Gypsum crystals may be mistaken for quartz. Gypsum is soft and can easily be broken between thumbnail and forefinger. Quartz is hard and cannot be broken except by hammering.

Gypsic horizons may be associated with *calcic* horizons but usually occur in separate positions within the soil profile, because of the higher solubility of gypsum compared with lime.

Additional characteristics

Determination of the amount of gypsum in the soil to verify the required content and increase, as well as thin section analysis, is helpful to establish the presence of a gypsic horizon and the distribution of the gypsum in the soil mass.

Relationships with some other diagnostic horizons

When gypsic horizons become indurated, transition takes place to the *petrogypsic* horizon, the expression of which may be as massive or platy structures.

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[1] See Annex 1.

[2] Fulvic horizons may also be found in aluandic-type of soils derived from other material than pyroclastics.

[3] The percentage gypsum is calculated as the product of gypsum content, expressed as $cmol_c\ kg^{-1}$ soil, and the equivalent mass of gypsum (86) expressed as a percentage.

In dry regions, gypsic horizons are associated with *calcic* or *salic* horizons. *Calcic* and gypsic horizons usually occupy distinct positions in the soil profile as the solubility of calcium carbonate is different from that of gypsum. They normally can be distinguished clearly from each other by the morphology (see *calcic* horizon). *Salic* and gypsic horizons also occupy different positions for the same reasons.

Histic horizon

General description

The histic horizon (from Greek *histos*, tissue) is a surface horizon, or a subsurface horizon occurring at shallow depth, that consists of poorly aerated *organic* material.

Diagnostic criteria

A histic horizon consists of *organic* material that:

1. is saturated with water for 30 consecutive days or more in most years (unless drained); ***and***
2. has a thickness of 10 cm or more. If the layer with *organic* material is less than 20 cm thick, the upper 20 cm of the soil after mixing, or if continuous rock is present within 20 cm depth, the entire soil above after mixing, must contain 20 percent or more organic carbon.

Relationships with some other diagnostic horizons

The *folic* horizon has similar characteristics to the histic horizon; however, the *folic* horizon is saturated with water for less than one month in most years. Moreover, the composition of the histic horizon is generally different from that of the *folic* horizon as the vegetative cover is often different.

The lower limit of organic carbon content, varying from 12 percent (20 percent organic matter) to 18 percent organic carbon (30 percent organic matter), sets the histic horizon apart from *mollic* or *umbric* horizons, which have these contents as upper limits.

Histic horizons with less than 25 percent organic carbon may have *andic* or *vitric* properties.

Hortic horizon

General description

A hortic horizon (from Latin *hortus*, garden) is a human-induced mineral surface horizon that results from deep cultivation, intensive fertilization and/or long-continued application of human and animal wastes and other organic residues (e.g. manures, kitchen refuse, compost and night soil).

Diagnostic criteria

A hortic horizon is a mineral surface horizon and has:

1. a Munsell colour value and chroma (moist) of 3 or less; ***and***
2. a weighted average organic carbon content of 1 percent or more; **and**
3. a 0.5 *M* $NaHCO_3$[1] extractable P_2O_5 content of 100 mg kg^{-1} fine earth or more in the upper 25 cm[2]; ***and***
4. a base saturation (by 1 *M* NH_4OAc) of 50 percent or more; ***and***
5. 25 percent (by volume) or more of animal pores, coprolites or other traces of soil animal activity; ***and***
6. a thickness of 20 cm or more.

[1] Known as the Olsen routine method (Olsen *et al.*, 1954).

[2] Gong *et al.*, 1997.

Field identification
The hortic horizon is thoroughly mixed. Potsherds and other artefacts are common although often abraded. Tillage marks or evidence of mixing of the soil can be present.

Relationships with some other diagnostic horizons
Hortic horizons closely resemble *mollic* horizons. Therefore, the human influence must be clearly established in order to separate the two diagnostic horizons.

Hydragric horizon

General description
A hydragric horizon (from Greek *hydor*, water, and Latin *ager*, field) is a human-induced subsurface horizon associated with wet cultivation.

Diagnostic criteria
A hydragric horizon is associated with wet cultivation and has:
1. one or more of the following:
   a. Fe or Mn coatings or Fe or Mn concretions; ***or***
   b. dithionite-citrate extractable Fe 2 times or more, or dithionite-citrate extractable Mn 4 times or more that of the surface horizon; ***or***
   c. redox depleted zones with a Munsell colour value 4 or more and a chroma of 2 or less (both moist) in macropores; ***and***
2. a thickness of 10 cm or more.

Field identification
The hydragric horizon occurs below the puddled layer and the plough pan. It has either reduction features in pores, such as coatings or halos with a colour hue of 2.5 Y or yellower and a chroma (moist) of 2 or less, or segregations of Fe and/or Mn in the matrix as a result of the oxidative environment. It usually shows grey clay-fine silt and clay-silt-humus cutans on ped faces.

Irragric horizon

General description
The irragric horizon (from Latin *irrigare*, to irrigate, and *ager*, field) is a human-induced mineral surface horizon that builds up gradually through continuous application of irrigation water with substantial amounts of sediments, and which may include fertilizers, soluble salts, organic matter, etc.

Diagnostic criteria
An irragric horizon is a mineral surface horizon and has:
1. a uniformly structured surface layer; ***and***
2. a higher clay content, particularly fine clay, than the underlying original soil; ***and***
3. relative differences among medium, fine and very fine sand, clay and carbonates less than 20 percent among parts within the horizon; ***and***
4. a weighted average organic carbon content of 0.5 percent or more, decreasing with depth but remaining at 0.3 percent or more at the lower limit of the irragric horizon; ***and***
5. 25 percent (by volume) or more of animal pores, coprolites or other traces of soil animal activity; ***and***
6. a thickness of 20 cm or more.

Field identification

Soils with an irragric horizon show evidence of surface raising, which may be inferred either from field observation or from historical records. The irragric horizon shows evidence of considerable biological activity. The lower boundary is clear and irrigation deposits or buried soils may be present below.

Relationships with some other diagnostic horizons

Irragric horizons differ from *fluvic* materials in lacking evidence of stratification owing to continuous ploughing.

Melanic horizon

General description

The melanic horizon (from Greek *melas*, black) is a thick, black horizon at or near the surface, which is typically associated with short-range-order minerals (commonly allophane) or with organo-aluminium complexes. It has a low bulk density and contains highly humified organic matter that shows a lower ratio of fulvic acids to humic acids compared with the fulvic horizon.

Diagnostic criteria

A melanic horizon has:

1. *andic* properties; ***and***
2. a Munsell colour value and chroma (both moist) of 2 or less, ***and***
3. a melanic index[1] of less than 1.70; ***and***
4. a weighted average of 6 percent or more organic carbon, and 4 percent or more organic carbon in all parts; ***and***
5. a cumulative thickness of 30 cm or more with less than 10 cm *non-melanic* material in between.

Field identification

The intense dark colour, its thickness, as well as its common association with pyroclastic deposits help to recognize the melanic horizon in the field. However, laboratory analyses to determine the type of organic matter may be necessary to identify the melanic horizon unambiguously.

Mollic horizon

General description

The mollic horizon (from Latin *mollis*, soft) is a well-structured, dark-coloured surface horizon with a high base saturation and a moderate to high content of organic matter.

Diagnostic criteria

A mollic horizon, after mixing either the upper 20 cm of the mineral soil or, if *continuous rock*, a *cryic*, *petrocalcic*, *petroduric*, *petrogypsic* or *petroplinthic* horizon is present within 20 cm of the mineral soil surface, the entire mineral soil above, has:

1. a soil structure sufficiently strong that the horizon is not both massive and hard or very hard when dry in both the mixed part and the underlying unmixed part if the minimum thickness is larger than 20 cm (prisms larger than 30 cm in diameter are included in the meaning of massive if there is no secondary structure within the prisms); ***and***
2. Munsell colours with a chroma of 3 or less when moist, a value of 3 or less when moist and 5 or less when dry on broken samples in both the mixed part and the underlying unmixed part if the minimum thickness is greater than 20 cm. If

[1] See Annex 1.

there is 40 percent or more finely divided lime, the limits of dry colour value are waived; the colour value, moist, is 5 or less. The colour value is one unit or more darker than that of the parent material (both moist and dry), unless the parent material has a colour value of 4 or less, moist, in which case the colour contrast requirement is waived. If a parent material is not present, comparison must be made with the layer immediately underlying the surface layer; ***and***

3. an organic carbon content of 0.6 percent or more in both the mixed part and the underlying unmixed part if the minimum thickness is larger than 20 cm. The organic carbon content is 2.5 percent or more if the colour requirements are waived because of finely divided lime, or 0.6 percent more than in the parent material if the colour requirements are waived because of dark coloured parent materials; ***and***
4. a base saturation (by 1 *M* NH_4OAc) of 50 percent or more on a weighted average throughout the depth of the horizon; ***and***
5. a thickness of one of the following:
   a. 10 cm or more if directly overlying continuous rock, or a cryic, petrocalcic, petroduric, petrogypsic or petroplinthic horizon; ***or***
   b. 20 cm or more and one-third or more of the thickness between the soil surface and the upper boundary of continuous rock, or a calcic, cryic, gypsic, petrocalcic, petroduric, petrogypsic, petroplinthic or salic horizon or calcaric, fluvic or gypsyric material within 75 cm; ***or***
   c. 20 cm or more and one-third or more of the thickness between the soil surface and the lower boundary of the lowest diagnostic horizon within 75 cm and, if present, above any of the diagnostic horizons listed under b.; ***or***
   d. 25 cm or more.

Field identification

A mollic horizon may easily be identified by its dark colour, caused by the accumulation of organic matter, well-developed structure (usually a granular or fine subangular blocky structure), an indication of high base saturation (e.g. $pH_{water} > 6$), and its thickness.

Relationships with some other diagnostic horizons

The base saturation of 50 percent separates the mollic horizon from the *umbric* horizon, which is otherwise similar. The upper limit of organic carbon content varies from 12 percent (20 percent organic matter) to 18 percent organic carbon (30 percent organic matter), which is the lower limit for the *histic* horizon, or 20 percent, the lower limit for a *folic* horizon.

A special type of mollic horizon is the *voronic* horizon. It has a higher organic carbon content (1.5 percent or more), a specific structure (granular or fine subangular blocky), a very dark colour in its upper part, a high biological activity, and a minimum thickness of 35 cm.

Natric horizon

General description

The natric horizon (from Arabic *natroon*, salt) is a dense subsurface horizon with distinct higher clay content than the overlying horizon or horizons. It has a high content in exchangeable Na and/or Mg.

Diagnostic criteria

A natric horizon:

1. has a texture of loamy sand or finer and 8 percent or more clay in the fine earth fraction; ***and***

2. one or both of the following:
   a. has, if an overlying coarser textured horizon is present that is not ploughed and not separated from the natric horizon by a *lithological discontinuity*, more clay than this overlying horizon such that:
      i. if the overlying horizon has less than 15 percent clay in the fine earth fraction, the natric horizon must contain at least 3 percent more clay; ***or***
      ii. if the overlying horizon has 15 percent or more and less than 40 percent clay in the fine earth fraction, the ratio of clay in the natric horizon to that of the overlying horizon must be 1.2 or more; ***or***
      iii. if the overlying horizon has 40 percent or more clay in the fine earth fraction, the natric horizon must contain at least 8 percent more clay; ***or***
   b. has evidence of clay illuviation in one or more of the following forms:
      i. oriented clay bridging the sand grains; ***or***
      ii. clay films lining pores; ***or***
      iii. clay films on both vertical and horizontal surfaces of soil aggregates; ***or***
      iv. in thin sections, oriented clay bodies that constitute 1 percent or more of the section; ***or***
      v. a COLE of 0.04 or higher, and a ratio of fine clay[1] to total clay in the natric horizon greater by 1.2 times or more than the ratio in the overlying coarser textured horizon; ***and***
3. has, if an overlying coarser textured horizon is present that is not ploughed and not separated from the natric horizon by a *lithological discontinuity*, an increase in clay content within a vertical distance of 30 cm; ***and***
4. has one or more of the following:
   a. a columnar or prismatic structure in some part of the horizon; ***or***
   b. a blocky structure with tongues of an overlying coarser textured horizon in which there are uncoated silt or sand grains, extending 2.5 cm or more into the natric horizon; ***or***
   c. a massive appearance; ***and***
5. has an exchangeable Na percentage (ESP[2]) of 15 or more within the upper 40 cm, or more exchangeable Mg plus Na than Ca plus exchange acidity (at pH 8.2) within the same depth if the saturation with exchangeable Na is 15 percent or more in some subhorizon within 200 cm of the soil surface; ***and***
6. has a thickness of one-tenth or more of the sum of the thicknesses of all overlying horizons, if present, and one of the following:
   a. 7.5 cm or more, if it is not entirely composed of lamellae (that are 0.5 cm or more thick) and the texture is finer than loamy sand; ***or***
   b. 15 cm or more (combined thickness, if composed entirely of lamellae that are 0.5 cm or more thick).

Field identification

The colour of the natric horizon ranges from brown to black, especially in the upper part. The structure is coarse columnar or prismatic, sometimes blocky or massive. Rounded and often whitish tops of the structural elements are characteristic.

Both colour and structural characteristics depend on the composition of the exchangeable cations and the soluble salt content in the underlying layers. Often, thick and dark-coloured clay coatings occur, especially in the upper part of the horizon. Natric horizons have a poor aggregate stability and very low permeability under wet conditions. When dry, the natric horizon becomes hard to extremely hard. Soil reaction is strongly alkaline; pH (H_2O) is more than 8.5.

[1] Fine clay: < 0.2 µm equivalent diameter.
[2] ESP = exchangeable Na × 100/CEC (at pH 7).

Additional characteristics

Natric horizons are characterized by a high pH (H_2O), which is frequently more than 9.0. Another measure to characterize the natric horizon is the sodium adsorption ratio (SAR), which has to be 13 or more. The SAR is calculated from soil solution data (Na^+, Ca^{2+}, Mg^{2+} given in $mmol_c$/litre): $SAR = Na^+/[(Ca^{2+} + Mg^{2+})/2]^{0.5}$.

Micromorphologically, natric horizons show a specific fabric. The peptized plasma shows a strong orientation in a mosaic or parallel-striated pattern. The plasma separations also show a high content in associated humus. Microcrusts, cutans, papules and infillings appear when the natric horizon is impermeable.

Relationships with some other diagnostic horizons

A surface horizon usually rich in organic matter overlies the natric horizon. This horizon of humus accumulation varies in thickness from a few centimetres to more than 25 cm, and may be a *mollic* horizon. An *albic* horizon may be present between the surface and the natric horizon.

Frequently, a salt-affected layer occurs below the natric horizon. The salt influence may extend into the natric horizon, which besides being sodic then also becomes saline. Salts present may be chlorides, sulphates or carbonates/bicarbonates.

The humus-illuvial part of natric horizons has a base saturation (by 1 *M* NH_4OAc) of more than 50 percent, which separates it from the *sombric* horizon.

Nitic horizon

General description

The nitic horizon (from Latin *nitidus*, shiny) is a clay-rich subsurface horizon. It has moderately to strongly developed polyhedric or nutty structure with many shiny ped faces, which cannot or can only partially be attributed to clay illuviation.

Diagnostic criteria

A nitic horizon has:

1. less than 20 percent change (relative) in clay content over 12 cm to layers immediately above and below; ***and***
2. all of the following:
   a. 30 percent or more clay; ***and***
   b. a water-dispersible clay to total clay ratio less than 0.10; ***and***
   c. a silt to clay ratio less than 0.40; ***and***
3. moderate to strong, angular blocky structure breaking to flat-edged or nut-shaped elements with shiny ped faces. The shiny faces are not, or are only partially, associated with clay coatings; ***and***
4. all of the following:
   a. 4.0 percent or more citrate-dithionite extractable Fe (*free* iron) in the fine earth fraction; ***and***
   b. 0.20 percent or more acid oxalate (pH 3) extractable Fe (*active* iron) in the fine earth fraction; ***and***
   c. a ratio between *active* and *free* iron of 0.05 or more; ***and***
5. a thickness of 30 cm or more.

Field identification

A nitic horizon has a clay loam or finer texture but feels loamy. The change in clay content with the overlying and underlying horizons is gradual. Similarly, there is no abrupt colour change with the horizons above and below. The colours are of low value and chroma with hues often 2.5 YR, but sometimes redder or yellower. The structure is moderate to strong angular blocky, breaking to flat-edged or nut-shaped elements showing shiny faces.

Additional characteristics
In many nitic horizons, the CEC (by 1 *M* NH_4OAc) is less than 36 $cmol_c$ kg^{-1} clay, or even less than 24 $cmol_c$ kg^{-1} clay[1]. The ECEC (sum of exchangeable bases plus exchangeable acidity in 1 *M* KCl) is about half of the CEC. The moderate to low CEC and ECEC reflect the dominance of 1:1 lattice clays (either kaolinite and/or [meta]halloysite).

Relationships with some other diagnostic horizons
The nitic horizon may be considered as a special type of *argic* horizon, or a strongly expressed *cambic* horizon, with specific properties such as a low amount of water-dispersible clay and a high amount of active iron. As such, the nitic horizon has preference over both for classification purposes. Its mineralogy (kaolinitic/[meta]halloysitic) sets it apart from most *vertic* horizons, which have dominantly a smectitic mineralogy. However, nitic horizons may grade laterally into *vertic* horizons in lower landscape positions. The well-expressed soil structure, the high amount of active iron, and the frequently intermediate CEC in nitic horizons set them apart from *ferralic* horizons.

Nitic horizons in cool and moist, freely drained soils of high plateaus and mountains in tropical and subtropical regions may occur in association with *sombric* horizons.

Petrocalcic horizon
General description
A petrocalcic horizon (from Greek *petros*, rock, and Latin *calx*, lime) is an indurated *calcic* horizon that is cemented by calcium carbonate and, in places, by calcium and some magnesium carbonate. It is either massive or platy in nature, and extremely hard.

Diagnostic criteria
A petrocalcic horizon has:
1. very strong effervescence after adding a 10-percent HCl solution; ***and***
2. induration or cementation, at least partially by secondary carbonates, to the extent that air-dry fragments do not slake in water and roots cannot enter except along vertical fractures (which have an average horizontal spacing of 10 cm or more and which occupy less than 20 percent [by volume] of the layer); ***and***
3. extremely hard consistence when dry, so that it cannot be penetrated by spade or auger; ***and***
4. a thickness of 10 cm or more, or 1 cm or more if it is laminar and rests directly on *continuous rock*.

Field identification
Petrocalcic horizons occur as non-platy calcrete (either massive or nodular) or as platy calcrete, of which the following types are the most common:
- *Lamellar calcrete*: superimposed, separate, petrified layers varying in thickness from a few millimetres to several centimetres. The colour is generally white or pink.
- *Petrified lamellar calcrete*: one or several extremely hard layers, grey or pink in colour. They are generally more cemented than the lamellar calcrete and very massive (no fine lamellar structures, but coarse lamellar structures may be present).

Non-capillary pores in petrocalcic horizons are filled, and the hydraulic conductivity is moderately slow to very slow.

[1] See Annex 1.

Relationships with some other diagnostic horizons

In arid regions, petrocalcic horizons may occur in association with *(petro-) duric* horizons, into which they may grade laterally. The cementing agent differentiates petrocalcic and *duric* horizons. In petrocalcic horizons, calcium and some magnesium carbonate constitute the main cementing agent while some accessory silica may be present. In *duric* horizons, silica is the main cementing agent, with or without calcium carbonate.

Petrocalcic horizons also occur in association with *gypsic* or *petrogypsic* horizons.

Petroduric horizon

General description

A petroduric horizon (from Greek *petros*, rock, and Latin *durus*, hard), also known as duripan or dorbank (South Africa), is a subsurface horizon, usually reddish or reddish brown in colour, that is cemented mainly by secondary silica (SiO_2, presumably opal and microcrystalline forms of silica). Air-dry fragments of petroduric horizons do not slake in water, even after prolonged wetting. Calcium carbonate may be present as accessory cementing agent.

Diagnostic criteria

A petroduric horizon has:

1. induration or cementation in 50 percent or more of some subhorizon; ***and***
2. evidence of silica accumulation (opal or other forms of silica), e.g. as coatings in some pores, on some structural faces or as bridges between sand grains; ***and***
3. when air-dry, less than 50 percent slakes in 1 *M* HCl even after prolonged soaking, but 50 percent or more slake in concentrated KOH, concentrated NaOH or in alternating acid and alkali; ***and***
4. a lateral continuity such that roots cannot penetrate except along vertical fractures (which have an average horizontal spacing of 10 cm or more and which occupy less than 20 percent [by volume] of the layer); ***and***
5. a thickness of 1 cm or more.

Field identification

A petroduric horizon has a very to extremely firm consistence when moist, and is very or extremely hard when dry. Effervescence after applying 1 *M* HCl may take place, but is probably not as vigorous as in *petrocalcic* horizons, which appear similar. However, it may occur in conjunction with a *petrocalcic* horizon.

Relationships with some other diagnostic horizons

In dry and arid climates, petroduric horizons may grade laterally into *petrocalcic* horizons, and/or occur in conjunction with *calcic* or *gypsic* horizons, which they normally overlie. In more humid climates, petroduric horizons may grade laterally into *fragic* horizons.

Petrogypsic horizon

General description

A petrogypsic horizon (from Greek *petros*, rock, and *gypsos*) is a cemented horizon containing secondary accumulations of gypsum ($CaSO_4.2H_2O$).

Diagnostic criteria

A petrogypsic horizon has:

1. 5 percent[1] or more gypsum and 1 percent or more (by volume) visible secondary gypsum; ***and***

[1] The percentage gypsum is calculated as the product of gypsum content, expressed as $cmol_c\ kg^{-1}$ soil, and the equivalent mass of gypsum (86) expressed as a percentage.

2. induration or cementation by secondary gypsum, at least partially, to the extent that air-dry fragments do not slake in water and that it cannot be penetrated by roots except along vertical fractures (which have an average horizontal spacing of 10 cm or more and which occupy less than 20 percent [by volume] of the layer); ***and***
3. a thickness of 10 cm or more.

Field identification
Petrogypsic horizons are hard, whitish and composed predominantly of gypsum. They may be capped by a thin, laminar layer about 1 cm thick.

Additional characteristics
Determinations of the amount of gypsum in the soil to verify the required content and increase, as well as thin section analysis, are helpful techniques to establish the presence of a petrogypsic horizon and the distribution of the gypsum in the soil mass.

In thin sections, the petrogypsic horizon shows a compacted microstructure with only a few cavities. The matrix is composed of densely packed lenticular gypsum crystals mixed with small amounts of detrital material. The matrix has a faint yellow colour in plain light. Irregular nodules formed by colourless transparent zones consist of coherent crystal aggregates with a hypidiotopic or xenotopic fabric and are mostly associated with pores or former pores. Traces of biological activity (pedotubules) are sometimes visible.

Relationships with some other diagnostic horizons
As the petrogypsic horizon develops from a *gypsic* horizon, the two are closely linked. Petrogypsic horizons frequently occur associated with *calcic* horizons. Calcic and gypsic accumulations usually occupy different positions in the soil profile because the solubility of calcium carbonate is different from that of gypsum. Normally, they can be distinguished clearly from each other by their morphology (see *calcic* horizon).

Petroplinthic horizon

General description
A petroplinthic horizon (from Greek *petros*, rock, and *plinthos*, brick) is a continuous, fractured or broken layer of indurated material, in which Fe (and in cases also Mn) is an important cement and in which organic matter is either absent or present only in traces.

Diagnostic criteria
A petroplinthic horizon:

1. is a continuous, fractured or broken sheet of connected, strongly cemented to indurated
   a. reddish to blackish nodules; ***or***
   b. reddish, yellowish to blackish mottles in platy, polygonal or reticulate patterns; ***and***
2. has a penetration resistance[1] of 4.5 MPa or more in 50 percent or more of the volume; ***and***
3. has a ratio between acid oxalate (pH 3) extractable Fe and citrate-dithionite extractable Fe of less than 0.10[2]; ***and***
4. has a thickness of 10 cm or more.

[1] Asiamah (2000). From this point onwards, the horizon will start hardening irreversibly.
[2] Estimated from data given by Varghese and Byju (1993).

Field identification
Petroplinthic horizons are extremely hard; typically rusty brown to yellowish brown; either massive, or show an interconnected nodular, or a reticulate, platy or columnar pattern that encloses non-indurated material. They may be fractured or broken.

Relationships with some other diagnostic horizons
Petroplinthic horizons are closely associated with *plinthic* horizons from which they develop. In some places, *plinthic* horizons can be traced by following petroplinthic layers, which have formed, for example, in road cuts.

The low ratio between acid oxalate (pH 3) extractable Fe and citrate-dithionite extractable Fe separates the petroplinthic horizon from thin iron pans, bog iron and indurated *spodic* horizons as occurring in, for example, *Podzols*, which in addition contain a fair amount of organic matter.

Pisoplinthic horizon

General description
A pisoplinthic horizon (from Latin *pisum*, pea, and Greek *plinthos*, brick) contains nodules that are strongly cemented to indurated with Fe (and in some cases also with Mn).

Diagnostic criteria
A pisoplinthic horizon has:
1. 40 percent or more of the volume occupied by discrete, strongly cemented to indurated, reddish to blackish nodules with a diameter of 2 mm or more; ***and***
2. a thickness of 15 cm or more.

Relationships with some other diagnostic horizons
A pisoplinthic horizon results if a *plinthic* horizon hardens in the form of discrete nodules. The hardness and the amount of the nodules separate it also from the *ferric* horizon.

Plaggic horizon

General description
A plaggic horizon (from Dutch *plag*, sod) is a black or brown human-induced mineral surface horizon that has been produced by long-continued manuring. In medieval times, sod and other materials were commonly used for bedding livestock and the manure was spread on fields being cultivated. The mineral materials brought in by this kind of manuring eventually produced an appreciably thickened horizon (in places as much as 100 cm or more thick) that is rich in organic carbon. Base saturation is typically low.

Diagnostic criteria
A plaggic horizon is a mineral surface horizon and:
1. has a texture of sand, loamy sand, sandy loam or loam, or a combination of them; ***and***
2. contains *artefacts*, but less than 20 percent, or has spade marks below 30 cm depth; ***and***
3. has Munsell colours with a value of 4 or less, moist, 5 or less, dry, and a chroma of 2 or less, moist; ***and***
4. has an organic carbon content of 0.6 percent or more; ***and***
5. occurs in locally raised land surfaces; ***and***
6. has a thickness of 20 cm or more.

Field identification

The plaggic horizon has brownish or blackish colours, related to the origin of source materials. Its reaction is slightly to strongly acid. It shows evidence of agricultural operations such as spade marks as well as old cultivation layers. Plaggic horizons commonly overlie buried soils although the original surface layers may be mixed. The lower boundary is typically clear.

Additional characteristics

The texture is in most cases sand or loamy sand. Sandy loam and silt loam are rare. The P_2O_5 content (extractable in 1-percent citric acid) in plaggic horizons may be high, often more than 0.25 percent within 20 cm of the surface, but frequently more than 1 percent. Owing to the abandonment of the practice, phosphate contents may have lowered considerably, and can no longer be seen as diagnostic for the plaggic horizon.

Relationships with some other diagnostic horizons

Few soil characteristics differentiate the *terric* and plaggic horizons from each other. *Terric* horizons usually show a high biological activity, have a neutral to slightly alkaline soil reaction (pH [H_2O] is normally more than 7.0), and may contain free lime. The colour is strongly related to the source material or the underlying substrate. Buried soils may be observed at the base of the horizon although mixing can obscure the contact.

The plaggic horizon has many characteristics in common with *umbric* horizons, and evidence of human influences, such as the spade marks or surface raising, is often required to distinguish between the two.

Plinthic horizon

General description

A plinthic horizon (from Greek *plinthos*, brick) is a subsurface horizon that consists of an Fe-rich (in some cases also Mn-rich), humus-poor mixture of kaolinitic clay (and other products of strong weathering, such as gibbsite) with quartz and other constituents, and which changes irreversibly to a layer with hard nodules, a hardpan or irregular aggregates on exposure to repeated wetting and drying with free access of oxygen.

Diagnostic criteria

A plinthic horizon has:

1. within 15 percent or more of the volume single or in combination:
   a. discrete nodules that are firm to weakly cemented, with a redder hue or stronger chroma than the surrounding material, and which change irreversibly to strongly cemented or indurated nodules on exposure to repeated wetting and drying with free access of oxygen; ***or***
   b. mottles in platy, polygonal or reticulate patterns that are firm to weakly cemented, with a redder hue or stronger chroma than the surrounding material, and which change irreversibly to strongly cemented or indurated mottles on exposure to repeated wetting and drying with free access of oxygen; ***and***
2. less than 40 percent of the volume strongly cemented or indurated nodules and no continuous, fractured or broken sheets; ***and***
3. both:
   a. 2.5 percent (by mass) or more citrate-dithionite extractable Fe in the fine earth fraction or 10 percent or more in the nodules or mottles; ***and***
   b. a ratio between acid oxalate (pH 3) extractable Fe and citrate-dithionite extractable Fe of less than 0.10[1]; ***and***
4. a thickness of 15 cm or more.

[1] Estimated from data given by Varghese and Byju (1993).

Field identification

A plinthic horizon shows red nodules or mottles in platy, polygonal, vesicular or reticulate patterns. In a perennially moist soil, many nodules or mottles are not hard but firm or very firm and can be cut with a spade. They do not harden irreversibly as a result of a single cycle of drying and rewetting but repeated wetting and drying will change them irreversibly to hard nodules or a hardpan (ironstone) or irregular aggregates, especially if also exposed to heat from the sun.

Additional characteristics

Micromorphological studies may reveal the extent of impregnation of the soil mass by Fe. The plinthic horizon with nodules has developed under redoximorphic conditions caused by temporally stagnating water and shows a *stagnic colour pattern*. The plinthic horizon with mottles in platy, polygonal or reticulate patterns has developed under oximorphic conditions in the capillary fringe of groundwater. In this case, the plinthic horizon shows a *gleyic colour pattern* with oximorphic colours and is in many cases underlain by a whitish horizon. In many plinthic horizons, there are no prolonged *reducing conditions*.

Relationships with some other diagnostic horizons

If the plinthic horizon hardens to a continuous sheet (which later may be broken or fractured), it becomes a *petroplinthic* horizon. If nodules reach 40 percent or more of the volume and harden separately, it becomes a *pisoplinthic* horizon.

