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Peculiarities of soil structure in urban, industrial and mining areas and their effects on soil functions

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Abstract

In part the soil structure of urban, industrial and mining areas has been strongly changed.

Numerous peculiar structures occure. The reasons are transport and deposition of substrates, young age of the soils, lack of bio-turbation, man-made materials, compaction, mixing and stratification of soils, skeleton content, crystallization.

From import of sand and stones soils with single grain structure are wide spread in cities. A peculiarity of rubble, ashes, slag is the porosity of the grains. Cementation occurs with high content of iron, carbonate and sulfate. Coherent structure is formed from deposits of not structured loam and clay through high pressure. Transport of loam and clay soils by water in pipes will create round roll aggregates.

Excavation, transport and tipping of natural soil material results in mixtures or layers of different forms of structure.

Usually soils of urban, industrial and mining areas are young soils. Therefore the degree of aggregate formation is weak. Bio-turbation for crumb formation is not very advanced.

Platy aggregates are created by a greater number of processes such as high pressure, dust deposits and setting of surface soils through lack of bio-turbation. High pressure on already aggregated soils will create structures of deformed aggregates or thick platy structure which lock in the aggregates.

Soils of high skeleton content have two forms of structure: either fine earth fills loose and not totally the gaps between stones or aggregates are formed by the shape and size of the gaps.

The variation and heterogeneity of porosity of soils of urban, industrial and mining areas is very high. Soil functions will be very diverse.

The new forms of structure will influence soil mechanical properties and soil air and water household. The aeration, decay, root penetration, storage and transport of water and dissolved compounds as well as other features will differ from other soils. That means the soils have altered their qualities to fulfil functions in the living sphere of humans. The altered or new forms of structure are also diagnostic properties for the designation of horizons and some soil types of urban and industrial areas.

Examples are occurrence of stagnic water from compaction. Therefore Pseudogleys (Stagnogleys) are found often. Or until now unknown, cemenation from secondary formation of carbonate from e.g. slag is a characteristic of Carbonatosol.

Keywords: urban soils, soil structure, man-made material, soil function, soil classification, compaction

Introduction

Structure is often neglected in soil research and classification. On the other hand it has strong influence on soil properties and soil functions. From soil structure are dependent rooting, amount and availability of water, permeability, aeration, decay of organic substances, redox potential, exposure to pollutants and dust, preferential flow, solute dilution and groundwater contamination, silting, erosion, bearing capacity, and others. Therefore structure is an important quality characteristic of soils. It wonders that it does not play a dominant role in soil sciences.

In addition for urban, industrial, traffic and mining areas attention of structure has importance in two other aspects: the soils are often very young. Structure is one of the major criteria to distinguish young soils. Beside this the most dominant and visible impact on soils of urban areas is the change to single grain structure and the compaction. The significance for urban soils, their quality and functions for a better life of humans in cities must become one of the important discussion points of urban development.

Anthropogenic Influenced Types of Soil Structure

The structure types we were confronted in our work in urban, industrial and mining areas during the last 15 years are compiled in Table 1. They are classified according to their relationship to the known structure types of natural soils. They will complete the existing scheme. That means not that the new added structure types are occurring only in urban areas. According to the concentration of soil science on good soils for farmland, the features of soils of other land use forms are under-represented in soil description.

Soil structure is dependent on fundamental soil features such as texture, stone/fine earth content, filling and binding compounds such as humus, carbonates, gypsum, sodium and other salts, and iron, on bulk density, water household dynamic and biological activity. For evaluation the anthropogenic impact on soils in cities and other human changed areas we have to investigate these properties.

Urban agglomerations are areas of large import of sand and gravel. Therefore the soil texture gets more coarse. Areas with spots or complete cover of sandy and gravelly soils increase. The result will be that there is a shift to single grain structure in urban areas. This development occurs also due to a second and third process (Table 2). Urban areas are locations of production of coarse sized materials. The rubble from demolition of buildings stays totally or in part in the city. In modern cities much of the material is recycled to be used again. Residual materials (Table 3) such as ashes from domestic heating, steam generators and power plants, such as slag from iron and metal plants, mining waste and all other kinds of waste contain high amounts of sandy, gravelly and stony materials. The fine earth content is reduced (Table 3).

