# Classification of urban & industrial soils in the World Reference Base for Soil Resources: Working Document

D G Rossiter[1]
International Institute for Geo-information Science
& Earth Observation (ITC)
Enschede (NL)

Prof. Dr. Wolfgang Burghardt[2]
University of Duisburg–Essen
Essen (D)

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[1] rossiter@itc.nl; http://www.itc.nl/personal/rossiter
[2] Wolfgang.Burghardt@uni-essen.de; http://www.urban-soil.de/

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# Contents

**Summary**

The World Reference Base for Soil Resources (WRB) is the internationally-accepted soil classification system, endorsed by the International Union of Soil Science (IUSS), and hence by the International Council of Scientific Unions (ICSU). It is intended for correlation of soil individuals as defined by the pedon concept and for defining map units of medium– and small–scale maps. It is ideally suited to discussing world soils, their major properties and genesis. The WRB is a two-level classification: 30 reference groups which have major differences in terms of pedogenesis, geography, and use potential. These are further specified by a set of qualifiers: strong expression, intergrades, and weak expression. As many qualifiers as apply to a soil may be used.

The WRB should be used to correlate local efforts in urban and industrial soil studies, and as a legend for correlative mapping, exactly as it is used for rural soils. However, the current WRB was developed from the various national classifications and pedogenetic studies that were skewed in favour of rural soils, so that some of the names that are assigned to urban soils are less connotative than they could be. The aim of this study was to propose changes to the WRB to better classify urban and industrial soils, keeping in mind the intended role and current structure of the WRB.

We discuss the current classification of urban and industrial soils in five groups, according to the type of substrate and the manner of modification by humans: (1) more-or-less natural soils; (2) natural soils heavily modified *in situ* by human activities; (3) young soils formed in natural materials displaced by human activity; (4) young soils formed from technogenic materials; and (5) soils from displaced natural materials or technogenic materials, with significant pedogenesis since deposition.

We present and justify an expanded and re-organised list of substrate modifiers for the Regosols, an expanded definition of the andic and vitric horizons to explicitly include technogenic ashes or glass, the addition of a Relictic modifier for soils whose pedogenetic environment has changed, an expansion and subdivision of the Toxic modifier, expanding the Anthropic Regosols to include all raw technogenic soils, including skeletal, sandy, and frozen materials (with appropriate qualifiers), allowing anthropogenic qualifiers in Andosols, Gleysols, and Cambisols, a clarification of the definition of continuous hard rock to explicitly include technogenic materials such as pavements, and a clarification of the definition of fluvic soil material to exclude industrial sludges.

# 1 Introduction

Urban areas are of prime importance to human populations, and the soil resource of these areas plays a vital role in the life of the city. In addition, industrial areas occupy an ever-large portion of the Earth's surface, and soils are major factors in their environmental function and eventual reclamation. Urban and industrial soils have been much studied in recent years [e.g. 13, 19] and special techniques have been developed to map them [e.g. 18]. Their importance was recognised by the establishment of the working group *Soils of Urban, Industrial, Traffic and Mining Areas* (SUITMA) of the International Union of Soil Science (IUSS) at the 16$^{th}$IUSS World Congress in 1998. This group has had two international conferences, in 2000 at Essen (D) and in 2003 at Nancy (F). This working group is naturally concerned with classification of urban and industrial soils for both local and international purposes.

Soil classification is the process of grouping soil individuals defined by the pedon concept [20, p. 10] into classes which provide maximum information with respect to defined objectives [4]. At the local level, the main objective is to provide connotative names for relatively homogeneous mapping units at large scales about which many specific statements regarding use and management can be made. At the international level, the main objectives are: (1) to allow exchange of scientific knowledge of soil behaviour and properties; and (2) to provide names for soilscape units which can be consistently mapped at medium and small scales.

The World Reference Base for Soil Resources (WRB) [11, 5] is the internationally-accepted soil classification system, recognized as such by the IUSS, and hence by the International Council of Scientific Unions (ICSU). In this working paper we examine the role which the WRB can play in the international study of urban and industrial soils. We first review the purpose, principles and structure of the WRB, and how urban and industrial soils are currently classified. We then identify shortcomings of the present system, and propose modifications to the WRB which, while respecting its purpose and structure, improve the classification of urban and industrial soils. We intend to refine this working paper into a formal proposal to the WRB Forum, after receiving comments from participants in SUITMA 2003.

# 2 The World Reference Base for Soil Resources

The WRB is fully described elsewhere [11, 6, 5]. Here we highlight the key features of the system that must be respected in any proposal for modification.

## 2.1 Versions

The current WRB used by FAO and classifiers active in the WRB working group is that presented in FAO World Soil Resources Report 94 [6] and at the 2002 IUSS meeting. This has an updated list of qualifiers, some relevant to urban soils, compared to the original WRB presented in FAO Soils Bulletin 84 [11] and adopted at the 1998 IUSS meeting. Although the WSSR94 version was not formally adopted at the 2002 IUSS meeting, it is used as the current classification by active workers. In addition this report includes extensive discussions of the rationale of the different groups, which are much easier to interpret than the dry language of the keys when trying to understand the intention of certain classification decisions.

## 2.2 Objectives

The WRB is intended as a high-level correlation system of soil individuals and as a mapping legend at regional and world scales. It was not designed as a detailed mapping legend nor to deal with situations of only local interest. It is ideally suited to discussing the geography, properties and genesis of world soils [6] and mapping their geographical distribution at regional [e.g. 15] to world scales.

The WRB descends from the project to make a world soil map at 1:5M, at which scale most urban areas can not even be represented (Minimum Legible Area = 625 $km^2$). Recent updating of this map at 1:1M (MLA = 25 $km^2$) shows areas 25 times smaller, but still much larger than homogeneous areas of urban and industrial soils.

## 2.3 Structure

The WRB has only two categorical levels: (1) the *Reference Group*, of which there are 30; and (2) the *subdivisions* of these, often called the "second level", denoted by combinations of a set of prefixes as qualifiers (also called modifiers) added to the reference soil group name. Each group has a list of approved qualifiers. In the WRB 1998 and 2002 it is explicitly permitted to use any number of relevant qualifiers in any order (subject to logical constraints, for example where one qualifier precludes or supersedes another). This allows closer matching with local systems. There is, however, strong sentiment for a fixed order of qualifiers, so that soil scientists worldwide would agree on the same name for the same soil.

These two levels are clearly not sufficient for describing soil variability at the level needed for detailed mapping and studies of soil behaviour. This role is filled by families, series, subtrates, or forms as defined by national systems. For example, the WRB second level (with all applicable qualifiers specified) is roughly equivalent to US Soil Taxonomy [20] subgroups ($4^{th}$ level, after orders, suborders, and great groups), under which are families (with information on particle-size class, mineralogy, clay activity, etc.) and series (with detailed information on parent material, horizon thicknesses, etc.), followed by mapping phases in which any relevant properties for soil use can be mentioned.

