THE IMPORTANCE OF MINERALOGICAL AND MICROMORPHOLOGICAL INVESTIGATIONS FOR THE ASSESSMENT OF SOIL STRUCTURE

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A b s t r a c t. The aim of this study was to emphasize the relevance of mineralogical and micromorphological investigations for the assessment of the soil structural status. Moreover, this kind of approach and its applicability to different soils were discussed.

K e y w o r d s: soil structure, mineralogical and micromorphological investigations of soil structure

INTRODUCTION

There are many definitions of soil structure. For this presentation the definition of Brewer [10] was chosen, considering 'the physical constitution of solid soil materials as expressed by the size, shape and arrangement of the solid particles and voids, including both the primary and newly formed particles. The soil fabric is the element of the soil structure which deals with the particle arrangement'. Moreover, the soil structure may be considered as the 'architectural arrangement of soil particles' [26]. Status and stability of the soil structure are influenced by various chemical, physical, mineralogical and biological parameters, depending on natural factors (soil forming factors such as climate, weathering, parent material etc.) as well as on anthropogenic influences (pollution, landuse).

Soil mineralogy and soil micromorphology are closely related to the structural status of soils and contribute to understand the soil structure per se and its functionality within a soil profile. Soil micromorphology describes not only soil components but also their organization within the pedon, soil features and phenomena related to genetical soil processes at a microscopical scale.

The solid soil phase consists of coarse clastogene (detrital) components, which are inherited from parent rocks or sediments (so-called 'primary' minerals) and fine (colloidal) minerals which can be inherited, transformed and/or neoformed in the soils (pedogenetical 'secondary' neoformations such as clay minerals, carbonates, sulphates, sesquioxides, salts), as a consequence of weathering and transport processes. The distribution of minerals in soils is in some way related to the particle size distribution. 'Primary' coarse minerals are mostly concentrated in the sand fraction (2 000 to 50 μm), whereas the secondary minerals accumulate in the silt (50 to 2 μm) and especially in the clay fraction (<2 μm), see Fig. 1.

The most abundant coarse minerals in soils are quartz, felspars, amphibole, pyroxene, hornblende, micas, calcite and dolomite. Volcanic soils also contain allophane. 'Primary' minerals play an important role in the formation of soil structure by influencing the distribution of coarse pores (e.g., soil aeration and water infiltration), especially if the degree of aggregation is rather low. Moreover, the chemistry of primary minerals also influences the long-term release of ions.
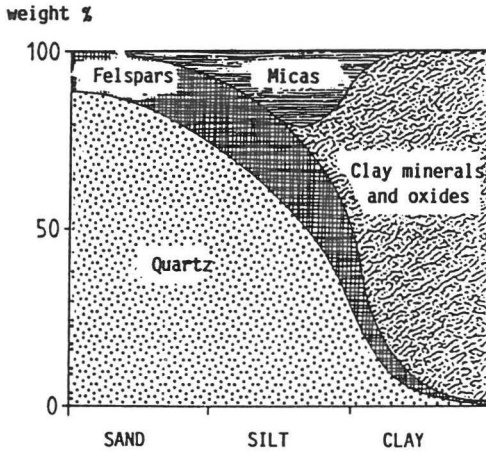
weight %

Fig. 1. Distribution of primary and secondary minerals in different texture fractions.

The most abundant secondary neoformations in soils are clay minerals and Fe, Al, and Mn oxides.

Clay minerals (phyllosilicates) are hydrous layer alumosilicates (Fig. 2) which influence many pedological processes because of their following particular characteristics:

- Net negative permanent electrical layer charge due to isomorphous substitution of Si^{4+} by Al^{3+} in their tetrahedra and of Al^{3+} by Fe^{2+}/Mg^{2+} in their octahedra.

- Small particle size and high specific surface, (especially the 'internal' surface of the interlayers of expandable clay minerals). Especially 2:1-clay minerals have high negative charge density and therefore high CEC, high water and cation adsorption capacity.
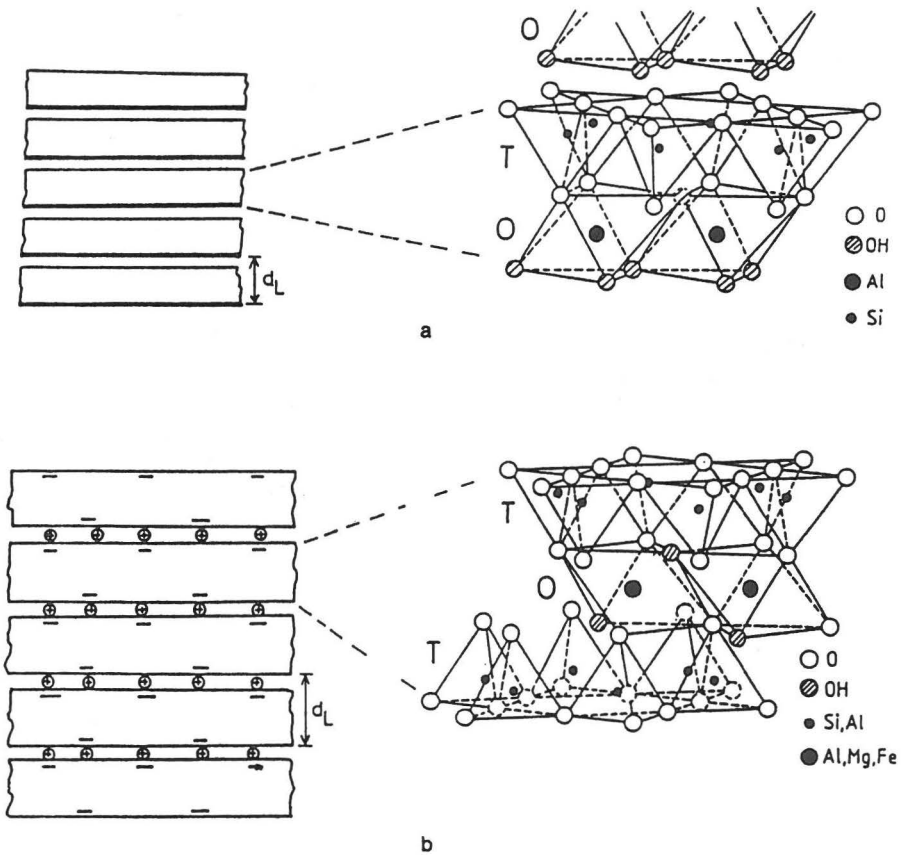