Some of the man-made materials have specialties. Grains of ashes, bricks, and some slag are porous. Ashes and bricks but also in general materials broken or formed for their use can be sharp edged. That means the space between the grains will differ from other materials and influence the porosity. For slag sand the porosity is increased by the occurrence of cavities at the slag surface. One result of the porosity and shape of grains are the differences in bulk densities (Table 4).

Table 1 Forms of structure of soils of urban, industrial and mining areas (Arbeitskreis Stadtböden, 1997, completed).

Elementary structure				
Single grain structure				
si-na natural sediments	si-tis tipped and transposed substrates	si-cri from crystallization processes	si-pog porous grains	
Cemented structure				
cem-na intercalation of OS, CA, FE, AL, MN, SI ETC.	cem-si cemented material fractured to single grains	cem-cru crusts		
Coherent structure				
coh-na unstructured cohesive mass OF wet clay and silt	coh-pre by pressure unstructured mass of different moisture			
Stratification structure				
str-na of natural sediments	str-meb by mechanical bring up	str-lad artificial lagoon deposits		
Man-made objects structure				
mmo-i Individual shape	mmo-dsm dense made sealing material			
Aggregate structure				
Macro coarse structure, aggregates > 50mm				
mac-cra cracks	mac-col columns			
Macro fine structure, aggregates < 50 mm				
Crumb structure				
cru - na natural crumbs	cru - pre by pressure coarse made crumbs			
Prismatic to angular structure				
pri-na natural prisms	ang-na natural angular blocky aggregates	sub-na natural subangular blocky aggregates		
Plate like structure				
pla-pre plates by pressure	pla-lokin in plates loked in aggregates	pla-sil plates by silting	pla-dud plates by dust deposition	pla-dib plates by disturbed biological activity
Structure of macro-intergranulare voids (voids between dense packed stones)				
miv-dif dense intergranular fillings	miv - lif loose intergranular fillings			
Superimposed structure				
su-fra mechanical fragments	su-med structure medley	su-rol roll-aggregates		

Table 2 Causes of single grain structure in urban areas.

1 Import of sand and gravel
2 Demolition, war raids -stay of rubble from demolition -recycling and reuse of demolition material
3 Residues deposited and used in the city - ashes - slag - mining waste - domestic and industrial wastes

Table 3 Relative frequency of fine earth content of man-made materials.

Fine earth content		0-25	26-50	51-70	71-90
Man - made material	n		%		
Ashes from					
- power plant	17	0	35	29	35
- railway	27	18	52	22	8
- waste incinerator	11	9	72	9	9
Mean	55	11	51	22	16
Construction rubble from					
- bombardment	7	0	0	43	57
- historical ruins	4	0	50	50	0
- demolition	13	0	30	62	8
- bricks	6	33	67	0	0
Mean	30	7	33	43	17

Table 4 Bulk density of soils from man made materials.

Rubble from bricks, mortar	1.18-1.24
Ashes	
-fly ash	0.60-0.68
-domestic ash	0.62 0.74
-steam generator ash	0.64-0.82
Domestic waste	0.70-0.98
Slag sand	1.01-1.09

Gravel and stone content in urban soils vary. There seem to be certain ratios of fine earth to skeleton content for some man-made materials (Table 3) which will be a characteristic of the materials single grain structure.

With increase of stone content the shape of the voids between the stones will determine also the shape of aggregates from fine earth. Increase of gravel and stone content over a level of about 75 to 80% will result in the situation that the fine earth will either not fill the macro-intergranular voids between the stones or will have a low bulk density. Often pure stones or gravel are tipped. With time and near the surface the voids will be filled by dust and humus. Examples of a hard coal mining spoil heap indicate that the bulk density of fine earth between the skeleton may become very low in the subsoil with increasing stone content (Figure 1). The bulk density of fine earth between stones of the top soil varies according to the intrusion of dust and weathering processes (Figure 1).

