4 Classification of urban soils

1. Introduction

Permanent technogenic disturbances of urban environments and formation of technogenic sediments result in short cycles of soils' formation and 'young' age of soils of urban areas. Different susceptibility of urban soil materials to anthropogenic disturbances result in different ages of urban soils' horizons. Dust sedimentation and greenery maintenance contribute to the vertical growth of soil layers. This trend of 'topsoil' buildup is referred as 'synlithogenic' trend in soil forming process. Synlithogenic soil formation is typical for urban soils and, in contrast, is rare for natural soils, where the major soil processes usually are directed down in the profile except for alluvial, colluvial and volcanic soils (Dobrovolsky and Urussevskaya 2004). As a result, the relative age of urban topsoil is mostly younger than that of subsoil layers.

Various types of soil transformations in urban areas can be distinguished: (i) transport and deposition; (ii) long-term deposition; (iii) mixing; (iv) sealing (Hulisz et al. 2016). The most typical features of soil formation in described areas include: i) vertical growth of topsoil layers and predominantly synlithogenic soil formation process; ii) short time periods for soil formation, resulting in the early stages of pedogenesis; iii) abrupt and clear boundaries of layers and horizons; iv) specific chemical features, caused by dust deposition and anthropogenic disturbances, including alkaline pH, contamination with heavy metals and hydrocarbons, elevated carbon and phosphorous content; v) altered physical features, including high bulk density and high share of technogenic materials (artefacts) within the profile; and vi) specific community of living organisms both in terms of biodiversity and total biomass. Urban soils are then frequently characterized by a substantial horizontal and vertical heterogeneity. The differentiation of the soil sites is significantly related to the site age, technogenic impact intensity and the form of land use (Greinert 2015).

Specific factors of formation of urban soils and their unique features determines substantial differences between technogenic and non-urban soils, recognized by many national and international classifications, which distinguish presently urban soils as an individual taxon. However, modern soil science, derived from agronomy and forestry, since its beginning in late 19th century was focused on natural zonal and azonal soils, whereas soils of the urban areas were absent in soil classification schemes for a long time. Present-day status of these soils in the international and selected national classifications will be presented in this chapter.

2. Anthropogenic and technogenic soils in the World Reference Base (WRB) for soil resources

Among the variety of soils existing in urbanized areas, the soils intentionally changed by humans to improve its productivity (e.g. in gardens) were more professionally described as first, at least since early 19th century (Jäger 1864). Also Darwin provided extensive observation and explanation, how humans may induce the development of deep garden soils by improving earthworm activity with organic household remains (Johnson and Schaetzl 2015). Such deeply mixed, black-coloured, and rich in nutrients Hortisols were probably the first soils of urban areas that appeared in soil classifications. In most national classifications, Hortisols were placed together with other intentionally improved agricultural soils, sometimes named Culturozems (Classification of Polish Soils 2011, Stroganova et al. 1998). The group includes Plaggosols (soils built-up by adding of earthy sod used as litter thus saturated with nutrients from the animal excrements), soils built-up by adding other fertile earthy materials (e.g. river dredging sediments), soils built-up with mineral-organic sediments in course of irrigation, soils with a morphology deeply changed due to "wet cultivation" (as in rice fields), and recently added Terra Preta – dark arable soils particularly enriched with charcoal. All these soils are included in WRB as Anthrosols and are distinguished at the second classification level using the following qualifiers: Hortic, Plaggic, Terric, Irragric, Anthraquic, and Pretic, respectively, having the same names as respective diagnostic horizons (IUSS Working Group WRB 2015).

Each of these horizons must have the thickness of at least 20 cm to be "diagnostic", and at least 50 cm to allow soil classification in Anthrosols group. So called Rigosols (or Rigolen), soils mixed or disturbed by digging or ploughing down to 90–110 cm, but less fertile than Hortisols, are not included into Anthrosols (if they do not have one of the above mentioned diagnostic horizons), but may be indicated in other reference soil groups by using the Anthric, Aric, and Relocatic qualifiers. Although Anthrosols are mainly agricultural soils, at least some of them have still been preserved in urbanized areas, and, due to its special fertility, have been continuously used for food production (e.g. in the family, allotment, and monastery gardens), and may play ecological roles as sources of biodiversity (Bullock and Gregory 2009, Greinert 2015). However, soil contamination with trace elements and other xenobiotics resulting from atmospheric deposition or long-term fertilization/liming may create risk for human health and influences their management (Kabala et al. 2009, Matinian and Bakhmatova 2016).

The true understanding of soil functions in the industrial, mining, and urban areas was born in the 1970s, and first new specific soil units were suggested to allow complete soil mapping on a larger scales (Avery 1980). However, there initially prevailed an opinion that the recently stored (sedimented) anthropogenic materials have specific characteristics, distinguishing them from natural rocks and sediments, but the ongoing soil-forming processes are the same in human-made and in the natural soil substrates (Blume 1989, Meusner and Blume 2001). Starting from this point of view, the poorly developed soils of urban and industrial areas, having no diagnostic horizons, have been classified as Regosols in the 1st edition of WRB (FAO-ISRIC-IUSS 1998). Five specific qualifiers were initially introduced, based mainly on particular human-made or human-transformed soil materials (Table 4-1). One of qualifiers (Urbic) was directly dedicated to urban soils; however, at least three other (Anthropic, Spolic, and Garbic) were also useful in naming and mapping of soils in urbanized areas.

Rapidly increasing number of new investigations in urban areas has provided, at the turn of the century, a lot of new data on unique characteristics and functions of soils developed in human-created or human-transformed substrates (Burghardt 1994, Schleuss et al. 1998, Rusakov and Novikov 2003, Scharenbroch et al. 2005, Lehmann 2006, Nehls et al. 2006). Also, the new

Table 4-1. Qualifiers for soils of urban, mining and industrial areas in a Regosols diagnostic group (FAO-ISRIC-IUSS 1998).