If the nodules or mottles that harden on exposure to repeated wetting and drying do not reach 15 percent of the volume, it may be a *ferric* horizon if it has 5 percent or more nodules or 15 percent or more mottles fulfilling certain additional requirements.

Salic horizon

General description

The salic horizon (from Latin *sal*, salt) is a surface or shallow subsurface horizon that contains a secondary enrichment of readily soluble salts, i.e. salts more soluble than gypsum ($CaSO_4.2H_2O$; log Ks = -4.85 at 25 °C).

Diagnostic criteria

A salic horizon has:

1. averaged over its depth an electrical conductivity of the saturation extract (EC_e) of 15 dS m^{-1} or more at 25 °C at some time of the year, ***or*** an EC_e of 8 dS m^{-1} or more at 25 °C if the pH (H_2O) of the saturation extract is 8.5 or more; ***and***
2. averaged over its depth a product of thickness (in centimetres) and EC_e (in dS m^{-1}) of 450 or more; ***and***
3. a thickness of 15 cm or more.

Field identification

Salicornica or halophyte vegetation such as *Tamarix* and salt-tolerant crops are first indicators. Salt-affected layers are often puffy. Salts precipitate only after evaporation of the soil moisture; if the soil is moist, salt may not be visible.

Salts may precipitate at the surface (external *Solonchaks*) or at depth (internal *Solonchaks*). A salt crust is part of the salic horizon.

Additional characteristics

An EC_e of 8 dS m^{-1} or more at 25 °C if the pH (H_2O) of the saturation extract is 8.5 or more is very common in alkaline carbonate soils.

Sombric horizon

General description

A sombric horizon (from French *sombre*, dark) is a dark-coloured subsurface horizon containing illuvial humus that is neither associated with Al nor dispersed by Na.

Diagnostic criteria

A sombric horizon:

1. has a lower Munsell colour value or chroma than the overlying horizon; ***and***
2. has a base saturation (by 1 *M* NH_4OAc) less than 50 percent; ***and***
3. shows evidence of humus accumulation, by a higher organic carbon content with respect to the overlying horizon, or through illuvial humus on ped surfaces or in pores visible in thin sections; ***and***
4. does not underlie an *albic* horizon; ***and***
5. has a thickness of 15 cm or more.

Field identification

Dark-coloured subsoils, associated with cool and moist, well-drained soils of high plateaus and mountains in tropical and subtropical regions. They resemble buried horizons but, in contrast to many of these, sombric horizons more or less follow the shape of the surface.

Relationships with some other diagnostic horizons

Sombric horizons may form or have been formed in *argic*, *cambic*, *ferralic* or *nitic* horizons. *Umbric* horizons, as well as the dark-coloured *melanic* and *fulvic* horizons of Andosols, form at the surface and, as such, are different from sombric horizons. *Spodic* horizons are differentiated from sombric horizons by their much higher CEC of the clay fraction. The humus-illuvial part of *natric* horizons has a base saturation (by 1 *M* NH_4OAc) of more than 50 percent, which separates it from the sombric horizon.

Spodic horizon

General description

The spodic horizon (from Greek *spodos*, wood ash) is a subsurface horizon that contains illuvial amorphous substances composed of organic matter and Al, or of illuvial Fe. The illuvial materials are characterized by a high pH-dependent charge, a relatively large surface area and high water retention.

Diagnostic criteria

A spodic horizon:

1. has a pH (1:1 in water) of less than 5.9 in 85 percent or more of the horizon, unless the soil is cultivated; ***and***
2. has an organic carbon content of 0.5 percent or more *or* an optical density of the oxalate extract (ODOE) value of 0.25 or more, at least in some part of the horizon; ***and***
3. has one or both of the following:
   a. an *albic* horizon directly overlying the spodic horizon and has, directly under the *albic* horizon, one of the following Munsell colours, when moist (crushed and smoothed sample):
      i. a hue of 5 YR or redder; ***or***
      ii. a hue of 7.5 YR with a value of 5 or less and a chroma of 4 or less; ***or***
      iii. a hue of 10 YR or neutral and a value and a chroma of 2 or less; ***or***
      iv. a colour of 10 YR 3/1; ***or***

b. with or without an *albic* horizon, one of the colours listed above, or a hue of 7.5 YR, a value of 5 or less and chroma of 5 or 6, both when moist (crushed and smoothed sample), ***and*** one or more of the following:
   i. cementation by organic matter and Al with or without Fe, in 50 percent or more of the volume and a very firm or firmer consistency in the cemented part; ***or***
   ii. cracked coatings on sand grains covering 10 percent or more of the surface of the horizon; ***or***
   iii. 0.50 percent or more Al_{ox} + ½Fe_{ox}[1] and a value less than one-half that amount in an overlying mineral horizon; ***or***
   iv. an ODOE value of 0.25 or more, and a value less than one-half that amount in an overlying mineral horizon; ***or***
   v. 10 percent or more (by volume) Fe lamellae[2] in a layer 25 cm or more thick.

c. does not form part of a *natric* horizon; ***and***
d. has a thickness of 2.5 cm or more.

Field identification

A spodic horizon normally underlies an *albic* horizon and has brownish-black to reddish-brown colours. Spodic horizons can also be characterized by the presence of a thin iron pan, when weakly developed by the presence of organic pellets, or by the accumulation of Fe in lamellar form.

Relationships with some other diagnostic horizons

Spodic horizons are usually associated with *albic* horizons, which they underlie; there may be an *anthric*, *hortic*, *plaggic*, *terric* or *umbric* horizons at the surface.

Spodic horizons may exhibit *andic* properties owing to the alumino-organic complexes. Spodic horizons have at least twice as much the Al_{ox} + ½Fe_{ox} percentages as overlying layers, such as an *albic*, *anthric*, *hortic*, *plaggic*, *terric* or *umbric* horizon. This criterion does not normally apply to non-spodic layers with *andic* properties in which the alumino-organic complexes are hardly mobile.

Similar to many spodic horizons, *sombric* horizons also contain more organic matter than an overlying layer. They can be differentiated from each other by the clay mineralogy (kaolinite usually dominating in *sombric* horizons, whereas the clay fraction of spodic horizons commonly contains significant amounts of vermiculite and Al-interlayered chlorite) and the much higher CEC of the clay fraction in spodic horizons.

Similarly, *plinthic* horizons, which contain large amounts of illuvial Fe, are dominated by kaolinitic clay minerals and, therefore, have a much lower CEC of the clay fraction than that of spodic horizons.

Takyric horizon

General description

A takyric horizon (from Turkic languages *takyr*, barren land) is a heavy-textured surface horizon comprising a surface crust and a platy structured lower part. It occurs under arid conditions in periodically flooded soils.

Diagnostic criteria

A takyric horizon has:

1. *aridic* properties; ***and***

[1] Al_{ox} and Fe_{ox}: acid oxalate-extractable aluminium and iron, respectively (Blakemore, Searle and Daly, 1981), expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.

[2] Iron lamellae are non-cemented bands of illuvial iron less than 2.5 cm thick.

2. a platy or massive structure; ***and***
3. a surface crust that has ***all*** of the following:
   a. thickness enough that it does not curl entirely upon drying; ***and***
   b. polygonal cracks extending 2 cm or more deep when the soil is dry; ***and***
   c. sandy clay loam, clay loam, silty clay loam or finer texture; ***and***
   d. very hard consistence when dry, and very plastic and sticky consistence when wet; ***and***
   e. an electrical conductivity (EC_e) of the saturated extract of less than 4 dS m^{-1}, or less than that of the layer immediately below the takyric horizon.

Field identification
Takyric horizons occur in depressions in arid regions, where surface water, rich in clay and silt but relatively low in soluble salts, accumulates and leaches the upper soil horizons. Periodic leaching of salt disperses clay and forms a thick, compact, fine-textured crust with prominent polygonal cracks when dry. The crust often contains more than 80 percent clay and silt.

Relationships with some other diagnostic horizons
Takyric horizons occur in association with many diagnostic horizons, the most important ones being the *salic*, *gypsic*, *calcic* and *cambic* horizons. The low EC and low soluble-salt content of takyric horizons set them apart from the *salic* horizon.

Terric horizon

General description
A terric horizon (from Latin *terra*, earth) is a human-induced mineral surface horizon that develops through addition of earthy manures, compost, beach sands or mud over a long period of time. It builds up gradually and may contain stones, randomly sorted and distributed.

Diagnostic criteria
A terric horizon is a mineral surface horizon and:
1. has a colour related to the source material; ***and***
2. contains less than 20 percent artefacts (by volume); ***and***
3. has a base saturation (by 1 *M* NH_4OAc) of 50 percent or more; ***and***
4. occurs in locally raised land surfaces; ***and***
5. does not show stratification but has an irregular textural differentiation; ***and***
6. has a lithological discontinuity at its base; **and**
7. has a thickness of 20 cm or more.

Field identification
Soils with a terric horizon show a raised surface that may be inferred either from field observation or from historical records. The terric horizon is not homogeneous, but subhorizons are thoroughly mixed. It commonly contains artefacts such as pottery fragments, cultural debris and refuse, which are typically very small (less than 1 cm in diameter) and much abraded.

Relationships with some other diagnostic horizons
Few soil characteristics differentiate the terric and *plaggic* horizons from each other. Terric horizons commonly show a high biological activity, have a neutral to slightly alkaline soil reaction (pH [H_2O] is normally more than 7.0), and may contain free lime, whereas *plaggic* horizons have an acid soil reaction. The colour of the terric horizon is strongly related to the source material. Buried soils may be observed at the base of the horizon although mixing can obscure the contact.

Thionic horizon

General description

The thionic horizon (from Greek *theion*, sulphur) is an extremely acid subsurface horizon in which sulphuric acid is formed through oxidation of sulphides.

Diagnostic criteria

A thionic horizon has:

1. a pH (1:1 in water) of less than 4.0; ***and***
2. one or more of the following:
   a. yellow jarosite or yellowish-brown schwertmannite mottles or coatings; ***or***
   b. concentrations with a Munsell hue of 2.5 Y or yellower and a chroma of 6 or more, moist; ***or***
   c. direct superposition on *sulphidic* material; ***or***
   d. 0.05 percent (by mass) or more water-soluble sulphate; ***and***
2. a thickness of 15 cm or more.

Field identification

Thionic horizons generally exhibit pale yellow jarosite or yellowish-brown schwertmannite mottles or coatings. Soil reaction is extremely acid; pH (H_2O) of 3.5 is not uncommon.

While mostly associated with recent sulphidic coastal sediments, thionic horizons also develop inland in *sulphidic* materials exposed by excavation or erosion.

Relationships with some other diagnostic horizons

The thionic horizon often underlies a strongly mottled horizon with pronounced redoximorphic features (reddish to reddish-brown iron hydroxide mottles and a light-coloured, Fe-depleted matrix).

Umbric horizon

General characteristics

The umbric horizon (from Latin *umbra*, shade) is a thick, dark-coloured, base-depleted surface horizon rich in organic matter.

Diagnostic criteria

An umbric horizon, after mixing either the upper 20 cm of the mineral soil or, if *continuous rock*, a *cryic*, *petroduric* or *petroplinthic* horizon is present within 20 cm of the mineral soil surface, the entire mineral soil above, has:

1. a soil structure sufficiently strong that the horizon is not both massive and hard or very hard when dry in both the mixed part and the underlying unmixed part, if the minimum thickness is larger than 20 cm (prisms larger than 30 cm in diameter are included in the meaning of massive if there is no secondary structure within the prisms); ***and***
2. Munsell colours with a chroma of 3 or less when moist, a value of 3 or less when moist and 5 or less when dry, both on broken samples in both the mixed part and the underlying unmixed part, if the minimum thickness is greater than 20 cm. The colour value is one unit or more darker than that of the parent material unless the parent material has a colour value of 4 or less, moist, in which case the colour contrast requirement is waived. If a parent material is absent, comparison must be made with the layer immediately underlying the surface layer; ***and***
3. an organic carbon content of 0.6 percent or more, in both the mixed part and the underlying unmixed part, if the minimum thickness is larger than 20 cm. The organic carbon content is at least 0.6 percent more than in the parent material if

the colour requirements are waived because of dark coloured parent materials; ***and***

4. a base saturation (by 1 *M* NH_4OAc) of less than 50 percent on a weighted average throughout the depth of the horizon; ***and***
5. a thickness of one of the following:
   a. 10 cm or more if directly overlying *continuous rock*, a *cryic*, *petroplinthic* or *petroduric* horizon; ***or***
   b. 20 cm or more and one-third or more of the thickness between the soil surface and the upper boundary of *continuous rock*, or a *cryic*, *gypsic*, *petroduric*, *petrogypsic*, *petroplinthic* or *salic* horizon or *calcaric*, *fluvic* or *gypsyric* material within 75 cm; ***or***
   c. 20 cm or more and one-third or more of the thickness between the soil surface and the lower boundary of the lowest diagnostic horizon within 75 cm and, if present, above any of the diagnostic horizons listed under b.; ***or***
   d. 25 cm or more.

Field identification

The main field characteristics of an umbric horizon are its dark colour and its structure. In general, umbric horizons tend to have a lesser grade of soil structure than *mollic* horizons.

Most umbric horizons have an acid reaction (pH [H_2O, 1:2.5] of less than about 5.5), which represents a base saturation of less than 50 percent. An additional indication for the acidity is a shallow, horizontal rooting pattern in the absence of a physical barrier.

Relationships with some other diagnostic horizons

The base saturation requirement sets the umbric horizon apart from the *mollic* horizon, which is otherwise very similar. The upper limit of organic carbon content varies from 12 percent (20 percent organic matter) to 18 percent (30 percent organic matter), which is the lower limit for the *histic* horizon, or 20 percent, the lower limit of a *folic* horizon.

Some thick, dark-coloured, organic-rich, base-desaturated surface horizons occur, which are formed as a result of human activities, such as deep cultivation and manuring, the addition of organic manures, the presence of ancient settlements, and kitchen middens (*anthragric*, *hortic*, *plaggic* or *terric* horizons). These horizons can usually be recognized in the field by the presence of artefacts, spade marks, contrasting mineral inclusions or stratification indicating the intermittent addition of manurial material, a relative higher position in the landscape, or by checking the agricultural history of the area.

Vertic horizon

General description

The vertic horizon (from Latin *vertere*, to turn) is a clayey subsurface horizon that, as a result of shrinking and swelling, has slickensides and wedge-shaped structural aggregates.

Diagnostic criteria

A vertic horizon:

1. contains 30 percent or more clay throughout; ***and***
2. has wedge-shaped structural aggregates with a longitudinal axis tilted between 10 ° and 60 ° from the horizontal; ***and***
3. has slickensides[1]; ***and***

[1] Slickensides are polished and grooved ped surfaces that are produced by aggregates sliding one past another.

4. has a thickness of 25 cm or more.

Field identification
Vertic horizons are clayey, with a hard to very hard consistency. When dry, vertic horizons show cracks of 1 cm or more wide. Polished, shiny ped surfaces (*slickensides*), often at sharp angles, are distinctive.

Additional characteristics
The COLE is a measure for the shrink–swell potential and is defined as the ratio of the difference between the moist length and the dry length of a clod to its dry length: $(L_m - L_d)/L_d$, in which L_m is the length at 33 kPa tension and L_d the length when dry. In vertic horizons, the COLE is more than 0.06.

Relationships with some other diagnostic horizons
Several other diagnostic horizons may also have high clay content, viz. the *argic*, *natric* and *nitic* horizons. These horizons lack the characteristic typical for the vertic horizon; however, they may be laterally linked in the landscape with the vertic horizon usually taking up the lowest position.

Voronic horizon

General description
The voronic horizon (from Russian *voronoj*, black) is a special type of *mollic* horizon. It is a deep, well-structured, blackish surface horizon with a high base saturation, a high content of organic matter and a high biological activity.

Diagnostic criteria
A voronic horizon is a mineral surface horizon and has:
1. granular or fine subangular blocky soil structure; ***and***
2. Munsell colours with a chroma of less than 2.0 when moist, a value less than 2.0 when moist and 3.0 when dry on broken samples. If there is 40 percent or more finely divided lime, or if the texture of the horizon is loamy sand or coarser, the limits of colour value when dry are waived; the colour value when moist is 3.0 or less. The colour value is one unit or more darker than that of the parent material (both moist and dry), unless the parent material has a colour value less than 4.0, moist. If a parent material is not present, comparison must be made with the layer immediately underlying the surface layer. The above colour requirements apply to the upper 15 cm of the voronic horizon, or immediately below any plough layer; ***and***
3. 50 percent or more (by volume) of the horizon consisting of worm burrows, worm casts, and filled burrows; ***and***
4. an organic carbon content of 1.5 percent or more. The organic carbon content is 6 percent or more if the colour requirements are waived because of finely divided lime, or 1.5 percent more than in the parent material if the colour requirements are waived because of dark coloured parent materials; ***and***
5. a base saturation (by 1 *M* NH_4OAc) of 80 percent or more; ***and***
6. a thickness of 35 cm or more.

Field identification
The voronic horizon is identified by its blackish colour, well-developed structure (usually granular), high activity of worms and other burrowing animals, and its thickness.

Relationships with some other diagnostic horizons
Its higher organic carbon content, the darker colours required, the high biological contribution to the soil structure, and its greater minimum depth express the special character of the voronic horizon with respect to the *mollic* horizon.

Yermic horizon
General description
The yermic horizon (from Spanish *yermo*, desert) is a surface horizon that usually, but not always, consists of surface accumulations of rock fragments (*desert pavement*) embedded in a loamy vesicular layer that may be covered by a thin aeolian sand or loess layer.

Diagnostic criteria
A yermic horizon has:
1. *aridic* properties; ***and***
2. one or more of the following:
    a. a pavement that is varnished or includes wind-shaped gravel or stones (*ventifacts*); ***or***
    b. a pavement associated with a vesicular layer; ***or***
    c. a vesicular layer below a platy surface layer.

Field identification
A yermic horizon comprises a pavement and/or a vesicular layer that has a loamy texture. The vesicular layer shows a polygonal network of desiccation cracks, often filled with in-blown material, that extend into the underlying layers. The surface layers have a weak to moderate platy structure.

Relationships with some other diagnostic horizons
Yermic horizons often occur in association with other diagnostic horizons characteristic for desert environments (*salic*, *gypsic*, *duric*, *calcic* and *cambic* horizons). In very cold deserts (e.g. Antarctica), they may occur associated with *cryic* horizons. Under these conditions, coarse cryoclastic material dominates and there is little dust to be deflated and deposited by wind. Here, a dense pavement with varnish, ventifacts, aeolian sand layers and soluble mineral accumulations may occur directly on loose deposits, without a vesicular layer.

DIAGNOSTIC PROPERTIES

Abrupt textural change
General description
An abrupt textural change (from Latin *abruptus*) is a very sharp increase in clay content within a limited depth range.

Diagnostic criteria
An abrupt textural change requires 8 percent or more clay in the underlying layer ***and***:
1. doubling of the clay content within 7.5 cm if the overlying layer has less than 20 percent clay; ***or***
2. 20 percent (absolute) increase in clay content within 7.5 cm if the overlying layer has 20 percent or more clay.

Albeluvic tonguing
General description
The term albeluvic tonguing (from Latin *albus*, white, and *eluere*, to wash out) is connotative of penetrations of clay- and Fe-depleted material into an *argic* horizon.

When peds are present, albeluvic tongues occur along ped surfaces.

Diagnostic criteria

Albeluvic tongues:

1. have the colour of an *albic* horizon; ***and***
2. have greater depth than width, with the following horizontal dimensions:
   a. 5 mm or more in clayey *argic* horizons; ***or***
   b. 10 mm or more in clay loam and silty *argic* horizons; ***or***
   c. 15 mm or more in coarser (silt loam, loam or sandy loam) *argic* horizons; ***and***
3. occupy 10 percent or more of the volume in the first 10 cm of the *argic* horizon, measured on both vertical and horizontal sections; ***and***
4. have a particle-size distribution matching that of the coarser textured horizon overlying the *argic* horizon.

Andic properties

General description

Andic properties (from Japanese *an*, dark, and *do*, soil) result from moderate weathering of mainly pyroclastic deposits. However, some soils develop andic properties from non-volcanic materials (e.g. loess, argillite and ferralitic weathering products). The presence of short-range-order minerals and/or organo-metallic complexes is characteristic for andic properties. These minerals and complexes are commonly part of the weathering sequence in pyroclastic deposits (*tephric* soil material ® *vitric* properties ® *andic* properties).

Andic properties may be found at the soil surface or in the subsurface, commonly occurring as layers. Many surface layers with andic properties contain a high amount of organic matter (more than 5 percent), are commonly very dark coloured (Munsell value and chroma, moist, are 3 or less), have a fluffy macrostructure and, in some places, a smeary consistence. They have a low bulk density and commonly have a silt loam or finer texture. Andic surface layers rich in organic matter may be very thick, having a thickness of 50 cm or more (*pachic* characteristic) in some soils. Andic subsurface layers are generally somewhat lighter coloured.

Andic layers may have different characteristics, depending on the type of the dominant weathering process acting upon the soil material. They may exhibit thixotropy, i.e. the soil material changes, under pressure or by rubbing, from a plastic solid into a liquefied stage and back into the solid condition. In perhumid climates, humus-rich andic layers may contain more than twice the water content of samples that have been oven-dried and rewetted (*hydric* characteristic).

Two major types of andic properties are recognized: one in which allophane and similar minerals are predominant (the *sil-andic* type); and one in which Al complexed by organic acids prevails (the *alu-andic* type). The sil-andic property typically gives a strongly acid to neutral soil reaction, while the alu-andic property gives an extremely acid to acid reaction.

Diagnostic criteria

Andic properties[1] require:

1. an $Al_{ox} + ½Fe_{ox}$[2] value of 2.0 percent or more; ***and***
2. a bulk density[3] of 0.90 kg dm^{-3} or less; ***and***
3. a phosphate retention of 85 percent or more; ***and***

[1] Shoji *et al*., 1996; Takahashi, Nanzyo and Shoji, 2004.

[2] Al_{ox} and Fe_{ox} are acid oxalate-extractable aluminium and iron, respectively (Blakemore, Searle and Daly, 1981), expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.

[3] For bulk density, the volume is determined after an undried soil sample has been desorbed at 33 kPa (no prior drying) and afterwards weighed oven-dried (see Annex 1).

4. if occurring under *tephric material* that meets the requirements of an *albic* horizon, a C_{py}/OC[1] or a C_f/C_{py}[4] of less than 0.5; ***and***
5. less than 25 percent (by mass) organic carbon.

Andic properties may be divided into sil-andic and alu-andic properties. Sil-andic properties show an acid-oxalate (pH 3) extractable silica (Si_{ox}) content of 0.6 percent or more or an Al_{py}[2]$/Al_{ox}$ of less than 0.5; alu-andic properties show a Si_{ox} content of less than 0.6 percent and an Al_{py}/Al_{ox} of 0.5 or more. Transitional alu-sil-andic properties that show a Si_{ox} content between 0.6 and 0.9 percent and an Al_{py}/Al_{ox} between 0.3 and 0.5 may occur (Poulenard and Herbillon, 2000).

Field identification

Andic properties may be identified using the sodium fluoride field test of Fieldes and Perrott (1966). A pH in NaF of more than 9.5 indicates allophane and/or organo-aluminium complexes. The test is indicative for most layers with andic properties, except for those very rich in organic matter. However, the same reaction occurs in *spodic* horizons and in certain acid clays that are rich in Al-interlayered clay minerals.

Uncultivated, organic matter-rich surface layers with sil-andic properties typically have a pH (H_2O) of 4.5 or higher, while uncultivated surface layers with alu-andic properties and rich in organic matter typically have a pH (H_2O) of less than 4.5. Generally, pH (H_2O) in sil-andic subsoil layers is more than 5.0.

Relationships with some diagnostic horizons and properties

Vitric properties are distinguished from andic properties by a lesser degree of weathering. This is evidenced by a lower amount of non-crystalline or paracrystalline pedogenetic minerals, as characterized by the moderate amount of acid oxalate (pH 3) extractable Al and Fe in layers with *vitric* properties (Al_{ox} + ½Fe_{ox} = 0.4–2.0 percent), by a higher bulk density (BD > 0.9 kg dm^{-3}), or by a lower phosphate retention (25 – <85 percent).

Histic or *folic* horizons with less than 25 percent organic carbon may have andic properties. In organic layers with 25 percent or more organic carbon, andic properties are not considered.

Spodic horizons, which also contain complexes of sesquioxides and organic substances, can have similar characteristics to those of layers with andic properties rich in alumino-organic complexes. Many *spodic* horizons have at least twice as much Al_{ox} + ½Fe_{ox} as an overlying layer. This normally does not apply to layers with andic properties in which the alumino-organic complexes are virtually immobile. However, particularly in Podzols to which the Entic qualifier applies and which have a *spodic* horizon without the requirement of at least twice as much Al_{ox} + ½Fe_{ox} as an overlying layer, other diagnostic criteria such as the bulk density are needed in order to discriminate between layers with andic properties and *spodic* horizons.

Some layers with andic properties are covered by relatively young, light-coloured volcanic ejecta that are difficult to distinguish from an *albic* horizon. Therefore, in a number of cases, analytical tests are needed in order to verify the difference between layers with andic properties and *spodic* horizons, in particular the C_{py} to OC or C_f to C_{py} ratio tests.

Aridic properties

General description

The term aridic properties (from Latin *aridus*, dry) combines a number of properties that are common in surface horizons of soils occurring under arid conditions and

[1] C_{py}, C_f and OC are pyrophosphate-extractable C, fulvic acid C and organic C, respectively (Ito *et al.*, 1991), expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.

[2] Al_{py}: pyrophosphate-extractable aluminium, expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.

where pedogenesis exceeds new accumulation at the soil surface by aeolian or alluvial activity.

Diagnostic criteria
Aridic properties require all of the following:

1. an organic carbon content of less than 0.6 percent[1] if the texture is sandy loam or finer, or less than 0.2 percent if the texture is coarser than sandy loam, as a weighted average in the upper 20 cm of the soil or down to the top of a diagnostic subsurface horizon, a cemented layer, or to *continuous rock*, whichever is shallower; ***and***
2. evidence of aeolian activity in one or more of the following forms:
   a. the sand fraction in some layer or in in-blown material filling cracks contains rounded or subangular sand particles showing a matt surface (use a ×10 hand-lens). These particles make up 10 percent or more of the medium and coarser quartz sand fraction; ***or***
   b. wind-shaped rock fragments (*ventifacts*) at the surface; ***or***
   c. aeroturbation (e.g. cross-bedding); ***or***
   d. evidence of wind erosion or deposition; ***and***
3. both broken and crushed samples with a Munsell colour value of 3 or more when moist and 4.5 or more when dry, and a chroma of 2 or more when moist; ***and***
4. base saturation (by 1 *M* NH_4OAc) of 75 percent or more.

Additional remarks
The presence of acicular (*needle-shaped*) clay minerals (e.g. sepiolite and palygorskite) in soils is considered connotative of a desert environment, but it has not been reported in all desert soils. This may be due either to the fact that, under arid conditions, acicular clays are not produced but only preserved, provided they exist in the parent material or in the dust that falls on the soil, or that, in some desert environments, there has not been sufficient weathering to produce detectable quantities of secondary clay minerals.

Continuous rock

Definition
Continuous rock is consolidated material underlying the soil, exclusive of cemented pedogenetic horizons such as *petrocalcic*, *petroduric*, *petrogypsic* and *petroplinthic* horizons. Continuous rock is sufficiently consolidated to remain intact when an air-dried specimen 25–30 mm on a side is submerged in water for 1 hour. The material is considered continuous only if cracks into which roots can enter are on average 10 cm or more apart and occupy less than 20 percent (by volume) of the continuous rock, with no significant displacement of the rock having taken place.

Ferralic properties

General description
Ferralic properties (from Latin *ferrum*, iron, and *alumen*, alum) refer to mineral soil material that has a relatively low CEC. It also includes soil materials that fulfil the requirements of a *ferralic* horizon except texture.

Diagnostic criteria
Ferralic properties require in some subsurface layer:

1. a CEC (by 1 *M* NH_4OAc) of less than 24 $cmol_c$ kg^{-1} clay[2]; ***or***

[1] The organic carbon content may be higher if the soil is periodically flooded, or if it has an EC_e of 4 dS m^{-1} or more somewhere within 100 cm of the soil surface.

[2] See Annex 1.

2. a CEC (by 1 *M* NH_4OAc) of less than 4 $cmol_c\ kg^{-1}$ soil and a Munsell chroma of 5 or more, moist.

Geric properties

General description

Geric properties (from Greek *geraios*, old) refer to mineral soil material that has a very low ECEC or even acts as an anion exchanger.

Diagnostic criteria

Geric properties require:

1. an ECEC (sum of exchangeable bases plus exchangeable acidity in 1 *M* KCl) of less than 1.5 $cmol_c\ kg^{-1}$ clay[1]; *or*
2. a delta pH (pH_{KCl} minus pH_{water}) of +0.1 or more.

Gleyic colour pattern

General description

Soil materials develop a gleyic colour pattern (from Russian ***gley***, mucky soil mass) if they are saturated with groundwater, unless drained, for a period that allows reducing conditions to occur (this may range from a few days in the tropics to a few weeks in other areas), and show a gleyic colour pattern.

Diagnostic criteria

A gleyic colour pattern shows one or both of the following:

1. 90 percent or more reductimorphic colours, which comprise neutral white to black (Munsell N1/ to N8/) or bluish to greenish (Munsell 2.5 Y, 5 Y, 5 G, 5 B); ***or***
2. 5 percent or more mottles of oximorphic colours, which comprise any colour, excluding reductimorphic colours.

Field identification

A *gleyic colour pattern* results from a redox gradient between groundwater and capillary fringe causing an uneven distribution of iron and manganese (hydr)oxides. In the lower part of the soil and/or inside the peds, the oxides are either transformed into insoluble Fe/Mn(II) compounds or they are translocated; both processes lead to the absence of colours with a hue redder than 2.5 Y. Translocated Fe and Mn compounds can be concentrated in the oxidized form (Fe[III], Mn[IV]) on ped surfaces or in biopores (rusty root channels), and towards the surface even in the matrix. Manganese concentrations can be recognized by strong effervescence using a 10-percent H_2O_2 solution.