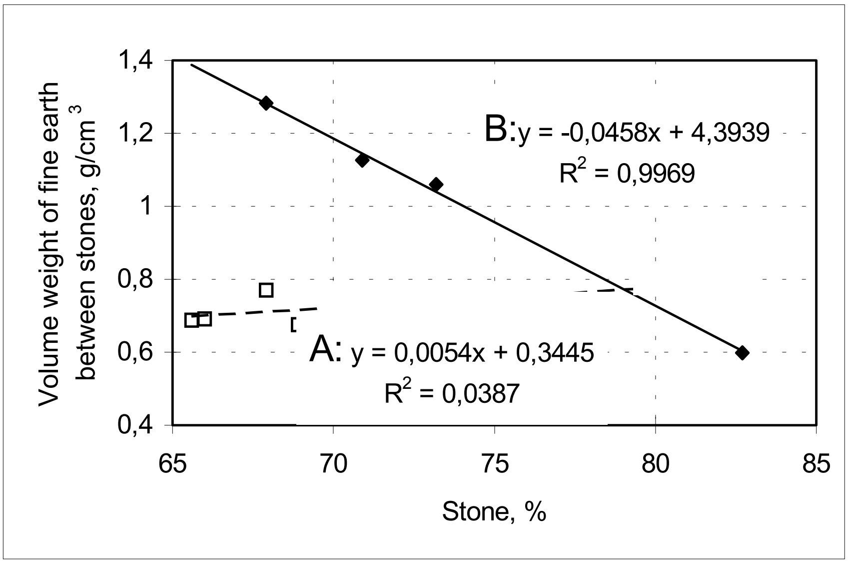

Figure 1 Ratio of bulk density (volume weight) of fine earth to stone content in surface horizons (A: 0-5 cm depth) and subsurface horizons (B: 5-20 cm) of a hard coal mining spoil heap.

Visible within a short time will be the weathering of slag of iron plants when the slag has a low quality. Such slag are normally not used and therefore tipped. What happens is that the minerals of the solid slag change from di-calciumsilicates to mono-calcium silicates. The turn of crystallization will disintegrate the slag from compact to single grain structure. Disintegration in short time is visible also for some bricks. Bricks are from different composition of sand, silt and clay. In the Ruhr area e.g. for the short life time of mining buildings bricks from the local loamy silt were produced. Rubble from them show very low stability. Another example are spots where water infiltration into the ground is concentrated. Cementing agents are solved and insoluble grains are left. Some of the man-made materials are tipped as large single grains composed from cemented and cementing material. Examples are pieces from brick wall or concrete. They will loose with time the cementing compounds, become porous and disintegrate.

Rubble and other man-made material contain carbonates. The release by weathering, solution, redistribution and translocation of carbonates results in cementation. It can be assumed that similar effects occur in soils of high gypsum, iron, manganese and soluble silica content. In some sites the occurrence of crusts at the surface (Figure 2) or near the surface can be observed. Even not proper investigated the existing examples show that there are numerous cementing compounds in the soils.

Strong crusts were found on iron plants (Figure 3) and by the formation of Carbonatosols of abandoned slag deposits (Burghardt *et al.*, 2000).

Figure 2 Surface crust from iron-manganese slag grains.

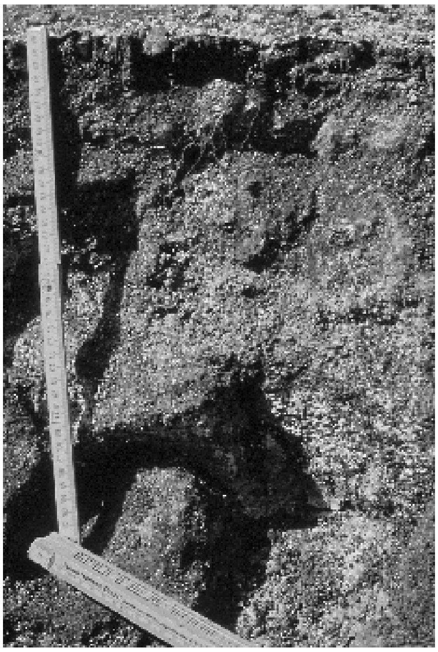

Figure 3 Carbonate accumulation in a Carbonatosol from iron plant slag.

Crusts appear when at the surface of slag tips transferred calcium-hydroxide will form with the atmospheric CO_2 carbonates. The carbonates formed by weathering of slag acts again as cementing compound of the grains of the disintegrated slag.

Younger urban soils are mostly compacted by pressure. Crumb structure will be made coarse already by low pressure. High pressure results in different types of structure. Extreme pressures will create coherent structure. Slightly lower pressures will produce large brick like aggregates. Often observed is platy structure (Figure 4) of different sizes. High pressure on already aggregated soils creates structure of deformed aggregates or thick platy structure with locked in aggregates (Figure 5).