## 2.4 Classification principles

**World Soil Geography** The Reference Groups should be representative of major soil regions in order to provide a comprehensive overview of the world's soil cover. The second-level qualifiers should represent important properties which also have a geographical expression, either as strong properties, intergrades, or weak properties. The WRB is not meant to substitute for national soil classification systems, nor to reflect all local diversity and properties important for soil management.

**Applicability to mapping** Classes should reflect spatial linkages within the landscape at small and medium scales, allowing the WRB (perhaps with mapping phases) to be used as a map legend. This purpose is inherited from the FAO Soil Map of the World [9, 10], whose legend the WRB has replaced. Several international collaborations [e.g. 6] and re-compilations of national maps at small scales [e.g. 21] have successfully used the WRB.

**Diagnostic properties** Classification should be based on soil properties defined by diagnostic horizons and characteristics, which to the greatest extent possible should be measurable and observable in the field; laboratory measurements are kept to a minimum and, whenever possible, field indicators are allowed. Diagnostic horizons and characteristics are selected based on presumed relationship with soil forming processes, but these processes are not differentiating criteria as such. Consistent with the above, diagnostic properties should be as far as possible significant for soil management.

**Long-term properties** Classification should not change seasonally nor over a few years. Rapidly-changing properties such as fertility status, short-term pollution, or compaction that will soon be removed by natural causes or normal soil use may be named in monitoring studies, but not in the relatively permanent soil name given in the WRB.

**Correlation** Classes should allow easy embedding and correlation of national classification systems, and serve as a consistent communication tool for compiling global soil databases. This implies that limiting values should as far as possible match those established by national systems.

**Names** The nomenclature should retain terms which have been traditionally used or which can easily be introduced in current language; however, these terms must be precisely defined.

**Soil properties only** The WRB does not classify or map meteorological, agricultural, ecological or soil climate, except insofar as these are reflected in measureable soil properties. For example, there are no Aridisols (as in Soil Taxonomy [20]) but there are 'aridic soil properties' which are typical of arid climates.

The WRB does not name soils based on their geomorphology or land form; these can be used at other levels in a soil–terrain map, e.g. SOTER [8] or as mapping phases.

Soils are not classified by their parent material (substrates), except in the case of Anthropic Regosols (see §3.5.5). However, three reference groups (Andosols, Arenosols, and Vertisols) are mineral soils whose properties and genesis are dominated by their parent material; but they are defined by their current properties, not by their parent material as such.

Climate, geomorphology, and substrate may all be used in map unit names, as phases or at higher categorical levels in a map legend (e.g. agro-ecological zone)

## 2.5 Classification keys

A soil individual is assigned to one of the 30 reference groups by means of a binary key. That is, a soil is compared to the first group (Histosols (HS)), and if it matches the criteria, it is classified as such. If it fails, it is compared to the criteria of the next group (Cryosols (CR)), and so forth. A soil that does not match any of the first 29 groups is classified as a Regosol (RG), which is thus a "rest group", which includes many urban and industrial soils.

## 2.6 Evaluating the WRB

The success of the WRB is evaluated with respect to its objectives:

**Homogeneity** Does it place soil individuals (from actual databases) into homogeneous groups with respect to function, properties, interpretations, and genesis? In this sense 'homogeneous' means above all a restricted range of soil functions, properties, and interpretations.

**Correlation** Does it keep groups established by national classification systems? Or, if individuals from such groups are split in the WRB, is the division reflected at a lower level in the national system?

**Geography** Are map units named by their WRB components geographically-compact? Do they have landscape expression, that is, occupy well-defined and mappable segments of the landscape?

**Level of Detail** Are the soil units suitable for medium– and small–scale mapping, and correlation of soil studies over large areas?

Proposals are evaluated by comparing these two criteria in light of the current and proposed classifications.

# 3 Urban and industrial soils in the current WRB

We now discuss the classification of urban and industrial soils according to the current WRB in five groups, according to the type of substrate and the manner of modification by humans: (1) more-or-less natural soils; (2) natural soils heavily modified *in situ* by human activities; (3) young soils formed in natural materials displaced by human activity; (4) young soils formed from technogenic materials; (5) soils from displaced natural materials or technogenic materials, with significant pedogenesis since deposition.

## 3.1 Natural Soils

All classes in the WRB except the Anthrosols (AT) were designed to classify so-called 'natural' soils, i.e. soils which formed in place under natural conditions and which have only limited modification by human activities[1]. Natural soils occur in urban and industrial areas, and may be largely unaffected by human activity, in which case they are classified as if they were in rural areas.

However, natural soils of urban areas are often affected by atmospheric deposition of heavy metals, technogenic dust, or acid rain; this holds also for natural soils far removed from the sources of such pollution, but usually to a much lesser degree. In extreme cases soil morphology and properties may change so much that classification is affected; for example a spodic horizon can be destroyed by long-term additions of lime dust from a cement works. In less extreme cases the classification at the WRB levels is not affected, but the mapper may want to establish contaminated phases.

## 3.2 Natural soils heavily modified by human activities

Soils that are derived from natural soils heavily modified *in situ* by human activities as a special kind of pedogenesis are placed in the *Anthrosols* (AT) reference group. These are formed from natural soils by addition of organic materials or predominantly-organic

[1] however, see [7], who argue that human modification is much more widespread than generally acknowledged

household wastes, irrigation or deep cultivation; these are considered pedogenetic processes. This group was designed primarily for agricultural soils with long-standing and profound human influence, for example, plaggen and paddy soils. Soils from unaltered anthropogeomorphic soil material are excluded from the Anthrosols, and instead form a separate group within the Regosols, namely the *Anthropic Regosols*.

Anthrosols (AT) have a horizon indicative of anthropic pedogensis. In urban soils, this is most likely to be a *hortic* horizon in gardens, resulting from deep cultivation, intensive fertilization and repeated applications of human and animal wastes and other organic residues. It is indentified in part by colour, organic P and C, and base saturation, and in part by its history. These soils are *Hortic Anthrosols*.

Another diagnostic horizon is the *terric* horizon, used for soils with thick surface applications of organic-rich materials. These soils are are *Terric Anthrosols*. It is not clear if the current definition include sludges and organic-rich colluvium (see the proposal of §4.1.9).

Other useful modifiers reflecting conditions that may well be found in urban areas are Gleyic, Stagnic, Arenic, and Regic. These are of lower priority than Hortic, leading to names such as Stagni-Hortic Anthrosols. *Regi-Hortic Anthrosols* are those without identifiable buried horizons.