Qualifier	Description
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
Garbic	having accumulations of anthropogeomorphic soil material containing more than 35% (vol.) organic waste materials
Reductic	having anaerobic conditions caused by gaseous emissions (e.g. methane, carbon dioxide, etc.)
Spolic	having accumulations of anthropogeomorphic soil material containing more than 35% (vol.) industrial waste (mine soil, river dredgings, highway constructions, etc.)
Urbic	having accumulations of anthropogeomorphic soil material containing more than 35% (vol.) earthy materials mixed with building rubble and artifacts

challenges of local and regional environmental cartography, modelling, and management have strengthened the pressure to classify separately the human-impacted soils and "natural" Regosols

Table 4-2. Selected primary and supplementary qualifiers in Technosols reference soil group (IUSS Working Group WRB 2015), related more specifically to soils of urban and industrial areas.

Qualifier	Description
Principal qualifier	
Ekranic	having technic hard material starting ≤ 5 cm from the soil surface
Linic	having a continuous, very slowly permeable to impermeable constructed geomembrane of any thickness starting ≤ 100 cm from the soil surface
Urbic	having a layer ≥ 20 cm thick, within ≤ 100 cm of the soil surface, with ≥ 20% (vol.) artefacts containing ≥ 35% (vol.) rubble and refuse of human settlements
Spolic	having a layer ≥ 20 cm thick, within ≤ 100 cm of the soil surface, with ≥ 20% (vol.) artefacts containing ≥ 35% (vol.) industrial waste (mine spoil, dredgings, slag, ash, rubble, etc.)
Garbic	having a layer ≥ 20 cm thick, within ≤ 100 cm of the soil surface, with ≥ 20% (vol.) artefacts containing ≥35% (vol.) organic waste
Isolatic	having, above technic hard material, above a geomembrane or above a continuous layer of artefacts starting ≤ 100 cm from the soil surface, soil material containing fine earth without any contact to other soil material containing fine earth
Reductic	having reducing conditions in ≥ 25% of the volume of the fine earth within 100 cm of the soil surface, caused by gaseous emissions, e.g. methane or carbon dioxide, or caused by liquid intrusions other than water, e.g. gasoline
Supplementary qualifier	
Carbonic	having a layer ≥ 10 cm thick, and starting ≤ 100 cm from the soil surface, with ≥ 20% (by mass) organic carbon that meets the diagnostic criteria of artefacts
Hyperartefactic	having ≥ 50% (vol.) artefacts within 100 cm of the soil surface or to continuous rock, technic hard material
Imissic	having at the soil surface a layer ≥ 10 cm thick, with ≥ 20% (mass) recently sedimented dust, soot or ash that meets the criteria of artefacts
Lignic	having inclusions of intact wood fragments that make up ≥ 25% of the soil volume, within 50 cm from the soil surface
Relocatic	being in situ remodelled by human activity to a depth of ≥ 100 cm (e.g. by deep ploughing, refilling soil pits or levelling land) and no horizon development after remodelling throughout, at least between 20 cm and 100 cm from the soil surface or between the lower limit of any plough layer, > 20 cm thick, and 100 cm from the soil surface
Sulfidic	having sulfidic material ≥ 15 cm thick, and starting ≤ 100 cm from the soil surface
Toxic	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, or having radioactivity dangerous to humans
Transportic	having at the soil surface a layer ≥ 20 cm thick, or with a thickness of ≥ 50% of the entire soil if continuous rock or technic hard material is starting ≤ 40 cm from the soil surface, with soil material that does not meet the criteria of artefacts; and 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

(Schmidt et al. 2004). Finally, the term "Technosols", as suggested e.g. by Lehmann (2006), was introduced to the 2nd edition of WRB (IUSS Working Group WRB 2006). Technosols are identified based on (1) higher than 20% addition of anthropogenic materials (artefacts) to the depth of 100 cm from the soil surface, (2) the presence of constructed impermeable geomembrane (qualifier Linic), or (3) the presence of continuous impermeable technic hard material at or near the surface (qualifier Ekranic). The variety of anthropogenic materials was unified under the term "artefacts", defined as "solid or liquid substances that are (1) created or substantially modified by humans as part of an industrial or artisanal manufacturing process; and/or (2) brought to the surface by human activity from a depth, where they were not influenced by surface processes, and deposited in an environment, where they do not commonly occur, with properties substantially different from the environment where they are placed; and (3) have substantially the same chemical and mineralogical properties as when first manufactured, modified or excavated" (IUSS Working Group WRB 2015). Among the diagnostic soil properties listed in WRB, the "technic hard material" is particularly common in urban soils. Technic hard material is defined as "(1) consolidated material resulting from an industrial process; (2) having properties substantially different from those of natural materials; and (3) continuous or has free space covering < 5% of its horizontal extension". Examples of technic hard materials are asphalt, concrete or a continuous layer of worked stones.

At the first classification level, Technosols do not separate soils of urban and industrial/mining areas, which may be justified by common occurrence of post-mining and post-industrial terrains within the urban space, as well as common development of settlements on the former industrial and mining sites (Burghardt 1994, Matinian and Bakhmatova 2016, Rossiter 2007). At the second classification level, WRB provides seven principal and eight supplementary qualifiers, exclusive or specific for urban and industrial sites (Table 4-2). Beside the "traditional" four qualifiers related to main anthropogenic substrates (Garbic, Spolic, Reductic, and Urbic), specific qualifiers for urban sites were added such as Ekranic, used for description of soils sealed with asphalt, concrete and other impermeable materials (Piotrowska-Długosz and Charzyński 2015), and Isolatic, used to indicate the soil bodies artificially separated from the litospehere, e.g. on buildings or other constructions (Charzyński et al. 2015). Among the supplementary qualifiers, Hyperartefactic (artefacts prevail over the native soil material in the depth control section), Relocatic (soils *in situ* deeply mixed, e.g. due to land levelling), Transportic (soils covered with material transported from other sites), and Toxic (harmful radioactivity or excessive concentration of elements in soils) are these ones particularly useful in urban ecosystems (IUSS Working Group WRB 2015). These specific qualifiers, separately, or in combinations, also taking into account the "non-specific" qualifiers (e.g. Skeletic, Gleyic, qualifiers related to soil texture, etc.) allow detailed and accurate reflection of variable composition and properties of urban soils. As shown above, no specific diagnostic horizons are dedicated to a recognition and classification of Technosols, in contrast to Anthrosols.