Beside pressure processes of platy structure formation are surface silting, annual dust deposition layers, setting of soil by lack of biological activity.

Figure 4 Strong platy structure from compaction.

Figure 5 In plates locked in subangular aggregates.

Soil pieces will be broken by excavation, transport and leveling. By this mechanical soil fragments will be created. Soil transport with water in pipes forms ball like roll-aggregates from clay and loam. Mixing of soils of different horizons and origin can result in a mixture of different structures. Structure medley will occur such as e.g. from crumbs rich in humus and subangular blocky aggregates (subpolyeder) from loess loam (Figure 6) or angular blocky aggregates (polyeder) enclosed in sandy single grain structure. Arbitrary sequences of structure types are found in material tipped and spread in layers such as single grain structure from coarse sandy gravel underneath of subangular blocky loam covered by blocky clay loam.

Extreme types of structure are those of man-made materials of individual shapes such as from nylons (Figure 7), large plastic sheets, news paper layers.

Figure 6 Structure medley from subangular loess loam and crumbs.

Figure 7 Man made object structures, domestic waste with nylons.

Structure as Characteristic of Diagnostic Soil Properties and Horizons

In soil taxonomy such as World Reference Base (Spaargaren, 1994) only few examples of structure characteristics as diagnostic properties are in use.

Obviously is in urban, industrial, traffic and mining areas the frequent occurrence of structure types which indicate compaction. In regions of wet climate they will generate stagnic properties (WRB) found in Stagnosols. Compaction can also diminish soil aeration. Reductomorphic horizons will develop when organic matter is present and decomposes without oxygen supply.

Compaction will also produce coarse interped faces and streaks known as diagnostic characteristics of fragipans.

Soil layers of abrupt textural change can occure by tipping. Associated with stagnic properties they are the diagnostic properties of Planosol horizons.

Fragipans can be created by Si accumulation in soils from slag and ashes.

The diagnostic horizon of Carbonatosol is the new formation of a carbonate horizon (Burghardt *et al.,* 2000).

Stratification structure known in nature from Fluvisol will appear in urban areas as lagoon deposits but also as dry deposits.

Other features of soil structure are in soil taxonomy not considered today.

Low fine earth content may be a diagnostic characteristic of some types of Leptosols. This will result in loose intergranular filling structure. Soils of urban, industrial, traffic and mining areas are often very young. Only a limited number of processes which will result in diagnostic properties in a short time occur or are known up to now. Structure has a strong influence on soil quality and soil degradation. It can be surveyed easily. Table 1 shows that there are diverse structure characteristics. By that fact structure should be used as diagnostic characteristic in soil taxonomy to differentiate urban soils. Table 5 contains some proposals for designation of soils of anthropogenic influenced structure.

Table 5 Soil designation according to anthropogenic structure.

Coarse single grain structure soil, similar to Arenolith.

Compacted soil, subdivided in those with

- Stagnosol, stagnic properties
- Reductosol, without water influence, but reductomorphic properties
- Compactosol, compacted, but without stagnic and reductomorphic signs
  * coherent pase
  * platy phase
  * coarse made crumb phase
  * plate lock in aggregate phase

Structolith, shallow soils from dust deposits, more or less platy

Meiktolith, medley soil, structure phase

Interpsepholith, loose and dense phase, intergranular filling between stones.

Soil Functions

Soil functions deal with the benefit of soil for humans. The German soil protection act contains three groups of soil functions: (1) natural soil functions, (2) functions of soils as archive of history of landscape and civilization and (3) functions for different kinds of soil use (Bundesregierung 1998). We will deal here only with the relationship of peculiar structure of soils of urban, industrial, traffic and mining areas and natural soil functions (Table 6).

Detailed studies on relationships of soil functions to soil structure are lacking. We can assume the following dependencies. Single grain structure indicate a loose soil, which will be well aerated and drained, but of low water and nutrient retention potential. This may be different in single grain structure from porous grains. The shape of grains of man-made material such as rubble and ashes may increase the shear resistance. Rooting will be diminished.