## 3.3 Young soils formed from natural materials moved by human activity

In urban settings, large areas are covered by natural materials (both soil and regolith) which have been moved and shaped[2]. This process destroys profile morphology and diagnostic horizons, creating a new soil profile, in which traces of the original horizons may still be visible. This also sets a new "time zero" of pedogenesis. As explained in the previous section, these are excluded from the Anthrosols and are mostly placed in the Anthropic Regosols, until there has been significant pedogenesis since the disturbance.

These materials are included in the definition of *anthropogeomorphic soil material*, which also includes technogenic materials (see next section):

> "Anthropogeomorphic soil material (from Gr. *anthropos*, human) refers to unconsolidated mineral or organic material resulting largely from land fills, mine spoil, urban fill, garbage dumps, dredgings, etc., produced by human activities. It has, however, not been subject to a sufficiently long period of time to find significant expression of pedogenetic processes." [11, p. 68]

These are listed in Table 1. Note that the degree of pedogenesis is included in this definition, by analogy to the definition *fluvic* soil material, which must still show stratification. Transported natural materials are mostly *aria* (if from disturbed natural soils) and *spolic* materials (if from regolith or dredgings).

## 3.4 Young soils formed from technogenic materials

Technogenic materials are those formed by industrial processes[3]. These materials are placed on the landscape and become soils as soon as they support biological activity.

[2] In German soil descriptions [2], horizons or layers formed from these materials are shown by the *j* prefix.

[3] In German soil descriptions [2], horizons or layers formed from these materials are shown by the *y* prefix.

The nature of the materials, as well as the depositional process, dominates the properties and behaviour of these soils on the landscape. They are included in the definition of *anthropogeomorphic soil material* (Table 1), in particular *garbic*, *reductic*, *urbic*, and *spolic* materials. Note that the latter group includes both natural and technogenic materials; among the natural spolic materials are soil, regolith, and rock (e.g. mine spoil).

Reducting conditions are common in *garbic* materials, so most of these would also qualify as *reductic* materials as currently defined (but see proposal at §5).

These materials often have extreme chemical conditions, rarely or never found in nature, that lead to rapid weathering, chemical reactions, and pollution; an example is tailings from hard coal mines [12, 19]. In addition, they may have extreme physical conditions (compaction, skeletal), which however are more likely than extreme chemical conditions to be found in nature.

## 3.5 Classification of soils from anthropogeomorphic materials

Soils from both natural and technogenic anthropogeomorphic materials are classified according to their diagnostic horizons and properties, without explicit reference to their origin (except as this excludes them from the Anthrosols). Most are classified as Leptosols (LP), Arenosols (AR), Fluvisols (FL), or Regosols (RG), with the latter predominanting. Organic soils are classified as Histosols (HS). If enough time has passed since the anthropogeomorphic material was moved ("time zero" of pedogenesis), soils developed on these materials may be classified in several other groups, as explained in the next section. We now discuss these groups, in key order.

### 3.5.1 Histosols (HS)

Soils with sufficient *organic soil material* are Histosols. There is nothing in the definition of the material or group to exclude organic sludges, e.g. sewage. Many will be Eutric Histosols. There is no qualifier to indicate anthropogeomorphic origin.

Table 1: Anthropogeomorphic soil materials defined in the WRB [11, p. 68]

| | |
|---|---|
| Aria | Mineral soil material which has, in one or more layers between 25 and 100 cm from the soil surface, 3% or more (by volume) fragments of diagnostic horizons which are not arranged in any discernible order. |
| Garbic | Organic waste material; land fill containing dominantly organic waste products. |
| Reductic | Waste products producing gaseous emissions (e.g. methane, carbon dioxide) resulting in anaerobic conditions in the material. |
| Spolic | Earthy material resulting from industrial activities (mine spoil, river dredgings, highway constructions, etc.). |
| Urbic | Earthy material containing building rubble and artifacts (cultural debris > 35% by volume). |

### 3.5.2 Leptosols (LP)

The central concept of the Leptosols is soils with very low water-holding capacity, either because of shallowness ($<25$ cm to hard rock, not including pedogenetic indurated horizons) or extremely low content by weight ($<10\%$) of fines. The definition of hard rock can be interpreted to include pavement (see the proposal in §4.1.3), although this certainly was not intended in the definition. This group also includes the historical Rendzinas: soils with a mollic horizon directly over highly carbonitic materials (see §3.6.2).

**Hyperskeletic Leptosols** Soils dominated by skeletal material, defined as $> 90\%$ skeleton by weight, are *Hyperskeletic Leptosols*. No further distinction is made by type of skeleton (coal, cinders, ballast, ...), which may have a major effect on soil behaviour (e.g. chemical composition of leachate), nor is there a distinction based on dominant fragment size.

However, many of these soils formed in industrial materials (such as railroad ballast) have a pore volume of $> 20\%$, much of this being large voids, because of the loose packing inherent in their deposition (dumping or tipping). This is in contrast to hyperskeletic soils derived from *in situ* weathering of rock, which have $< 10\%$ large voids, none of them coarse. The coarse voids in industrial soils are at first filled by air and water, but in time a portion becomes filled with fine earth such as aeolian dust, at which point the weight proportion may drop below the required $90\%$ and the soils become Skeletic Regosols[4].

Some urban Leptosols form when solid slag, streets, foundations etc. are weathered; these fit the WRB concept of Hyperskeletic Leptosols.

Note that Soil Taxonomy [20] defines *fragmental* soils (as well as various *skeletal* families on a volume, not weight basis.

**Lithic Leptosols** Thin soils over hard rock form the other group of Leptosols, with many possible modifiers. *Lithic Leptosols* are those $< 10$ cm thick. Soils $10 - 25$ cm thick will usually have the *Humic*, *Dystric*, or *Eutric* qualifiers instead. It seems that the Haplic qualifier would never be used, since a soil is either Dystric or Eutric in the 5 cm above the lithic contact.

**"Pavement" Leptosols** If the phrase "limitated in depth by continuous hard rock within 25 cm from the soil surface" in the definition of the Leptosols is interpreted to include the surface itself, i.e. a soil with hard rock or pavement at the surface, then paved areas are included in the Leptosols. Currently they would be classified as Lithic Leptosols; but this is certainly not the intent of this group. See the proposal at §4.1.3.

### 3.5.3 Fluvisols (FL)

The definition of *fluvic* soil material does not explicitly exclude water-laid deposits from industrial processes:

> "Fluvic soil material is soil material which shows stratification in at least 25% 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% to a depth of 100 cm. ..."

[4]These are "Particle Intrusols"; an example is Profile 5 of Excursion A of SUITMA 2000

Although the accompanying discussion mentions “fluviatile, marine and lacustrine sediments, which receive fresh material at regular intervals”, this is not diagnostic, only indicative. Flotation sludges qualify as Fluvisols by this definition. However, there are no second-level modifiers to indicate a non-fluvial origin, and it is unclear whether the designers of the Fluvisols intended that they be included.