At present, WRB provides a well elaborated set of terms related to urban soils and will serve as a model or impression for national soil classifications. However, there is no doubt that the terminology and statements related to urban soils will further evolve in WRB system, under the influence of numerous new proposals (like it was between 2nd and 3rd editions, e.g. Charzyński et al. 2013) from research teams and discussions within SUITMA and other professional working groups.

3. Classifications for Urban Soils in Soil Taxonomy

Differentiae and taxa for classification and survey of human-transported (HTM) and human-altered (HAM) materials and soils found in urban areas were introduced to Soil Taxonomy in 2010 and 2014 (Soil Survey Staff 2010, 2014). The differentiae include presence on/above anthropogenic landforms or microfeatures, artifacts, and the use of historical records, best professional judgement, and majority of evidence. This approach is taken because of the unique nature and variability of urban soils and parent materials. Anthropogenic landforms (e.g., landfill or pit) can be shown at mapping scales and are either constructional or destructional and are built by humans for a purpose. Microfeatures are smaller forms such as ditches. Urban soils are often low in carbon (but often have buried horizons), higher in pH, contain artifacts and are highly compacted, and many contain an anthropic epipedon (Soil Survey Staff 2014).

There is no central concept of urban HAHT soils, and they may occur in all 12 soil orders and all soil moisture and temperature regimes. Therefore, adding taxa from the order level down would have resulted in many empty classes above the subgroup level. Scattered taxa at higher levels (Arents and Anthrepts) were eliminated. One of seven specific subgroups is now added to any existing great group, provided the human-altered or human-transported material is at least 50 cm thick. Subgroups for urban soils are: Anthraquic (paddy agriculture), Anthrodensic (densic contact < 100 cm deep), Anthropic (anthropic epipedon), Plaggic and Haploplaggic (plaggen epipedon material > 25 cm thick); and Anthroportic (HTM) and Anthraltic (HAM) > 50 cm thick. Proposed additions for future editions of Soil Taxonomy are Sulfuric (acid-sulfate soils) and Excavatic (to unearth). A new family class was developed to add more detailed information about types of materials that affect human health and safety or identify the anthropogenic soil altering process (Table 4-3).

Table 4-3. Human-altered (HA) and human-transported (HT) family classes (Soil Survey Staff 2014).

HAHT family class	Description
Methanogenic	Methane or methanethiol gas evolution
Asphaltic	> 35% by volume Asphalt (bitumen) artifacts
Concretic	> 35% by volume Concrete artifacts
Gypsifactic	> 40% by volume Flue gas gypsum, phosphogypsum, drywall artifacts
Combustic	> 35% by volume Combustion by-products (bottom ash, coal slag)
Ashifactic	> 15% by volume Very light-weight combustion by-products (fly ash)
Pyrocarbonic	Artifacts of pyrolysis (fuel coke, biochar)
Artifactic	> 35% by volume discrete (> 2 mm) artifacts
Pauciartifactic	15 to 35% by volume discrete (> 2 mm) artifacts
Dredgic	Finely-stratified HTM transported in water
Spolic	HTM
Araric	> 3% by volume detached, reoriented diagnostic material

Asphaltic, Concretic, Gypsifactic, Combustic, Ashifactic, Pyrocarbonic, and Araric layers must be > 7.5 cm thick. Artifactic, Pauciartifactic, Dredgic, and Spolic layers must be > 50 cm thick. Manufactured layers (impervious materials such as geotextile liners, asphalt or concrete layers) are defined because they are root-limiting layers. Anthropogenic landforms and microfeatures are defined for use as evidence of HAHT soil presence, and there are clear guidelines for defining artifacts (USDA-Natural Resources Conservation Service 2013; Part 629 and 618A). Exclusions now prevent buried soils on anthropogenic landforms from being allocated in taxa designed for naturally buried soils.

Terms for describing urban HAHT soils are found in USDA publications (USDA-Natural Resources Conservation Service. 2013) and field books (Schoeneberger et al. 2012). Recent changes make it easy to find HAHT soils in database searches. Setting up new soil series and mapping urban areas is simpler and harmonized. Artifacts that cause human health and safety concerns are identified at the family level to improve our ability to provide soil survey users with important information. The changes for urban soils (and all HAHT soils) are novel, and additional improvements will be needed as the HAHT soil differentiae and taxa are field and lab tested.

4. Technogenic surface formations of classification and diagnostic system of Russian Soils

New substantive-genetic "Classification and Diagnostic System of Russian Soils" (CSR; Shishov et al. 2004) with its priority of soil properties implemented in diagnostic horizons and genetic properties was adopted by the Dokuchaev Soil Scientists Society in 2004. According to this approach, the substrate formation/pedogenesis ratio is addressed to at the highest level of this system – trunks being responsible for grouping soils into synlithogenic and postlithogenic (pedogenesis is simultaneous with the mineral substrate formation or occurs on a deposited material, respectively), and organogenic trunks (Shishov et al. 2004). The diagnostic horizons become important on the second level – orders identified by common pedogenetic processes producing horizons inherent to all soils of the order. Still more important are the diagnostic horizons at the third taxonomic level – soil types are identified by certain combinations of horizons; finally, the diagnostic properties serve as criteria at the subtype level.