Reductimorphic colours reflect permanently wet conditions. In loamy and clayey material, blue-green colours dominate owing to Fe (II, III) hydroxy salts (green rust). If the material is rich in sulphur (S), blackish colours prevail owing to colloidal iron sulphides such as greigite or mackinawite (easily recognized by smell after applying 1 *M* HCl). In calcareous material, whitish colours are dominant owing to calcite and/or siderite. Sands are usually light grey to white in colour and often also impoverished in Fe and Mn. Bluish-green and black colours are unstable and often oxidize to a reddish brown within a few hours of exposure to air.

The upper part of a reductimorphic layer may show up to 10 percent rusty colours, mainly around channels of burrowing animals or plant roots.

Oximorphic colours reflect alternating reducing and oxidizing conditions, as is the case in the capillary fringe and in the surface horizons of soils with fluctuating

[1] See Annex 1.

groundwater levels. Specific colours indicate ferrihydrite (reddish brown), goethite (bright yellowish brown), lepidocrocite (orange), and jarosite (pale yellow). In loamy and clayey soils, the iron oxides/hydroxides are concentrated on aggregate surfaces and the walls of larger pores (e.g. old root channels).

Additional characteristics
If a layer has a gleyic colour pattern in 50 percent of its volume, the layer has in the other 50 percent a matrix of oximorphic colours, i.e. neither reductimorphic colours nor mottles of oximorphic colours.

Lithological discontinuity

General description
Lithological discontinuities (from Greek *lithos*, stone, and Latin *continuare*, to continue) are significant changes in particle-size distribution or mineralogy that represent differences in lithology within a soil. A lithological discontinuity can also denote an age difference.

Diagnostic criteria
A lithological discontinuity requires one or more of the following:

1. an abrupt change in particle-size distribution that is not solely associated with a change in clay content resulting from pedogenesis; ***or***
2. a relative change of 20 percent or more in the ratios between coarse sand, medium sand, and fine sand; ***or***
3. rock fragments that do not have the same lithology as the underlying continuous rock; ***or***
4. a layer containing rock fragments without weathering rinds overlying a layer containing rocks with weathering rinds; ***or***
5. layers with angular rock fragments overlying or underlying layers with rounded rock fragments; ***or***
6. abrupt changes in colour not resulting from pedogenesis; ***or***
7. marked differences in size and shape of resistant minerals between superimposed layers (as shown by micromorphological or mineralogical methods).

Additional characteristics
In cases, a horizontal line of rock fragments (stone line) overlying and underlying layers with smaller amounts or rock fragments or a decreasing percentage of rock fragments with increasing depth may also be suggestive of a lithological discontinuity, although the sorting action of small fauna such as termites can produce similar effects in what would initially have been lithologically uniform parent material.

Reducing conditions

Definition
Reducing conditions (from Latin *reducere*) show one or more of the following:

1. a negative logarithm of the hydrogen partial pressure (rH) of less than 20; ***or***
2. the presence of free Fe^{2+}, as shown on a freshly broken and smoothed surface of a field-wet soil by the appearance of a strong red colour after wetting it with a 0.2-percent a,a, dipyridyl solution in 10-percent acetic acid[1]; ***or***
3. the presence of iron sulphide; ***or***
4. the presence of methane.

[1] This test may not give the strong red colour in soil materials with a neutral or alkaline soil reaction.

Secondary carbonates

General description

The term secondary carbonates (from Latin *carbo*, coal) refers to translocated lime, precipitated in place from the soil solution rather than inherited from a soil parent material. As a diagnostic property, it should be present in significant quantities.

Field identification

Secondary carbonates either may disrupt the soil structure or fabric, forming masses, nodules, concretions or spheroidal aggregates (*white eyes*) that are soft and powdery when dry, or may be present as soft coatings in pores, on structural faces or on the undersides of rock or cemented fragments. If present as coatings, secondary carbonates cover 50 percent or more of the structural faces and are thick enough to be visible when moist. If present as soft nodules, they occupy 5 percent or more of the soil volume.

Filaments (*pseudomycelia*) are only included in the definition of secondary carbonates if they are permanent and do not come and go with changing moisture conditions. This can be checked by spraying some water.

Stagnic colour pattern

General description

Soil material has a stagnic colour pattern (from Latin *stagnare*, to stagnate) if it is, at least temporarily, saturated with surface water, unless drained, for a period long enough to allow reducing conditions to occur (this may range from a few days in the tropics to a few weeks in other areas).

Diagnostic criteria

A *stagnic colour pattern* shows mottling in such a way that the surfaces of the peds (or parts of the soil matrix) are lighter (at least one Munsell value unit more) and paler (at least one chroma unit less), and the interiors of the peds (or parts of the soil matrix) are more reddish (at least one hue unit) and brighter (at least one chroma unit more) than the non-redoximorphic parts of the layer, or than the mixed average of the interior and surface parts.

Additional characteristics

If a layer has a stagnic colour pattern in 50 percent of its volume the other 50 percent of the layer are neither lighter and paler nor more reddish and brighter.

Vertic properties

Diagnostic criteria

Soil material with vertic properties (from Latin *vertere*, to turn) has one or both of the following:

1. 30 percent or more clay throughout a thickness of 15 cm or more and one or both of the following:
   a. slickensides or wedge-shaped aggregates; ***or***
   b. cracks that open and close periodically and are 1 cm or more wide; ***or***
2. a COLE of 0.06 or more averaged over depth of 100 cm from the soil surface.

Vitric properties

General description

Vitric properties (from Latin *vitrum*, glass) apply to layers with volcanic glass and other primary minerals derived from volcanic ejecta and which contain a limited amount of short-range-order minerals.

Diagnostic criteria
Vitric properties[1] require:

1. 5 percent or more (by grain count) volcanic glass, glassy aggregates and other glass-coated primary minerals, in the fraction between 0.05 and 2 mm, ***or*** in the fraction between 0.02 and 0.25 mm; ***and***
2. an $Al_{ox} + ½Fe_{ox}$[2] value of 0.4 percent or more; ***and***
3. a phosphate retention of 25 percent or more; ***and***
4. if occurring under *tephric material* that meets the requirements of an *albic* horizon, a C_{py}/OC[3] or a C_f/C_{py}[4] of less than 0.5; ***and***
5. less than 25 percent (by mass) organic carbon.

Field identification
Vitric properties can occur in a surface layer. However, they can also occur under some tens of centimetres of recent pyroclastic deposits. Layers with vitric properties can have an appreciable amount of organic matter. The sand and coarse silt fractions of layers with vitric properties have a significant amount of unaltered or partially altered volcanic glass, glassy aggregates and other glass-coated primary minerals (coarser fractions may be checked by ×10 hand-lens; finer fractions may be checked by microscope).

Relationships with some diagnostic horizons, properties and materials
Vitric properties are, on the one hand, closely linked with *andic* properties, into which they may eventually develop. On the other hand, layers with vitric properties develop from *tephric materials*.

Mollic and umbric horizons may exhibit vitric properties as well.

DIAGNOSTIC MATERIALS

Artefacts
Definition
Artefacts (from Latin *ars*, art, and *facere*, to make) are solid or liquid substances that are:

1. one or both of the following:
   a. created or substantially modified by humans as part of an industrial or artisanal manufacturing process; ***or***
   b. brought to the surface by human activity from a depth where they were not influenced by surface processes, with properties substantially different from the environment where they are placed; ***and***
2. have substantially the same properties as when first manufactured, modified or excavated.

Examples of artefacts are bricks, pottery, glass, crushed or dressed stone, industrial waste, garbage, processed oil products, mine spoil and crude oil.

Calcaric material
Definition
Calcaric material (from Latin *calcarius*) effervescences strongly with 1 *M* HCl in most of the fine earth. It applies to material that contains 2 percent or more calcium carbonate equivalent.

[1] Adapted after Takahashi, Nanzyo and Shoji (2004) and findings of the COST 622 Action.
[2] Al_{ox} and Fe_{ox} are acid oxalate-extractable aluminium and iron, respectively (Blakemore, Searle and Daly, 1987), expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.
[3] C_{py}, C_f and OC are pyrophosphate-extractable C, fulvic acid C and organic C, respectively (Ito *et al.*, 1991), expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.

Colluvic material

General description

Colluvic (from Latin *colluere*, to wash) material is formed by sedimentation through human-induced erosion. It normally accumulates in foot slope positions, in depressions or above hedge walls. The erosion may have taken place since Neolithic times.

Field identification

The upper part of the colluvic material shows characteristics (texture, colour, pH and organic carbon content) similar to the surface layer of the source in the neighbourhood. Many colluvic materials have artefacts such as pieces of bricks, ceramics and glass. Stratification is common although not always easily detectable, and many colluvic materials have a lithological discontinuity at their base.

Fluvic material

General description

Fluvic material (from Latin *fluvius*, river) refers to fluviatile, marine and lacustrine sediments that receive fresh material at regular intervals or have received it in the recent past[1].

Diagnostic criteria

Fluvic material is of fluviatile, marine or lacustrine origin that shows stratification in at least 25 percent of the soil volume over a specified depth; stratification may also be evident from an organic carbon content decreasing irregularly with depth, or remaining above 0.2 percent to a depth of 100 cm from the mineral soil surface. Thin strata of sand may have less organic carbon if the finer sediments below meet the latter requirement.

Field identification

Stratification, taking such forms as alternating darker coloured soil layers, reflects an irregular decrease in organic carbon content with depth. Fluvic material is always associated with *organized water bodies* and should be distinguished from colluvial deposits (sheet colluvia, splays and colluvial cones), even though they look very much the same.

Gypsiric material

Definition

Gypsiric material (from Greek *gypsos*) is mineral material that contains 5 percent or more gypsum (by volume).

Limnic material

Diagnostic criteria

Limnic material (from Greek *limnae*, pool) includes both organic and mineral materials that are:

1. deposited in water by precipitation or through action of aquatic organisms, such as diatoms and other algae; ***or***
2. derived from underwater and floating aquatic plants and subsequently modified by aquatic animals.

Field identification

Limnic material occurs as subaquatic deposits (or at the surface after drainage). Four types of limnic material are distinguished:

[1] Recent past covers the period during which the soil has been protected from flooding, e.g. by empoldering, embanking, canalization or artificial drainage, and during which time soil formation has not resulted in the development of any diagnostic subsurface horizon apart from a *salic* or *sulphuric* horizon.

1. *Coprogenous earth or sedimentary peat*: dominantly organic, identifiable through many faecal pellets, Munsell colour value (moist) 4 or less, slightly viscous water suspension, non- or slightly plastic and non-sticky consistence, shrinking upon drying, difficult to rewet after drying, and cracking along horizontal planes.
2. *Diatomaceous earth*: mainly diatoms (siliceous), identifiable by irreversible changing of the matrix colour (Munsell value 3, 4 or 5 in field moist or wet condition) as a result of the irreversibly shrinkage of the organic coatings on diatoms (use 440× microscope).
3. *Marl*: strongly calcareous, identifiable by a Munsell colour value, moist, of 5 or more, and a reaction with 10-percent HCl. The colour of marl does not usually change upon drying.
4. *Gyttja*: small coprogenic aggregates of strongly humified organic matter and minerals of predominantly clay to silt size, 0.5 percent or more organic carbon, a Munsell colour hue of 5 Y, GY or G, strong shrinkage after drainage and an rH value of 13 or more.

Mineral material

General description

In mineral material (from Celtic *mine*, mineral), the soil properties are dominated by mineral components.

Diagnostic criteria

Mineral material has one or both of the following:

1. less than 20 percent organic carbon in the fine earth (by mass) if saturated with water for less than 30 consecutive days in most years without being drained; ***or***
2. one or both of the following:
   a. less than (12 + [clay percentage of the mineral fraction × 0.1]) percent organic carbon in the fine earth (by mass), ***or***
   b. less than 18 percent organic carbon in the fine earth (by mass), if the mineral fraction has 60 percent or more clay.

Organic material

General description

Organic material (from Greek *organon*, tool) consists of a large amount of organic debris that accumulates at the surface under either wet or dry conditions and in which the mineral component does not significantly influence the soil properties.

Diagnostic criteria

Organic material has one or both of the following:

1. 20 percent or more organic carbon in the fine earth (by mass); ***or***
2. if saturated with water for 30 consecutive days or more in most years (unless drained), one or both of the following:
   a. (12 + [clay percentage of the mineral fraction × 0.1]) percent or more organic carbon in the fine earth (by mass), ***or***
   b. 18 percent or more organic carbon in the fine earth (by mass).

Ornithogenic material

General description

Ornithogenic material (from Greek *ornithos*, bird, and *genesis*, origin) is material with strong influence of bird excrement. It often has a high content of gravel that has been transported by birds.

Diagnostic criteria

Ornithogenic material has:

1. remnants of birds or bird activity (bones, feathers, and sorted gravel of similar size); **and**
2. a P_2O_5 content of 0.25 percent or more in 1-percent citric acid.

Sulphidic material

General description

Sulphidic material (from English *sulphide*) is a waterlogged deposit containing S, mostly in the form of sulphides, and only moderate amounts of calcium carbonate.

Diagnostic criteria

Sulphidic material has:

1. 0.75 percent or more S (dry mass) and less than three times as much calcium carbonate equivalent as S; ***and***
2. pH (1:1 in water) of 4.0 or more.

Field identification

In moist or wet conditions, deposits containing sulphides often show a golden shine, the colour of pyrite. Forced oxidation with a 30-percent hydrogen peroxide solution lowers the pH to 2.5 or less, the reaction may be vigorous in sunlight or on heating. Munsell colours range: hues of N, 5 Y, 5 GY, 5 BG, or 5 G; values of 2, 3 or 4; chroma always 1. The colour is usually unstable, and blackens upon exposure. Sulphidic clay is usually practically unripe. If the soil is disturbed, a whiff of rotten eggs may be noticed. This is accentuated by application of 1 *M* HCl.

Technic hard rock

Definition

Technic hard rock (from Greek *technikos*, skilfully made or constructed) is consolidated material resulting from an industrial process, with properties substantially different from those of natural materials.

Tephric material

General description

Tephric material[1] (from Greek *tephra*, pile ash) consists either of tephra, i.e. unconsolidated, non- or only slightly weathered primary pyroclastic products of volcanic eruptions (including ash, cinders, lapilli, pumice, pumice-like vesicular pyroclastics, blocks and volcanic bombs), or of tephric deposits, i.e. tephra that has been reworked and mixed with material from other sources. This includes tephric loess, tephric blown sand and volcanogenic alluvium.

Diagnostic criteria

Tephric material has:

1. 30 percent or more (by grain count) volcanic glass, glass-coated primary minerals, glassy materials, and glassy aggregates in the 0.02–2 mm particle-size fraction; ***and***
2. no *andic* or *vitric* properties.

Relationships with some diagnostic horizons

The low amount of acid oxalate extractable Al and Fe sets tephric material apart from layers with *vitric* or *andic* properties.

[1] Description and diagnostic criteria are adapted from Hewitt (1992).

Chapter 3

Key to the reference soil groups of the WRB with lists of prefix and suffix qualifiers

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Soils having *organic* material, *either* 1. 10 cm or more thick starting at the soil surface and immediately overlying ice, *continuous rock*, or fragmental materials, the interstices of which are filled with *organic* material; *or* 2. cumulatively within 100 cm of the soil surface either 60 cm or more thick if 75 percent (by volume) or more of the material consists of moss fibres *or* 40 cm or more thick in other materials and starting within 40 cm of the soil surface. **HISTOSOLS**	Folic Limnic Lignic Fibric Hemic Sapric Floatic Subaquatic Glacic Ombric Rheic Technic Cryic Leptic Vitric Andic Salic Calcic	Thionic Ornithic Calcaric Sodic Alcalic Toxic Dystric Eutric Turbic Gelic Petrogleyic Placic Drainic Transportic Novic
Other soils having 1. *either* a *hortic*, *irragric*, *plaggic* or *terric* horizon 50 cm or more thick; *or* 2. an *anthraquic* horizon and an underlying *hydragric* horizon with a combined thickness of 50 cm or more. **ANTHROSOLS**	Hydragric Irragric Terric Plaggic Hortic Escalic Technic Fluvic Salic Gleyic Stagnic Spodic Ferralic Regic	Sodic Alcalic Dystric Eutric Oxyaquic Arenic Siltic Clayic Novic

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having	Ekranic	Calcaric
1. 20 percent or more (by volume, by weighted average) *artefacts* in the upper 100 cm from the soil surface or to *continuous rock* or a cemented or indurated layer, whichever is shallower; *or*	Linic	Ruptic
	Urbic	Toxic
2. a continuous, very slowly permeable to impermeable, constructed geomembrane of any thickness starting within 100 cm of the soil surface; *or*	Spolic	Reductic
	Garbic	Humic
3. *technic hard rock* starting within 5 cm of the soil surface and covering 95 percent or more of the horizontal extent of the soil.	Folic	Densic
	Histic	Oxyaquic
TECHNOSOLS[1]	Cryic	Skeletic
	Leptic	Arenic
	Fluvic	Siltic
	Gleyic	Clayic
	Vitric	Drainic
	Stagnic	Novic
	Mollic	
	Alic	
	Acric	
	Luvic	
	Lixic	
	Umbric	
Other soils having	Glacic	Gypsiric
1. a *cryic* horizon starting within 100 cm of the soil surface; *or*	Turbic	Calcaric
2. a *cryic* horizon starting within 200 cm of the soil surface *and* evidence of cryoturbation[2] in some layer within 100 cm of the soil surface.	Folic	Ornithic
	Histic	Dystric
CRYOSOLS	Technic	Eutric
	Hyperskeletic	Reductaquic
	Leptic	Oxyaquic
	Natric	Thixotropic
	Salic	Aridic
	Vitric	Skeletic
	Spodic	Arenic
	Mollic	Siltic
	Calcic	Clayic
	Umbric	Drainic
	Cambic	Novic
	Haplic	
Other soils having	Nudilithic	Brunic
1. one of the following:	Lithic	Gypsiric
a. limitation of depth by *continuous rock* within 25 cm of the soil surface; *or*	Hyperskeletic	Calcaric
	Rendzic	Ornithic
b. less than 20 percent (by volume) fine earth averaged over a depth of 75 cm from the soil surface or to *continuous rock*, whichever is shallower; *and*	Folic	Tephric
	Histic	Humic
2. no *calcic*, *gypsic or spodic* horizon.	Technic	Sodic
LEPTOSOLS	Vertic	Dystric
	Salic	Eutric
	Gleyic	Oxyaquic
	Vitric	Gelic
	Andic	Placic
	Stagnic	Greyic
	Mollic	Yermic
	Umbric	Aridic
	Cambic	Skeletic
	Haplic	Drainic
		Novic

[1] Buried layers occur frequently in this RSG and can be indicated with the specifier thapto- followed by a qualifier or a RSG.
[2] Evidence of cryoturbation includes frost heave, cryogenic sorting, thermal cracking, ice segregation, patterned ground, etc.

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having 1. a *vertic* horizon starting within 100 cm of the soil surface; *and* 2. after the upper 20 cm have been mixed, 30 percent or more clay between the soil surface and the *vertic* horizon throughout; *and* 3. cracks[1] that open and close periodically. **VERTISOLS**	Grumic Mazic Technic Endoleptic Salic Gleyic Sodic Stagnic Mollic Gypsic Duric Calcic Haplic	Thionic Albic Manganesic Ferric Gypsiric Calcaric Humic Hyposalic Hyposodic Mesotrophic Eutric Pellic Chromic Novic
Other soils having *1.* *fluvic* material starting within 25 cm of the soil surface or starting immediately below a plough layer of any depth and continuing to a depth of 50 cm or more; *and* 2. no layers with *andic or vitric* properties with a combined thickness of 30 cm or more within 100 cm of the soil surface *and* starting within 25 cm of the soil surface. **FLUVISOLS**[2]	Subaquatic Tidalic Limnic Folic Histic Technic Salic Gleyic Stagnic Mollic Gypsic Calcic Umbric Haplic	Thionic Anthric Gypsiric Calcaric Tephric Petrogleyic Gelic Oxyaquic Humic Sodic Dystric Eutric Greyic Takyric Yermic Aridic Skeletic Arenic Siltic Clayic Drainic
Other soils having a *natric* horizon starting within 100 cm of the soil surface. **SOLONETZ**	Technic Vertic Gleyic Salic Stagnic Mollic Gypsic Duric Petrocalcic Calcic Haplic	Glossalbic Albic Abruptic Colluvic Ruptic Magnesic Humic Oxyaquic Takyric Yermic Aridic Arenic Siltic Clayic Novic

[1] A crack is a separation between big blocks of soil. If the surface is self-mulching, or if the soil is cultivated while cracks are open, the cracks may be filled mainly by granular materials from the soil surface but they are open in the sense that the blocks are separated; it controls the infiltration and percolation of water. If the soil is irrigated, the upper 50 cm has a COLE of 0.06 or more.

[2] Buried layers occur frequently in this RSG and can be indicated with the specifier thapto- followed by a qualifier or a RSG.

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having	Petrosalic	Sodic
1. a *salic* horizon starting within 50 cm of the soil surface; *and*	Hypersalic	Aceric
2. no *thionic* horizon starting within 50 cm of the soil surface.	Puffic	Chloridic
SOLONCHAKS	Folic	Sulphatic
	Histic	Carbonatic
	Technic	Gelic
	Vertic	Oxyaquic
	Gleyic	Takyric
	Stagnic	Yermic
	Mollic	Aridic
	Gypsic	Arenic
	Duric	Siltic
	Calcic	Clayic
	Haplic	Drainic
		Novic
Other soils having	Folic	Thionic
1. within 50 cm of the mineral soil surface in some parts *reducing conditions* and in half or more of the soil volume a *gleyic colour pattern*; *and*	Histic	Abruptic
	Anthraquic	Calcaric
2. no layers with *andic or vitric* properties with a combined thickness of *either*	Technic	Tephric
	Endosalic	Colluvic
a. 30 cm or more within 100 cm of the soil surface *and* starting within 25 cm of the soil surface; *or*	Vitric	Humic
	Andic	Sodic
b. 60 percent or more of the entire thickness of the soil when *continuous rock* or a cemented or indurated layer is starting between 25 and 50 cm from the soil surface.	Spodic	Alcalic
	Plinthic	Alumic
GLEYSOLS	Mollic	Toxic
	Gypsic	Dystric
	Calcic	Eutric
	Alic	Petrogleyic
	Acric	Turbic
	Luvic	Gelic
	Lixic	Greyic
	Umbric	Takyric
	Haplic	Arenic
		Siltic
		Clayic
		Drainic
		Novic

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having 1. one or more layers with *andic or vitric* properties with a combined thickness of *either* a. 30 cm or more within 100 cm of the soil surface *and* starting within 25 cm of the soil surface; *or* b. 60 percent or more of the entire thickness of the soil when *continuous rock* or a cemented or indurated layer is starting between 25 and 50 cm from the soil surface; *and* 2. no *argic*, *ferralic*, *petroplinthic*, *pisoplinthic*, *plinthic* or *spodic* horizon (unless buried deeper than 50 cm). **ANDOSOLS**[1]	Vitric Aluandic Eutrosilic Silandic Melanic Fulvic Hydric Folic Histic Technic Leptic Gleyic Mollic Gypsic Petroduric Duric Calcic Umbric	Anthric Fragic Calcaric Colluvic Acroxic Sodic Dystric Eutric Turbic Gelic Oxyaquic Placic Greyic Thixotropic Skeletic Arenic Siltic Clayic Drainic Novic
Other soils having a *spodic* horizon starting within 200 cm of the mineral soil surface. **PODZOLS**	Placic Ortsteinic Carbic Rustic Entic Albic Folic Histic Technic Hyperskeletic Leptic Gleyic Vitric Andic Stagnic Umbric Haplic	Hortic Plaggic Terric Anthric Ornithic Fragic Ruptic Turbic Gelic Oxyaquic Lamellic Skeletic Drainic Novic

[1] Buried layers occur frequently in this RSG and can be indicated with the specifier thapto- followed by a qualifier or a RSG.

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having *either* 1. a *plinthic*, *petroplinthic* or *pisoplinthic* horizon starting within 50 cm of the soil surface; *or* 2. a *plinthic* horizon starting within 100 cm of the soil surface and, directly above, a layer 10 cm or more thick, that has in some parts *reducing conditions* for some time during the year and in half or more of the soil volume, single or in combination a. a *stagnic colour pattern*; or b. an *albic* horizon. **PLINTHOSOLS**	Petric Fractipetric Pisolithic Gibbsic Posic Geric Vetic Folic Histic Technic Stagnic Acric Lixic Umbric Haplic	Albic Manganiferric Ferric Endoduric Abruptic Colluvic Ruptic Alumic Humic Dystric Eutric Oxyaquic Pachic Umbriglossic Arenic Siltic Clayic Drainic Novic
Other soils having 1. a *nitic* horizon starting within 100 cm of the soil surface; *and* 2. gradual to diffuse[1] horizon boundaries between the soil surface and the *nitic* horizon; *and* 3. no *ferric*, *petroplinthic*, *pisoplinthic*, *plinthic* or *vertic* horizon starting within 100 cm of the soil surface; ***and*** 4. no *gleyic* or *stagnic colour pattern* starting within 100 cm of the soil surface. **NITISOLS**	Vetic Technic Andic Ferralic Mollic Alic Acric Luvic Lixic Umbric Haplic	Humic Alumic Dystric Eutric Oxyaquic Colluvic Rhodic Novic
Other soils having 1. a *ferralic* horizon starting within 150 cm of the soil surface; *and* 2. no *argic* horizon that has, in the upper 30 cm, 10 percent or more water-dispersible clay unless the upper 30 cm of the *argic* horizon has one or both of the following: *a.* *geric* properties; *or* b. 1.4 percent or more organic carbon. **FERRALSOLS**	Gibbsic Posic Geric Vetic Folic Technic Andic Plinthic Mollic Acric Lixic Umbric Haplic	Sombric Manganiferric Ferric Colluvic Humic Alumic Dystric Eutric Ruptic Oxyaquic Arenic Siltic Clayic Rhodic Xanthic Novic

[1] As defined in FAO (2006).

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having	Solodic	Thionic
1. an *abrupt textural change* within 100 cm of the soil surface and, directly above or below, a layer 5 cm or more thick, that has in some parts *reducing conditions* for some time during the year and in half or more of the soil volume, single or in combination	Folic	Albic
	Histic	Manganiferric
	Technic	Ferric
a. a *stagnic colour pattern*; *or*	Vertic	Geric
b. an *albic* horizon; *and*	Endosalic	Ruptic
2. no *albeluvic tonguing* starting within 100 cm of the soil surface.	Plinthic	Calcaric
PLANOSOLS	Endogleyic	Sodic
	Mollic	Alcalic
	Gypsic	Alumic
	Petrocalcic	Dystric
	Calcic	Eutric
	Alic	Gelic
	Acric	Greyic
	Luvic	Arenic
	Lixic	Siltic
	Umbric	Clayic
	Haplic	Chromic
		Drainic
		Novic
Other soils having	Folic	Thionic
1. within 50 cm of the mineral soil surface in some parts *reducing conditions* for some time during the year and in half or more of the soil volume, single or in combination,	Histic	Albic
	Technic	Manganiferric
a. a *stagnic* colour pattern; *or*	Vertic	Ferric
b. an *albic* horizon; *and*	Endosalic	Ruptic
2. no *albeluvic tonguing* starting within 100 cm of the soil surface.	Plinthic	Geric
STAGNOSOLS	Endogleyic	Calcaric
	Mollic	Ornithic
	Gypsic	Sodic
	Petrocalcic	Alcalic
	Calcic	Alumic
	Alic	Dystric
	Acric	Eutric
	Luvic	Gelic
	Lixic	Greyic
	Umbric	Placic
	Haplic	Arenic
		Siltic
		Clayic
		Rhodic
		Chromic
		Drainic
		Novic

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having 1. a *mollic* horizon with a moist chroma of 2 or less to a depth of 20 cm or more, or having this chroma directly below any plough layer that is 20 cm or more deep; *and* 2. a *calcic* horizon, or concentrations of *secondary carbonates* starting within 50 cm below the lower limit of the *mollic* horizon and, if present, above a cemented or indurated layer; *and* 3. a base saturation (by 1 *M* NH_4OAc) of 50 percent or more from the soil surface to the *calcic* horizon or the concentrations of *secondary carbonates* throughout. **CHERNOZEMS**	Voronic Vermic Technic Leptic Vertic Endofluvic Endosalic Gleyic Vitric Andic Stagnic Petrogypsic Gypsic Petroduric Duric Petrocalcic Calcic Luvic Haplic	Anthric Glossic Tephric Sodic Pachic Oxyaquic Greyic Skeletic Arenic Siltic Clayic Novic
Other soils having 1. a *mollic* horizon; *and* 2. a *calcic* horizon, or concentrations of *secondary carbonates* starting within 50 cm below the lower limit of the *mollic* horizon and, if present, above a cemented or indurated layer; *and* 3. a base saturation (by 1 *M* NH_4OAc) of 50 percent or more from the soil surface to the *calcic* horizon or the concentrations of *secondary carbonates* throughout. **KASTANOZEMS**	Vermic Technic Leptic Vertic Endosalic Gleyic Vitric Andic Stagnic Petrogypsic Gypsic Petroduric Duric Petrocalcic Calcic Luvic Haplic	Anthric Glossic Tephric Sodic Oxyaquic Greyic Skeletic Arenic Siltic Clayic Chromic Novic
Other soils having 1. a *mollic* horizon; *and* 2. a base saturation (by 1 *M* NH_4OAc) of 50 percent or more throughout to a depth of 100 cm or more from the soil surface or to *continuous rock* or a cemented or indurated layer, whichever is shallower. **PHAEOZEMS**	Vermic Greyic Technic Rendzic Leptic Vertic Endosalic Gleyic Vitric Andic Ferralic Stagnic Petrogypsic Petroduric Duric Petrocalcic Calcic Luvic Haplic	Anthric Albic Abruptic Glossic Calcaric Tephric Sodic Pachic Oxyaquic Skeletic Arenic Siltic Clayic Chromic Novic

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having	Petric	Ruptic
1. a *petrogypsic* horizon starting within 100 cm of the soil surface; *or*	Hypergypsic	Sodic
2. a *gypsic* horizon starting within 100 cm of the soil surface *and* no *argic* horizon unless the *argic* horizon is permeated with gypsum or calcium carbonate.	Hypogypsic	Hyperochric
	Arzic	Takyric
GYPSISOLS	Technic	Yermic
	Leptic	Aridic
	Vertic	Skeletic
	Endosalic	Arenic
	Endogleyic	Siltic
	Petroduric	Clayic
	Duric	Novic
	Petrocalcic	
	Calcic	
	Luvic	
	Haplic	
Other soils having a *petroduric* or *duric* horizon starting within 100 cm of the soil surface.	Petric	Ruptic
	Fractipetric	Sodic
DURISOLS	Technic	Takyric
	Leptic	Yermic
	Vertic	Aridic
	Endogleyic	Hyperochric
	Gypsic	Arenic
	Petrocalcic	Siltic
	Calcic	Clayic
	Luvic	Chromic
	Lixic	Novic
	Haplic	
Other soils having	Petric	Ruptic
1. a *petrocalcic* horizon starting within 100 cm of the soil surface; *or*	Hypercalcic	Sodic
2. a *calcic* horizon starting within 100 cm of the soil surface *and*	Hypocalcic	Takyric
a. a calcareous matrix between 50 cm from the soil surface and the *calcic* horizon throughout if the *calcic* horizon starts below 50 cm; *and*	Technic	Yermic
	Leptic	Aridic
b. no *argic* horizon unless the *argic* horizon is permeated with calcium carbonate.	Vertic	Hyperochric
	Endosalic	Skeletic
CALCISOLS	Endogleyic	Arenic
	Gypsic	Siltic
	Luvic	Clayic
	Lixic	Chromic
	Haplic	Novic
Other soils having an *argic* horizon starting within 100 cm of the soil surface with *albeluvic tonguing* at its upper boundary.	Fragic	Anthric
	Cutanic	Manganiferric
ALBELUVISOLS	Folic	Ferric
	Histic	Abruptic
	Technic	Ruptic
	Gleyic	Alumic
	Stagnic	Dystric
	Umbric	Eutric
	Haplic	Gelic
		Oxyaquic
		Greyic
		Arenic
		Siltic
		Clayic
		Drainic
		Novic

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having	Hyperalic	Anthric
1. an *argic* horizon, which has a CEC (by 1 *M* NH_4OAc) of 24 cmol$_c$ kg^{-1} clay[1] or more throughout or to a depth of 50 cm below its upper limit, whichever is shallower, either starting within 100 cm of the soil surface, or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout; *and*	Lamellic	Fragic
	Cutanic	Manganiferric
	Albic	Ferric
2. a base saturation (by 1 *M* NH_4OAc) of less than 50 percent in the major part between 50 and 100 cm.	Technic	Abruptic
	Leptic	Ruptic
ALISOLS	Vertic	Alumic
	Fractiplinthic	Humic
	Petroplinthic	Hyperdystric
	Pisoplinthic	Epieutric
	Plinthic	Turbic
	Gleyic	Gelic
	Vitric	Oxyaquic
	Andic	Greyic
	Nitic	Profondic
	Stagnic	Hyperochric
	Umbric	Skeletic
	Haplic	Arenic
		Silltic
		Clayic
		Rhodic
		Chromic
		Novic
Other soils having	Vetic	Anthric
1. an *argic* horizon that has a CEC (by 1 *M* NH_4OAc) of less than 24 cmol$_c$ kg^{-1} clay[2] in some part to a maximum depth of 50 cm below its upper limit, either starting within 100 cm of the soil surface, or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout, *and*	Lamellic	Albic
	Cutanic	Fragic
	Technic	Sombric
	Leptic	Manganiferric
2. a base saturation (by 1 *M* NH_4OAc) of less than 50 percent in the major part between 50 and 100 cm.	Fractiplinthic	Ferric
ACRISOLS	Petroplinthic	Abruptic
	Pisoplinthic	Ruptic
	Plinthic	Alumic
	Gleyic	Humic
	Vitric	Hyperdystric
	Andic	Epieutric
	Nitic	Oxyaquic
	Stagnic	Greyic
	Umbric	Profondic
	Haplic	Hyperochric
		Skeletic
		Arenic
		Siltic
		Clayic
		Rhodic
		Chromic
		Novic

[1] See Annex 1.
[2] See Annex 1.