### 3.5.4 Arenosols (AR)

Soils with a texture throughout of loamy sand or coarser, but not dominated by skeleton ($< 35\%$) key out as *Arenosols*. These are defined as a distinct reference group mainly because of their special importance to subsistence agriculture. This group is thus defined based on properties, not genesis. There is nothing in the current definition to exclude technogenic sands. However, as with the Fluvisols from flotation sludge, there are no second-level modifiers to indicate this origin, and it is unclear whether the designers of the Arenosols intended techhnogenic sands be included. As in the Hyperskeletic Leptosols, the parent material may have a major effect on soil behaviour (e.g. chemical composition of leachate). Soils from sand-size ash or cinders currently classify as *Dystric* or *Eutric Arenosols*.

### 3.5.5 Regosols (RG)

Most anthropogeomorphic soils key out at the end of the key as *Regosols*. Their central concept is a very weakly developed mineral soils in loose materials that have only an ochric surface horizon and that are not, in the urban context, skeletal (Leptosols) or sandy (Arenosols). Since this is a “rest group”, i.e. defined by what it is *not*, the second-level qualifiers are very important in distinguishing major properties. Relevant to technogenic urban soils are, in order of preference:

- *Garbic*: “having soil material containing $> 35\%$ (by volume) organic waste materials (in Anthropic Regosols only)”
- *Reductic*: “having anaerobic conditions caused by gaseous emissions (e.g. methane, carbon dioxide, . . . ) (in Anthropic Regosols only)”
- *Spolic*: “having soil material containing $> 35\%$ (by volume) industrial waste, e.g. mine spoil, dredge spoil, etc. (in Anthropic Regosols only)”
- *Urbic*: “having soil material containing $> 35\%$ (by volume) earthy materials mixed with building rubble and artefacts (in Anthropic Regosols only)”
- *Anthropic*: “consisting of anthropogeomorphic soil material, or showing profound modification of the soil by human activity caused by other factors than those related to cultivation”

The term *anthropogeomorphic* is not explicitly defined, but obviously refers to the situation where the landform (geomorphology) was created by human activity (dumping, shaping etc.).

The *Anthropic* qualifier is listed after substrate qualifiers, leading to names such as *Anthropi-Spolic Regosols*. This is redundant, since the substrate qualifiers are only allowed in the Anthropic Regosols. See the proposal on this issue in §4.1.8.

Another important qualifier in the Regosols is *Skeletic*, for those technogenic soils with from 40–90% coarse fragments, i.e. intergrading to the Hyperskeletic Leptosols.

## 3.6 Developed soils formed from anthropogeomorphic materials

If sufficient pedogensis has taken place, the WRB classifies the resulting soils as if they were formed *in situ*. The most common reference groups here are Gleysols (GL), Andosols (AN) and Cambisols (CM), but there may also be some Cryosols (CR), Leptosols (LP) and Arensosols (AR) in this group. We now discuss these in key order.

### 3.6.1 Cryosols (CR)

These have a *cryic* horizon, i.e. they are permanently frozen and have developed a characteristic structure due to this. Mining tailings and slag in arctic conditions would seem to qualify, if they have undergone sufficient pedogenesis (freeze-thaw cycles) as there is nothing in the definition of this horizon that restricts the type of material.

### 3.6.2 Leptosols (LP)

The Leptosols group also includes shallow ($< 25$ cm) soils with a *mollic* horizon directly over strongly carbonitic, but not necessarily indurated, material; these are the *Rendzic Leptosols*. Nothing in the definition excludes technogenic carbonitic materials, although significant time for pedogenesis is needed for the mollic horizon to form.

### 3.6.3 Gleysols (GL)

In areas where mineral anthropogeomorphic materials are saturated with groundwater for long enough periods to develop a gleyic colour pattern and evidence of reducing conditions, they may classify as Gleysols.

### 3.6.4 Andosols (AN)

Some technogenic ashes may rapidly develop all the properties of a vitric or andic horizon [14], and will key out as *Andosols*. There is presently nothing in the definition of these horizons to exclude such industrial ashes, nor any second-level qualifier to indicate their presence.

### 3.6.5 Cambisols (CM)

These are soils that have had sufficient time for significant pedogenesis and have developed *cambic horizons* (which by definition are not sandy). There are presently no qualifiers in this group to express technogenic origin. The identification of the cambic horizon is one of the more subjective procedures in soil morphology, so the Regosol – Cambisol boundary in feature space is likewise subjective. There are no intergrades between the Cambisols and Regosols; either a horizon is considered cambic or not; in a sense these two reference groups are by design already intergrades to each other.

### 3.6.6 Arenosols (AR)

As Arenosols from technogenic or transported materials undergo pedogenesis, they may form weathered horizons that do not qualify as cambic horizons only because of their texture. Their classification will not change.

## 3.7 Evaluation of the current classification

The current classification of urban and industrial soils in the WRB is fairly logical and consistent. However, there are some clear shortcomings with reference to the stated objectives of the WRB.

The most glaring problem is that there is nothing in the name of soils from technogenic materials to indicate this substrate, except in the Anthropic Regosols. This is especially unfortunate for less-developed soils: Leptosols (LP), Fluvisols (FL), and Arenosols (AR), where the soil properties are dominated by the substrate. However, properties of developed soils such as Cryosols (CR), Gleysols (GL) , Andosols (AN), and Cambisols (CM) may also be affected by the technogenic substrate.

Related to this, it is unclear from the whether soils from technogenic sludges were intended to be included in the Fluvisols (FL). Similarly, it is unclear if soils from technogenic sands were intended to be included in the Arenosols (AR), or if soils from technogenic ashes in the Andosols (AN), or if soils from technogenic spoil in arctic conditions in the Cryosols (CR). (It seems that more developed soils, including the Gleysols (GL) and Cambisols (CM), were intended to include soils from such materials.)

Then there are some less far-ranging problems:

- The Hyperskeletic Leptosols include soils with both high (ballast etc.) and low (natural rock) volume of coarse pores, with no further distinction.
- The order of second-level qualifiers in the anthropic Regosols leads to redundant names.

# 4 Possible changes to the WRB

In this section we present possible changes to the WRB so that it may better meet its objectives with respect to urban and industrial soils (see §2.6), namely (1) homogeneity of properties and interpretations, (2) correlation to national systems, and (3) geography. Geographical success is evaluated by how well a modified WRB is able to mapping at semi-detailed to reconaissance scales in urban landscapes.

Our approach is essentially conservative: change as little as possible, while meeting the evaluation criteria. So, we first (§4.1) propose changes in existing definitions that, in our opinion, clarify the current situation with respect to urban soils, but do not fundamentally change the system. Second (§4.2), we discuss the idea of introducing a new "Technosols" reference group. Third (§4.3), we examine a less radical proposal, namely to unite the undeveloped technogenic soils in the Regosols.