For human-modified soils in the new Russian classification system, (agro-)soils and Agrozems, and also chemically-polluted and Chemozems are provided. CSR distinguish SUITMA objects beyond the system as the 'Technogenic Surface Formations' (TSF). The TSF, or non-soils, are described apart from soils, and their clumsy names (artilithostrat, naturfabricat) emphasize this separation (Tonkonogov and Lebedeva 1999). Different kinds of technogenic substrates distinguished in CSR are presented in Table 4-4. The difference, in principle concerns first of all the

Table 4-4. Correspondence of technogenic surface formations with types of technogenic deposits (Prokof'eva et al. 2014, modified).

Types of deposit (distinguished by composition and genesis)	Group in CSR	Subgroups of TSF in CSR
Natural		
Natural occurrence	Naturfabricats	Abraliths
Technogenic		
Naturally filled	Naturfabricats	Lithostrats, Organostrats, Organolithostrats
Technogenic proper (natural substrate with inclusions of construction waste)		Lithostrats, Organostrats, Organolithostrats
Industrial (nontoxic artificial material)	Artifabricats	Artiindustrats
Recrementogenic (sewage sludge, household waste)		Artifimostrats, Artiurbostrats
Dredged (anthrohydrogenic)	Naturfabricats	Lithostrats
Anthropogenic (cultural layer)	Quasizem	Urbiquasizems
Reclaimed soil-like bodies on different deposits		Technozems

perception of soil. In CSR soils are defined as (quasi)natural surface bodies composed of genetic horizons; if there are artificial layers instead of horizons, the body is qualified for a TSF.

Many professionals working with urban soils for many years used the classification proposal of Stroganova et al. (1998). The important role of a cultural layer accumulated during the settlement's history and exposed to zonal-forming processes is thoroughly described in the approach, developed to classify urban soils in Moscow city. For the first time soils, typical for urban environments, were defined as 'urbanozem' and the synlithogenic trend in their formation was explored for the city of Moscow.

Now, a group of authors prepared a proposal for the incorporation of SUITMA objects in different taxonomic groups of the Russian classification system based on system of Stroganova and their new experiences (Prokof'eva et al. 2011, 2013, 2014). Approaches in both systems are similar, i.e. priority of diagnostic horizons and their combinations as criteria to identify soil types. *Urbic* diagnostic horizon (UR) is proposed. Heterogeneity of urban soils constrains identifying and diagnostics of this horizons judging by chemical features. Considering this, diagnostic criteria to identify the horizon are given in comparison with the natural reference soils. Another diagnostic horizon distinguished in urban soils and referred as *rehabilitation* horizon (RAT) includes organic substrates of different origin (peat, composts, fertilizers) implemented to rehabilitate damaged lands or reclaim poor mineral substrates. The RAT horizon is usually almost unchanged by pedogenesis. Some soil and ground materials reworked by human activity usually observed in urban soil profiles relate to the technogenic deposits of different composition and origin. These materials are aggregated in a *technogenic* horizon (TCH). The TCH substrates in urban soils' profile are usually identifies in combination with either UR and/or RAT horizons, or with the natural ones.

Different urban soil's horizons occurring in various combinations with natural soil horizons and with each other provide the variability of urban soils. Soil profiles, where urban horizons (usually, UR or UR and RAT) are less than 40 cm depth and are overlying natural soil horizons, are identified as transitional natural-urban soils, referred as 'urbo-soils' (or urbostratified soils). Urbo-soils are soils with urbic horizons and clear remnants of initial natural subsoil, these may be urbo-podzolic, urbo-chernozem soils etc. Urban soils, which profiles include mainly UR horizons $\geq$ 40 cm thick covering natural subsoil horizons, or UR horizons covering technogenic sediment correspond the central group of urban soils, are referred to as 'urbanozems' or 'urbastratozems' (Stroganova et al. 1998, Prokof'eva et al. 2011, 2013, 2014). Urban soils, including one or several RAT horizons are widely spread on the newly urbanized areas as a result of greenery and reclaiming procedures. They all were related to 'technozems'. Such soils with simple profiles (RAT-TCH) are referred to as 'replantozems'. Soils distinguished by their depths and sequence of the preliminary engineering design (for example, soil construction of the golf courses or football fields) are referred as urban constructed soils or 'constructozems' (Prokof'eva et al. 2011, Vasenev 2011). 'Recreazems' are urban soils experiencing different stages of restoring, reflected by a set of RAT horizons in soil profile. *Urbochemozems* is a term, which can be used for soil with very different soil profiles if contaminants' (mainly heavy metals and petroleum) concentrations in at least one of the horizons substantially exceed health thresholds. In this unit diagnostic is X horizon, containing extremely polluted material – dangerous level for living organisms).

Since the relative age for the major part of urban soils is very young compared to natural soils, they are exposed to substantial and rather fast evolution. The major temporal trends of urban soil's evolution include transformation of parent technogenic or natural material and gradual increase of the depths of urban horizons. All urban soils can represent numerous transitional stages of soil formation from technogenic substrates exposed to the very primitive pedogenesis to urbanozems (urbastratozems) with typical synlithogenic features.

5. Classification of urban soils by The Soil Mapping Guidelines of Germany

For many years experiences about urban soil classification in Germany were available and used. They are from soil maps of more than 15 German cities. Among them the urban soil map of Berlin was published as early as in 1983. The 5th edition of *The Soil Mapping Guidelines of Germany,* called KA 5 (AKS 1997, Arbeitsgruppe Boden 2005) should enable the description and designation of urban soils compared to natural soils. The soil forming processes of young urban soils are few and are in an incipient/beginning stage. The emphasis in the designation of different urban soils lies, therefore, not only on the kind, stage, and characteristics of soil development, but particularly on the kind and characteristics of the consolidated and unconsolidated parent materials of the soils. These materials are called substrates and primarily determine the soil's properties.

The Soil Mapping Guidelines of Germany should allow the differentiation and description of soil characteristics. In that way, they establish soil information systems and soil maps of different scales, as well as soil evaluation maps for purposes of urban planning, diverse soil uses and soil function descriptions.