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having an *argic* horizon with a CEC (by 1 *M* NH_4OAc) of 24 $cmol_c$ kg^{-1} clay[1] or more throughout or to a depth of 50 cm below its upper limit, whichever is shallower, either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout. **LUVISOLS**	Lamellic Cutanic Albic Escalic Technic Leptic Vertic Gleyic Vitric Andic Nitic Stagnic Calcic Haplic	Anthric Fragic Manganiferric Ferric Abruptic Ruptic Humic Sodic Epidystric Hypereutric Turbic Gelic Oxyaquic Greyic Profondic Hyperochric Skeletic Arenic Siltic Clayic Rhodic Chromic Novic
Other soils having an *argic* horizon, either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout. **LIXISOLS**	Vetic Lamellic Cutanic Technic Leptic Gleyic Vitric Andic Fractiplinthic Petroplinthic Pisoplinthic Plinthic Nitic Stagnic Calcic Haplic	Anthric Albic Fragic Manganiferric Ferric Abruptic Ruptic Humic Epidystric Hypereutric Oxyaquic Greyic Profondic Hyperochric Skeletic Arenic Siltic Clayic Rhodic Chromic Novic

[1] See Annex 1.

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having an *umbric* or *mollic* horizon.	Folic	Anthric
UMBRISOLS	Histic	Albic
	Technic	Brunic
	Leptic	Ornithic
	Vitric	Thionic
	Andic	Glossic
	Endogleyic	Humic
	Ferralic	Alumic
	Stagnic	Hyperdystric
	Mollic	Endoeutric
	Cambic	Pachic
	Haplic	Turbic
		Gelic
		Oxyaquic
		Greyic
		Laxic
		Placic
		Skeletic
		Arenic
		Siltic
		Clayic
		Chromic
		Drainic
		Novic
Other soils having	Lamellic	Ornithic
1. a weighted average texture of loamy sand or coarser, if cumulative layers of finer texture are less than 15 cm thick, either to a depth of 100 cm from the soil surface or to a *petroplinthic*, *pisoplinthic*, *plinthic* or *salic* horizon starting between 50 and 100 cm from the soil surface; *and*	Hypoluvic	Gypsiric
	Hyperalbic	Calcaric
	Albic	Tephric
	Rubic	Hyposalic
2. less than 40 percent (by volume) of gravels or coarser fragments in all layers within 100 cm of the soil surface or to a *petroplinthic*, *pisoplinthic*, *plinthic* or *salic* horizon starting between 50 and 100 cm from the soil surface; *and*	Brunic	Dystric
	Hydrophobic	Eutric
	Protic	Petrogleyic
3. no *fragic*, *irragric*, *hortic*, *plaggic* or *terric* horizon; *and*	Folic	Turbic
4. no layers with *andic or vitric* properties with a combined thickness of 15 cm.	Technic	Gelic
ARENOSOLS	Endosalic	Greyic
	Endogleyic	Placic
	Fractiplinthic	Hyperochric
	Petroplinthic	Yermic
	Pisoplinthic	Aridic
	Plinthic	Transportic
	Ferralic	Novic
	Haplic	

Key to the reference soil groups	Prefix qualifiers	Suffix qualifiers
Other soils having	Folic	Fragic
1. a *cambic* horizon starting within 50 cm of the soil surface and having its base 25 cm or more below the soil surface or 15 cm or more below any plough layer; *or*	Anthraquic	Manganiferric
	Hortic	Ferric
2. an *anthraquic*, *hortic*, *hydragric*, *irragric*, *plaggic* or *terric* horizon; *or*	Irragric	Ornithic
3. a *fragic*, *petroplinthic*, *pisoplinthic*, *plinthic*, *salic* or *vertic* horizon starting within 100 cm of the soil surface; *or*	Plaggic	Ruptic
	Terric	Colluvic
4. one or more layers with *andic or vitric* properties with a combined thickness of 15 cm or more within 100 cm of the soil surface.	Technic	Gypsiric
CAMBISOLS	Leptic	Calcaric
	Vertic	Tephric
	Fluvic	Alumic
	Endosalic	Sodic
	Vitric	Alcalic
	Andic	Humic
	Endogleyic	Dystric
	Fractiplinthic	Eutric
	Petroplinthic	Laxic
	Pisoplinthic	Turbic
	Plinthic	Gelic
	Ferralic	Oxyaquic
	Gelistagnic	Greyic
	Stagnic	Hyperochric
	Haplic	Takyric
		Yermic
		Aridic
		Skeletic
		Siltic
		Clayic
		Rhodic
		Chromic
		Escalic
		Novic
Other soils.	Aric	Ornithic
REGOSOLS	Colluvic	Gypsiric
	Technic	Calcaric
	Leptic	Tephric
	Endogleyic	Humic
	Thaptovitric	Hyposalic
	Thaptandic	Sodic
	Gelistagnic	Dystric
	Stagnic	Eutric
	Haplic	Turbic
		Gelic
		Oxyaquic
		Vermic
		Hyperochric
		Takyric
		Yermic
		Aridic
		Skeletic
		Arenic
		Siltic
		Clayic
		Escalic
		Transportic

Chapter 4
Description, distribution, use and management of reference soil groups

This chapter gives an overview of all the RSGs recognized in the WRB. A brief description is provided with corresponding names in other major soil classification systems, followed by the regional distribution of each group. Land use and management concludes each description. More detailed information on each RSG, including morphological, chemical and physical characteristics and genesis, is available in FAO (2001a) and a number of CD-ROMs (FAO, 2001b, 2003 and 2005). All these publications reflect the first edition of the WRB (FAO, 1998); new publications based on the current second edition are planned for the near future.

ACRISOLS

Acrisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. Acrisols have in certain depths a low base saturation and low-activity clays. Many Acrisols correlate with *Red Yellow Podzolic soils* (e.g. Indonesia), *Argissolos* (Brazil), *sols ferralitiques fortement ou moyennement désaturés* (France), *Red and Yellow Earths*, and *Ultisols* with low-activity clays (United States of America).

Summary description of Acrisols

Connotation: From Latin *acer*, very acid. Strongly weathered acid soils with low base saturation at some depth.

Parent material: On a wide variety of parent materials, most extensive from weathering of acid rocks, and notably in strongly weathered clays that are undergoing further degradation.

Environment: Mostly old land surfaces with hilly or undulating topography, in regions with a wet tropical/monsoonal, subtropical or warm temperate climate. Forest is the natural vegetation type.

Profile development: Pedogenetic differentiation of clay content with a lower content in the topsoil and a higher content in the subsoil; leaching of base cations owing to the humid environment and advanced degree of weathering.

Regional distribution of Acrisols

Acrisols are found in humid tropical, humid subtropical and warm temperate regions and are most extensive in Southeast Asia, the southern fringes of the Amazon Basin, the southeast of the United States of America, and in both East and West Africa. There are about 1 000 million ha of Acrisols worldwide.

Management and use of Acrisols

Preservation of the surface soil with its all-important organic matter and preventing erosion are preconditions for farming on Acrisols. Mechanical clearing of natural forest by extraction of root balls and filling of the holes with surrounding surface soil produces land that is largely sterile where Al concentrations of the former subsoil reach toxic levels.

Adapted cropping systems with complete fertilization and careful management are required if sedentary farming is to be practised on Acrisols. The widely used *slash-and-burn* agriculture (shifting cultivation) may seem primitive but it is a well-adapted form of land use, developed over centuries of trial and error. If occupation periods are short (one or a few years only) and followed by a sufficiently long generation period (up to several decades), this system makes a good use of the limited resources of Acrisols. Agroforestry is recommended as a soil-protecting alternative to shifting cultivation to achieve higher yields without requiring expensive inputs.

Low-input farming on Acrisols is not very rewarding. Undemanding, acidity-tolerant cash crops such as pineapple, cashew, tea and rubber can be grown with some success. Increasing areas of Acrisols are planted to oil-palm (e.g. in Malaysia and on Sumatra). Large areas of Acrisols are under forest, ranging from high, dense rain forest to open woodland. Most of the tree roots are concentrated in the humous surface horizon with only a few tap-roots extending down into the subsoil. In South America, Acrisols are also found under savannah. Acrisols are suitable for production of rainfed and irrigated crops only after liming and full fertilization. Rotation of annual crops with improved pasture maintains the organic matter content.

ALBELUVISOLS

Albeluvisols are soils that have, beginning within 1 m of the soil surface, a clay illuviation horizon with an irregular or broken upper boundary resulting in tonguing of bleached soil material into the illuviation horizon. Many Albeluvisols correlate with: *Podzoluvisols* (FAO); *Sod-podzolic* or *Podzolic* soils (Russian Federation); *Fahlerden* (Germany); and *Glossaqualfs*, *Glossocryalfs* and *Glossudalfs* (United States of America).

Summary description of Albeluvisols

Connotation: From Latin *albus*, white, and Latin *eluere*, to wash out.

Parent material: Mostly unconsolidated glacial till, materials of lacustrine or fluvial origin and aeolian deposits (loess).

Environment: Flat to undulating plains under coniferous forest (including boreal taiga) or mixed forest. The climate is temperate to boreal with cold winters, short and cool summers, and an average annual precipitation sum of 500–1 000 mm. Precipitation is distributed evenly over the year or, in the continental part of the Albeluvisol belt, has a peak in early summer.

Profile development: A thin, dark surface horizon over an *albic* subsurface horizon that tongues into an underlying brown *argic* horizon. Temporarily *reducing conditions* with a *stagnic colour pattern* are common in boreal Albeluvisols.

Regional distribution of Albeluvisols

Albeluvisols cover an estimated 320 million ha in Europe, North Asia and Central Asia, with minor occurrences in North America. Albeluvisols are concentrated in two regions, each having a particular set of climate conditions:

- the continental regions that had permafrost in the Pleistocene of northeast Europe, northwest Asia and southwest Canada, which constitute by far the largest areas of Albeluvisols;
- the loess and cover sand areas and old alluvial areas in moist temperate regions, such as France, central Belgium, the southeast of the Netherlands and the west of Germany.

Management and use of Albeluvisols

The agricultural suitability of Albeluvisols is limited because of their acidity, low nutrient levels, tillage and drainage problems and because of the climate, with its short growing season and severe frost during the long winter. The Albeluvisols of the northern taiga zone are almost exclusively under forest; small areas are used as pasture or hay fields. In the southern taiga zone, less than 10 percent of the non-forested area is used for agricultural production. Livestock farming is the main agricultural land use on Albeluvisols (dairy production and cattle rearing); arable cropping (cereals, potatoes, sugar beet and forage maize) plays a minor role.

In the Russian Federation, the share of arable farming increases in southern and western directions, especially on Albeluvisols with higher base saturations in the subsoil. With careful tillage, liming and application of fertilizers, Albeluvisols can produce 25–30 tonnes of potatoes per hectare, 2–5 tonnes of winter wheat or 5–10 tonnes of dry herbage.

ALISOLS

Alisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. Alisols have a low base saturation at certain depths and high-activity clays throughout the *argic* horizon. They lack the *albeluvic tonguing* as in Albeluvisols. They occur predominantly in humid tropical, humid subtropical and warm temperate regions. Many Alisols correlate with: *Alissolos* (Brazil); *Ultisols* with high-activity clays (United States of America); *Kurosols* (Australia); and *Fersialsols* and *sols fersiallitiques très lessivés* (France).

Summary description of Alisols

Connotation: Soils with a low base saturation at some depths; from Latin *alumen*, alum.

Parent material: In a wide variety of parent materials. Most occurrences of Alisols reported so far are on weathering products of basic rocks and unconsolidated materials.

Environment: Most common in hilly or undulating topography, in humid tropical, humid subtropical and monsoon climates.

Profile development: Pedogenetic differentiation of clay contents with a lower content in the topsoil and a higher content in the subsoil, leaching of base cations owing to the humid environment without advanced weathering of high-activity clays; highly leached Alisols might have an *albic* eluviation horizon between the surface horizon and the *argic* subsurface horizon but lack the *albeluvic tonguing* of Albeluvisols.

Regional distribution of Alisols

Major occurrences of Alisols are found in Latin America (Ecuador, Nicaragua, Venezuela, Colombia, Peru and Brazil), in the West Indies (Jamaica, Martinique and Saint Lucia), in West Africa, the highlands of East Africa, Madagascar, and in Southeast Asia and northern Australia. FAO (2001a) estimates that about 100 million ha of these soils are used for agriculture in the tropics.

Alisols occur also in subtropical regions; they are found in China, Japan and the southeast of the United States of America, and minor occurrences have been reported from around the Mediterranean Sea (Italy, France and Greece). They also occur in humid temperate regions.

Management and use of Alisols

Alisols occur predominantly on hilly or undulating topography. The generally unstable surface soil of cultivated Alisols makes them susceptible to erosion; truncated soils are quite common. Toxic levels of Al at shallow depth and poor natural soil fertility are added constraints in many Alisols. As a consequence, many Alisols allow only cultivation of shallow-rooting crops and crops suffer from drought stress in the dry season. A significant part of the Alisols is unproductive under a wide variety of crops. The use of acidity-tolerant crops or low-volume grazing is common. The productivity of Alisols in subsistence agriculture is generally low as these soils have a limited capacity to recover from chemical exhaustion. Where fully limed and fertilized, crops on Alisols may benefit from the considerable CEC and good water-holding capacity, and the Alisols may eventually grade into Luvisols. Alisols are increasingly planted to Al-tolerant estate crops such as tea and rubber but also to oil-palm and, in places, to coffee and sugar cane.

ANDOSOLS

Andosols accommodate the soils that develop in volcanic ejecta or glasses under almost any climate (except under hyperarid climate conditions). However, Andosols may also develop in other silicate-rich materials under acid weathering in humid and perhumid climates. Many Andosols belong to: *Kuroboku* (Japan); *Andisols* (United States of America); *Andosols* and *Vitrisols* (France); and *volcanic ash soils*.

Summary description of Andosols

Connotation: Typically black soils of volcanic landscapes; from Japanese *an*, black, and *do*, soil.

Parent material: Volcanic glasses and ejecta (mainly ash, but also tuff, pumice, cinders and others) or other silicate-rich material.

Environment: Undulating to mountainous, humid, and arctic to tropical regions with a wide range of vegetation types.

Profile development: Rapid weathering of porous volcanic ejecta or glasses results in accumulation of stable organo-mineral complexes or short-range-order minerals such as allophane, imogolite and ferrihydrite. Acid weathering of other silicate-rich material in humid and perhumid climates also leads to the formation of stable organo-mineral complexes.

Regional distribution of Andosols

Andosols occur in volcanic regions all over the world. Important concentrations are found around the Pacific rim: on the west coast of South America, in Central America, Mexico, United States of America (the Rocky Mountains, Alaska), Japan, the Philippine Archipelago, Indonesia, Papua New Guinea, and New Zealand. They are also prominent on many islands in the Pacific: Fiji, Vanuatu, New Caledonia, Samoa and Hawaii. In Africa, major occurrences of Andosols are found along the Rift Valley, in Kenya, Rwanda and Ethiopia and in Madagascar. In Europe, Andosols occur in Italy, France, Germany and Iceland. The total Andosol area is estimated at some 110 million ha or less than 1 percent of the global land surface. More than half of this area is situated in the tropics. Andosols originating from parent materials other than volcanic ejecta or glasses occur in humid (often mountainous) regions.

Management and use of Andosols

Andosols have a high potential for agricultural production, but many of them are not used up to their capacity. Andosols are generally fertile soils, particularly Andosols in intermediate or basic volcanic ash and not exposed to excessive leaching. The strong phosphate fixation of Andosols (caused by active Al and Fe) is a problem. Ameliorative measures to reduce this effect include application of lime, silica, organic material, and phosphate fertilizer.

Andosols are easy to cultivate and have good rootability and water storage properties. Strongly hydrated Andosols are difficult to till because of their low bearing capacity and their stickiness.

Andosols are planted to a wide variety of crops including sugar cane, tobacco, sweet potato (tolerant of low phosphate levels), tea, vegetables, wheat and orchard crops. Andosols on steep slopes are perhaps best kept under forest. Paddy rice cultivation is a major land use on Andosols in lowlands with shallow groundwater.

ANTHROSOLS

Anthrosols comprise soils that have been modified profoundly through human activities, such as addition of organic materials or household wastes, irrigation and cultivation. The group includes soils otherwise known as: *Plaggen soils*, *Paddy soils*, *Oasis soils*, *Terra Preta do Indio* (Brazil), *Agrozems* (Russian Federation), *Terrestrische anthropogene Böden* (Germany), *Anthroposols* (Australia), and *Anthrosols* (China).

Summary description of Anthrosols

Connotation: Soils with prominent characteristics that result from human activities; from Greek *anthropos*, human being.

Parent material: Virtually any soil material, modified by long-continued cultivation or addition of material.

Environment: In many regions where people have been practising agriculture for a long time.

Profile development: Influence of humans is normally restricted to the surface horizons; the horizon differentiation of a buried soil may still be intact at some depth.

Regional distribution of Anthrosols

Anthrosols are found wherever people have practised agriculture for a long time. Anthrosols with plaggic horizons are most common in northwest Europe. Together with Anthrosols with a terric horizon, they cover more than 500 000 ha.

Anthrosols with irragric horizons are found in irrigation areas in dry regions, e.g. in Mesopotamia, near oases in desert regions and in parts of India. Anthrosols with an anthraquic horizon overlying a hydragric horizon (*paddy soils*) occupy vast areas in China and in parts of South and Southeast Asia (e.g. Sri Lanka, Viet Nam, Thailand and Indonesia). Anthrosols with hortic horizons are found all over the world where humans have fertilized the soil with household wastes and manure. The *Terra Preta do Indio* in the Amazon Region of Brazil belongs to this group.

Management and use of Anthrosols

Plaggic horizons have favourable physical properties (porosity, rootability and moisture availability), but many have less satisfactory chemical characteristics (acidity, and nutrient deficiencies). Rye, oats, barley, potato, and also the more demanding sugar beet and summer wheat are common crops on European Anthrosols with a *plaggic* horizon. Prior to the advent of chemical fertilizers, rye yields were 700–1 100 kg/ha, or 4–5 times the quantity of seed used. Today, these soils receive generous doses of fertilizers and average per-hectare yield levels for rye, barley and summer wheat are 5 000, 4 500 and 5 500 kg, respectively. Sugar beet and potato produce 40–50 tonnes/ha. Nowadays, they are increasingly used for production of silage maize and grass; per-hectare production levels of 12–13 tonnes of dry maize silage and 10–13 tonnes of dry grass are considered normal. In places, Anthrosols with *plaggic* horizons are used for tree nurseries and horticulture. The good drainage and the dark colour of the surface soil (early warming in spring) make it possible to till and sow or plant early in the season. Soils with deep *plaggic* horizons in the Netherlands were in demand for the cultivation of tobacco until the 1950s.

Anthrosols with a *hortic* horizon are *kitchen soils*. Well-known examples are situated on river terraces in south Maryland, United States of America, and along the Amazon River in Brazil. They have deep, black topsoils formed in layers of kitchen refuse (mainly oyster shells, fish bones, etc.) from early Indian habitations. Many countries possess small areas of soils that were modified by early inhabitants.

Long-continued wet cultivation of rice leads to an *anthraquic* horizon with an underlying *hydragric* horizon. Puddling of wetland rice fields (involving destruction of the natural soil structure by intensive tillage when the soil is saturated with water) is done intentionally, *inter alia* to reduce percolation losses.

Anthrosols with *irragric* horizons are formed as a result of prolonged sedimentation (predominantly silt) from irrigation water. A special case is found in depression areas where dryland crops are commonly planted on constructed ridges that alternate with drainage furrows. The original soil profile of the ridge areas is buried under a thick layer of added soil material. The ridge-and-furrow system is known from such different environments as the wet forests of western Europe and the coastal swamps of Southeast Asia where the ridges are planted to dryland crops and rice is grown in the shallow ditch areas.

In parts of western Europe, notably in Ireland and the United Kingdom, calcareous materials (e.g. beach sands) were carted to areas with acid Arenosols, Podzols, Albeluvisols and Histosols. Eventually these modified surface layers of mineral material turned into *terric* horizons that give the soil much improved properties for arable cropping than the original surface soil. In Central Mexico, deep soils were constructed of organic-matter-rich lacustrine sediments, thus forming a system of artificial islands and channels (*chinampas*). These soils have a *terric* horizon and were the most productive lands of the Aztec empire; now most of these soils are affected by salinization.

ARENOSOLS

Arenosols comprise sandy soils, including both soils developed in residual sands after *in situ* weathering of usually quartz-rich sediments or rock, and soils developed in recently deposited sands such as dunes in deserts and beach lands. Corresponding soils in other classification systems include *Psamments* of the US Soil Taxonomy and the *sols minéraux bruts* and *sols peu évolués* in the French classification system of the CPCS (1967). Many Arenosols belong to *Arenic Rudosols* (Australia), *Psammozems* (Russian Federation) and *Neossolos* (Brazil).

Summary description of Arenosols

Connotation: Sandy soils; from Latin *arena*, sand.

Parent material: Unconsolidated, in places calcareous, translocated materials of sandy texture; relatively small areas of Arenosols occur in extremely weathered siliceous rock.

Environment: From arid to humid and perhumid, and from extremely cold to extremely hot; landforms vary from recent dunes, beach ridges and sandy plains to very old plateaus; the vegetation ranges from desert over scattered vegetation (mostly grassy) to light forest.

Profile development: In the dry zone, there is little or no soil development. Arenosols in the perhumid tropics tend to develop thick *albic* eluviation horizons (with a *spodic* horizon below 200 m from the soil surface) whereas most Arenosols of the humid temperate zone show signs of alteration or transport of humus, Fe or clay, but too weak to be diagnostic.

Regional distribution of Arenosols

Arenosols are one of the most extensive RSGs in the world; including shifting sands and active dunes, they cover about 1 300 million ha, or 10 percent of the land surface. Vast expanses of deep aeolian sands are found on the Central African plateau between the equator and 30 °S. These *Kalahari Sands* form the largest body of sands on earth. Other areas of Arenosols occur in the Sahelian region of Africa, various parts of the Sahara, central and western Australia, the Near East, and China. Sandy coastal plains and coastal dune areas are of smaller geographic extent.

Although most Arenosols occur in arid and semi-arid regions, they are typical azonal soils; they are found in the widest possible range of climates, from very arid to very humid and from cold to hot. Arenosols are widespread in aeolian landscapes but occur also in marine, littoral, and lacustrine sands and in coarse-grained weathering mantles of siliceous rocks, mainly sandstone, quartzite and granite. There is no limitation as to age or period in which soil formation took place. Arenosols occur on very old surfaces as well as in very recent landforms, and may be associated with almost any type of vegetation.

Management and use of Arenosols

Arenosols occur in widely different environments, and possibilities to use them for agriculture vary accordingly. The characteristic that all Arenosols have in common is their coarse texture, accounting for their generally high permeability and low water and nutrient storage capacity. On the other hand, Arenosols offer ease of cultivation, rooting and harvesting of root and tuber crops.

Arenosols in **arid lands**, where the annual rainfall is less than 300 mm, are predominantly used for extensive (nomadic) grazing. Dry farming is possible where the annual rainfall exceeds 300 mm. Low coherence, low nutrient storage capacity and high sensitivity to erosion are serious limitations of Arenosols in the dry zone. Good yields of small grains, melons, pulses and fodder crops have been realized on irrigated Arenosols, but high percolation losses may make surface irrigation impracticable. Drip or trickle irrigation, possibly combined with careful dosage of fertilizers, may remedy the situation. Many areas with Arenosols in the Sahelian zone (annual rainfall of 300–600 mm) are transitional to the Sahara, and their soils are covered with sparse vegetation. Uncontrolled grazing and clearing for cultivation without appropriate soil conservation measures can easily make these soils unstable and revert them to shifting dunes.

Arenosols in the **humid and subhumid temperate zone** have similar limitations as those of the dry zone, albeit that drought is a less serious constraint. In some instances, e.g. in horticulture, the low water storage of Arenosols is considered advantageous because the soils warm up early in the season. In mixed farming systems (which are much more common) with cereals, fodder crops and grassland, supplemental sprinkler irrigation is applied during dry spells. A large part of the Arenosols of the temperate zone is under forest, either production forest or *natural* stands in carefully managed nature reserves.

Arenosols in the **humid tropics** are best left under their natural vegetation, particularly so the deeply weathered Arenosols with an *albic* horizon. As nutrient elements are all concentrated in the biomass and in the soil organic matter, clearing of the land will inevitably produce infertile badlands without ecological or economic value. Under forest, the land can still produce some timber (e.g. *Agathis* spp.) and wood for the pulp and paper industry. Permanent cultivation of annual crops would require management inputs that are usually not economically justifiable. In places, Arenosols have been planted to perennial crops such as rubber and pepper; coastal sands are widely planted to estate crops such as coconut, cashew, casuarinas and pine, especially where good quality groundwater is within reach of the root system. Root and tuber crops benefit from the ease of harvesting, notably cassava, with its tolerance of low nutrient levels. Groundnut and bambara groundnut can be found on the better soils.

Arenosols and related soils with a sandy surface texture in some regions (e.g. west Australia and parts of South Africa) may be prone to develop water-repellency, typically caused by hydrophobic exudates of soil fungi that coat sand grains. Water-repellency is most intense after lengthy spells of hot, dry weather and leads to differential water infiltration. This is thought to have ecological significance in promoting plant species diversity (e.g. in Namaqualand). Wetting agents (surfactants such as calcium lignosulphonate) are sometimes used to achieve more uniform water penetration under irrigation. Dryland wheat farmers in Australia mine clay and apply it to their sandy soils with specialized machinery. The results (more uniform germination and better herbicide efficiency) can be economically attractive where a local source of clay is available.

CALCISOLS

Calcisols accommodate soils in which there is substantial secondary accumulation of lime. Calcisols are common in highly calcareous parent materials and widespread in arid and semi-arid environments. Formerly used soil names for many Calcisols include *Desert soils* and *Takyrs*. In the US Soil Taxonomy, most of them belong to the *Calcids*.

Summary description of Calcisols

Connotation: Soils with substantial accumulation of secondary lime; from Latin *calx*, lime.

Parent material: Mostly alluvial, colluvial and aeolian deposits of base-rich weathering material.

Environment: Level to hilly land in arid and semi-arid regions. The natural vegetation is sparse and dominated by xerophytic shrubs and trees and/or ephemeral grasses.

Profile development: Typical Calcisols have a pale brown surface horizon; substantial secondary accumulation of lime occurs within 100 cm of the surface.