In the following discussion, proposed changes are indicated *like this*.

## 4.1 Option 1: Changes to current definitions

In this section we propose what we consider to be minimum changes to allow a satisfactory treatment of urban and industrial soils in the WRB. We discuss these in key order of the reference groups, followed by diagnostic horizons.

### 4.1.1 Histosols (HS) Reference Group

We propose (§5) adding an *sludge-organic* soil material for organic-rich sludges (mainly sewage); this would then be referred to by a new *sludge-organic* qualifier:

"**Sludge-organic**: having a histic or folic horizon composed of *sludge-organic* soil material, within 50cm of the soil surface.

### 4.1.2 Cryosols (CR) Reference Group

We propose that the **Anthropic** qualifier be allowed in the Cryosols, in order to separate soils from anthropogeomorphic materials, generally mine spoil and fill. This qualifier's definition would be changed from "(*in Regosols only*)" to "(*in Regosols, Cyrosols, Fluvisols, Gleysols, Andosols and Cambisols only*)". In the Cryosols, this strong property qualifier would go just before *Lithic*. It seems excessive to add the detailed qualifers Spolic, Garbic, Reductic, Aric, or Urbic. Almost all these soils would be Spolic in any case.

### 4.1.3 Leptosols (LP) Reference Group

We propose explicitly including streets and other paved areas with some accumulated fines:

1. "Limited in depth by continuous hard rock *or hard, largely unfractured technogenic material* within 25 cm from the soil surface;"

This may be redundant if we already understand 'rock' to include such materials, but nowhere is 'rock' defined in the WRB, so the common definition, referring to natural material, is assumed.

To distinguish natural and technogenic Hyperskeletic Leptosols, we propose adding the **Spolic** and **Urbic** qualifiers to this groups. These are strong property qualifiers, and should be added immediately after the Rendzic Leptosols.

**Hyperskeletic Leptosols** As pointed out in §3.5.2, the definition of skeleton by weight, rather than volume as in Soil Taxonomy, combines soils formed in industrial materials (such as railroad ballast) with a high volume of coarse voids and loose packing with hyperskeletic soils derived from *in situ* weathering of rock. This also applies to soils formed in natural rockfalls. We propose a new qualifier, with limits to be modified based on a closer study of actual profiles:

"**Voidic**: having $>10\%$ by volume coarse ( $>5$ mm) voids in all material that qualifies as hyperskeletic. (*in Hyperskeletic Leptosols only*)"

**"Ekranosols"** Stroganova & Prokofieva [22] proposed the Russian name "Ekranozems" (Russian 'ekran' = 'screen', from French 'écran'; 'zemlya' = 'land' or 'soil') for areas of pavement underlain by looser material within the vertical limits of a pedon. Although there is little flux at the surface, processes in the subsoil are similar to those in other soils. Also, these areas are connected laterally to other pedons, and participate in the environmental function of the city.

These may be brought into the WRB as a subgroup of the Leptosols, with a new strong property qualifier for the situation where the surface is completely sealed. There seems to be no need to change the definition of the Leptsols as such, as long as the phrase "limitated in depth by continuous hard rock within 25 cm from the soil surface" is interpreted to include the surface itself, i.e. a soil with hard rock (which is interpreted to include pavement) at the surface. The qualifier would be defined as:

> "**Ekranic**: having technogenic hard rock at the surface, underlain at some depth shallower than 200 cm by material that qualifies as hyperskeletic or finer. (*in Leptosols only*)"

This would be the first qualifier in the list. Thus paved areas would be shown on soil maps as "Ekranic Leptosols".

### 4.1.4 Fluvisols (FL) Reference Group

Technogenic materials such as flotation sludges seem to qualify as fluvic materials in the current WRB. This seems satisfactory, since the layering and irregular distribution of organic matter is a highly-significant feature of these soils, whether deposited by natural or natural waters, as long as a the **Anthropic** qualifier is modifed to allow its use in the Fluvisols (see §4.1.2). This qualifier would be placed in the key after the strong property qualifiers, and before the other qualifiers that indicate the type of material, i.e. just before the Tephric Fluvisols.

### 4.1.5 Gleysols (GL) Reference Group

We propose that the **Anthropic** qualifier be allowed in the Gleysols (see §4.1.2), in order to distinguish gleyed anthropogeomorphic materials from natural soils. This strong property qualifier would go just before *Gelic*. It seems excessive to add the detailed qualifers Spolic, Garbic, Reductic, or Urbic, since the area of such soils is limited.

### 4.1.6 Andosols (AN) and Cambisols (CM) Reference Groups

We propose that the **Anthropic** qualifier be allowed in both the Cambisols and Andosols (see §4.1.2), in order to distinguish weakly-developed natural and technogenic soils. In these two groups, this qualifier would go just before *Skeletic* in both cases. It seems excessive to add the detailed qualifers Spolic, Garbic, Reductic, or Urbic. Almost all these soils would be Spolic in any case.

### 4.1.7 Arenosols (AR) Reference Group

We propose adding the **Spolic** qualifier to this groups, to distinguish natural and technogenic Arenosols. This is a strong property qualifier, and would be added immediately before the Tephric Arenosols. Since "spolic" implies "anthropic", there is no need for the latter qualifier also. It is difficult to imagine non-Spolic Anthropic Arenosols. This qualifier's definition would be changed from "(*in Anthropic Regosols only*)" to "(*in Anthropic Regosols and Arenosols only*)".

### 4.1.8 Regosols (RG) Reference Group

In the current keys, the four technogenic substrate qualifiers (**garbic**, **reductic**, **urbic**, and **spolic**) are of higher priority than the **anthropic** qualifier; yet they are only allowed in the Anthropic Regosols. This leads to redundant names such as **Anthropi-Spolic Regosols**.

One possibility would be to disallow the **Anthropic** qualifier in those cases where one of the four technogenic substrate qualifiers is already used, and reserve the **Anthropic Regosols** for only those cases where no more specific qualifier could be used.

Another possibility is to give the **Anthropic** qualifier a higher priority than the four technogenic substrate qualifiers, leading to names such as **Spoli-Anthropic Regosols**. That is, the new qualifiers become, in effect, subclasses of Anthropic Regosols. An anthropic soil not meeting any other qualifier would then be a Hapli-Anthropic Regosol, and this Hapli- qualifier would be *required* for Anthropic Regosols.

Of these two, we prefer the second, because the anthropic nature of these soils is always explicit in the name, and the more specific qualifiers (or Haplic if none apply) become, in effect, a third level of the classification.

So in [6, p. 334], the **Anthropic** qualifier, currently near the bottom of the list, just above Skeletic, should be moved up near the top, just before **Aric** and the other substrate qualifiers.