To achieve the above objectives, the German soil taxonomy is developed as a dual system. First, it determines and designates classes, types, and sub-types of soils and substrates separately by their different characteristics. Classes, types, and sub-types of soils are classified according to the soil profile of diagnostic horizons and their sequences in the soil profiles that developed due to the soil forming processes. Similarly, the substrate taxonomy classifies substrates according to the diagnostic substrate layers of the substrate profile and their sequences in the substrate profile (Kühn 2000, 2007a).

Finally, the determined soil type and substrate units are combined into soil form. The soil form is the top soil classification unit (see Fig. 4-2).

Urban soils of low age rarely exhibit the distinct pedogenic characteristics of normal soil formation. With time, for most of them, similar processes of soil formation can be expected as for natural soils. Common soil types are Regosols and Pararendzinas (Calcaric Regosols) for the carbonate containing urban soils (Blume 1989, Bauriegel et al 2015) or tipped soils with deep humus accumulation which can be designated as Colluvisols (KA 5). Soils developed specifically from artificial materials (artifacts) (Burghardt 2001) have not been included in *The Soil Mapping Guidelines of Germany* (KA 5) to date. An exception is the already defined Reductosol (Blume 1997) which was developed from emanation of gases, such as methane and carbon dioxide.

There are numerous consolidated and unconsolidated natural rocks and artificial materials, and mixtures of natural rocks and artificial materials which can enter soils or are deposited on

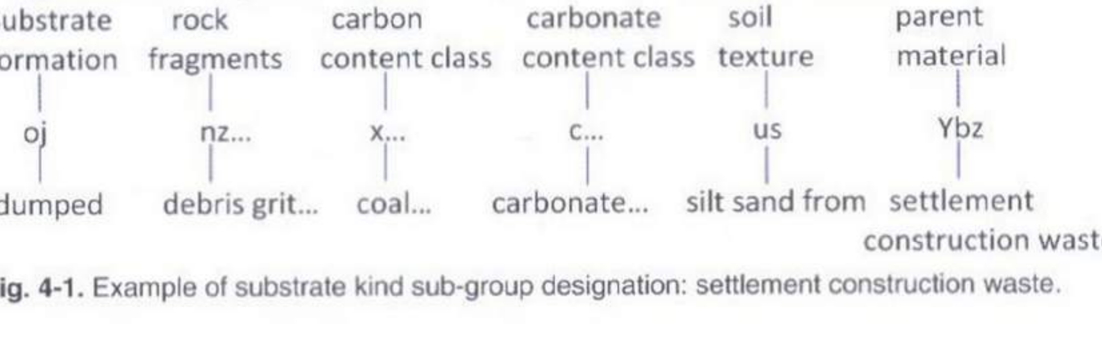

Fig. 4-1. Example of substrate kind sub-group designation: settlement construction waste.

Concrete example

C-underground horizon
M-colluviual/deposited horizon
<u>Substrate (material):</u> j-natural,
y-arteficial, l-loose, e-carbonatic

Lower border	Horizon symbol	Substrate kind: Sub-group	Substrate kind: Group	Substrate kind: Main group
10 cm	ylC	oj-zzss(Yse)	oj-zs(Yse)	o-vs
20 cm	yelC1	oj-(x)clszz(Ybz)	oj-esz(Ybz)	o-esv
35 cm	jeM1	oj-zz(x)(c)ss(Ybz,Sp)	oj-zs(Ybz,Sp)	o-vs
50 cm	yelC2	oj-nz(x)css(Ybz)	oj-zes(Ybz)	o-ves
60 cm	jeM2	oj-(zz4)xcss(Ybz,Sp)	oj-(z)xes(Ybz,Sp)	o-(v)es
90 cm	jM	oj-(x)ss(Sp)	oj-s(Sp)	o-s

Soil systematic unit	Substrate systematic unit:	
OL\YK	Substrate subtype	oj-zzss(Yse)\oj-nz(x)css(Ybz)/oj-(x)ss(Sp)
	Substrate type	oj-zes(Ybz) / oj-s(Sp)
	Substrate class	o-ves / o-s

Soil form: **OL\YK : oj-zes(Ybz) / oj-s(Sp)**

Symbol explanation of the soil form:

OL	Syrozem from unconsolidated rock
YK	Colluvisol
.../...	above → change in depth of 0.3 – 0.7 m
oj-...	dumped → substrate formation of anthropogenic tipped material
z...	grit, prefix to fine earth → angular skeleton < 63mm, content 25 - 50 Vol.-%
...s	sand, symbol placed after symbol of rock fragments → main group of fine soil, >50 Vol.-% of total soil
e...	carbonate, placed in front of fine earth → 2 - 75 mass-% carbonates
(Yse)	iron work slag/blast furnace slag
(Ybz)	Settlement construction waste
(Sp)	(Morain) cover sand

Verbalized soil form: Flat Syrozem from unconsolidated material above Colluvisol from dumped grit carbonate sand (Settlement construction waste) above tilted sand (Cover sand)

Fig. 4-2. Example of urban soil with vertical changes of substrates from artificial to artificial-natural mixed substrate according to KA5. Soil formation and substrate are recorded separately according to the German dual classification system. Syrozem designates the stage of soil formation which is just at the beginning. The most characteristics are determined by the kind, properties and sequences of deposed substrates (materials) which is the material soil characteristics and quality are based on.

existing soils and substrates. These materials (substrates) can be specified and classified according *The Soil Mapping Guidelines of Germany* (KA 5, see an example in Fig. 4-1).