Regional distribution of Calcisols

It is difficult to quantify the worldwide extent of Calcisols with any measure of accuracy. Many Calcisols occur together with Solonchaks that are actually salt-affected Calcisols and/or with other soils having secondary accumulation of lime that do not key out as Calcisols. The total Calcisol area may well amount to some 1 000 million ha, nearly all of it in the arid and semi-arid tropics and subtropics of both hemispheres.

Land use and management of Calcisols

Vast areas of so-called natural Calcisols are under shrubs, grasses and herbs and are used for extensive grazing. Drought-tolerant crops such as sunflower might be grown rainfed, preferably after one or a few fallow years, but Calcisols reach their full productive capacity only where carefully irrigated. Extensive areas of Calcisols are used for production of irrigated winter wheat, melons, and cotton in the Mediterranean zone. *Sorghum bicolor* (el sabeem) and fodder crops, such as Rhodes grass and alfalfa, are tolerant of high Ca levels. Some 20 vegetable crops have been grown successfully on irrigated Calcisols fertilized with nitrogen (N), phosphorus (P) and trace elements (Fe and zinc [Zn]).

Furrow irrigation is superior to basin irrigation on *slaking* Calcisols because it reduces surface crusting/caking and seedling mortality; pulse crops in particular are very vulnerable in the seedling stage. In places, arable farming is hindered by stoniness of the surface soil and/or a *petrocalcic* horizon at shallow depth.

CAMBISOLS

Cambisols combine soils with at least an incipient subsurface soil formation. Transformation of parent material is evident from structure formation and mostly brownish discoloration, increasing clay percentage, and/or carbonate removal. Other soil classification systems refer to many Cambisols as: *Braunerden* (Germany), *Sols bruns* (France), *Brown soils/Brown Forest soils* (older US systems), or *Burozems* (Russian Federation). FAO coined the name *Cambisols*, adopted by Brazil (*Cambissolos*); US Soil Taxonomy classifies most of these soils as *Inceptisols*.

Summary description of Cambisols

Connotation: Soils with at least the beginnings of horizon differentiation in the subsoil evident from changes in structure, colour, clay content or carbonate content; from Italian *cambiare*, to change.

Parent material: Medium and fine-textured materials derived from a wide range of rocks.

Profile development: Cambisols are characterized by slight or moderate weathering of parent material and by absence of appreciable quantities of illuviated clay, organic matter, Al and/or Fe compounds.

Environment: Level to mountainous terrain in all climates; wide range of vegetation types.

Regional distribution of Cambisols

Cambisols cover an estimated 1 500 million ha worldwide. This RSG is particularly well represented in temperate and boreal regions that were under the influence of glaciations during the Pleistocene, partly because the parent material of the soil is still young, but also because soil formation is slow in cool regions. Erosion and deposition cycles explain the occurrence of Cambisols in mountain regions. Cambisols also occur in dry regions but are less common in the humid tropics and subtropics where weathering and soil formation proceed at much faster rates than in temperate, boreal and dry regions. The young alluvial plains and terraces of the Ganges–Brahmaputra system are probably the largest continuous surface of Cambisols in the tropics. Cambisols are also common in areas with active geologic erosion, where they may occur in association with mature tropical soils.

Management and use of Cambisols

Cambisols generally make good agricultural land and are used intensively. Cambisols with high base saturation in the temperate zone are among the most productive soils on earth. More acid Cambisols, although less fertile, are used for mixed arable farming and as grazing and forest land. Cambisols on steep slopes are best kept under forest; this is particularly true for Cambisols in highlands.

Cambisols on irrigated alluvial plains in the dry zone are used intensively for production of food and oil crops. Cambisols in undulating or hilly terrain (mainly colluvial) are planted to a variety of annual and perennial crops or are used as grazing land.

Cambisols in the humid tropics are typically poor in nutrients but are still richer than associated Acrisols or Ferralsols and they have a greater CEC. Cambisols with groundwater influence in alluvial plains are highly productive *paddy soils*.

CHERNOZEMS

Chernozems accommodate soils with a thick black surface layer that is rich in organic matter. The Russian soil scientist Dokuchaev coined the name *Chernozem* in 1883 to denote the typical *zonal* soil of the tall grass steppes in continental Russia. Many Chernozems correspond to: *Calcareous Black Soils* and *Kalktschernoseme* (Germany); *Chernosols* (France); *Eluviated Black Soils* (Canada); several suborders (especially *Udolls*) of the *Mollisols* (United States of America); and *Chernossolos* (Brazil).

Summary description of Chernozems

Connotation: Black soils rich in organic matter; from Russian *chernij*, black, and *zemlja*, earth or land.

Parent material: Mostly aeolian and re-washed aeolian sediments (loess).

Environment: Regions with a continental climate with cold winters and hot summers, which are dry at least in the late summer; in flat to undulating plains with tall-grass vegetation (forest in the northern transitional zone).

Profile development: Dark brown to black *mollic* surface horizon, in many cases over a *cambic* or *argic* subsurface horizon; with *secondary carbonates* or a *calcic* horizon in the subsoil.

Regional distribution of Chernozems

Chernozems cover an estimated 230 million ha worldwide, mainly in the middle latitude steppes of Eurasia and North America, north of the zone with Kastanozems.

Management and use of Chernozems

Russian soil scientists rank the deep, central Chernozems among the best soils in the world. With less than half of all Chernozems in Eurasia being used for arable cropping, these soils constitute a formidable resource for the future. Preservation of the favourable soil structure through timely cultivation and careful irrigation at low watering rates prevents ablation and erosion. Application of P fertilizers is required for high yields. Wheat, barley and maize are the principal crops grown, alongside other food crops and vegetables. Part of the Chernozem area is used for livestock rearing. In the northern temperate belt, the possible growing period is short and the principal crops grown are wheat and barley, in places in rotation with vegetables. Maize is widely grown in the warm temperate belt. Maize production tends to stagnate in drier years unless the crop is irrigated adequately.

CRYOSOLS

Cryosols comprise mineral soils formed in a permafrost environment. Where water is present, it occurs primarily in the form of ice. Cryogenic processes are the dominant soil-forming processes. Cryosols are widely known as *permafrost soils*. Other common names for many Cryosols are: *Gelisols* (United States of America), *Cryozems* (Russian Federation), *Cryomorphic soils* and *Polar desert soils*.

Summary description of Cryosols

Connotation: Frost-affected soils; from Greek *kryos*, cold.

Parent material: A wide variety of materials, including glacial till and aeolian, alluvial, colluvial and residual materials.

Environment: Flat to mountainous areas in Antarctic, Arctic, subarctic and boreal regions affected by permafrost, notably in depressions. Cryosols are associated with sparsely to continuously vegetated tundra, open-canopy lichen coniferous forest and closed-canopy coniferous or mixed coniferous and deciduous forest.

Profile development: In the presence of water, cryogenic processes produce cryoturbated horizons, frost heave, thermal cracking, ice segregation and patterned ground microrelief.

Regional distribution of Cryosols

Geographically, Cryosols are circumpolar in both the Northern and Southern Hemispheres. They cover an estimated 180 million km^2, or about 13 percent of the global land surface. Cryosols occur in the permafrost regions of the Arctic, and are widespread in the subarctic zone, discontinuous in the boreal zone, and sporadic in more temperate mountainous regions. Major areas with Cryosols are found in the Russian Federation (100 million ha), Canada (25 million ha), China (19 million ha), Alaska (11 million ha), and in parts of Mongolia. Smaller occurrences have been reported from northern Europe, Greenland and the ice-free areas of Antarctica.

Management and use of Cryosols

Natural and human-induced biological activity in Cryosols is confined to the active surface layer that thaws every summer and also protects the underlying permafrost. Removal of the peat layer on top of the soil or of the vegetation and/or disturbance of the surface soil often lead to alterations of the permafrost depth and to rapid and drastic environmental changes, with possible damage to structures created by humans.

Most areas of Cryosols in North America and Eurasia are in the natural state and support sufficient vegetation for grazing animals, such as caribou, reindeer and musk oxen. Large herds of caribou still migrate seasonally in the northern part of North America; reindeer herding is an important industry in the vast northern areas, especially in northern Europe. Overgrazing leads rapidly to erosion and other environmental damage.

Human activities, mainly relating to agriculture, oil and gas production, and mining, have had a major impact on these soils. Severe *thermokarsting* has occurred on land cleared for agriculture. Improper management of pipelines and mining can cause oil spills and chemical pollution that affect large areas.

DURISOLS

Durisols are associated mainly with old surfaces in arid and semi-arid environments and accommodate very shallow to moderately deep, moderately well- to well-drained soils that contain cemented secondary silica (SiO_2) within 100 cm of the soil surface. Many Durisols are known as: *hardpan soils* (Australia), *dorbank* (South Africa), *Durids* (United States of America), or as *duripan phase* of other soils, e.g. of *Calcisols* (FAO).

Summary description of Durisols

Connotation: Soils with hardened secondary silica; from Latin *durus*, hard.

Parent material: Silicate-rich materials, mainly alluvial and colluvial deposits of all texture classes.

Environment: Level and slightly sloping alluvial plains, terraces and gently sloping piedmont plains in arid, semi-arid and Mediterranean regions.

Profile development: Strongly weathered soils with a hard layer of secondary silica (*petroduric* horizon); eroded Durisols with exposed *petroduric* horizons are common in gently sloping terrain.

Regional distribution of Durisols

Extensive areas of Durisols occur in Australia, in South Africa and Namibia, and in the United States of America (notably, Nevada, California and Arizona); minor occurrences have been reported from Central and South America and from Kuwait. Durisols are a relatively new introduction in international soil classification and have not often been mapped as such. A precise indication of their extent is not yet available.

Land use and management of Durisols

The agricultural use of Durisols is limited to extensive grazing (rangeland). Durisols in natural environments generally support enough vegetation to contain erosion, but elsewhere erosion of the surface soil is widespread.

Stable landscapes occur in dry regions where Durisols were eroded down to their resistant *duripan*. Durisols may be cultivated with some success where sufficient irrigation water is available. A *petroduric* horizon may need to be broken up or removed altogether if it forms a barrier to root and water penetration. Excess levels of soluble salts may affect Durisols in low-lying areas. Hard *duripan* material is widely used in road construction.

FERRALSOLS

Ferralsols represent the classical, deeply weathered, red or yellow soils of the humid tropics. These soils have diffuse horizon boundaries, a clay assemblage dominated by low-activity clays (mainly kaolinite) and a high content of sesquioxides. Local names usually refer to the colour of the soil. Many Ferralsols are known as: *Oxisols* (United States of America); *Latossolos* (Brazil); *Alítico*, *Ferrítico* and *Ferralítico* (Cuba); *Sols ferralitiques* (France); and *Ferralitic soils* (Russian Federation).

Summary description of Ferralsols

Connotation: Red and yellow tropical soils with a high content of sesquioxides; from Latin *ferrum*, iron, and *alumen*, alum.

Parent material: Strongly weathered material on old, stable geomorphic surfaces; more commonly in material weathered from basic rock than from siliceous material.

Environment: Typically in level to undulating land of Pleistocene age or older; less common on younger, easily weathering rocks. Perhumid or humid tropics; minor occurrences elsewhere are considered to be relics from past eras with a warmer and wetter climate than today.

Profile development: Deep and intensive weathering has resulted in a residual concentration of resistant primary minerals (e.g. quartz) alongside sesquioxides and kaolinite. This mineralogy and the relatively low pH explain the stable microstructure (pseudo-sand) and yellowish (goethite) or reddish (hematite) soil colours.

Regional distribution of Ferralsols

The worldwide extent of Ferralsols is estimated at some 750 million ha, almost exclusively in the humid tropics on the continental shields of South America (especially Brazil) and Africa (especially Congo, Democratic Republic of the Congo, southern Central African Republic, Angola, Guinea and eastern Madagascar). Outside the continental shields, Ferralsols are restricted to regions with easily weathering basic rock and a hot and humid climate, e.g. in Southeast Asia.

Management and use of Ferralsols

Most Ferralsols have good physical properties. Great soil depth, good permeability and stable microstructure make Ferralsols less susceptible to erosion than most other intensely weathered tropical soils. Moist Ferralsols are friable and easy to work. They are well drained but may in times be droughty because of their low available water storage capacity.

The chemical fertility of Ferralsols is poor; weatherable minerals are scarce or absent, and cation retention by the mineral soil fraction is weak. Under natural vegetation, nutrient elements that are taken up by the roots are eventually returned to the surface soil with falling leaves and other plant debris. The bulk of all cycling plant nutrients is contained in the biomass; available plant nutrients in the soil are concentrated in the soil organic matter. If the process of *nutrient cycling* is interrupted, e.g. upon introduction of low-input sedentary subsistence farming, the rootzone will rapidly become depleted of plant nutrients.

Maintaining soil fertility by manuring, mulching and/or adequate (i.e. long enough) fallow periods or agroforestry practices, and prevention of surface soil erosion are important management requirements.

Strong retention (*fixing*) of P is a characteristic problem of Ferralsols (and several other soils, e.g. Andosols). Ferralsols are normally also low in N, K, secondary nutrients (Ca, Mg and S), and some 20 micronutrients. Silica deficiency is possible where silica-demanding crops (e.g. grasses) are grown. In Mauritius, soils are tested for available silica and fertilized with silica amendments. Manganese and Zn, which are very soluble at low pH, may at some time reach toxic levels in the soil or become deficient after intense leaching of the soil. Boron and copper deficiencies may also be encountered.

Liming is a means of raising the pH value of the rooted surface soil. Liming combats Al toxicity and raises the ECEC. On the other hand, it lowers the anion exchange capacity, which might lead to collapse of structure elements and slaking at the soil surface. Therefore, frequent small doses of lime or basic slag are preferable to one massive application; 0.5–2 tonnes/ha of lime or dolomite are normally enough to supply Ca as a nutrient and to buffer the low soil pH of many Ferralsols. Surface application of gypsum, as a suitably mobile form of Ca, can increase the depth of crop root development (in addition, the sulphate in the gypsum reacts with sesquioxides to produce a “self-liming” effect). This relatively recent innovation is now practised widely, especially in Brazil.

Fertilizer selection and the mode and timing of fertilizer application determine to a great extent the success of agriculture on Ferralsols. Slow-release phosphate (phosphate rock) applied at a rate of several tonnes per hectare eliminates P deficiency for a number of years. For a quick fix, much more soluble double or triple superphosphate is used, needed in much smaller quantities, especially if placed in the direct vicinity of the roots. The phosphate rock option is probably only viable economically where it is locally available and when other P fertilizers are not easily purchased.

Sedentary subsistence farmers and shifting cultivators on Ferralsols grow a variety of annual and perennial crops. Extensive grazing is also common and considerable areas of Ferralsols are not used for agriculture at all. The good physical properties of Ferralsols and the often level topography would encourage more intensive forms of land use if problems caused by poor chemical properties could be overcome.

FLUVISOLS

Fluvisols accommodate genetically young, azonal soils in alluvial deposits. The name *Fluvisols* may be misleading in the sense that these soils are not confined only to *river* sediments (Latin *fluvius*, river); they also occur in lacustrine and marine deposits. Many Fluvisols correlate with: *Alluvial soils* (Russian Federation); *Hydrosols* (Australia); *Fluvents* and *Fluvaquents* (United States of America); *Auenböden*, *Marschen*, *Strandböden*, *Watten* and *Unterwasserböden* (Germany); *Neossolos* (Brazil); and *Sols minéraux bruts d’apport alluvial ou colluvial* or *Sols peu évolués non climatiques d’apport alluvial ou colluvial* (France).

Summary description of Fluvisols

Connotation: Soils developed in alluvial deposits; from Latin *fluvius*, river.

Parent material: Predominantly recent, fluvial, lacustrine and marine deposits.

Environment: Alluvial plains, river fans, valleys and tidal marshes on all continents and in all climate zones; many Fluvisols under natural conditions are flooded periodically.

Profile development: Profiles with evidence of stratification; weak horizon differentiation but a distinct topsoil horizon may be present. *Redoximorphic* features are common, in particular in the lower part of the profile.

Regional distribution of Fluvisols

Fluvisols occur on all continents and in all climates. They occupy some 350 million ha worldwide, of which more than half are in the tropics. Major concentrations of Fluvisols are found:

- along rivers and lakes, e.g. in the Amazon basin, the Ganges Plain of India, the plains near Lake Chad in Central Africa, and the marshlands of Brazil, Paraguay and northern Argentina;
- in deltaic areas, e.g. the deltas of the Ganges–Brahmaputra, Indus, Mekong, Mississippi, Nile, Niger, Orinoco, Plate, Po, Rhine and Zambezi;
- in areas of recent marine deposits, e.g. the coastal lowlands of Sumatra, Kalimantan and Irian (Indonesia and Papua New Guinea).

Major areas of Fluvisols with a *thionic* horizon or *sulphidic* material (*Acid Sulphate Soils*) are found in the coastal lowlands of Southeast Asia (Indonesia, Viet Nam and Thailand), West Africa (Senegal, Gambia, Guinea Bissau, Sierra Leone and Liberia) and along the northeast coast of South America (French Guiana, Guyana, Suriname and Venezuela).

Management and use of Fluvisols

The good natural fertility of most Fluvisols and attractive dwelling sites on river levees and on higher parts in marine landscapes were recognized in prehistoric times. Later, great civilizations developed in river landscapes and on marine plains.

Paddy rice cultivation is widespread on tropical Fluvisols with satisfactory irrigation and drainage. Paddy land should be dry for at least a few weeks every year in order to prevent the redox potential of the soil from becoming so low that nutritional problems (Fe or H_2S) arise. A dry period also stimulates microbial activity and promotes mineralization of organic matter. Many dryland crops are grown on Fluvisols as well, normally with some form of water control.

Tidal lands that are strongly saline are best kept under mangroves or some other salt-tolerant vegetation. Such areas are ecologically valuable and can, with caution, be used for fishing, hunting, salt pans or woodcutting for charcoal or fuelwood. Fluvisols with a *thionic* horizon or *sulphidic* material suffer from severe acidity and high levels of Al toxicity.

GLEYSOLS

Gleysols are wetland soils that, unless drained, are saturated with groundwater for long enough periods to develop a characteristic *gleyic colour pattern*. This pattern is essentially made up of reddish, brownish or yellowish colours at ped surfaces and/or in the upper soil layer or layers, in combination with greyish/bluish colours inside the peds and/or deeper in the soil. Common names for many Gleysols are: *gley* and *meadow soils* (former Soviet Union); *Gleyzems* (Russian Federation); *Gleye* (Germany); *Gleissolos* (Brazil); and *groundwater soils*. Many of the WRB Gleysols correlate with the aquic suborders of the US Soil Taxonomy (*Aqualfs*, *Aquents*, *Aquepts*, *Aquolls*, etc).

Summary description of Gleysols

Connotation: Soils with clear signs of groundwater influence; from Russian *gley*, mucky mass.

Parent material: A wide range of unconsolidated materials, mainly fluvial, marine and lacustrine sediments of Pleistocene or Holocene age, with basic to acidic mineralogy.

Environment: Depression areas and low landscape positions with shallow groundwater.

Profile development: Evidence of reduction processes with segregation of Fe compounds within 50 cm of the soil surface.

Regional distribution of Gleysols

Gleysols occupy an estimated 720 million ha worldwide. They are azonal soils and occur in nearly all climates, from perhumid to arid. The largest extent of Gleysols is in subarctic areas in the north of the Russian Federation (especially Siberia), Canada and Alaska, and in humid temperate and subtropical lowlands, e.g. in China and Bangladesh. An estimated 200 million ha of Gleysols are found in the tropics, mainly in the Amazon region, equatorial Africa, and the coastal swamps of Southeast Asia.

Management and use of Gleysols

The main obstacle to utilization of Gleysols is the necessity to install a drainage system to lower the groundwater table. Adequately drained Gleysols can be used for arable cropping, dairy farming and horticulture. Soil structure will be destroyed for a long time if soils are cultivated when too wet. Therefore, Gleysols in depression areas with unsatisfactory possibilities to lower the groundwater table are best kept under a permanent grass cover or swamp forest. Liming of drained Gleysols that are high in organic matter and/or of low pH value creates a better habitat for micro- and meso-organisms and enhances the rate of decomposition of soil organic matter (and the supply of plant nutrients).

Gleysols can be put under tree crops only after the water table has been lowered with deep drainage ditches. Alternatively, the trees are planted on ridges that alternate with shallow depressions in which rice is grown. This *sorjan* system is applied widely in tidal swamp areas with pyritic sediments in Southeast Asia. Gleysols can be well used for wetland rice cultivation where the climate is appropriate. Gleysols with a *thionic* horizon or *sulphidic* material suffer from severe acidity and high levels of Al toxicity.

GYPSISOLS

Gypsisols are soils with substantial secondary accumulation of gypsum ($CaSO_4.2H_2O$). These soils are found in the driest parts of the arid climate zone, which explains why leading soil classification systems labelled many of them *Desert soils* (former Soviet Union), and *Yermosols* or *Xerosols* (FAO–UNESCO, 1971–1981). The US Soil Taxonomy terms most of them *Gypsids*.

Summary description of Gypsisols

Connotation: Soils with substantial accumulation of secondary calcium sulphate; from Greek *gypsos*, gypsum.

Parent material: Mostly unconsolidated alluvial, colluvial or aeolian deposits of base-rich weathering material.

Environment: Predominantly level to hilly land and depression areas (e.g. former inland lakes) in regions with an arid climate. The natural vegetation is sparse and dominated by xerophytic shrubs and trees and/or ephemeral grasses.

Profile development: Light-coloured surface horizon; accumulation of calcium sulphate, with or without carbonates, is concentrated in the subsoil.

Regional distribution of Gypsisols

Gypsisols are exclusive to arid regions; their worldwide extent is probably of the order of 100 million ha. Major occurrences are in and around Mesopotamia, in desert areas in the Near East and adjacent Central Asian republics, in the Libyan and Namib deserts, in southeast and central Australia and in the southwest of the United States of America.

Management and use of Gypsisols

Gypsisols that contain only a low percentage of gypsum in the upper 30 cm can be used for the production of small grains, cotton, alfalfa, etc. Dry farming on deep Gypsisols makes use of fallow years and other water harvesting techniques but is rarely very rewarding because of the adverse climate conditions. Gypsisols in young alluvial and colluvial deposits have a relatively low gypsum content. Where such soils are in the vicinity of water resources, they can be very productive; many irrigation projects are established on such soils. However, even soils containing 25 percent powdery gypsum or more could still produce excellent yields of alfalfa hay (10 tonnes/ha), wheat, apricots, dates, maize and grapes if irrigated at high rates in combination with forced drainage. Irrigated agriculture on Gypsisols is plagued by rapid dissolution of soil gypsum, resulting in irregular subsidence of the land surface, caving in canal walls, and corrosion of concrete structures. Large areas with Gypsisols are in use for extensive grazing.

HISTOSOLS

Histosols comprise soils formed in *organic material*. These vary from soils developed in predominantly moss peat in boreal, arctic and subarctic regions, via moss peat, reeds/sedge peat (fen) and forest peat in temperate regions to mangrove peat and swamp forest peat in the humid tropics. Histosols are found at all altitudes, but the vast majority occurs in lowlands. Common names are *peat soils*, *muck soils*, *bog soils* and *organic soils*. Many Histosols belong to: *Moore*, *Felshumusböden* and *Skeletthumusböden* (Germany); *Organosols* (Australia); *Organossolos* (Brazil); *Organic order* (Canada); and *Histosols* and *Histels* (United States of America).

Summary description of Histosols

Connotation: Peat and muck soils; from Greek *histos*, tissue.

Parent material: Incompletely decomposed plant remains, with or without admixtures of sand, silt or clay.

Environment: Histosols occur extensively in boreal, arctic and subarctic regions. Elsewhere, they are confined to poorly drained basins and depressions, swamp and marshlands with shallow groundwater, and highland areas with a high precipitation–evapotranspiration ratio.

Profile development: Mineralization is slow and transformation of plant remains through biochemical disintegration, and formation of humic substances creates a surface layer of mould with or without prolonged water saturation. Translocated organic material may accumulate in deeper tiers but is more often leached from the soil.

Regional distribution of Histosols

The total extent of Histosols in the world is estimated at some 325–375 million ha, the majority located in the boreal, subarctic and low arctic regions of the Northern Hemisphere. Most of the remaining Histosols occur in temperate lowlands and cool montane areas; only one-tenth of all Histosols are found in the tropics. Extensive areas of Histosols occur in the United States of America and Canada, western Europe and northern Scandinavia, and in northern regions east of the Ural mountain range. Some 20 million ha of tropical forest peat border the Sunda shelf in Southeast Asia. Smaller areas of tropical Histosols are found in river deltas, e.g. in the Orinoco Delta and the delta of the River Mekong, and in depression areas at some altitude.

Management and use of Histosols

The properties of the organic material (botanical composition, stratification, degree of decomposition, packing density, wood content, mineral admixtures, etc.) and the type of peat bog (basin peat [fen], raised bog, etc.) determine the management requirements and use possibilities of Histosols. Histosols without prolonged water saturation are often formed in cold environments unattractive for agricultural use. Natural peats need to be drained and, normally, also limed and fertilized in order to permit cultivation of normal crops. Centrally guided reclamation projects are almost exclusive to the temperate zone, where millions of hectares have been opened. In many instances, this has initiated the gradual degradation, and ultimately the loss, of the precious peat. In the tropics, increasing numbers of landless farmers venture onto the peat lands, where they clear the forest and cause raging peat fires in the process. Many of them abandon their land again after only a few years; the few that succeed are on shallow, topogenous peat. In recent decades, increasing areas of tropical peat land have been planted to oil-palm and pulp wood tree species such as *Acacia mangium*, *Acacia crassicarpa* and *Eucalyptus* sp. This practice may be less than ideal but it is far less destructive than arable subsistence farming.

Another common problem encountered when Histosols are drained is the oxidation of sulphidic minerals, which accumulate under anaerobic conditions, especially in coastal regions. The sulphuric acid produced effectively destroys productivity unless lime is applied copiously, making the cost of reclamation prohibitive.

In summary, it is desirable to protect and conserve fragile peat lands because of their intrinsic value (especially their common function as sponges in regulating stream flow and in supporting wetlands containing unique species of animals) and because prospects for their sustained agricultural use are meagre. Where their use is imperative, sensible forms of forestry or plantation cropping are to be preferred over annual cropping, horticulture or, the worst option, harvesting of the peat material for power generation or production of horticultural growth substrate, *active carbon*, flower pots, etc. Peat that is used for arable crop production will mineralize at sharply increased rates because it must be drained, limed and fertilized in order to ensure satisfactory crop growth. Under these circumstances, the drain depth should be kept as shallow as possible and prudence exercised when applying lime and fertilizers.

KASTANOZEMS

Kastanozems accommodate dry grassland soils, among them the *zonal* soils of the short-grass steppe belt, south of the Eurasian tall-grass steppe belt with Chernozems. Kastanozems have a similar profile to that of Chernozems but the humus-rich surface horizon is thinner and not as dark as that of the Chernozems and they show more prominent accumulation of secondary carbonates. The chestnut-brown colour of the surface soil is reflected in the name *Kastanozem*; common names for many Kastanozems are: *(Dark) Chestnut Soils* (Russian Federation), *Kalktschernoseme* (Germany), *(Dark) Brown Soils* (Canada), and *Ustolls* and *Xerolls* (United States of America).

Summary description of Kastanozems

Connotation: Dark brown soils rich in organic matter; from Latin *castanea* and Russian *kashtan*, chestnut, and *zemlja*, earth or land.

Parent material: A wide range of unconsolidated materials; a large part of all Kastanozems has developed in loess.

Environment: Dry and continental with relatively cold winters and hot summers; flat to undulating grasslands dominated by ephemeral short grasses.

Profile development: A brown *mollic* horizon of medium depth, in many cases over a brown to cinnamon *cambic* or *argic* horizon; with *secondary carbonates* or a *calcic* horizon in the subsoil, in some cases also with secondary gypsum.

Regional distribution of Kastanozems

The total extent of Kastanozems is estimated to be about 465 million ha. Major areas are in the Eurasian short-grass steppe belt (southern Ukraine, the south of the Russian Federation, Kazakhstan and Mongolia), in the Great Plains of the United States of America, Canada and Mexico, and in the pampas and chaco regions of northern Argentina, Paraguay and southern Bolivia.

Management and use of Kastanozems

Kastanozems are potentially rich soils; periodic lack of soil moisture is the main obstacle to high yields. Irrigation is nearly always necessary for high yields; care must be taken to avoid secondary salinization of the surface soil. Phosphate fertilizers might be necessary for good yields. Small grains and irrigated food and vegetable crops are the principal crops grown. Wind and water erosion is a problem on Kastanozems, especially on fallow lands.

Extensive grazing is another important land use on Kastanozems. However, the sparsely vegetated grazing lands are inferior to the tall-grass steppes on Chernozems, and overgrazing is a serious problem.

LEPTOSOLS

Leptosols are very shallow soils over continuous rock and soils that are extremely gravelly and/or stony. Leptosols are azonal soils and particularly common in mountainous regions. Leptosols include the: *Lithosols* of the Soil Map of the World (FAO–UNESCO, 1971–1981); *Lithic* subgroups of the *Entisol* order (United States of America); *Leptic Rudosols* and *Tenosols* (Australia); and *Petrozems* and *Litozems* (Russian Federation). In many national systems, Leptosols on calcareous rocks belong to *Rendzinas*, and those on other rocks to *Rankers*. Continuous rock at the surface is considered non-soil in many soil classification systems.

Summary description of Leptosols

Connotation: Shallow soils; from Greek *leptos*, thin.

Parent material: Various kinds of continuous rock or of unconsolidated materials with less than 20 percent (by volume) fine earth.

Environment: Mostly land at high or medium altitude and with strongly dissected topography. Leptosols are found in all climate zones (many of them in hot or cold dry regions), in particular in strongly eroding areas.

Profile development: Leptosols have continuous rock at or very close to the surface or are extremely gravelly. Leptosols in calcareous weathering material may have a *mollic* horizon.

Regional distribution of Leptosols

Leptosols are the most extensive RSG on earth, extending over about 1 655 million ha. Leptosols are found from the tropics to the cold polar tundra and from sea level to the highest mountains. Leptosols are particularly widespread in montane areas, notably in Asia and South America, in the Sahara and the Arabian deserts, the Ungava Peninsula of northern Canada and in the Alaskan mountains. Elsewhere, Leptosols can be found on rocks that are resistant to weathering or where erosion has kept pace with soil formation, or has removed the top of the soil profile. Leptosols with *continuous rock* at less than 10 cm depth in montane regions are the most extensive Leptosols.