#### 4.1.9 Terric horizon

We propose explicitly including sludges that have similar properties to earthy manures, if they meet the other criteria of the terric horizon.

> "A terric horizon (from L. *terra*, earth) develops through addition of earthy manures, compost, *organic-rich sludge* or mud over a long period of time. *It can also develop by colluviation of such materials . . .* "

#### 4.1.10 Andic horizon

We propose explicitly including technogenic ashes that have developed into andic materials:

> "The andic horizon (from Japanese An, dark, and Do, soil) is a horizon resulting from moderate weathering of mainly pyroclastic deposits. However, they may also be found in association with non-volcanic materials (e.g. loess, argilites, *technogenic ashes* and ferralitic weathering products)."

#### 4.1.11 Vitric horizon

We propose explicitly including technogenic ashes that have developed into vitric materials:

1. 10 percent or more volcanic glass, *technogenic glass*, and other primary minerals in the fine earth fraction . . .

#### 4.1.12 "Relict" soils

If the soil-forming environment is altered by human activity, the soil may retain morphological features and properties from the previous environment, now not active, for some time. These features may influence soil behaviour even in the new environment, and if so should be mentioned in the soil name without, however, implying that the previous soil-forming environment is still active.

A good example in natural soils are drained Gleysols, which are common in "reclaimed" agricultural landscapes, as well as urban areas. As soon as they no longer have long-term reducing conditions induced by high ground water, they will be excluded from Gleysols. because they no longer meet either of the first two diagnostic criteria (low rH or presence of free $Fe^{2+}$). However, they will keep their morphology and associated segregated iron phases for some time. They will most likely be classified as Phaeozems (PH) if they have a mollic horizon or Cambisols (CM) otherwise. They will receive the *gleyic* qualifier only if reducing conditions are still present below 100 cm. Nothing in the name indicates the relict gleying at shallower depths. (After some time they will completely lose their gley morphology, at which point there is no controversy about their classification.)

In urban areas, land use changes that affect the soil-forming environment are quite common. We have found the following soils in the Ruhr (the names are in quotes to emphasize that these are not their actual WRB classifications, but rather their classifications before modification):

- relict "Gleysols": due to drainage, as explained just above;
- relict "Reductic Regosols": due to aeration, so that reducing conditions are no longer active, yet with much of the soil mass still reduced (although not actively reducing); this includes so-called "Necrosols" where most organic material has decomposed;
- drowned terrestrial soils (mostly relict "Luvisols" and "Cambisols"), due to diking and controlled flooding;
- relict "Hortic Anthrosols" : due to disuse; these fail either the $P_2O_5$ or base saturation criteria, but meet morphologic criteria.

In the current WRB these are classified according to actual conditions. The mapper may then establish series or mapping phase criterion to indicate their origin, e.g. "Haplic Phaeozems (relict Mollic Gleysols phase)". However, the transitional nature of these soils (having both a previous and current soil-forming regime) can be emphasized by defining a new qualifier, to be applied to the classification based on *current* properties:

> "**Relict**: Having a strong morphological expression of a previous soil-forming environment within 100cm of the soil surface"

In all relevant groups, this would be placed as a strong property qualifier, leading to names like "Relictic Phaeozems". However, this does not show the nature of the relict properties. So it seems preferable to define a list of qualifiers for specific relict conditions, for example:

> "**Relictogleyic**: Meeting the morphological, but not the chemical, requirements for *gleyic* properties within 100cm of the soil surface."
> "**Relictoreductic**: Having morphological evidence of previous, no longer active, anaerobic conditions caused by gaseous emissions (e.g. methane, carbon dioxide, etc...) (*in Anthropic Regosols only*).[5]
> "**Relictohortic**: Having a horizon that meets the morphological, but not the chemical, requirements of the *hortic* horizon; in Anthrosols 50 cm or more thick, in other soils less than 50 cm thick."

In all relevant groups, this would be placed as an intergrade qualifier, leading to names like "Relictogleyic Phaeozems".

[5] This definition could be tightened in parallel with the *reductic* qualifier itself.

### 4.1.13 Toxic soils

The WRB has a *toxic* qualifier, used only in the Histosols and Gleysols:

> "**Toxic**: having, within 50 cm from the soil surface, ions other than aluminium, iron, sodium, calcium or magnesium, in concentrations toxic to plants"

Two aspects of this definition make it unsuitable for urban soils: (1) the exclusive use of ions as indicators, not considering organic compounds and metals, and (2) the exclusive use of plants as test organisms, not considering animals (including humans) or soil fauna.

Contamination of urban soils by metals [e.g. 17] and organics [e.g. 16] is widespread. It may affect human health by direct contact (fumes, dust, aerosols) or by high concentrations in plants eaten from gardens. Urban and industrial contamination can also affect soil ecology, especially the population of mesofauna. Finally, grazing animals may be affected by contaminants or mineral imbalences (e.g. excess or deficient Se [23]).

To better distinguish these, we propose renaming the current *toxic* qualifier to **herbotoxic**, and defining three new qualifiers, whose quantitative definition should be refined by specialists:

> "**Anthrotoxic**: having sufficiently high and persistent concentrations of metals or organic compounds to markedly affect the health of humans who come in regular contact with the soil."

> "**Ecotoxic**: having sufficiently high and persistent concentrations of metals or organic compounds to markedly affect soil ecology, in particular the population of mesofauna."

> "**Zootoxic**: having sufficiently high and persistent concentrations of metals or organic compounds to markedly affect the health of animals, including humans, who ingest plants grown on these soils.

These four would be defined as weak property qualifiers in all reference groups where they are documented. We expect to document, among others, Zootoxic Hortic Anthrosols and Anthrotoxic Spolic Regosols.

## 4.2 Option 2: A "Technosols" Reference Group?

The modifications of Option 1 simply clarify the current situation. However, they do nothing to place technogenic soils more centrally in the WRB. A more radical option is to define a new "Technosol" reference group[6], combining developed and raw soils from anthropogenic soil materials, including skeletal and sandy materials

To propose a new WRB Reference Group, we must decide that technogenic soils have "major differences in terms of genesis, geography, and use potential" compared to the 30 existing groups. The closest analogy is the Anthrosols, whose central concept (heavily human-influenced natural soils) seems has been accepted by the WRB.

In this option, we would define a new ($31^{st}$) reference group: the **Technosols (TS)** at the second position in the key, after the Histosols (HS). It could be defined as:

[6] This name has also been used in a proposal by Andreas Lehmann of the Institut für Bodenkunde und Standortslehre, Universität Hohenheim, Stuttgart (D), which is quite different in detail from the present proposal

> "Other soils dominated by *technogenic soil materials* to a depth of 100 cm or a lithic or paralithic contact, whichever is shallower.
> **TECHNOSOLS (TS)**"

This would require a new soil material, namely **technogenic**[7], which would be the same as the current **anthropogeomorphic** soil material, but excluding aria and purely natural spolic material (e.g. dredgings and clean landfill). Thus soils from anthropogeomorphic activity, but natural materials, would remain mostly in the Regosols.