Comparable to the soil type classification which is based on diagnostic horizons, substrate systematic units can be established. They consist of typified substrate sequences. That means that they are consisted of one or more substrate kinds and number of layers and that there are depth limits of the layers. Similar to soil systematic units for substrate systematic units, three hierarchical levels are distinguished: substrate classes, substrate types, and substrate sub-types. Finally, soil systematic units and substrate systematic units together in combination with soil forms are the content of soil maps and define legends (Kühn 2007, Bauriegel et al. 2015). The coded soil form (see Fig. 4-2) allows optimized data handling and analysis.

To establish substrate systematic units, substrate classifications are identified by the way the substrates are formed and their substrate composition. The substrate formations are distinguished

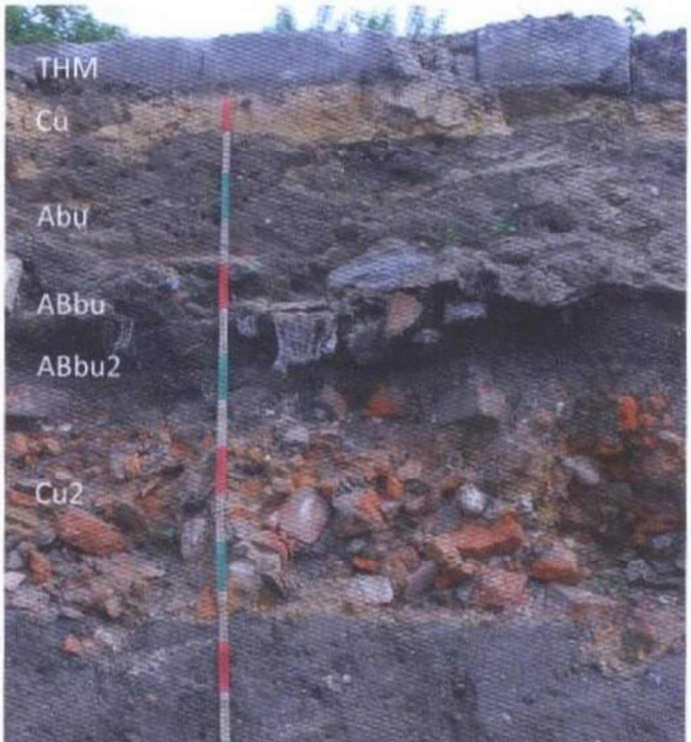

Fig. 4-3. Example of urban soil classified according to: WRB – Urbic Ekranic Technosol (Epiarenic, Calcaric, Endohyperartefactic, Skeletic). Soil Taxonomy: Artifactic, siliceous, mesic family of Anthropic Anthroportic Ustipsamments. KA 5 (soil form): Flat Syrozem from consolidated material above Colluvisol from dumped grit carbonate sand (Settlement construction waste) above tilted sand (Cover sand). Classification and Diagnostic System of Russian Soils: Lithostrat very intensive skeletal, loamy sandy, sealed by cobblestone cover.

between two main groups of substrates: natural substrates and anthropogenic/technogenic substrates. The next lower level is split into the following: on-site mixed substrates, dry and wet deposited substrates, dumped substrates, casted substrates, and sealing substrates. The designation of substrate composition (see Fig. 4-1) contains the following material characteristics: (i) Percentage of rock fragment and artefact fraction; (ii) contents of carbonates and lithogenic carbon (e.g., from lignite and hard coal mining waste); (iii) soil texture (fine earth composition); and (iv) kind of natural and artificial (technogenic) components (parent material) and their mixtures.

Frequently occurring artificially produced or deposited materials are construction waste (rubble), ash, slag, mining spoil, technogenic solid rocks (concrete, asphalt), natural soil material (compost, dredged material), garbage, and numerous/diverse type of sludge from industry and cleaning processes. The three hierarchical substrate levels are the substrate kind main group, the substrate kind group, and the substrate kind sub-group. An example of the substrate kind sub-group designation is shown in Fig. 4-1.

The sequence of substrates with depth and the limits of substrate layers are recorded according to depth segment groups. The depth segment groups are also classified in three hierarchical levels: depth to 1.2 m with depth steps 0.3–0.7 m and 0.7–1.2 m; depth to 1.2 m with depth steps 0–0.3 m, 0.3–0.7 m and 0.7–1.2 m; and depth to 2 m with depth steps 0–0.3 m, 0.3–0.7 m, 0.7–1.2 m and 1.2–2.0 m. Figure 4-2 shows an example, with symbols according to KA 5, of substrate kinds on three levels and substrate units on three levels. The middle level is explained. There are rules to classify and combine the symbols of each parent material's characteristics, usually depending on the specific content.

6. Case study – comparison of urban soil classification in international and national systems

The concept and efficiency of a classification system in relation to SUITMAs is revealed best when trying to describe a particular soil profile. An example of urban soil, commonly occurring in cities, is presented below. Numerous features resulted from human activity are visible in this profile: truncation of a native sandy soil, build-up of a topsoil, *in situ* mixing of material, deposition of transported material, and sealing with a concrete pavement. To compare various attempts, the profile from Toruń, Poland (Fig. 4-3) is classified according to all systems described it this chapter.

7. Summary

Technogenic soils debuted in national soil classification system in Soil Classification for England and Wales (Avery 1980) in a major group of *Man made soils as a* group resulting from "restoration of soil material following mining or quarrying" named *Disturbed soils*. In the following decades many other national soil classification systems were supplemented with units, such as "Anthrozems" of The Czech Taxonomic Soil Classification System (Němeček et al. 2001), and an order of "Industrial earth and urbanistic soils" with four types (Polish Soil Classification 1989). A milestone in the development of classification of SUITMAs was undoubtedly the introduction of Technosols of Reference Soil Group into WRB 2nd edition from 2006 (IUSS WG WRB 2006). A broad variety of classification options were further enlarged in the 3rd edition (IUSS WG WRB 2014), and some are already being incorporated into national soil classification systems (e.g., sealed soils). Since that introduction, sealed or "ekranic" soils in WRB have been included in several national classification systems, e.g., the Polish Soil Classification (2011), Romanian (Romanian System for Soil Classification 2013) or Slovak (Societas Pedologica Slovaca

2014) (Charzyński et al. 2017). Several examples of the rationale behind classification system updates are explained in this chapter.