Management and use of Leptosols

Leptosols have a resource potential for wet-season grazing and as forest land. Leptosols to which the rendzic qualifier applies are planted to teak and mahogany in Southeast Asia; those in the temperate zone are under mainly deciduous mixed forest whereas acid Leptosols are commonly under coniferous forest. Erosion is the greatest threat to Leptosol areas, particularly in montane regions in the temperate zones where high population pressure (tourism), overexploitation and increasing environmental pollution lead to deterioration of forests and threaten large areas of vulnerable Leptosols. Leptosols on hill slopes are generally more fertile than their counterparts on more level land. One or a few good crops could perhaps be grown on such slopes but at the price of severe erosion. Steep slopes with shallow and stony soils can be transformed into cultivable land through terracing, the removal of stones by hand and their use as terrace fronts. Agroforestry (a combination of rotation of arable crops and forest under strict control) holds promise but is still largely in an experimental stage. The excessive internal drainage and the shallowness of many Leptosols can cause drought even in a humid environment.

LIXISOLS

Lixisols comprise soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. Lixisols have a high base saturation and low-activity clays at certain depths. Many Lixisols are included in: *Red Yellow Podzolic soils* (e.g. Indonesia); *Argissolos* (Brazil); *sols ferralitiques faiblement desaturés appauvris* (France); and *Red and Yellow Earths*, *Latosols* or *Alfisols* with low-activity clays (United States of America).

Summary description of Lixisols

Connotation: Soils with a pedogenetic clay differentiation (especially clay migration) between a topsoil with a lower and a subsoil with a higher clay content, low-activity clays and a high base saturation at some depths; from Latin *lixivia*, washed-out substances.

Parent material: In a wide variety of parent materials, notably in unconsolidated, strongly weathered and strongly leached, finely textured materials.

Environment: Regions with a tropical, subtropical or warm temperate climate with a pronounced dry season, notably on old erosion or deposition surfaces. Many Lixisols are surmised to be polygenetic soils with characteristics formed under a more humid climate in the past.

Regional distribution of Lixisols

Lixisols are found in seasonally dry tropical, subtropical and warm temperate regions on Pleistocene and older surfaces. These soils cover a total area of about 435 million ha, of which more than half occur in sub-Sahelian and East Africa, about one-quarter in South and Central America, and the remainder on the Indian subcontinent and in Southeast Asia and Australia.

Management and use of Lixisols

Areas with Lixisols that are still under natural savannah or open woodland vegetation are widely used for low volume grazing. Preservation of the surface soil with its all-important organic matter is of utmost importance. Degraded surface soils have low aggregate stability and are prone to slaking and/or erosion where exposed to the direct impact of raindrops. Tillage of wet soil or use of excessively heavy machinery compacts the soil and causes serious structure deterioration. Tillage and erosion control measures such as terracing, contour ploughing, mulching and use of cover crops help to conserve the soil. The low absolute level of plant nutrients and the low cation retention by Lixisols makes recurrent inputs of fertilizers and/or lime a precondition for continuous cultivation. Chemically and/or physically deteriorated Lixisols regenerate very slowly where not reclaimed actively.

Perennial crops are to be preferred to annual crops, particularly on sloping land. Cultivation of tuber crops (cassava and sweet potato) or groundnut increases the danger of soil deterioration and erosion. Rotation of annual crops with improved pasture has been recommended in order to maintain or improve the content of soil organic matter.

LUVISOLS

Luvisols are soils that have a higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes (especially clay migration) leading to an *argic* subsoil horizon. Luvisols have high-activity clays throughout the *argic* horizon and a high base saturation at certain depths. Many Luvisols are or were known as: *Textural-metamorphic soils* (Russian Federation), *sols lessivés* (France), *Parabraunerden* (Germany), *Chromosols* (Australia), *Luvissolos* (Brazil), *Grey-Brown Podzolic soils* (earlier terminology of the United States of America), and *Alfisols* with high-activity clays (US Soil Taxonomy).

Summary description of Luvisols

Connotation: Soils with a pedogenetic clay differentiation (especially clay migration) between a topsoil with a lower and a subsoil with a higher clay content, high-activity clays and a high base saturation at some depth; from Latin *luere*, to wash.

Parent material: A wide variety of unconsolidated materials including glacial till, and aeolian, alluvial and colluvial deposits.

Environment: Most common in flat or gently sloping land in cool temperate regions and in warm regions (e.g. Mediterranean) with distinct dry and wet seasons.

Profile development: Pedogenetic differentiation of clay content with a lower content in the topsoil and a higher content in the subsoil without marked leaching of base cations or advanced weathering of high-activity clays; highly leached Luvisols might have an *albic* eluviation horizon between the surface horizon and an *argic* subsurface horizon, but lack the *albeluvic tonguing* of Albeluvisols.

Regional distribution of Luvisols

Luvisols extend over 500–600 million ha worldwide, mainly in temperate regions such as in the west and centre of the Russian Federation, the United States of America, and Central Europe, but also in the Mediterranean region and southern Australia. In subtropical and tropical regions, Luvisols occur mainly on young land surfaces.

Management and use of Luvisols

Most Luvisols are fertile soils and suitable for a wide range of agricultural uses. Luvisols with a high silt content are susceptible to structure deterioration where tilled when wet or with heavy machinery. Luvisols on steep slopes require erosion control measures.

The eluvial horizons of some Luvisols are depleted to the extent that an unfavourable platy structure is formed. In places, the dense subsoil causes temporarily *reducing* *conditions* with a *stagnic colour pattern*. These are the reasons why truncated Luvisols are in many instances better soils for farming than the original, non-eroded soils.

Luvisols in the temperate zone are widely grown to small grains, sugar beet and fodder; in sloping areas, they are used for orchards, forests and/or grazing. In the Mediterranean region, where Luvisols (many with the chromic, calcic or vertic qualifier) are common in colluvial deposits of limestone weathering, the lower slopes are widely sown to wheat and/or sugar beet while the often eroded upper slopes are used for extensive grazing or planted to tree crops.

NITISOLS

Nitisols are deep, well-drained, red, tropical soils with diffuse horizon boundaries and a subsurface horizon with more than 30 percent clay and moderate to strong angular blocky structure elements that easily fall apart into characteristic shiny, polyhedric (*nutty*) elements. Weathering is relatively advanced but Nitisols are far more productive than most other red, tropical soils. Many Nitisols correlate with: *Nitossolos* (Brazil); kandic Great Groups of *Alfisols* and *Ultisols,* and different Great Groups of *Inceptisols* and *Oxisols* (United States of America); *Sols Fersialitiques* or *Ferrisols* (France); and *Red Earths*.

Summary description of Nitisols

Connotation: Deep, well-drained, red, tropical soils with a clayey *nitic* subsurface horizon that has typical *nutty*, polyhedric, blocky structure elements with shiny ped faces; from Latin *nitidus*, shiny.

Parent material: Finely textured weathering products of intermediate to basic parent rock, in some regions rejuvenated by recent admixtures of volcanic ash.

Environment: Nitisols are predominantly found in level to hilly land under tropical rain forest or savannah vegetation.

Profile development: Red or reddish-brown clayey soils with a *nitic* subsurface horizon of high aggregate stability. The clay assemblage of Nitisols is dominated by kaolinite/(meta)halloysite. Nitisols are rich in Fe and have little water-dispersible clay.

Regional distribution of Nitisols

There are about 200 million ha of Nitisols worldwide. More than half of all Nitisols are found in tropical Africa, notably in the highlands (> 1 000 m) of Ethiopia, Kenya, Congo and Cameroon. Elsewhere, Nitisols are well represented at lower altitudes, e.g. in tropical Asia, South America, Central America, Southeast Africa and Australia.

Management and use of Nitisols

Nitisols are among the most productive soils of the humid tropics. The deep and porous solum and the stable soil structure of Nitisols permit deep rooting and make these soils quite resistant to erosion. The good workability of Nitisols, their good internal drainage and fair water holding properties are complemented by chemical (fertility) properties that compare favourably with those of most other tropical soils. Nitisols have relatively high contents of weathering minerals, and surface soils may contain several percent of organic matter, in particular under forest or tree crops. Nitisols are planted to plantation crops such as cocoa, coffee, rubber and pineapple, and are also widely used for food crop production on smallholdings. High P sorption calls for application of P fertilizers, usually provided as slow-release, low-grade phosphate rock (several tonnes per hectare, with maintenance doses every few years) in combination with smaller applications of better soluble *superphosphate* for short-term response by the crop.

PHAEOZEMS

Phaeozems accommodate soils of relatively wet grassland and forest regions in moderately continental climates. Phaeozems are much like Chernozems and Kastanozems but are leached more intensively. Consequently, they have dark, humus-rich surface horizons that, in comparison with Chernozems and Kastanozems, are less rich in bases. Phaeozems may or may not have secondary carbonates but have a high base saturation in the upper metre of the soil. Commonly used names for many Phaeozems are: *Brunizems* (Argentina and France); *Dark grey forest soils* and *Leached and podzolized chernozems* (former Soviet Union); *Tschernoseme* (Germany); *Dusky-red prairie soils* (older classification of the United States of America); *Udolls* and *Albolls* (US Soil Taxonomy); and *Phaeozems* (including most of the former *Greyzems*) (FAO).

Summary description of Phaeozems

Connotation: Dark soils rich in organic matter; from Greek *phaios*, dusky, and Russian *zemlja*, earth or land.

Parent material: Aeolian (loess), glacial till and other unconsolidated, predominantly basic materials.

Environment: Warm to cool (e.g. tropical highlands) moderately continental regions, humid enough that there is, in most years, some percolation through the soil, but also with periods in which the soil dries out; flat to undulating land; the natural vegetation is grassland such as tall-grass steppe and/or forest.

Profile development: A *mollic* horizon (thinner and in many soils less dark than in Chernozems), mostly over a *cambic* or *argic* subsurface horizon.

Regional distribution of Phaeozems

Phaeozems cover an estimated 190 million ha worldwide. Some 70 million ha of Phaeozems are found in the humid and subhumid Central Lowlands and easternmost parts of the Great Plains of the United States of America. Another 50 million ha of Phaeozems are in the subtropical pampas of Argentina and Uruguay. The third largest area of Phaeozems (18 million ha) is in northeast China, followed by extensive areas in the centre of the Russian Federation. Smaller, mostly discontinuous areas are found in Central Europe, notably the Danube area of Hungary and adjacent countries and in montane areas in the tropics.

Management and use of Phaeozems

Phaeozems are porous, fertile soils and make excellent farmland. In the United States of America and Argentina, Phaeozems are in use for the production of soybean and wheat (and other small grains). Phaeozems on the high plains of Texas produce good yields of irrigated cotton. Phaeozems in the temperate belt are planted to wheat, barley and vegetables alongside other crops. Wind and water erosion are serious hazards. Vast areas of Phaeozems are used for cattle rearing and fattening on improved pastures.

PLANOSOLS

Planosols are soils with a light-coloured, surface horizon that shows signs of periodic water stagnation and abruptly overlies a dense, slowly permeable subsoil with significantly more clay than the surface horizon. The US Soil Classification coined the name *Planosols* in 1938; its successor, the US Soil Taxonomy, includes most of the original Planosols in the Great Groups of the *Albaqualfs*, *Albaquults* and *Argialbolls*. The name has been adopted in Brazil (*Planossolos*).

Summary description of Planosols

Connotation: Soils with a coarse-textured surface horizon abruptly over a dense and finer textured subsoil, typically in seasonally waterlogged flat lands; from Latin *planus*, flat.

Parent material: Mostly clayey alluvial and colluvial deposits.

Environment: Seasonally or periodically wet, level (plateau) areas, mainly in subtropical and temperate, semi-arid and subhumid regions with light forest or grass vegetation.

Profile development: Geological stratification or pedogenesis (destruction and/or removal of clay), or both, has produced relatively coarse-textured, light-coloured surface soil abruptly overlying finer textured subsoil; impeded downward percolation of water causes temporarily *reducing conditions* with a *stagnic colour pattern*, at least close to the *abrupt textural change*.

Regional distribution of Planosols

The world's major Planosol areas occur in subtropical and temperate regions with clear alternation of wet and dry seasons, e.g. in Latin America (southern Brazil, Paraguay and Argentina), Africa (Sahelian zone, East and Southern Africa), the east of the United States of America, Southeast Asia (Bangladesh and Thailand), and Australia. Their total extent is estimated at some 130 million ha.

Management and use of Planosols

Natural Planosol areas support a sparse grass vegetation, often with scattered shrubs and trees that have shallow root systems and can cope with temporary waterlogging. Land use on Planosols is normally less intensive than that on most other soils under the same climate conditions. Vast areas of Planosols are used for extensive grazing. Wood production on Planosols is much lower than on other soils under the same conditions.

Planosols in the temperate zone are mainly in grass or they are planted to arable crops such as wheat and sugar beet. Yields are modest even on drained and deeply loosened soils. Root development on natural unmodified Planosols is hindered severely by oxygen deficiency in wet periods, dense subsoil and, in places, by toxic levels of Al in the rootzone. The low hydraulic conductivity of the dense subsurface soil makes narrow drain spacing necessary. Surface modification such as ridge and furrow can lessen crop yield losses from waterlogging.

Planosols in Southeast Asia are widely planted to a single crop of paddy rice, produced on bunded fields that are inundated in the rainy season. Efforts to produce dryland crops on the same land during the dry season have met with little success; the soils seem better suited to a second crop of rice with supplemental irrigation. Fertilizers are needed for good yields. Paddy fields should be allowed to dry out at least once a year in order to prevent or minimize microelement deficiencies or toxicity associated with prolonged soil reduction. Some Planosols require application of more than just NPK fertilizers, and their low fertility level may prove difficult to correct. Where temperature permits paddy rice cultivation, this is probably superior to any other kind of land use.

Grasslands with supplemental irrigation in the dry season are a good land use in climates with long dry periods and short infrequent wet spells. Strongly developed Planosols with a very silty or sandy surface soil are perhaps best left untouched.

PLINTHOSOLS

Plinthosols are soils with plinthite, petroplinthite or pisoliths. Plinthite is an Fe-rich (in some cases also Mn-rich), humus-poor mixture of kaolinitic clay (and other products of strong weathering such as gibbsite) with quartz and other constituents that changes irreversibly to a layer with hard nodules, a hardpan or irregular aggregates on exposure to repeated wetting and drying. Petroplinthite is a continuous, fractured or broken sheet of connected, strongly cemented to indurated nodules or mottles. Pisoliths are discrete strongly cemented to indurated nodules. Both petroplinthite and pisoliths develop from plinthite by hardening. Many of these soils are known as: *Groundwater Laterite Soils*, *Perched Water Laterite Soils* and *Plintossolos* (Brazil); *Sols gris latéritiques* (France); and *Plinthaquox*, *Plinthaqualfs*, *Plinthoxeralfs*, *Plinthustalfs*, *Plinthaquults*, *Plinthohumults*, *Plinthudults* and *Plinthustults* (United States of America).

Summary description of Plinthosols

Connotation: Soils with plinthite, petroplinthite or pisoliths; from Greek *plinthos*, brick.

Parent material: Plinthite is more common in weathering material from basic rock than in acidic rock weathering. In any case, it is crucial that sufficient Fe be present, originating either from the parent material itself or brought in by seepage water or ascending groundwater from elsewhere.

Environment: Formation of plinthite is associated with level to gently sloping areas with fluctuating groundwater or stagnating surface water. A widely held view is that plinthite is associated with rain forest areas whereas petroplinthic and pisolithic soils are more common in the savannah zone.

Profile development: Strong weathering with subsequent segregation of plinthite at the depth of groundwater fluctuation or impeded surface water drainage. Hardening of plinthite to pisoliths or petroplinthite takes place upon repeated drying and wetting. This may occur during the intervals of recession of a seasonally fluctuating water table or after geological uplift of the terrain, topsoil erosion, lowering of the groundwater level, increasing drainage capacity, and/or climate change towards drier conditions. Petroplinthite may break up into irregular aggregates or gravels, which may be transported to form colluvial or alluvial deposits. Hardening or induration requires a certain minimum concentration of iron oxides.

Regional distribution of Plinthosols

The global extent of Plinthosols is estimated at some 60 million ha. Soft plinthite is most common in the wet tropics, notably in the eastern Amazon basin, the central Congo basin and parts of Southeast Asia. Extensive areas with pisoliths and petroplinthite occur in the Sudano-Sahelian zone, where petroplinthite forms hard caps on top of uplifted/exposed landscape elements. Similar soils occur in the Southern African savannah, on the Indian subcontinent, and in drier parts of Southeast Asia and northern Australia.

Management and use of Plinthosols

Plinthosols present considerable management problems. Poor natural soil fertility caused by strong weathering, waterlogging in bottomlands and drought on Plinthosols with petroplinthite, pisoliths or gravels are serious limitations. Many Plinthosols outside of the wet tropics have shallow, continuous petroplinthite, which limits the rooting volume to the extent that arable farming is not possible; such land can at best be used for low-volume grazing. Soils with high contents of pisoliths (up to 80 percent) are still planted to food crops and tree crops (e.g. cocoa in West Africa, and cashew in India) but the crops suffer from drought in the dry season. Many soil and water conservation techniques are used to improve these soils for urban and peri-urban agriculture in West Africa.

Civil engineers have a different appreciation of petroplinthite and plinthite than do agronomists. To them, plinthite is a valuable material for making bricks, and massive petroplinthite is a stable surface for building or it can be cut to building blocks. Gravels of broken petroplinthite can be used in foundations and as surfacing material on roads and airfields. In some instances, petroplinthite is a valuable ore of Fe, Al, Mn and/or Ti.

PODZOLS

Podzols are soils with a typically ash-grey upper subsurface horizon, bleached by loss of organic matter and iron oxides, on top of a dark accumulation horizon with brown, reddish or black illuviated humus and/or reddish Fe compounds. Podzols occur in humid areas in the boreal and temperate zones and locally also in the tropics. The name *Podzol* is used in most national soil classification systems; other names for many of these soils are: *Spodosols* (China and United States of America), *Espodossolos* (Brazil), and *Podosols* (Australia).

Summary description of Podzols

Connotation: Soils with a *spodic* illuviation horizon under a subsurface horizon that has the appearance of ash and is covered by an organic layer; from Russian *pod*, underneath, and *zola*, ash.

Parent material: Weathering materials of siliceous rock, including glacial till and alluvial and aeolian deposits of quartzite sands. Podzols in the boreal zone occur on almost any rock.

Environment: Mainly in humid temperate and boreal regions of the Northern Hemisphere, in level to hilly land under heather and/or coniferous forest; in the humid tropics under light forest.

Profile development: Complexes of Al, Fe and organic compounds migrate from the surface soil downwards with percolating rainwater. The metal–humus complexes precipitate in an illuvial *spodic* horizon; the overlying eluvial horizon remains bleached and is in many Podzols an *albic* horizon. This is covered by an organic layer whereas dark mineral topsoil horizons are absent in most boreal Podzols.

Regional distribution of Podzols

Podzols cover an estimated 485 million ha worldwide, mainly in the temperate and boreal regions of the Northern Hemisphere. They are extensive in Scandinavia, the northwest of the Russian Federation, and Canada. Besides these *zonal* Podzols, there are smaller occurrences of *intrazonal* Podzols in both the temperate zone and the tropics.

Tropical Podzols occur on less than 10 million ha, mainly in residual sandstone weathering in perhumid regions and in alluvial quartz sands, e.g. in uplifted coastal areas. The exact distribution of tropical Podzols is not known; important occurrences are found along the Rio Negro and in French Guiana, Guyana and Suriname in South America, in the Malaysian region (Kalimantan, Sumatra and Irian), and in northern and southern Australia. They seem to be less common in Africa.

Management and use of Podzols

Zonal Podzols occur in regions with unattractive climate conditions for most arable land uses. Intrazonal Podzols are more frequently reclaimed for arable use than are zonal Podzols, particularly those in temperate climates. The low nutrient status, low level of available moisture and low pH make Podzols unattractive soils for arable farming. Aluminium toxicity and P deficiency are common problems. Deep ploughing (to improve the moisture storage capacity of the soil and/or to eliminate a dense illuviation horizon or hardpan), liming and fertilization are the main ameliorative measures taken. Trace elements may migrate with the metal–humus complexes. In the

Western Cape region of South Africa, deeper rooted orchards and vineyards suffer fewer trace element deficiencies than do shallow-rooted vegetable crops.

Most zonal Podzols are under forest; intrazonal Podzols in temperate regions are mostly under forest or shrubs (heath). Tropical Podzols normally sustain a light forest that recovers only slowly after cutting or burning. Mature Podzols are generally best used for extensive grazing or left idle under their natural (climax) vegetation.

REGOSOLS

Regosols form a taxonomic remnant group containing all soils that could not be accommodated in any of the other RSGs. In practice, Regosols are very weakly developed mineral soils in unconsolidated materials that do not have a *mollic* or *umbric* horizon, are not very shallow or very rich in gravels (*Leptosols*), sandy (*Arenosols*) or with *fluvic* materials (*Fluvisols*). Regosols are extensive in eroding lands, particularly in arid and semi-arid areas and in mountainous terrain. Many Regosols correlate with soil taxa that are marked by incipient soil formation such as: *Entisols* (United States of America); *Rudosols* (Australia); *Regosole* (Germany); *Sols peu évolués régosoliques d'érosion* or even *Sols minéraux bruts d'apport éolien ou volcanique* (France); and *Neossolos* (Brazil).

Summary description of Regosols

Connotation: Weakly developed soils in unconsolidated material; from Greek *rhegos*, blanket.

Parent material: unconsolidated, finely grained material.

Environment: All climate zones without permafrost and at all elevations. Regosols are particularly common in arid areas (including the dry tropics) and in mountain regions.

Profile development: No diagnostic horizons. Profile development is minimal as a consequence of young age and/or slow soil formation, e.g. because of aridity.

Regional distribution of Regosols

Regosols cover an estimated 260 million ha worldwide, mainly in arid areas in the mid-west of the United States of America, northern Africa, the Near East, and Australia. Some 50 million ha of Regosols occur in the dry tropics and another 36 million ha in mountain areas. The extent of most Regosol areas is only limited; consequently, Regosols are common inclusions in other map units on small-scale maps.

Management and use of Regosols

Regosols in desert areas have minimal agricultural significance. Regosols with rainfall of 500–1 000 mm/year need irrigation for satisfactory crop production. The low moisture holding capacity of these soils calls for frequent applications of irrigation water; sprinkler or trickle irrigation solves the problem but is rarely economic. Where rainfall exceeds 750 mm/year, the entire profile is raised to its water holding capacity early in the wet season; improvement of dry farming practices may then be a better investment than installation of costly irrigation facilities.

Many Regosols are used for extensive grazing. Regosols on colluvial deposits in the loess belt of northern Europe and North America are mostly cultivated; they are planted to small grains, sugar beet and fruit trees. Regosols in mountainous regions are delicate and best left under forest.

SOLONCHAKS

Solonchaks are soils that have a high concentration of soluble salts at some time in the year. Solonchaks are largely confined to the arid and semi-arid climate zones and to coastal regions in all climates. Common international names are *saline soils* and *salt-affected soils*. In national soil classification systems, many Solonchaks belong to: *halomorphic soils* (Russian Federation), *Halosols* (China), and *Salids* (United States of America).

Summary description of Solonchaks

Connotation: Saline soils; from Russian *sol*, salt.

Parent material: Virtually any unconsolidated material.

Environment: Arid and semi-arid regions, notably in areas where ascending groundwater reaches the solum, with vegetation of grasses and/or halophytic herbs, and in inadequately managed irrigation areas. Solonchaks in coastal areas occur in all climates.

Profile development: From weakly to strongly weathered, many Solonchaks have a *gleyic colour pattern* at some depth. In low-lying areas with a shallow water table, salt accumulation is strongest at the soil surface of the soil (*external Solonchaks*). Solonchaks where ascending groundwater does not reach the topsoil (or even the solum) have the greatest accumulation of salts at some depth below the soil surface (*internal Solonchaks*).

Regional distribution of Solonchaks

The total extent of Solonchaks in the world is estimated at about 260 million ha. Solonchaks are most extensive in the Northern Hemisphere, notably in the arid and semi-arid parts of northern Africa, the Near East, the former Soviet Union and Central Asia; they are also widespread in Australia and the Americas.

Management and use of Solonchaks

Excessive accumulation of salts in soil affects plant growth in two ways:

- The salts aggravate drought stress because dissolved electrolytes create an osmotic potential that affects water uptake by plants. Before any water can be taken up from the soil, plants must compensate the combined forces of the matrix potential of the soil, i.e. the force with which the soil matrix retains water, and the osmotic potential. As a rule of thumb, the osmotic potential of a soil solution (in hectoPascals) amounts to some 650 × EC (dS/m). The total potential that can be compensated by plants (known as the *critical leaf water head*) varies strongly between plant species. Plant species that stem from the humid tropics have a comparatively low critical leaf water head. For example, green peppers can compensate a total soil moisture potential (matric plus osmotic forces) of only some 3 500 hPa whereas cotton, a crop that evolved in arid and semi-arid climates, survives some 25 000 hPa.
- The salts upset the balance of ions in the soil solution because nutrients are proportionately less available. Antagonistic effects are known to exist, e.g. between Na and K, between Na and Ca, and between Mg and K. In higher concentrations, the salts may be directly toxic to plants. Very harmful in this respect are Na ions and chloride ions (they disturb N metabolism).

Farmers on Solonchaks adapt their cultivation methods. For example, plants on furrow-irrigated fields are not planted on the top of the ridges but at half height. This ensures that the roots benefit from the irrigation water while salt accumulation is strongest near the top of the ridge, away from the root systems. Strongly salt-affected soils have little agricultural value. They are used for extensive grazing of sheep, goats, camels and cattle, or lie idle. Only after the salts have been flushed from the soil (which then ceases to be a Solonchak) may good yields be hoped for. Application of irrigation water must not only satisfy the needs of the crop, but excess water must be applied above the irrigation requirement in order to maintain a downward water flow in the soil and to flush excess salts from the rootzone. Irrigation of crops in arid and semi-arid regions must be accompanied by drainage whereby drainage facilities should be designed to keep the groundwater table below the critical depth. Use of gypsum assists in maintaining hydraulic conductivity while salts are being flushed out with irrigation water.

SOLONETZ

Solonetz are soils with a dense, strongly structured, clayey subsurface horizon that has a high proportion of adsorbed Na and/or Mg ions. Solonetz that contain free soda (Na_2CO_3) are strongly alkaline (field pH > 8.5). Common international names are *alkali soils* and *sodic soils*. In national soil classification systems many Solonetz correlate with: *Sodosols* (Australia), the *Solonetzic order* (Canada), various *Solonetz* types (Russian Federation), and to the natric Great Groups of several Orders (United States of America).

Summary description of Solonetz

Connotation: Soils with a high content of exchangeable Na and/or Mg ions; from Russian *sol*, salt.

Parent material: Unconsolidated materials, mostly fine-textured sediments.

Environment: Solonetz are normally associated with flat lands in a climate with hot, dry summers, or with (former) coastal deposits that contain a high proportion of Na ions. Major concentrations of Solonetz are in flat or gently sloping grasslands with loess, loam or clay in semi-arid, temperate and subtropical regions.

Profile development: A black or brown surface soil over a *natric* horizon with strong round-topped columnar structure elements. Well-developed Solonetz can have an *albic* eluviation horizon (beginning) directly over the *natric* horizon. A *calcic* or *gypsic* horizon may be present below the *natric* horizon. Many Solonetz have a field pH of about 8.5, indicative of the presence of free sodium carbonate.

Regional distribution of Solonetz

Solonetz occur predominantly in areas with a steppe climate (dry summers and an annual precipitation sum of not more than 400–500 mm), in particular in flat lands with impeded vertical and lateral drainage. Smaller occurrences are found on inherently saline parent materials (e.g. marine clays or saline alluvial deposits). Worldwide, Solonetz cover some 135 million ha. Major Solonetz areas are found in Ukraine, Russian Federation, Kazakhstan, Hungary, Bulgaria, Romania, China, United States of America, Canada, South Africa, Argentina and Australia.

Management and use of Solonetz

The suitability of virgin Solonetz for agricultural uses is dictated almost entirely by the depth and properties of the surface soil. A deep (> 25 cm) humus-rich surface soil is needed for successful arable crop production. However, most Solonetz have only a much shallower surface horizon, or have lost the surface horizon altogether.

Solonetz amelioration has two basic elements:

- improvement of the porosity of the surface or subsurface soil;
- lowering of the ESP.

Most reclamation attempts start with incorporation of gypsum or, exceptionally, calcium chloride in the soil. Where lime or gypsum occur at shallow depth in the soil body, deep ploughing (mixing the carbonate or gypsum containing subsoil with the surface soil) may make expensive amendments superfluous. Traditional reclamation strategies start with the planting of an Na-resistant crop, e.g. Rhodes grass, to gradually improve the permeability of the soil. Once a functioning pore system is in place, Na ions are carefully leached from the soil with *good-quality* (Ca-rich) water (relatively pure water should be avoided because it exacerbates the dispersion problem).

An extreme reclamation method (developed in Armenia and applied successfully to Solonetz with a *calcic* or *petrocalcic* horizon in the Arax Valley) uses diluted sulphuric acid (a waste product of the metallurgical industry) to dissolve $CaCO_3$ contained in the soil. This brings Ca ions in the soil solution, which displace exchangeable Na. The practice improves soil aggregation and soil permeability. The resulting sodium sulphate (in the soil solution) is subsequently flushed out of the soil. In India, pyrite was applied to Solonetz to produce sulphuric acid, thus lowering extreme alkalinity and overcoming Fe deficiency. Ameliorated Solonetz can produce a fair crop foodgrain or forage. The majority of the world's Solonetz have never been reclaimed and are used for extensive grazing or lie idle.

STAGNOSOLS

Stagnosols are soils with a perched water table showing redoximorphic features caused by surface water. Stagnosols are periodically wet and mottled in the topsoil and subsoil, with or without concretions and/or bleaching. A common name in many national classification systems for most Stagnosols is *pseudogley*. In the US Soil Taxonomy, many of them belong to the *Aqualfs*, *Aquults*, *Aquents*, *Aquepts* and *Aquolls*.

Summary description of Stagnosols

Connotation: From Latin *stagnare*, to flood.

Parent material: A wide variety of unconsolidated materials including glacial till, and loamy aeolian, alluvial and colluvial deposits, but also physically weathered silt stone.

Environment: Most common in flat or gently sloping land in cool temperate to subtropical regions with humid to perhumid climate conditions.