> "**Technogenic soil material**: Technogenic soil material (from Gr. technos, artificial) refers to all anthropogeomorphic soil materials (*q.v.*) except aria and spolic material of natural origin (e.g. dredgings and clean fill) created as the result of technical processes. It does not include aria or natural spoil."

This group would appear second in the key to keep soils developed from technogenic materials out of the Cryosols and Anthrosols. Organic soils formed from, for example, sludges would remain in the Histosols, following the long-standing tradition that separates organic from mineral soils.

This group would then have qualifiers for the type of material, strong property qualifiers for soils formerly in the Arenosols (arenic) and Leptosols (hyperskeletic), and intergrades to natural soils, e.g Gelic, Gleyic, Cambic, and Andic. The difference between "Cambic Technosols" and Cambisols, between "Gleyic Technosols" and Gleysols, and so forth would then be in the type of material, not the profile morphology. Proposed qualifiers, in priority order, are:

| |
|---|
| Cryic<br>Gelic<br>Leptic<br>Hyperskeletic (see §4.3)<br>Hyperarenic (see §4.3) |
| Gleyic<br>Andic<br>Cambic |
| Garbic<br>Reductic<br>Spolic<br>Urbic |
| Stagnic<br>Humic |
| Skeletic<br>Arenic<br>Dystric<br>Eutric |

This would require a new qualifier:

> *Cambic*: "having a cambic horizon (in Technosols only)"

---
[7] similar to the *technic* material proposed by Lehmann

## 4.3 Option 3: Unite the undeveloped technogenic soils in the Anthropic Regosols

A middle way, between the modifications of Option 1 and the "Technosols" of Option 2, for classifying soils from technogenic materials in the WRB would be to change the key to reference groups in order to bring the technogenic Cryosols, Arenosols and Leptosols into the Anthropic Regosols. This would also require the definition of **technogenic** soil material, as in §4.2. Soils with significant pedogenesis would remain in the Gleysols, Andosols, and Cambisols, and soils with layering due to deposition in water would remain in the Fluvisols which would get added qualifiers as in §4.1.

The rationale of this option would be that sandy and skeletal technogenic substrates share more properties with other technogenic raw soils than with the natural soils in these two reference groups. In particular, the nature of the material may have a strong influence on leachates.

**Cryosols (CR) Reference Group** Add a second clause to the key:

> "…and are not dominated by *technogenic* soil material."

This is consistent with the current exclusion of frozen Histosols and Gleysols from the Cryosols.

**Leptosols (LP) Reference Group** Add a fifth item to the key:

> "5. Are not dominated by *technogenic* soil material."

**Arenosols (AR) Reference Group** Add a fourth item to the key:

> "4. Are not dominated by *technogenic* soil material."

**Added qualifiers in the Anthropic Regosols** Three new strong property qualifiers would be added at the current position of *Arenic*, to capture the soils moved from the Leptosol, Arenosols, and Cryosols:

- *Hyperskeletic*: "having more than 90% (by weight) gravel or other coarse fragments to a depth of 100 cm from the soil surface."
- *Hyperarenic*: "having a texture of loamy fine sand or coarser throughout the upper 100 cm of the soil."
- *Cryic*: "having a *cryic* horizon within 100 cm from the soil surface"

Note that the present *Arenic* and *Skeletic* qualifiers would remain.

The current priority order, with Arenic listed as a strong property qualifier, and Skeletic only as a modifier much further down the key, seems illogical. We propose that Hyperskeletic and Hyperarenic take the place of Arenic as a strong property qualifier, and Arenic be moved below Skeletic:

1. Gelic, Leptic, …Thaptoandic
2. Hyperskeletic, Hyperarenic, Cryic
3. Anthropic (see §4.1.8)

4. Aric, Garbic ... Urbic
5. Tephric, Gelistagnic, ... Hyperochric
6. Skeletic, Arenic
7. Hyposodic ... Eutric
8. (remove Haplic, since every soil must be at least Dystric or Eutric)

With this order, technogenic spoil would be classified as Anthropi-Hyperskeletic Regosols (Spolic).

**Added qualifiers in other reference groups** Most of the proposal of Option (§4.1.6) would also be included here, in particular the new qualifiers in the Gleysols, Andosols and Cambisols.

# 5 Soil parent materials (substrates) in the WRB

The WRB uses (but does not precisely define) the concept of *anthropogeomorphic* soil materials, and provides a short list of five types. These are examples of the more general concept of *substrates*, defined as the material from which a soil was formed, not reflecting subsequent pedogenesis. These are used in German soil maps along with the pedogenetic soil type to name map units, and are the subject of a detailed classification [1], which includes a wide variety of technogenic materials. Thus a map unit could be correlated to a WRB class, and at the same time be identified with a substrate. Only in the case of Regosols are substrates (the so-called anthropogeomorphic soil materials) explicitly used in the WRB classification.

Even within the anthropogeomorpic material, the list of five types is quite restricted when compared to detailed classification of substrates [3, 13], and misses important distinctions; in particular, the *spolic* materials include both natural and technogenic materials. Depending on the nature of the spolic material, there may be radically different properties and hence interpretations.

By comparaison, the detailed classification of Hiller & Meuser [13, Table 3.1], divides technogenic substrates into six major groups:

1. building material (WRB *urbic* material);
2. slag (WRB *spolic* material);
3. ash (WRB *spolic* material);
4. rock from mining, including coal and tailings (WRB *spolic* material);
5. garbage (WRB *garbic* material);
6. sludge (WRB *fluvic* and/or *organic* material).

Each major group is divided into several subgroups, and each of these into a list of specific materials. For example, sludge is divided by the process by which it was produced into (a) sewage sludge, (b) industrial sludge, (c) flotation sludge and (d) residual sludge from soil cleaning by washing.

An additional substrate is animal carcasses and human corpses, which form the parent material of the so-called 'Necrosols'.

One way to deal with the wide variety of materials is to ignore detailed differences, accept the current list, and force the mapper to define series or mapping phases based on substrate. However, if the differences are pronounced, they should be incorporated into a relatively high-level classification such as the WRB. The difficulty is matching the conceptual level of the WRB to the detailed knowledge of different substrates.

**Proposed changes to soil materials** Based on this, we propose the following changes:

1. Restrict the *reductic* material to non-garbage; it is understood that *garbic* material will also produce reducing conditions.

2. Add an *sludge-organic* material, for organic-rich sludges (mainly sewage); this would also qualify as *organic* material.