Undoubtedly, organizing and hierarchization of research objects according to established criteria (i.e., classification) is a basic requirement of all science and needs to be revised periodically as knowledge increases (Isbell 1996). In case of SUITMAs it is an especially important statement, because the history of their classification counts only three and half decades, so much less than the classification of naturally-formed soils. There is still a lot to research to better understand processes and phenomena taking place in these soils and thus to classify them in appropriate way.

References

AKS (Arbeitskreis Stadtboeden der Deutschen Bodenkundlichen Gesellschaft, Chair W. Burghardt) (1997): Empfehlungen des Arbeitskreises Stadtböden der Deutschen Bodenkundlichen Gesellschaft für die bodenkundliche Kartierung urban, gewerblich, industriell und montan überformter Flächen (Stadtböden) (Recommendation of the WG Urban Soils of the German Soil Science Society for a soil survey instruction of urban, commercial and industrial areas). 2nd edition, Part 1: Field Guide. – Sekretariat Büro für Bodenbewertung, Rehsenweg 75, 24148 Kiel, 111 pp.

Arbeitsgruppe Boden (2005): Bodenkundliche Kartieranleitung (KA 5, Soil Mapping Guidelines). 5th edition. Hannover. – E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 438 pp.

Avery, B.W. (1980): Soil Classification for England and Wales (Higher Categories). – Soil Survey Technical Monograph No. **14**, Harpenden, 67 p.

Bauriegel, A., Kühn, D., Hannemann, J. and Kainz, W. (2015): Bodenübersichtskarte 1:200,000 (BÜK200) (Soil survey sheet 1:200,000), Blatt (Sheet) CC 3942 Berlin V1.4, Hannover.

Blume, H.P. (1989): Classification of soils in urban agglomerations. – Catena **16**: 269–275.

Blume, H.P. (1997): Reduktosole – eine neue Klasse der deutschen Bodensystematik (Reductosols – a new class of the German soil systematic). – Mitteilungen der Deutschen Bodenkundlichen Gesellschaft **85** (3): 1103–1106.

Bullock, P. and Gregory, P.J. (eds.): (2009): Soils in the urban environment. – John Wiley & Sons, 174 pp.

Burghardt, W. (2001): Soils of low age as specific features of urban ecosystem. – In: Sobocka, J. (ed.), Soil Anthropization VI. Proceedings, International Workshop Bratislava, June 20–22, Soil Science and Conservation Research Institute, Bratislava, Slovakia, pp. 11–17.

Burghardt, W. (1994): Soils in urban and industrial environments. – Zeitschrift für Pflanzenernährung und Bodenkunde **157** (3): 205–214.

Charzyński, P., Bednarek, R., Greinert, A., Hulisz, P. and Uzarowicz, Ł. (2013): Classification of technogenic soils according to WRB system in the light of Polish experiences. – Soil Science Annual **64** (4): 145–150.

Charzyński, P., Hulisz, P., Bednarek, R., Piernik, A., Winkler, M. and Chmurzyński, M. (2015): Edifisols – a new soil unit of technogenic soils. – Journal of Soils and Sediments **15** (8): 1675–1686.

Charzyński, P., Hulisz, P., Piotrowska-Długosz, A., Kamiński, D. and Plak, A. (2017): Sealing Effects on Properties of Urban Soils. – In: Lal, R. (ed.): Advances in Soil Science. Urban Soils. CRC Press.

Classification of Polish Soils (1989): Roczniki Gleboznawcze – Soil Science Annual **40** (3/4), 150 pp. (in Polish with English summary).

Classification of Polish Soils (2011): Roczniki Gleboznawcze – Soil Science Annual **62** (3),193 pp. (in Polish with English summary).

Dobrovolsky, G.V. and Urusevskaya, I.S. (2004): Soil Geography. – State Univ. Press, Moscow, 720 pp. (in Russian).

FAO-ISRIC-IUSS (1998): World reference base for soil resources. – World Soil Resources Reports No. **84**. FAO, Rome, 88 pp.

Greinert, A. (2015): The heterogeneity of urban soils in the light of their properties. – Journal of Soils and Sediments **15**: 1725–1737.

Hulisz, P., Charzyński, P. and Greinert, A. (2016): Urban soil resources of medium-sized cities in Poland: a comparative case study of Toruń and Zielona Góra Journal of Soils and Sediments (in reviews).