Structures resulting from compaction will reduce porosity. The natural soil functions are changed in an unfavorable way. Figure 8 shows the example of a profile with bulk density increase with depth and the effect on permeability and content of large pores. The structure of the loess loam changed with depth from pressure coarse made crumbs (Ah), in plates locked in subangular aggregates (yjC, Figure 5), by pressure unstructured mass (jSd_1) to strong platy structure (jSd_2, Figure 4).

Table 6 Relationship of soil structure to natural soil functions.

Natural soil functions	Single grain structure	Compac-tion	Cementa-tion	Stratifica-tion	Structure medley	Macro-in-tergranular structure
Basis and space of life of humans, animals, plants and soil organisms	diverse	unfavor-able	mostly unfavor-able	unfavor-able	in part favorable	unfavor-able
Component of house-hold of nature, particu-larly of ist water and nutrient cycles	diverse	unfavor-able	unfavor-able	unfavor-able	in part favorable	unfavor-able
Agent for decomposi-tion, compensation, and build-up of substance effects on the strength of filter, buffer and transformation charac-teristics, particularly for the protection of ground water	diverse	unfavor-able	unfavor-able	in part favorable	in part favorable	unfavor-able

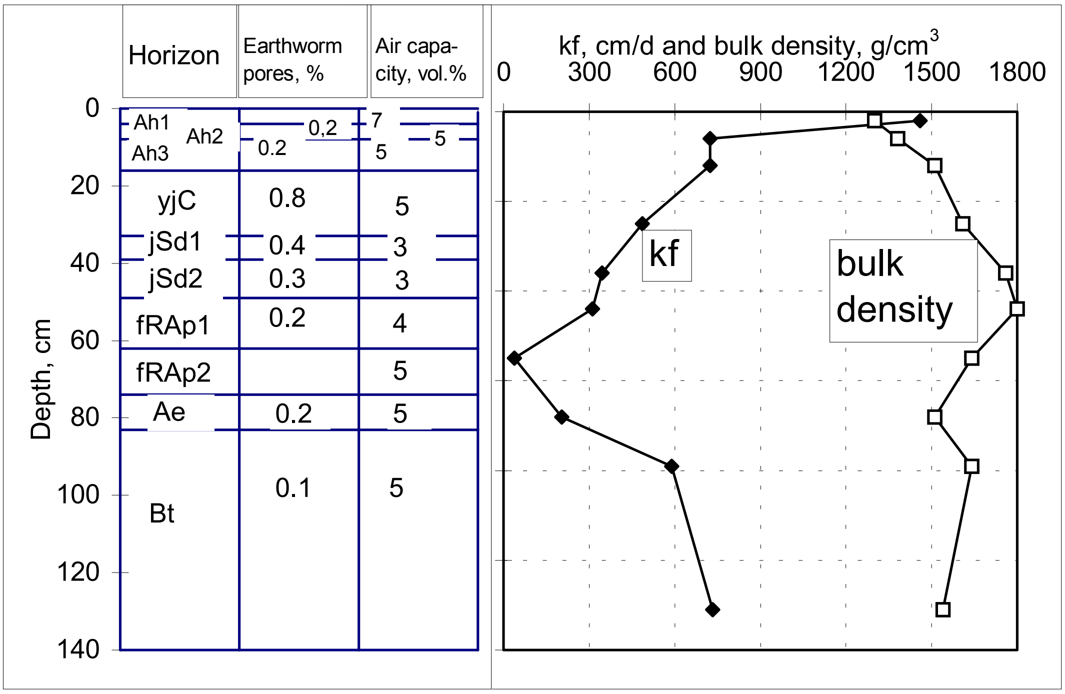

Figure 8 Regosol from tipped (j,y) above buried (f) Luvisol. Effect of soil compaction on saturated permeability (kf), air capacity (pf 1.8) and earthworm pores (in a cross sectional area of 1,600 cm^2).

Cementation has mostly unfavorable effects. But it can have the benefit of reduction of dust formation by crusts which increase surface stability.

Rooting, water and air permeability will be adversely effected by stratification. On the other hand stratification can have the effect of sequences of different transformation and filter processes which improve the natural function. Structure medley will not reduce rooting and permeability in that way as stratification. The filter and transformation effect will be not so expressed as in stratified soils. Macro-intergranular structure is always combined with reduction of fine earth mass. That means less soil mass for soil functions will be available.

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