   > "**Sludge-organic soil material**:
   >
   > **General description**: This is *organic soil material* which has been placed or spread by human action.
   >
   > **Diagnostic criteria**: As for *organic soil material*, and shows evidence of anthropogeomorphic origin."

3. Add a *sludge-mineral* material, for mineral sludges (industrial, flotation, residual); much of this would also qualify as *fluvic* material.

4. Divide the *spolic* material into:

   4.1. *slag-spolic*

   4.2. *ash-spolic*

   4.3. *rock-spolic*

# 6 Conclusion and next steps

All three options have their attractions. We feel that Option 1 is the absolute minimum that must be accepted for the WRB to deal adequately with urban and industrial soils. Option 2 is the most radical, since it recognizes technogenic soils at the highest level. However, adding a new reference group is not to be taken lightly, especially since the current structure of the Regosols has already been modified in a mostly satisfactory way. Option 3 represents a compromise which brings together soils whose properties are dominated by technogenic substrates but which have not undergone significant pedogenesis. This is our preference.

We invite comments on our proposals. Based on these, we will make a formal proposal to the WRB Forum, and recast this working paper into a journal article.

# References

[1] Altermann, M. & Kühn, D. 1998. *Systematik der bodenbildenden Substrate. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft* **86**:135–180

[2] Arbeitskreis für Bodensystematik. 1998. *Systematik der Böden und der bodenbildenden Substrate Deutschlands*. *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft* **86**:1–180

[3] Arbeitskreis Stadtböden. 1988. *Substrate und Substratmerkmale von Böden der Stadt- und Industriegebiete*. *Mitteilungen der Deutschen Bodenkundlichen Gesellschaft* **56**:311–316

[4] Cline, M. G. 1949. *Basic principles of soil classification*. *Soil Science* **2**:81–91

[5] Deckers, J. A.; Nachtergaele, F. O.; & Spaargaren, O. C. (eds.). 1998. *World Reference Base for soil resources : Introduction*. Leuven: ACCO

[6] Driessen, P.; Deckers, J.; Spaargaren, O.; & Nachtergaele, F. (eds.). 2001. *Lecture notes on the major soils of the world*. World Soil Resources Report 94. Rome: FAO

[7] Dudal, R.; Nachtergaele, F.; & Purnell, M. F. 2002. *The human factor of soil formation*. In *17th World Congress of Soil Science*, pp. CD–ROM, paper 93. Bangkok: International Union of Soil Sciences

[8] van Engelen, V. W. P. & Ting-tiang, W. (eds.). 1995. *Global and National Soils and Terrain Digital Databases (SOTER): Procedures Manual*. Wageningen: International Soil Reference and Information Centre (ISRIC)

[9] FAO. 1974. *Soil map of the world*, volume 1 : Legend. Rome: Food and Agriculture Organization of the United Nations

[10] FAO. 1990. *Soil map of the world : revised legend*. World Soil Resources Report 60. Rome: Food and Agriculture Organization of the United Nations

[11] FAO. 1998. *World Reference Base for soil resources*. World Soil Resources Report 84. Rome: Food and Agriculture Organization of the United Nations

[12] Galbraith, J. M.; Hernandez, L. A.; Goddard, T. M.; Mays, M. D.; & Harris Jr., W. G. 1999. *Properties of the Riker coal ash soil*. *Soil Survey Horizons* **40**(4):109–117

[13] Hiller, D. A. & Meuser, H. 1998. *Urbane Böden*. Berlin: Springer

[14] Jahn, R. & Zikeli, S. 2002. *Böden aus Asche der Braunkohleverbrennung und ihre Klassifikation*. In *Arbeitskreis Stadtböden und Arbeitskreis Bodensystematik: Workshop Klassifikation von Stadtböden, 09-Juni-2002*. Essen (D): (unpublished)

[15] Joisten, H.; Jahn, R.; Sinaplus, R.; Kabala, C.; Tomasek, M.; & Hoffman, R. 2002. *The first international joint soil map of Germany, the Czech Republic and Poland in a scale of 1:50000, sheet Zittau*. In *17th World Congress of Soil Science*, pp. CD–ROM, paper 2049. Bangkok: International Union of Soil Sciences. Have reprint

[16] Krauss, M. & Wilcke, W. 2003. *Polychlorinated naphthalenes in urban soils: analysis, concentrations, and relation to other persistent organic pollutants*. *Environmental Pollution* **122**(1):75–89

[17] Lu, Y.; Gong, Z.; Zhang, G.; & Burghardt, W. 2003. *Concentrations and chemical speciations of Cu, Zn, Pb and Cr of urban soils in Nanjing, China*. *Geoderma* **115**(1-2):101–111

[18] Schraps, V. W. G.; Kersting, A.; Pingel, P.; Schneider, S.; Baumgarten, H.; Burghardt, W.; Hiller, D. A.; Köppner, T.; Ohlemann, S.; & Metzger, F. 2000. *Stoffbestand, Eigenschaften un räumliche Verbreitung urban-industrieller Böden – Ergebnisse aus dem Projekt Stadtbodenkartierung Oberhausen–Brücktorvertiel*. Scriptum: Arbeitsergebnisse aus dem Geologischen Landesamt Nordrhein–Westfalen Heft 7, Geologischen Landesamt Nordrhein–Westfalen, D-47707 Krefeld

[19] Sencindiver, J. C. & Ammons, J. T. 2000. *Minesoil genesis and classification*. In Barnhisel, R. I.; Darmody, R. G.; & Daniels, W. L. (eds.), *Reclamation of drastically disturbed lands*, Agronomy ; no. 41. Madison, Wis.: American Society of Agronomy : Crop Science Society of America : Soil Science Society of America

[20] Soil Survey Staff. 1999. *Soil Taxonomy: a basic system of soil classification for making and interpreting soil surveys*. Agricultural Handbook 436. Washington, DC: US Department of Agriculture Soil Conservation Service, 2nd edition

[21] Stolbovoi, V. 2000. *Soils of Russia: correlated with the revised legend of the FAO soil map of the world and World Reference Base for Soil Resources*. RR-00-13. Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA)

[22] Stroganova, M. & Prokofieva, T. 2002. *Urban soils classification for Russian cities of the taiga zone*. In Micheli, E.; Nachtergaele, F. O.; Jones, R. J. A.; & Montanarella, L. (eds.), *Soil Classification 2001 (European Soil Bureau Research Report No. 7, EUR 2-398 EN)*, pp. 153–156. Luxembourg: Office for Official Publications of the European Community

[23] Tan, J.; Zhu, W.; Wang, W.; Li, R.; Hou, S.; Wang, D.; & Yang, L. 2002. *Selenium in soil and endemic diseases in China*. *The Science of The Total Environment* **284**(1-3):227–235