Profile development: Similar to strongly mottled Luvisols, Cambisols or Umbrisols; the topsoil can also be completely bleached (albic horizon).

Regional distribution of Stagnosols

Stagnosols cover 150–200 million ha worldwide; for the greater part in humid to perhumid temperate regions of West and Central Europe, North America, southeast Australia, and Argentina, associated with Luvisols as well as silty to clayey Cambisols and Umbrisols. They also occur in humid to perhumid subtropical regions, associated with Acrisols and Planosols.

Management and use of Stagnosols

The agricultural suitability of Stagnosols is limited because of their oxygen deficiency resulting from stagnating water above a dense subsoil. Therefore, they have to be drained. However, in contrast to Gleysols, drainage with channels or pipes is in many cases insufficient. It is necessary to have a higher porosity in the subsoil in order to improve the hydraulic conductivity. This may be achieved by deep loosening or deep ploughing. Drained Stagnosols can be fertile soils owing to their moderate degree of leaching.

TECHNOSOLS

Technosols comprise a new RSG and combine soils whose properties and pedogenesis are dominated by their *technical* origin. They contain a significant amount of artefacts (something in the soil recognizably made or extracted from the earth by humans), or are sealed by *technic hard rock* (material created by humans, having properties unlike natural rock). They include soils from wastes (landfills, sludge, cinders, mine spoils and ashes), pavements with their underlying unconsolidated materials, soils with geomembranes and constructed soils in human-made materials.

Technosols are often referred to as *urban* or *mine* soils. They are recognized in the new Russian soil classification system as *Technogenic Superficial Formations*.

Summary description of Technosols

Connotation: Soils dominated or strongly influenced by human-made material; from Greek *technikos*, skilfully made

Parent material: All kinds of materials made or exposed by human activity that otherwise would not occur at the Earth's surface; pedogenesis in these soils is affected strongly by materials and their organization.

Environment: Mostly in urban and industrial areas, in small areas, although in a complex pattern associated with other groups.

Profile development: Generally none, although in old dumps (e.g. Roman rubble) evidence of *natural* pedogenesis can be observed, such as clay translocation. Lignite and fly ash deposits may exhibit over time *vitric* or *andic* properties (Zikeli, Kastler and Jahn, 2004; Zevenbergen *et al.*, 1999). Original profile development may still be present in contaminated natural soils.

Regional distribution of Technosols

Technosols are found throughout the world where human activity has led to the construction of artificial soil, sealing of natural soil, or extraction of material normally not affected by surface processes. Thus, cities, roads, mines, refuse dumps, oil spills, coal fly ash deposits and the like are included in Technosols.

Management and use of Technosols

Technosols are affected strongly by the nature of the material or the human activity that placed it. They are more likely to be contaminated than soils from other RSGs. Many Technosols have to be treated with care as they may contain toxic substances resulting from industrial processes.

Many Technosols, in particular the ones in refuse dumps, are currently covered with a layer of *natural* soil material in order to permit revegetation. Such a layer forms part of the Technosol, provided that the requirement of *20 percent or more (by volume, by weighted average) artefacts in the upper 100 cm of the soil surface or to continuous rock or a cemented or indurated layer, whichever is shallower,* of the Technosol definition is met.

UMBRISOLS

Umbrisols accommodate soils in which organic matter has accumulated within the mineral surface soil (in most cases with low base saturation) to the extent that it significantly affects the behaviour and utilization of the soil. Umbrisols are the logical counterpart of soils with a *mollic* horizon and a high base saturation throughout (Chernozems, Kastanozems and Phaeozems). Not previously recognized at such a high taxonomic level, many of these soils are classified in other systems as: several Great Groups of *Entisols* and *Inceptisols* (United States of America); *Humic Cambisols* and *Umbric Regosols* (FAO); *Sombric Brunisols* and *Humic Regosols* (France); *Much dark-humus soils* (Russian Federation); *Brown Podzolic soils* (e.g. Indonesia); and *Umbrisols* (Romania).

Summary description of Umbrisols

Connotation: Soils with dark topsoil; from Latin *umbra*, shade.

Parent material: Weathering material of siliceous rock.

Environment: Humid climates; common in mountainous regions with little or no moisture deficit, in mostly cool areas but including tropical and subtropical mountains.

Profile development: Dark brown *umbric* (seldom: *mollic*) surface horizon, in many cases over a *cambic* subsurface horizon with low base saturation.

Regional distribution of Umbrisols

Umbrisols occur in cool, humid regions, mostly mountainous and with little or no soil moisture deficit. They occupy about 100 million ha throughout the world. In South America, Umbrisols are common in the Andean ranges of Colombia, Ecuador and, to a lesser extent, in Venezuela, Bolivia and Peru. They also occur in Brazil, e.g. in the Serra do Mar, and in Lesotho and South Africa, e.g. in the Drakensberg range. Umbrisols in North America are confined largely to the northwest Pacific seaboard. In Europe, Umbrisols occur along the northwest Atlantic seaboard, e.g. in Iceland, on the British Isles and in northwest Portugal and Spain. In Asia, they are found in the mountain ranges east and west of Lake Baikal, and on fringes of the Himalayas, notably in India, Nepal, China and Myanmar. Umbrisols occur at lower altitudes in Manipur (eastern India), in the Chin Hills (western Myanmar) and in Sumatra (Barisan range). In Oceania, Umbrisols are found in the mountain ranges of Papua New Guinea and southeast Australia and in the eastern parts of South Island, New Zealand.

Management and use of Umbrisols

Many Umbrisols are under a natural or near-natural vegetation cover. Umbrisols above the tree line in the Andean, Himalayan and Central Asian mountain ranges, or at lower altitudes in northern and western Europe where the former forest vegetation has been largely cleared, carry a vegetation of short grasses of low nutritional value. Coniferous forest predominates in Brazil (e.g. *Araucaria* spp.) and in the United States of America (mainly *Thuja*, *Tsuga* and *Pseudotsuga* spp.). Umbrisols in tropical mountain areas in South Asia and Oceania are under montane evergreen forest. In the mountains of southern Mexico, the vegetation varies from tropical semi-deciduous forest to much cooler montane cloud forest.

The predominance of sloping land and wet and cool climate conditions restricts utilization of many Umbrisols to extensive grazing. Management focuses on the introduction of improved grasses and correction of the soil pH by liming. Many Umbrisols are susceptible to erosion. The planting of perennial crops and bench or contour terracing offer possibilities for permanent agriculture on gentler slopes. Where conditions are suitable, cash crops may be grown, e.g. cereals and root crops in the United States of America, Europe and South America, or tea and cinchona in South Asia (Indonesia). Highland coffee on Umbrisols demands high management inputs to meet its stringent nutrient requirements. In New Zealand, Umbrisols have been transformed into highly productive soils, used for intensive sheep and dairy farming, and production of cash crops.

VERTISOLS

Vertisols are churning, heavy clay soils with a high proportion of swelling clays. These soils form deep wide cracks from the surface downward when they dry out, which happens in most years. The name Vertisols (from Latin *vertere*, to turn) refers to the constant internal turnover of soil material. Common local names for many Vertisols are: *black cotton soils*, *regur* (India), *black turf soils* (South Africa), *margalites* (Indonesia), *Vertosols* (Australia), *Vertissolos* (Brazil), and *Vertisols* (United States of America).

Summary description of Vertisols

Connotation: Churning, heavy clay soils; from Latin *vertere*, to turn.

Parent material: Sediments that contain a high proportion of swelling clays, or products of rock weathering that have the characteristics of swelling clays.

Environment: Depressions and level to undulating areas, mainly in tropical, subtropical, semi-arid to subhumid and humid climates with an alternation of distinct wet and dry seasons. The climax vegetation is savannah, natural grassland and/or woodland.

Profile development: Alternate swelling and shrinking of expanding clays results in deep cracks in the dry season, and formation of *slickensides* and wedge-shaped structural elements in the subsurface soil. *Gilgai* microrelief is peculiar to Vertisols although not commonly encountered.

Regional distribution of Vertisols

Vertisols cover 335 million ha worldwide. An estimated 150 million ha is potential cropland. Vertisols in the tropics cover some 200 million ha; one-quarter of this is considered to be useful land. Most Vertisols occur in the semi-arid tropics, with an average annual rainfall of 500–1 000 mm, but Vertisols are also found in the wet tropics, e.g. Trinidad (where the annual rainfall sum amounts to 3 000 mm). The largest Vertisol areas are on sediments that have a high content of smectitic clays or that produce such clays upon post-depositional weathering (e.g. in the Sudan), and on extensive basalt plateaus (e.g. in India and Ethiopia). Vertisols are also prominent in South Africa, Australia, the southwest of the United States of America (Texas), Uruguay, Paraguay and Argentina. Vertisols are typically found in lower landscape positions such as dry lake bottoms, river basins, lower river terraces, and other lowlands that are periodically wet in their natural state.

Management and use of Vertisols

Large areas of Vertisols in the semi-arid tropics are still unused or are used only for extensive grazing, wood chopping, charcoal burning and the like. These soils have considerable agricultural potential, but adapted management is a precondition for sustained production. The comparatively good chemical fertility and their occurrence on extensive level plains where reclamation and mechanical cultivation can be envisaged are assets of Vertisols. Their physical soil characteristics and, notably, their difficult water management cause problems. Buildings and other structures on Vertisols are at risk, and engineers have to take special precautions to avoid damage.

The agricultural uses of Vertisols range from very extensive (grazing, collection of fuelwood, and charcoal burning) through smallholder post-rainy season crop production (millet, sorghum, cotton and chickpeas) to small-scale (rice) and large-scale irrigated agriculture (cotton, wheat, barley, sorghum, chickpeas, flax, noug [*Guzotia abessynica*] and sugar cane). Cotton is known to perform well on Vertisols, allegedly because cotton has a vertical root system that is not damaged severely by cracking of the soil. Tree crops are generally less successful because tree roots find it difficult to establish themselves in the subsoil and are damaged as the soil shrinks and swells. Management practices for crop production should be directed primarily at water control in combination with conservation or improvement of soil fertility.

The physical properties and the soil moisture regime of Vertisols represent serious management constraints. The heavy soil texture and domination of expanding clay minerals result in a narrow soil moisture range between moisture stress and water excess. Tillage is hindered by stickiness when the soil is wet and hardness when it is dry. The susceptibility of Vertisols to waterlogging may be the single most important factor that reduces the actual growing period. Excess water in the rainy season must be stored for post-rainy season use (*water harvesting*) on Vertisols with very slow infiltration rates.

One compensation for the shrink–swell characteristics is the phenomenon of self-mulching that is common on many Vertisols. Large clods produced by primary tillage break down with gradual drying into fine peds, which provide a passable seed bed with minimal effort. For the same reason, gully erosion on overgrazed Vertisols is seldom severe because gully walls soon assume a shallow angle of repose, which allows grass to become re-established more readily.

Chapter 5
Definitions of formative elements for second-level units of the WRB

The definitions of the formative elements for the second-level units relate to RSGs, diagnostic horizons, properties and materials, attributes such as colour, chemical conditions, texture, etc. Reference to the RSGs defined in Chapters 3 and 4 and the diagnostic features listed in Chapter 2 is given in italics.

Usually, only a limited number of combinations will be possible; most of the definitions are mutually exclusive.

Abruptic (ap)
Having an *abrupt textural change* within 100 cm of the soil surface.

Aceric (ae)
Having a pH (1:1 in water) between 3.5 and 5 and jarosite mottles in some layer within 100 cm of the soil surface (*in Solonchaks only*).

Acric (ac)
Having an *argic* horizon that has a CEC (by 1 *M* NH_4OAc) of less than 24 $cmol_c$ kg^{-1} clay in some part to a maximum depth of 50 cm below its upper limit, either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout, and a base saturation (by 1 *M* NH_4OAc) of less than 50 percent in the major part between 50 and 100 cm from the soil surface.

Acroxic (ao)
Having less than 2 $cmol_c$ kg^{-1} fine earth exchangeable bases plus 1 *M* KCl exchangeable Al^{3+} in one or more layers with a combined thickness of 30 cm or more within 100 cm of the soil surface (*in Andosols only*).

Albic (ab)
Having an *albic* horizon starting within 100 cm of the soil surface.

Hyperalbic (ha)
Having an *albic* horizon starting within 50 cm of the soil surface and its lower boundary at a depth of 100 cm or more from the soil surface.

Glossalbic (gb)
Showing tonguing of an *albic* into an *argic* or *natric* horizon.

Alcalic (ax)
Having a pH (1:1 in water) of 8.5 or more throughout within 50 cm of the soil surface or to *continuous rock* or a cemented or indurated layer, whichever is shallower.

Alic (al)
Having an *argic* horizon that has a CEC (by 1 *M* NH_4OAc) of 24 $cmol_c$ kg^{-1} clay or more throughout or to a depth of 50 cm below its upper limit, whichever is shallower,

either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout, and a base saturation (by 1 *M* NH_4OAc) of less than 50 percent in the major part between 50 and 100 cm from the soil surface.

Aluandic (aa)

Having one or more layers, cumulatively 30 cm or more thick, with *andic* properties and an acid oxalate (pH 3) extractable silica content of less than 0.6 percent, and an Al_{py}[1]/Al_{ox}[2] of 0.5 or more, within 100 cm of the soil surface *(in Andosols only)*.

Thaptaluandic (aab)

Having one or more buried layers, cumulatively 30 cm or more thick, with *andic* properties and an acid oxalate (pH 3) extractable silica content of less than 0.6 percent, or an Al_{py}[3]/Al_{ox}[4] of 0.5 or more, within 100 cm of the soil surface.

Alumic (au)

Having an Al saturation (effective) of 50 percent or more in some layer between 50 and 100 cm from the surface.

Andic (an)

Having one or more layers, cumulatively 30 cm or more thick, with *andic* properties, within 100 cm of the soil surface.

Thaptandic (ba)

Having one or more buried layers, cumulatively 30 cm or more thick, with *andic* properties, within 100 cm of the soil surface.

Anthraquic (aq)

Having an *anthraquic* horizon.

Anthric (am)

Having an *anthric* horizon.

Arenic (ar)

Having a texture of loamy fine sand or coarser in a layer, 30 cm or more thick, within 100 cm of the soil surface.

Epiarenic (arp)

Having a texture of loamy fine sand or coarser in a layer, 30 cm or more thick, within 50 cm of the soil surface.

Endoarenic (arn)

Having a texture of loamy fine sand or coarser in a layer, 30 cm or more thick, between 50 and 100 cm from the soil surface.

[1] Al_{py}: pyrophosphate-extractable aluminium, expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.
[2] Al_{ox}: acid oxalate-extractable aluminium (Blakemore, Searle and Daly, 1981), expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.
[3] Al_{py}: pyrophosphate-extractable aluminium, expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105° C) basis.
[4] Al_{ox}: acid oxalate-extractable aluminium (Blakemore, Searle and Daly, 1981), expressed as percent of the fine earth (0–2 mm) fraction on an oven-dried (105 °C) basis.

Aric (ai)
Having only remnants of diagnostic horizons – disturbed by deep ploughing.

Aridic (ad)
Having *aridic* properties without a *takyric* or *yermic* horizon.

Arzic (az)
Having sulphate-rich groundwater in some layer within 50 cm of the soil surface during some time in most years and containing 15 percent or more gypsum averaged over a depth of 100 cm from the soil surface or to *continuous rock* or a cemented or indurated layer, whichever is shallower (*in Gypsisols only*).

Brunic (br)
Having a layer, 15 cm or more thick, which meets criteria 2–4 of the *cambic* horizon but fails criterion 1, starting within 50 cm of the soil surface.

Calcaric (ca)
Having *calcaric* material between 20 and 50 cm from the soil surface or between 20 cm and *continuous rock* or a cemented or indurated layer, whichever is shallower.

Calcic (cc)
Having a *calcic* horizon or concentrations of *secondary carbonates* starting within 100 cm of the soil surface.

Cambic (cm)
Having a *cambic* horizon starting within 50 cm of the soil surface.

Carbic (cb)
Having a *spodic* horizon that does not turn redder on ignition (*in Podzols only*).

Carbonatic (cn)
Having a *salic* horizon with a soil solution (1:1 in water) with a pH of 8.5 or more and $[HCO_3^-] > [SO_4^{2-}] >> [Cl^-]$ (*in Solonchaks only*).

Chloridic (cl)
Having a *salic* horizon with a soil solution (1:1 in water) with $[Cl^-] >> [SO_4^{2-}] > [HCO_3^-]$ *(in Solonchaks only)*.

Chromic (cr)
Having within 150 cm of the soil surface a subsurface layer, 30 cm or more thick, that has a Munsell hue redder than 7.5 YR or that has both, a hue of 7.5 YR and a chroma, moist, of more than 4.

Clayic (ce)
Having a texture of clay in a layer, 30 cm or more thick, within 100 cm of the soil surface.

Epiclayic (cep)
Having a texture of clay in a layer, 30 cm or more thick, within 50 cm of the soil surface.

Endoclayic (cen)

Having a texture of clay in a layer, 30 cm or more thick, within 50 and 100 cm of the soil surface.

Colluvic (co)

Having *colluvic* material, 20 cm or more thick, created by human-induced lateral movement.

Cryic (cy)

Having a *cryic* horizon starting within 100 cm of the soil surface or a *cryic* horizon starting within 200 cm of the soil surface with evidence of cryoturbation in some layer within 100 cm of the soil surface.

Cutanic (ct)

Having clay coatings in some parts of an *argic* horizon either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout.

Densic (dn)

Having natural or artificial compaction within 50 cm of the soil surface to the extent that roots cannot penetrate.

Drainic (dr)

Having a *histic* horizon that is drained artificially starting within 40 cm of the soil surface.

Duric (du)

Having a *duric* horizon starting within 100 cm of the soil surface.

Endoduric (nd)

Having a *duric* horizon starting between 50 and 100 cm from the soil surface.

Hyperduric (duh)

Having a *duric* horizon with 50 percent or more (by volume) durinodes starting within 100 cm of the soil surface.

Dystric (dy)

Having a base saturation (by 1 *M* NH_4OAc) of less than 50 percent in the major part between 20 and 100 cm from the soil surface or between 20 cm and *continuous rock* or a cemented or indurated layer, or, in *Leptosols*, in a layer, 5 cm or more thick, directly above *continuous rock*.

Endodystric (ny)

Having a base saturation (by 1 *M* NH_4OAc) of less than 50 percent throughout between 50 and 100 cm from the soil surface.

Epidystric (ed)

Having a base saturation (by 1 *M* NH_4OAc) of less than 50 percent throughout between 20 and 50 cm from the soil surface.

Hyperdystric (hd)
Having a base saturation (by 1 *M* NH_4OAc) of less than 50 percent throughout between 20 and 100 cm from the soil surface, and less than 20 percent in some layer within 100 cm of the soil surface.

Orthodystric (dyo)
Having a base saturation (by 1 *M* NH_4OAc) of less than 50 percent throughout between 20 and 100 cm from the soil surface.

Ekranic (ek)
Having *technic hard rock* starting within 5 cm of the soil surface and covering 95 percent or more of the horizontal extent of a pedon *(in Technosols only)*.

Endoduric (nd)
See Duric.

Endodystric (ny)
See Dystric.

Endoeutric (ne)
See Eutric.

Endofluvic (nf)
See Fluvic.

Endogleyic (ng)
See Gleyic.

Endoleptic (nl)
See Leptic.

Endosalic (ns)
See Salic.

Entic (et)
Not an *albic* horizon and a loose *spodic* horizon (*in Podzols only*).

Epidystric (ed)
See Dystric.

Epieutric (ee)
See Eutric.

Epileptic (el)
See Leptic.

Episalic (ea)
See Salic.

Escalic (ec)
Occurring in human-made terraces.

Eutric (eu)
Having a base saturation (by 1 *M* NH_4OAc) of 50 percent or more in the major part between 20 and 100 cm from the soil surface or between 20 cm and continuous rock or a cemented or indurated layer, or, in *Leptosols*, in a layer, 5 cm or more thick, directly above *continuous rock*.

Endoeutric (ne)
Having a base saturation (by 1 *M* NH_4OAc) of 50 percent or more throughout between 50 and 100 cm from the soil surface.

Epieutric (ee)
Having a base saturation (by 1 *M* NH_4OAc) of 50 percent or more throughout between 20 and 50 cm from the soil surface.

Hypereutric (he)
Having a base saturation (by 1 *M* NH_4OAc) of 50 percent or more throughout between 20 and 100 cm from the soil surface and 80 percent or more in some layer within 100 cm of the soil surface.

Orthoeutric (euo)
Having a base saturation (by 1 *M* NH_4OAc) of 50 percent or more throughout between 20 and 100 cm from the soil surface.

Eutrosilic (es)
Having one or more layers, cumulatively 30 cm or more thick, with *andic* properties and a sum of exchangeable bases of 15 $cmol_c\ kg^{-1}$ fine earth or more within 100 cm of the surface (*in Andosols only*).

Ferralic (fl)
Having a *ferralic* horizon starting within 200 cm of the soil surface *(in Anthrosols only)*, or *ferralic* properties in at least some layer starting within 100 cm of the soil surface *(in other soils)*.

Hyperferralic (flh)
Having a *Ferralic* properties and a CEC[1] (by 1 *M* NH_4OAc) of less than 16 $cmol_c\ kg^{-1}$ clay in at least some layer starting within 100 cm of the soil surface.

Hypoferralic (flw)
Having in a layer, 30 cm or more thick, within 100 cm of the soil surface a CEC (by 1 *M* NH_4OAc) of less than 4 $cmol_c\ kg^{-1}$ fine earth and a Munsell chroma, moist, of 5 or more or a hue redder than 10 YR (*in Arenosols only*).

Ferric (fr)
Having a *ferric* horizon starting within 100 cm of the soil surface.

Hyperferric (frh)
Having a *ferric* horizon with 40 percent or more of the volume discrete reddish to blackish nodules starting within 100 cm of the soil surface.

[1] See Annex 1.

Fibric (fi)
Having, after rubbing, two-thirds or more (by volume) of the *organic* material consisting of recognizable plant tissue within 100 cm of the soil surface (*in Histosols only*).

Floatic (ft)
Having *organic* material floating on water *(in Histosols only)*.

Fluvic (fv)
Having *fluvic* material in a layer, 25 cm or more thick, within 100 cm of the soil surface.

Endofluvic (nf)
Having *fluvic* material in a layer, 25 cm or more thick, between 50 and 100 cm from the soil surface.

Folic (fo)
Having a *folic* horizon starting within 40 cm of the soil surface.

Thaptofolic (fob)
Having a buried *folic* horizon starting between 40 and 100 cm from the soil surface.

Fractipetric (fp)
Having a strongly cemented or indurated horizon consisting of fractured or broken clods with an average horizontal length of less than 10 cm, starting within 100 cm of the soil surface.

Fractiplinthic (fa)
Having a *petroplinthic* horizon consisting of fractured or broken clods with an average horizontal length of less than 10 cm, starting within 100 cm of the soil surface.

Fragic (fg)
Having a *fragic* horizon starting within 100 cm of the soil surface.

Fulvic (fu)
Having a *fulvic* horizon starting within 30 cm of the soil surface.

Garbic (ga)
Having a layer, 20 cm or more thick within 100 cm of the soil surface, with 20 percent or more (by volume, by weighted average) *artefacts* containing 35 percent or more (by volume) organic waste materials (*in Technosols only*).

Gelic (ge)
Having a layer with a soil temperature of 0 °C or less for two or more consecutive years starting within 200 cm of the soil surface.

Gelistagnic (gt)
Having temporary water saturation at the soil surface caused by a frozen subsoil.

Geric (gr)
Having *geric* properties in some layer within 100 cm of the soil surface.

Gibbsic (gi)
Having a layer, 30 cm or more thick, containing 25 percent or more gibbsite in the fine earth fraction within 100 cm of the soil surface.

Glacic (gc)
Having a layer, 30 cm or more thick, containing 75 percent (by volume) or more ice within 100 cm of the soil surface.

Gleyic (gl)
Having within 100 cm of the mineral soil surface in some parts *reducing conditions* and in 25 percent or more of the soil volume a *gleyic colour pattern*.

Endogleyic (ng)
Having between 50 and 100 cm from the mineral soil surface in some parts *reducing conditions* and in 25 percent or more of the soil volume a *gleyic colour pattern*.

Epigleyic (glp)
Having within 50 cm of the mineral soil surface in some parts *reducing conditions* and in 25 percent or more of the soil volume a *gleyic colour pattern*.

Glossalbic (gb)
See Albic.

Glossic (gs)
Showing tonguing of a *mollic* or *umbric* horizon into an underlying layer.

Molliglossic (mi)
Showing tonguing of a *mollic* horizon into an underlying layer.

Umbriglossic (ug)
Showing tonguing of an *umbric* horizon into an underlying layer.

Greyic (gz)
Having Munsell colours with a chroma of 3 or less when moist, a value of 3 or less when moist and 5 or less when dry and uncoated silt and sand grains on structural faces within 5 cm of the mineral soil surface.

Grumic (gm)
Having a soil surface layer with a thickness of 3 cm or more with a strong structure finer than very coarse granular (*in Vertisols only*).

Gypsic (gy)
Having a *gypsic* horizon starting within 100 cm of the soil surface.

Gypsiric (gp)
Having a *gypsiric* material between 20 and 50 cm from the soil surface.

Haplic (ha)
Having a typical expression of certain features (typical in the sense that there is no further or meaningful characterization) and only used if none of the preceding qualifiers applies.

Hemic (hm)
Having, after rubbing, between two-thirds and one-sixth (by volume) of the *organic* material consisting of recognizable plant tissue within 100 cm from the soil surface (*in Histosols only*).

Histic (hi)
Having a *histic* horizon starting within 40 cm of the soil surface.

Thaptohistic (hib)
Having a buried *histic* horizon starting between 40 and 100 cm from the soil surface.

Hortic (ht)
Having a *hortic* horizon.

Humic (hu)
Having the following organic carbon contents in the fine earth fraction as a weighted average in *Ferralsols* and *Nitisols*, 1.4 percent or more to a depth of 100 cm from the mineral soil surface; in *Leptosols*, 2 percent or more to a depth of 25 cm from the mineral soil surface; in other soils, 1 percent or more to a depth of 50 cm from the mineral soil surface.

Hyperhumic (huh)
Having an organic carbon content of 5 percent or more as a weighted average in the fine earth fraction to a depth of 50 cm from the mineral soil surface.

Hydragric (hg)
Having an *anthraquic* horizon and an underlying *hydragric* horizon, the latter starting within 100 cm of the soil surface.

Hydric (hy)
Having within 100 cm of the soil surface one or more layers with a combined thickness of 35 cm or more, which have a water retention at 1 500 kPa (in undried samples) of 100 percent or more *(in Andosols only)*.

Hydrophobic (hf)
Water-repellent, i.e. water stands on a dry soil for the duration of 60 seconds or more *(in Arenosols only)*.

Hyperalbic (ha)
See Albic.

Hyperalic (hl)
Having an *argic* horizon that has a silt to clay ratio of less than 0.6 and an Al saturation (effective) of 50 percent or more, throughout or to a depth of 50 cm below its upper limit, whichever is shallower (*in Alisols only*).

Hypercalcic (hc)
Having a *calcic* horizon with 50 percent or more (by mass) calcium carbonate equivalent *(in Calcisols only)*.

Hyperdystric (hd)
See Dystric.

Hypereutric (he)
See Eutric.

Hypergypsic (hp)
Having a *gypsic* horizon with 50 percent or more (by mass) gypsum *(in Gypsisols only)*.

Hyperochric (ho)
Having a mineral topsoil layer, 5 cm or more thick, with a Munsell value, dry, of 5.5 or more that turns darker on moistening, an organic carbon content of less than 0.4 percent, a platy structure in 50 percent or more of the volume, and a surface crust.

Hypersalic (hs)
See Salic.

Hyperskeletic (hk)
Containing less than 20 percent (by volume) fine earth averaged over a depth of 75 cm from the soil surface or to *continuous rock*, whichever is shallower.

Hypocalcic (wc)
Having a *calcic* horizon with a calcium carbonate equivalent content in the fine earth fraction of less than 25 percent and starting within 100 cm of the soil surface *(in Calcisols only)*.

Hypogypsic (wg)
Having a *gypsic* horizon with a gypsum content in the fine earth fraction of less than 25 percent and starting within 100 cm of the soil surface *(in Gypsisols only)*.

Hypoluvic (wl)
Having an absolute clay increase of 3 percent or more within 100 cm of the soil surface (*in Arenosols only*).

Hyposalic (ws)
See Salic.

Hyposodic (wn)
See Sodic.

Irragric (ir)
Having an *irragric* horizon.

Lamellic (ll)
Having clay lamellae with a combined thickness of 15 cm or more within 200 cm of the soil surface.

Laxic (la)
Having a bulk density of less than 0.8 kg dm^{-3}, in a mineral soil layer, 20 cm or more thick, starting within 75 cm of the soil surface.

Leptic (le)
Having *continuous rock* starting within 100 cm of the soil surface.

Endoleptic (nl)
Having *continuous rock* starting between 50 and 100 cm from the soil surface.

Epileptic (el)
Having *continuous rock* starting within 50 cm of the soil surface.

Lignic (lg)
Having inclusions of intact wood fragments, which make up one-quarter or more of the soil volume, within 50 cm of the soil surface *(in Histosols only)*.

Limnic (lm)
Having *limnic material*, cumulatively 10 cm or more thick, within 50 cm of the soil surface.

Linic (lc)
Having a continuous, very slowly permeable to impermeable constructed geomembrane of any thickness starting within 100 cm of the soil surface.

Lithic (li)
Having *continuous rock* starting within 10 cm of the soil surface (*in Leptosols only*).

Nudilithic (nt)
Having *continuous rock* at the soil surface (*in Leptosols only*).

Lixic (lx)
Having an *argic* horizon that has a CEC (by 1 *M* NH_4OAc) of 24 $cmol_c$ kg^{-1} clay or more in some part to a maximum depth of 50 cm below its upper limit, either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout, and a base saturation (by 1 *M* NH_4OAc) of 50 percent or more in the major part between 50 and 100 cm from the soil surface.

Luvic (lv)
Having an *argic* horizon that has a CEC of 24 $cmol_c$ kg^{-1} clay or more throughout or to a depth of 50 cm below its upper limit, whichever is shallower, either starting within 100 cm of the soil surface or within 200 cm of the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout, and a base saturation (by 1 *M* NH_4OAc) of 50 percent or more in the major part between 50 and 100 cm from the soil surface.