Isbell, R.F. (1996): The Australian Soil Classification. – CSIRO Publishing, Collingwood, 144 pp.
IUSS Working Group WRB (2007): World References Base for Soil Resources 2006. Update 2007, World Soil Resources Reports, 103, FAO, Rome, 182 pp.
IUSS Working Group WRB (2015): World References Base for Soil Resources 2014. Update 2015, World Soil Resources Reports, 106, FAO, Rome, 128 pp.
Jäger, H. (1864): Illustriertes allgemeines Gartenbuch: Vollständige Anleitung zum Gartenbau nach jeder Richtung, zur Gartenkunst wie zur Landschaftsgärtnerei. – Spamer, Leipzig-Berlin, Germany, 539 pp.
Johnson, D.L. and Schaetzl, R.J. (2015): Differing views of soil and pedogenesis by two masters: Darwin and Dokuchaev. – Geoderma **237**: 176–189.
Kabała, C., Chodak, T., Szerszen, L., Karczewska, A., Szopka, K. and Fratczak, U. (2009): Factors influencing the concentration of heavy metals in soils of allotment gardens in the city of Wroclaw, Poland. – Fresenius Environmental Bulletin **18** (7): 1118–1124.
Kühn, D. (2000): Zum Sinn und Zweck der bodenkundlichen Substratsystematik. – In: Boden, Objekt menschlicher Forschung: Festschrift zu Ehren von Herrn Privatdozent Dr. Manfred Altermann. (Horizont; Bd. 3). Hrsg. Inst. f. Bodenkunde Universität Hannover. – Der Andere Verlag, Osnabrück.
Kühn, D. (2007a): Praktische Probleme der Klassifikation und Kartierung von anthropogenen Substraten. – Mitt. Dt. Bodenkdl. Ges. **110** (2): 499–500.
Kühn, D. (2007b): Beispiele für die Aufnahme anthropogener Böden in Städten und Interpretationsmöglichkeiten für die Kennzeichnung in Karten. – Berliner Geographische Arbeiten **108**: 9–19.
Lehman, A. (2006): Technosols and other proposals on urban soils for the WRB (World Reference Base for Soil Resources). – International Agrophysics **20** (2): 129.
Lehmann, A. and Stahr, K. (2007): Nature and significance of anthropogenic urban soils. – Journal of Soils and Sediments **7** (4): 247–260.
Matinian, N.N. and Bakhmatova, K.A. (2016): Urban soils of Saint Petersburg (Russia). – Hannoversches Jahrbuch **1**: 1–27.
Meuser, H. and Blume, H.P. (2001): Characteristics and classification of anthropogenic soils in the Osnabrück area, Germany. – Journal of Plant Nutrition and Soil Science **164** (4): 351–358.
Nehls, T., Jozefaciuk, G., Sokołowska, Z., Hajnos, M. and Wessolek, G. (2006): Pore-system characteristics of pavement seam materials of urban sites. – Journal of Plant Nutrition and Soil Science **169** (1): 16–24.
Nemeček, J., Macků, J., Vokoun, J., Vavříček, D. and Novák, P. (2001): Taxonomický Klasifikační Systém Půd České Republiky. ČZU Praha – VÚMOP Praha, Praha (in Czech with English summary).
Piotrowska-Długosz, A. and Charzyński, P. (2015): The impact of the soil sealing degree on microbial biomass, enzymatic activity, and physicochemical properties in the Ekranic Technosols of Toruń (Poland). – Journal of Soils and Sediments **15** (1): 47–59.
Prokof'eva, T.V., Martynenko, I.A. and Ivannikov, F.A. (2011): Classification of Moscow Soils and Parent Materials and Its Possible Inclusion in the Classification System of Russian Soils. – Eurasian Soil Science **44** (5): 561–571.
Prokof'eva, T.V., Gerasimova, M.I., Lebedeva, I. and Martynenko, I.A. (2013): An attempt of integrating the systematic of urban soils into the new Russian soil classification system. – Soil Science Annual **64** (1): 24–28.
Prokof'eva, T.V., Gerasimova, M.I., Bezuglova, O.S., Bakhmatova, K.A., Gol'eva, A.A., Gorbov, S.N., Zharikova, E.A., Matinyan, N.N., Nakvasina, E.N. and Sivtseva, N.E. (2014): Inclusion of soils and soil-like bodies of urban territories into the Russian soil classification system. – Eurasian Soil Science **47**: 959–967.
Romanian System for Soil Classification (2013): Sitech Edition, Craiova, 206 pp. (in Romanian).
Rossiter, D.G. (2007): Classification of urban and industrial soils in the World Reference Base for Soil Resources. – Journal of Soils and Sediments **7** (2): 96–100.
Rusakov, A.V. and Novikov, V.V. (2003): Biological activity in modern and buried soils of the historical center of St. Petersburg. – Microbiology **72** (1): 103–109.
Scharenbroch, B.C., Lloyd, J.E. and Johnson-Maynard, J.L. (2005): Distinguishing urban soils with physical, chemical, and biological properties. – Pedobiologia **49** (4): 283–296.
Schleuß, U., Wu, Q. and Blume, H.P. (1998): Variability of soils in urban and periurban areas in Northern Germany. – Catena **33** (3): 255–270.
Schmidt, R., Deumlich, D. and Reuter, H.I. (2004): From point over regions to the landscape-spatial generalization in the soil landscape research. – Archives of Agronomy and Soil Science **50** (3): 241–258.

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C. and Soil Survey Staff (2012): Field book for describing and sampling soils, Version 3.0. – Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Shishov, L.L., Tonkonogov, V.D., Lebedeva, I.I. and Gerasimova, M.I. (2004): Classification and Diagnostics of Soils of Russia. – Oikumena, Smolensk, 342 pp. (in Russian).

Societas Pedologica Slovaca (2014): Morfogenetický klasifikačný systém pôd Slovenska. Bazálna referenčná taxonómia. – Druhé upravené vydanie. Bratislava: NPPC – VÚPOP Bratislava , 96 pp. ISBN: 978-80-8163-005-7.

Soil Survey Staff (2010): Keys to Soil Taxonomy, 11th ed. – USDA-Natural Resources Conservation Service, Washington, DC.

Soil Survey Staff (2014): Keys to Soil Taxonomy, 12th ed. – USDA-Natural Resources Conservation Service, Washington, DC.

Stroganova, M.N., Miagkova, A.D., Prokof'eva, T.V. and Skvortsova, I.N. (1998): Soils of Moscow and Urban Environment. – PAIMS, Moscow, 178 pp.

Tonkonogov, V.D. and Lebedeva, I.I. (1999): A System for Categorizing Technogenic Surface Formations. – In: Kimble, J.M. et al. (eds.), Proceedings of Classification, Correlation and Management of Anthropogenic Soils, Nevada and California. USDA-NRCS, Lincoln, NE, pp. 186–192.

USDA-Natural Resources Conservation Service (2013): National Soil Survey Handbook, title 430-VI. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/ref/?cid=nrcs142p2_054242 accessed (Aug/23/2016).

Vasenev, V.I. (2011): Analyzing carbon pools and microbial respiration for functional-environmental assessment of urban constructed soils in Moscow Region. – Candidate dissertation. Moscow State University. Moscow.

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