Magnesic (mg)
Having an exchangeable Ca to Mg ratio of less than 1 in the major part within 100 cm of the soil surface or to *continuous rock* or a cemented or indurated layer, whichever is shallower.

Manganiferric (mf)
Having a *ferric* horizon starting within 100 cm of the soil surface in which half or more of the nodules or mottles are black.

Mazic (mz)
Massive and hard to very hard in the upper 20 cm of the soil (*in Vertisols only*).

Melanic (ml)
Having a *melanic* horizon starting within 30 cm of the soil surface (*in Andosols only*).

Mesotrophic (ms)
Having a base saturation (by 1 *M* NH_4OAc) of less than 75 percent at a depth of 20 cm from the soil surface (*in Vertisols only*).

Mollic (mo)
Having a *mollic* horizon.

Molliglossic (mi)
See Glossic.

Natric (na)
Having a *natric* horizon starting within 100 cm of the soil surface.

Nitic (ni)
Having a *nitic* horizon starting within 100 cm of the soil surface.

Novic (nv)
Having above the soil that is classified at the RSG level, a layer with recent sediments (new material), 5 cm or more and less than 50 cm thick.

Areninovic (anv)
Having above the soil that is classified at the RSG level, a layer with recent sediments (new material), 5 cm or more and less than 50 cm thick, which has a texture of loamy fine sand or coarser in its major part.

Clayinovic (cnv)
Having above the soil that is classified at the RSG level, a layer with recent sediments (new material), 5 cm or more and less than 50 cm thick, which has a texture of clay in its major part.

Siltinovic (snv)
Having above the soil that is classified at the RSG level, a layer with recent sediments (new material), 5 cm or more and less than 50 cm thick, which has a texture of silt, silt loam, silty clay loam or silty clay in its major part.

Nudilithic (nt)
See Lithic.

Ombric (om)
Having a *histic* horizon saturated predominantly with rainwater starting within 40 cm of the soil surface (*in Histosols only*).

Ornithic (oc)
Having a layer 15 cm or more thick with *ornithogenic* material starting within 50 cm of the soil surface.

Ortsteinic (os)
Having a cemented *spodic* horizon (*ortstein*) (*in Podzols only*).

Oxyaquic (oa)
Saturated with oxygen-rich water during a period of 20 or more consecutive days and not a *gleyic* or *stagnic colour pattern* in some layer within 100 cm of the soil surface.

Pachic (ph)
Having a *mollic* or *umbric* horizon 50 cm or more thick.

Pellic (pe)
Having in the upper 30 cm of the soil a Munsell value, moist, of 3.5 or less and a chroma, moist, of 1.5 or less (*in Vertisols only*).

Petric (pt)
Having a strongly cemented or indurated layer starting within 100 cm of the soil surface.

Endopetric (ptn)
Having a strongly cemented or indurated layer starting between 50 and 100 cm from the soil surface.

Epipetric (ptp)
Having a strongly cemented or indurated layer starting within 50 cm of the soil surface.

Petrocalcic (pc)
Having a *petrocalcic* horizon starting within 100 cm of the soil surface.

Petroduric (pd)
Having a *petroduric* horizon starting within 100 cm of the soil surface.

Petrogleyic (py)
Having a layer, 10 cm or more thick, with an oximorphic colour pattern[1], 15 percent or more (by volume) of which is cemented (*bog iron*), within 100 cm of the surface.

Petrogypsic (pg)
Having a *petrogypsic* horizon starting within 100 cm of the soil surface.

Petroplinthic (pp)
Having a *petroplinthic* horizon starting within 100 cm of the soil surface.

Petrosalic (ps)
Having within 100 cm of the soil surface, a layer, 10 cm or more thick, which is cemented by salts more soluble than gypsum.

Pisoplinthic (px)
Having a *pisoplinthic* horizon starting within 100 cm of the soil surface.

Placic (pi)
Having within 100 cm of the soil surface, an iron pan, between 1 and 25 mm thick, that is continuously cemented by a combination of organic matter, Fe and/or Al.

[1] As defined in the gleyic colour pattern.

Plaggic (pa)
Having a *plaggic* horizon.

Plinthic (pl)
Having a *plinthic* horizon starting within 100 cm of the soil surface.

Posic (po)
Having a zero or positive charge (pH_{KCl} - pH_{water}, both 1:1) in a layer, 30 cm or more thick, starting within 100 cm of the soil surface (*in Plinthosols and Ferralsols only*).

Profondic (pf)
Having an *argic* horizon in which the clay content does not decrease by 20 percent or more (relative) from its maximum within 150 cm of the soil surface.

Protic (pr)
Showing no soil horizon development (*in Arenosols only*).

Puffic (pu)
Having a crust pushed up by salt crystals (*in Solonchaks only*).

Reductaquic (ra)
Saturated with water during the thawing period and at some time of the year *reducing conditions* above a *cryic* horizon and within 100 cm of the soil surface (*in Cryosols only*).

Reductic (rd)
Having *reducing conditions* in 25 percent or more of the soil volume within 100 cm of the soil surface caused by gaseous emissions, e.g. methane or carbon dioxide (*in Technosols only*).

Regic (rg)
Not having buried horizons (*in Anthrosols only*).

Rendzic (rz)
Having a *mollic* horizon that contains or immediately overlies *calcaric* materials containing 40 percent or more calcium carbonate equivalent.

Rheic (rh)
Having a *histic* horizon saturated predominantly with groundwater or flowing surface water starting within 40 cm of the soil surface (*in Histosols only*).

Rhodic (ro)
Having within 150 cm of the soil surface a subsurface layer, 30 cm or more thick, with a Munsell hue redder than 5 YR (3.5 YR or redder), a value, moist, of less than 3.5 and a value, dry, no more than one unit higher than the moist value.

Rubic (ru)
Within 100 cm of the soil surface a subsurface layer, 30 cm or more thick, with a Munsell hue redder than 10 YR or a chroma, moist, of 5 or more (*in Arenosols only*).

Ruptic (rp)
Having a *lithological discontinuity* within 100 cm of the soil surface.

Rustic (rs)
Having a *spodic* horizon that turns redder on ignition (*in Podzols only*).

Salic (sz)
Having a *salic* horizon starting within 100 cm of the soil surface.

Endosalic (ns)
Having a *salic* horizon starting between 50 and 100 cm from the soil surface.

Episalic (ea)
Having a *salic* horizon starting within 50 cm of the soil surface.

Hypersalic (hs)
Having an EC_e of 30 dS m^{-1} or more at 25 °C in some layer within 100 cm of the soil surface.

Hyposalic (ws)
Having an EC_e of 4 dS m^{-1} or more at 25 °C in some layer within 100 cm of the soil surface.

Sapric (sa)
Having, after rubbing, less than one-sixth (by volume) of the *organic* material consisting of recognizable plant tissue within 100 cm of the soil surface (*in Histosols only*).

Silandic (sn)
Having one or more layers, cumulatively 30 cm or more thick, with *andic* properties and an acid oxalate (pH 3) extractable silica (Si_{ox}) content of 0.6 percent or more, or an Al_{py} to Al_{ox} ratio of less than 0.5 within 100 cm of the soil surface (*in Andosols only*).

Thaptosilandic (snb)
Having one or more buried layers, cumulatively 30 cm or more thick, with *andic* properties and an acid oxalate (pH 3) extractable silica (Si_{ox}) content of 0.6 percent or more, or an Al_{py} to Al_{ox} ratio of less than 0.5 within 100 cm of the soil surface.

Siltic (sl)
Having a texture of silt, silt loam, silty clay loam or silty clay in a layer, 30 cm or more thick, within 100 cm of the soil surface.

Endosiltic (sln)
Having a texture of silt, silt loam, silty clay loam or silty clay in a layer, 30 cm or more thick, within 50 and 100 cm of the soil surface.

Episiltic (slp)
Having a texture of silt, silt loam, silty clay loam or silty clay in a layer, 30 cm or more thick, within 50 cm of the soil surface.

Skeletic (sk)
40 percent or more (by volume) gravel or other coarse fragments averaged over a depth of 100 cm from the soil surface or to *continuous rock* or a cemented or indurated layer, whichever is shallower.

Endoskeletic (skn)
Having 40 percent or more (by volume) gravel or other coarse fragments averaged over a depth between 50 and 100 cm from the soil surface.

Episkeletic (skp)
Having 40 percent or more (by volume) gravel or other coarse fragments averaged over a depth of 50 cm from the soil surface.

Sodic (so)
Having 15 percent or more exchangeable Na plus Mg on the exchange complex within 50 cm of the soil surface throughout.

Endosodic (son)
Having 15 percent or more exchangeable Na plus Mg on the exchange complex between 50 and 100 cm from the soil surface throughout.

Hyposodic (sow)
Having 6 percent or more exchangeable Na on the exchange complex in a layer, 20 cm or more thick, within 100 cm of the soil surface.

Solodic (sc)
Having a layer, 15 cm or more thick within 100 cm of the soil surface, with the columnar or prismatic structure of the *natric* horizon, but lacking its sodium saturation requirements.

Sombric (sm)
Having a *sombric* horizon starting within 150 cm of the soil surface.

Spodic (sd)
Having a *spodic* horizon starting within 200 cm of the mineral soil surface.

Spolic (sp)
Having a layer, 20 cm or more thick within 100 cm of the soil surface, with 20 percent or more (by volume, by weighted average) *artefacts* containing 35 percent or more (by volume) of industrial waste (mine spoil, dredgings, rubble, etc.) (*in Technosols only*).

Stagnic (st)
Having within 100 cm of the mineral soil surface in some parts *reducing conditions* for some time during the year and in 25 percent or more of the soil volume, single or in combination, a *stagnic colour pattern* or an *albic* horizon.

Endostagnic (stn)
Having between 50 and 100 cm from the mineral soil surface in some parts *reducing conditions* for some time during the year and in 25 percent or more of the soil volume, single or in combination, a *stagnic colour pattern* or an *albic* horizon.

Epistagnic (stn)
Having within 50 cm of the mineral soil surface in some parts *reducing conditions* for some time during the year and in 25 percent or more of the soil volume, single or in combination, a *stagnic colour pattern* or an *albic* horizon.

Subaquatic (sq)
Being permanently submerged under water not deeper than 200 cm.

Sulphatic (su)
Having a *salic* horizon with a soil solution (1:1 in water) with $[SO_4^{2-}] >> [HCO_3^-] > [Cl^-]$ (*in Solonchaks only*).

Takyric (ty)
Having a *takyric* horizon.

Technic (te)
Having 10 percent or more (by volume, by weighted average) *artefacts* in the upper 100 cm from the soil surface or to *continuous rock* or a cemented or indurated layer, whichever is shallower.

Tephric (tf)
Having *tephric* material to a depth of 30 cm or more from the soil surface or to *continuous rock*, whichever is shallower.

Terric (tr)
Having a *terric* horizon.

Thaptandic (ba)
See Andic.

Thaptovitric (bv)
See Vitric.

Thionic (ti)
Having a *thionic* horizon or a layer with *sulphidic* material, 15 cm or more thick, starting within 100 cm of the soil surface.

Hyperthionic (tih)
Having a *thionic* horizon starting within 100 cm of the soil surface and a pH (1:1 in water) less than 3.5.

Orthothionic (tio)
Having a *thionic* horizon starting within 100 cm of the soil surface and a pH (1:1 in water) between 3.5 and 4.0.

Protothionic (tip)
Having a layer with *sulphidic* material, 15 cm or more thick, starting within 100 cm of the soil surface.

Thixotropic (tp)
Having in some layer within 50 cm of the soil surface material that changes, under pressure or by rubbing, from a plastic solid into a liquefied stage and back into the solid condition.

Tidalic (td)
Being flooded by tidewater but not covered by water at mean low tide.

Toxic (tx)
Having in some layer within 50 cm of the soil surface toxic concentrations of organic or inorganic substances other than ions of Al, Fe, Na, Ca and Mg.

Anthrotoxic (atx)
Having in some layer within 50 cm of the soil surface sufficiently high and persistent concentrations of organic or inorganic substances to markedly affect the health of humans who come in regular contact with the soil.

Ecotoxic (etx)
Having in some layer within 50 cm of the soil surface sufficiently high and persistent concentrations of organic or inorganic substances to markedly affect soil ecology, in particular the populations of the mesofauna.

Phytotoxic (ptx)
Having in some layer within 50 cm of the soil surface sufficiently high or low concentrations of ions other than Al, Fe, Na, Ca and Mg, to markedly affect plant growth.

Zootoxic (ztx)
Having in some layer within 50 cm of the soil surface sufficiently high and persistent concentrations of organic or inorganic substances to markedly affect the health of animals, including humans, that ingest plants grown on these soils.

Transportic (tn)
Having a layer, 30 cm or more thick, with solid or liquid material that has been moved from a source area outside the immediate vicinity of the soil by intentional human activity, usually with the aid of machinery, and without substantial reworking or displacement by natural forces

Turbic (tu)
Having cryoturbation features (mixed material, disrupted soil horizons, involutions, organic intrusions, frost heave, separation of coarse from fine materials, cracks or patterned ground) at the soil surface or above a *cryic* horizon and within 100 cm of the soil surface.

Umbric (um)
Having an *umbric* horizon.

Umbriglossic (ug)
See Glossic.

Urbic (ub)
Having a layer, 20 cm or more thick within 100 cm of the soil surface, with 20 percent or more (by volume, by weighted average) *artefacts* containing 35 percent or more (by volume) of rubble and refuse of human settlements (*in Technosols only*).

Vermic (vm)
Having 50 percent or more (by volume, by weighted average) of worm holes, casts, or filled animal burrows in the upper 100 cm of the soil or to *continuous rock* or a cemented or indurated layer, whichever is shallower.

Vertic (vr)
Having a *vertic* horizon or *vertic* properties starting within 100 cm of the soil surface.

Vetic (vt)
Having an ECEC (sum of exchangeable bases plus exchangeable acidity in 1 *M* KCl) of less than 6 $cmol_c\ kg^{-1}$ clay in some subsurface layer within 100 cm of the soil surface.

Vitric (vi)
Having one or more layers, cumulatively 30 cm or more thick, with *vitric* properties, within 100 cm of the soil surface.

Thaptovitric (bv)
Having one or more buried layers, cumulatively 30 cm or more thick, with *vitric* properties, within 100 cm of the soil surface.

Voronic (vo)
Having a *voronic* horizon (*in Chernozems only*).

Xanthic (xa)
Having a *ferralic* horizon that has in a subhorizon, 30 cm or more thick within 150 cm of the soil surface, a Munsell hue of 7.5 YR or yellower and a value, moist, of 4 or more and a chroma, moist, of 5 or more.

Yermic (ye)
Having a *yermic* horizon, including a desert pavement.

Nudiyermic (yes)
Having a *yermic* horizon without a desert pavement.

SPECIFIERS

The following **specifiers** may be used to indicate depth of occurrence, or to express the intensity of soil characteristics. Their code is always added after the qualifier code. The specifiers are combined with other elements into one word, e.g. Endoskeletic. A triple combination, e.g. Epihyperdystric, is allowed.

Bathy (..d)
Horizon, property or material starting between 100 and 200 cm from the soil surface.

Cumuli (..c)
Having a repetitive accumulation of material of 50 cm or more at the soil surface (e.g. cumulinovic and cumulimollic).

Endo (..n)
Horizon, property or material starting between 50 and 100 cm from the soil surface.

Epi (..p)
Horizon, property or material starting within 50 cm of the soil surface.

Hyper (..h)
Having a strong expression of certain features.

Hypo (..w)
Having a weak expression of certain features.

Ortho (..o)

Having a typical expression of certain features (typical in the sense that no further or meaningful characterization is made).

Para (..r)

Having a resemblance to certain features (e.g. Paralithic).

Proto (..t)

Indicating a precondition or an early stage of development of certain features (e.g. Protothionic).

Thapto (..b)

Having a buried horizon within 100 cm of the surface (given in combination with the buried diagnostic horizon, e.g. Thaptomollic).

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Annex 1
Summary of analytical procedures for soil characterization

This annex provides summaries of recommended analytical procedures to be used for soil characterization for the World Reference Base for Soil Resources. Full descriptions can be found in *Procedures for soil analysis* (Van Reeuwijk, 2006) and the USDA *Soil Survey Laboratory Methods Manual* (Burt, 2004).

1. SAMPLE PREPARATION

Samples are air-dried or, alternatively, oven-dried at a maximum of 40 °C. The fine earth fraction is obtained by sieving the dry sample with a 2-mm sieve. Clods not passing through the sieve are crushed (not ground) and sieved again. Gravel, rock fragments, etc. not passing through the sieve are treated separately.

In special cases where air-drying causes unacceptable irreversible changes in certain soil properties (e.g. in peat and soils with andic properties), samples are kept and treated in the field-moist state.

2. MOISTURE CONTENT

Calculation of results of soil analysis is done on the basis of *oven-dry* (105 °C) soil mass.

3. PARTICLE-SIZE ANALYSIS

The mineral part of the soil is separated into various size fractions and the proportion of these fractions is determined. The determination comprises all material, i.e. including gravel and coarser material, but the procedure itself is applied to the fine earth (< 2 mm) only.

The pre-treatment of the sample is aimed at complete dispersion of the primary particles. Therefore, cementing materials (usually of secondary origin) such as organic matter and calcium carbonate may have to be removed. In some cases, de-ferration also needs to be applied. However, depending on the aim of study, it may be fundamentally wrong to remove cementing materials. Thus, all pre-treatments are to be considered optional. However, for soil characterization purposes, removal of organic matter by H_2O_2 and of carbonates by HCl is routinely carried out. After this pre-treatment, the sample is shaken with a dispersing agent and sand is separated from clay and silt with a 63-µm sieve. The sand is fractionated by dry sieving, the clay and silt fractions are determined by the pipette method or, alternatively, by the hydrometer method.

4. WATER-DISPERSIBLE CLAY

This is the clay content found when the sample is dispersed with water without any pre-treatment to remove cementing compounds and without use of a dispersing agent. The proportion of natural clay to total clay can be used as a structure stability indicator.

5. SOIL WATER RETENTION

The water content is determined of soil samples that have been equilibrated with water at various suction (tension) values. For low suction values, undisturbed core samples are equilibrated on a silt and kaolin bath; for high suction values, disturbed samples are equilibrated in pressure plate extractors. The bulk density is calculated from the core sample mass.

6. BULK DENSITY

Soil bulk density is the mass per unit volume of soil. As bulk density changes with water content, the water status of the sample must be specified.

Two different procedures can be used:

- *Undisturbed core samples*. A metal cylinder of known volume is pressed into the soil. The moist sample mass is recorded. This may be the field-moist state or the state after equilibrating the sample at a specified water tension. The sample is then oven-dried and weighed again. The bulk density is the ratio of dry mass to volume at the determined water content and/or the specified water tension.
- *Coated clods.* Field-occurring clods are coated with plastic lacquer (e.g. Saran dissolved in methyl ethyl ketone) to allow determination of underwater mass. This gives the volume of the clod. The moist sample mass is recorded. This may be the field-moist state or the state after equilibrating the clod at specified water suction. The sample is then oven-dried and weighed again. The bulk density is the ratio of dry mass to volume at the specified water suction.

Note: The determination of bulk density is very sensitive to errors, particularly caused by non-representativeness of the samples (stones, cracks, roots, etc.). Therefore, determinations should always be made in triplicate.

7. COEFFICIENT OF LINEAR EXTENSIBILITY (COLE)

The COLE gives an indication of the reversible shrink–swell capacity of a soil. It is calculated from the *dry* bulk density and the bulk density at 33 kPa water suction. The COLE value is expressed in centimetres per centimetre or as a percentage value.

8. PH

The pH of the soil is potentiometrically measured in the supernatant suspension of a 1:2½ soil:liquid mixture. The liquid is either distilled water (pH-H_2O) or a 1 *M* KCl solution (pH-KCl). In some cases definitions for classifcation specify a 1:1 soil:water ratio.

9. ORGANIC CARBON

The Walkley–Black procedure is followed. This involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid at about 125 °C. The residual dichromate is titrated against ferrous sulphate. To compensate for incomplete destruction, an empirical correction factor of 1.3 is applied in the calculation of the result.

Note: Other procedures, including carbon analysers (dry combustion) may also be used. In these cases a qualitative test for carbonates on effervescence with HCl is recommended and, if present, a correction for inorganic C (see Carbonate below) is required.

10. CARBONATE

The *rapid titration method* by Piper (also called *acid neutralization method*) is used. The sample is treated with dilute HCl and the residual acid is titrated. The results are referred to as *calcium carbonate equivalent* as the dissolution is not selective for calcite and also other carbonates such as dolomite are dissolved to some extent.

Note: Other procedures such as the Scheibler volumetric method may also be used.

11. GYPSUM

Gypsum is dissolved by shaking the sample with water. It is then selectively precipitated from the extract by adding acetone. This precipitate is re-dissolved in water and the Ca concentration is determined as a measure for gypsum.

12. CATION EXCHANGE CAPACITY (CEC) AND EXCHANGEABLE BASES

The ammonium acetate pH 7 method is used. The sample is percolated with ammonium acetate (pH 7) and the bases are measured in the percolate. The sample is subsequently percolated with sodium acetate (pH 7), the excess salt is then removed and the adsorbed Na exchanged by percolation with ammonium acetate (pH 7). The Na in this percolate is a measure for the CEC.

Alternatively, after percolation with ammonium acetate, the sample can be washed free of excess salt, the whole sample distilled and the evolved ammonia determined.

Percolation in tubes may also be replaced by shaking in flasks. Each extraction must be repeated three times and the three extracts should be combined for analysis.

***Note 1*:** Other procedures for CEC may be used provided the determination is done at pH 7.

***Note 2*:** In special cases where CEC is not a diagnostic criterion, e.g. saline and alkaline soils, the CEC may be determined at pH 8.2.

***Note 3*:** The base saturation of saline, calcareous and gypsiferous soils can be considered to be 100 percent.

***Note 4*:** Where low-activity clays are involved, the CEC of the organic matter has to be deducted. This can be done by the graphical method (FAO, 1966), or by analysing the CEC of the organic matter or the mineral colloids separately.

13. EXCHANGEABLE ACIDITY

This is the acidity (H + Al) released upon exchange by an unbuffered 1 *M* KCl solution. It may also be designated *actual* acidity (as opposed to *potential* or *extractable acidity*). It is used to determine the so-called *effective cation exchange capacity* (ECEC) defined as: *sum of bases* + *(H + Al),* with bases being determined by ammonium acetate extraction.

When the exchangeable acidity is substantial, the Al may be determined separately in the extract as it may be toxic to plants.

***Note*:** Because the contribution of H^+ is often negligible, some laboratories only determine exchangeable Al. In that case, the ECEC is calculated as: *sum of bases* + *Al.*

14. EXTRACTABLE IRON, ALUMINIUM, MANGANESE AND SILICON

These analyses comprise:

- *Free* Fe, Al and Mn compounds in the soil extracted by a dithionite-citrate solution. (Both the *Mehra and Jackson* and *Holmgren* procedures may be used.)
- *Active*, *short-range-order* or *amorphous* Fe, Al and silica compounds extracted by an acid oxalate solution.
- *Organically bound* Fe and Al extracted by a pyrophosphate solution.

15. SALINITY

Attributes associated with salinity in soils are determined in the *saturation extract*. The attributes include: pH, electrical conductivity (EC_e), sodium adsorption ratio (SAR) and the cations and anions of the dissolved salts. These include Ca, Mg, Na, K, carbonate and bicarbonate, chloride, nitrate and sulphate. The SAR and the exchangeable sodium percentage (ESP) may be estimated from the concentrations of the dissolved cations.

16. PHOSPHATE RETENTION

The *Blakemore* procedure is used. The sample is equilibrated with a phosphate solution at pH 4.6 and the proportion of phosphate withdrawn from solution is determined.

17. OPTICAL DENSITY OF OXALATE EXTRACT (ODOE)

The sample is percolated or shaken with an acid ammonium oxalate solution. The optical density of the extract is measured at 430-nm wavelength.

18. MELANIC INDEX

The sample is shaken with a 0.5 *M* NaOH solution and the absorbance of the extract is measured at 450 and 520 nm, respectively. The *melanic index* is obtained by dividing the absorbance at 450 nm by the absorbance at 520 nm.

19. MINERALOGICAL ANALYSIS OF THE SAND FRACTION

After removal of cementing and coating materials, the sand is separated from the clay and silt by wet sieving. From the sand, the fraction 63–420 μm is separated by dry sieving. This fraction is divided into a *heavy* fraction and a *light* fraction with the aid of a high-density liquid: a solution of sodium polytungstate[1] with a specific density of 2.85 kg dm^{-3}. Of the *heavy fraction*, a microscopic slide is made; the *light fraction* is stained selectively for microscopic identification of feldspars and quartz.

Volcanic glass can usually be recognized as isotropic grains with vesicles.

20. X-RAY DIFFRACTOMETRY

The clay fraction is separated from the fine earth and deposited in an oriented fashion on glass slides or porous ceramic plates to be analysed on an X-ray diffractometer. Unoriented powder specimens of clay and other fractions are analysed on the same apparatus or with a Guinier X-ray camera (photographs).

[1] Bromoform can also be used as high density liquid but its use is discouraged because of its highly toxic vapour.

Annex 2

Recommended codes for the reference soil groups, qualifiers and specifiers

Reference Soil Groups							
Acrisol	AC	Chernozem	CH	Kastanozem	KS	Podzol	PZ
Albeluvisol	AB	Cryosol	CR	Leptosol	LP	Regosol	RG
Alisol	AL	Durisol	DU	Lixisol	LX	Solonchak	SC
Andosol	AN	Ferralsol	FR	Luvisol	LV	Solonetz	SN
Anthrosol	AT	Fluvisol	FL	Nitisol	NT	Stagnosol	ST
Arenosol	AR	Gleysol	GL	Phaeozem	PH	Technosol	TC
Calcisol	CL	Gypsisol	GY	Planosol	PL	Umbrisol	UM
Cambisol	CM	Histosol	HS	Plinthosol	PT	Vertisol	VR

Qualifiers							
Abruptic	ap	Duric	du	Gelistagnic	gt	Hypoluvic	wl
Aceric	ae	Dystric	dy	Geric	gr	Hyposalic	ws
Acric	ac	Ekranic	ek	Gibbsic	gi	Hyposodic	wn
Acroxic	ao	Endoduric	nd	Glacic	gc	Irragric	ir
Albic	ab	Endodystric	ny	Gleyic	gl	Lamellic	ll
Alcalic	ax	Endoeutric	ne	Glossalbic	gb	Laxic	la
Alic	al	Endofluvic	nf	Glossic	gs	Leptic	le
Aluandic	aa	Endogleyic	ng	Greyic	gz	Lignic	lg
Alumic	au	Endoleptic	nl	Grumic	gm	Limnic	lm
Andic	an	Endosalic	ns	Gypsic	gy	Linic	lc
Anthraquic	aq	Entic	et	Gypsiric	gp	Lithic	li
Anthric	am	Epidystric	ed	Haplic	ha	Lixic	lx
Arenic	ar	Epieutric	ee	Hemic	hm	Luvic	lv
Aric	ai	Epileptic	el	Histic	hi	Magnesic	mg
Aridic	ad	Episalic	ea	Hortic	ht	Manganiferric	mf
Arzic	az	Escalic	ec	Humic	hu	Mazic	mz
Brunic	br	Eutric	eu	Hydragric	hg	Melanic	ml
Calcaric	ca	Eutrosilic	es	Hydric	hy	Mesotrophic	ms
Calcic	cc	Ferralic	fl	Hydrophobic	hf	Mollic	mo
Cambic	cm	Ferric	fr	Hyperalbic	ha	Molliglossic	mi
Carbic	cb	Fibric	fi	Hyperalic	hl	Natric	na
Carbonatic	cn	Floatic	ft	Hypercalcic	hc	Nitic	ni
Chloridic	cl	Fluvic	fv	Hyperdystric	hd	Novic	nv
Chromic	cr	Folic	fo	Hypereutric	he	Nudilithic	nt
Clayic	ce	Fractipetric	fp	Hypergypsic	hp	Ombric	om
Colluvic	co	Fractiplinthic	fa	Hyperochric	ho	Ornithic	oc
Cryic	cy	Fragic	fg	Hypersalic	hs	Ortsteinic	os
Cutanic	ct	Fulvic	fu	Hyperskeletic	hk	Oxyaquic	oa
Densic	dn	Garbic	ga	Hypocalcic	wc	Pachic	ph
Drainic	dr	Gelic	ge	Hypogypsic	wg	Pellic	pe

Qualifiers (Continued)							
Petric	pt	Reductaquic	ra	Solodic	sc	Tidalic	td
Petrocalcic	pc	Reductic	rd	Sombric	sm	Toxic	tx
Petroduric	pd	Regic	rg	Spodic	sd	Transportic	tn
Petrogleyic	py	Rendzic	rz	Spolic	sp	Turbic	tu
Petrogypsic	pg	Rheic	rh	Stagnic	st	Umbric	um
Petroplinthic	pp	Rhodic	ro	Subaquatic	sq	Umbriglossic	ug
Petrosalic	ps	Rubic	ru	Sulphatic	su	Urbic	ub
Pisoplinthic	px	Ruptic	rp	Takyric	ty	Vermic	vm
Placic	pi	Rustic	rs	Technic	te	Vertic	vr
Plaggic	pa	Salic	sz	Tephric	tf	Vetic	vt
Plinthic	pl	Sapric	sa	Terric	tr	Vitric	vi
Posic	po	Silandic	sn	Thaptandic	ba	Voronic	vo
Profondic	pf	Siltic	sl	Thaptovitric	bv	Xanthic	xa
Protic	pr	Skeletic	sk	Thionic	ti	Yermic	ye
Puffic	pu	Sodic	so	Thixotropic	tp		

Specifiers							
Bathy	..d	Epi	..p	Ortho	..o	Thapto	..b
Cumuli	..c	Hyper	..h	Para	..r		
Endo	..n	Hypo	..w	Proto	..t		

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This publication is a revised and updated version of World Soil Resources Reports No. 84, a technical manual for soil scientists and correlators, designed to facilitate the exchange of information and experience related to soil resources, their use and management. The document provides a framework for international soil classification and an agreed common scientific language to enhance communication across disciplines using soil information. It contains definitions and diagnostic criteria to recognize soil horizons, properties and materials and gives rules and guidelines for classifying and subdividing soil reference groups.

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