Fig. 2. Spacial arrangement of the layer structure of 1:1-clay minerals (a) and 2:1-clay minerals (b); T = Tetrahedral layer, O = Octahedral layer, d_L = Basal spacing.

- As a consequence of water ad-/desorption, clay minerals are responsible for the plasticity, swelling and shrinking of soils. The presence of clay minerals is often correlated with typical soil microstructures (e.g., the prismatic structure in the Bv-horizon of Cambisols, the polyhedrical structure in the Bt-horizon of Luvisols).

Pedogenic ('secondary') Fe minerals (oxides, oxyhydroxides, and hydroxides) are also very important authigene phases in soils. They cause the hues between red and yellowish-red of most soils and their presence and abundance reflect the pedoenvironmental conditions under which they have formed. They play the role of cementing agents and can stabilize the soil structure. Like in clay minerals, Fe oxides are mainly present as very fine particles in the clay fraction (<2 μm) and the Fe ion in the oxides may be replaced by other metallic cations (isomorphous substitution). Substitution by Al occurs more frequently than by other cations.

Fe (Al, Mn) oxides have the following properties relevant to soils:

a) On the hydroxylated or hydrated surface, a positive or negative charge is created by adsorption or desorption of H^+ or OH^-. Because of its dependence on pH and ionic strength, this type of charge is called variable charge. The pH at which the net variable charge on the surface is zero, is called the point of zero charge (PZC). An excess of positive or negative surface charge is balanced by an equivalent amount of anions (A-) or cations (C+), respectively. For electrostatic (Coulombic) bonding, the adsorption is termed nonspecific and depends only on ionic charge. Some anions and cations can, however, be held much more strongly (specific adsorption) on the oxide surface.

b) Fe oxides also adsorb a wide range of organic compounds. Humic compounds such as humic (HA) and fulvic (FA) acids may be concentrated in Fe-oxide-rich horizons of soils under humid temperate conditions, such as Bs-horizons of Podzols. The amount of adsorbed FA and HA strongly increases with decreasing pH.

c) Fe oxides usually are believed to act as binding agents among other soil particles. This may result in cementation or aggregation of primary soil particles into larger units.

Soil micromorphology deals with the qualitative and quantitative analysis of undisturbed soil samples usually in thin sections and far less in polishing blocks (thick sections), using microscopic and submicroscopic techniques. Actually it is a branch of pedology which can be applied to a vide range of soil research, having the power to get better inside the microworld of soils.

Micromorphological techniques have been videly adopted and described in many monographs and papers [3,5,12,17,20,24].

Acoording to the definition given above [10], the soil structure refers to the spatial arrangement of soil components and associated voids. The way how the solid components arrange into aggregated forms (peds), leading to particular structures, depends on many factors. The primary factors for the soil structure formation are type and amount of colloids, humic substances, clay minerals, oxides of Fe, Al, Mn, Si and 'secondary' carbonates. These structure forming factors (structure makers) can also influence the structure stability. The size, shape and stability of soil aggregates (peds) reflect environmental conditions and are very variable. Soil micromorphology is an indispensable tool for the study of soil structure in several ways:

a) For the description (evaluation) of structure forming processes and factors (structure-forming and structure-following processes, [22]). The processes of structure formation have observable characteristics and can be evaluated by micromorphological methods which correlate them to the process of interest. At microscopical scale these processes are reflected in the location and the distribution of various components (sand, silt, organic/inorganic colloids, 'secondary' cementing minerals);

b) For the interpretation of soil structure features. The set of interactions between mineralogical, chemical and biological factors is resulting in soil features which are important

for the interpretation and evaluation of the soil structure profile. Among them, shape and size of peds, porosity, types of voids, grade of structure, pedofeatures (textural, crystalline pedofeatures, fabric, depletions, excrements, [8,9,12] are of main interest.

c) For the description (evaluation) of soil microstructures [12,20,24]. The soil microstructure is considered 'to encompass all aspects of soil structure that are revealed when soil material is examined at a magnification of 5x or greater' [12]. In describing soil structure, 4 main types of aggregates/peds have been recognized (spheroidal, blocky, platy, prismatic). The main types of microstructure are described in details [12].

The primary goal of micromorphological investigations should not only be the study of soil structure *per se*, but rather its functionality within the pedon and/or at greater scale. In this respect soil micromorphology offers the opportunity of 'seeing' many details, which are not recognizable with the nacked eye.

MATERIAL AND METHODS

Investigated soils

During the two years of cooperation, 19 soils were investigated. Their general chemical and physical properties are described in other paper [19]. In this study, only representative soils were discussed: a Cambisol and a Chernozem in Austria, a Chernozem in the Czech-Republic, a Solonetz in Hungary, an Orthic Luvisol in Poland, and a calcaro-haplic-Phaeozem in the Slovak-Republic [16].

Analytical methods

The bulk soils were air-dried and sieved at 2 mm mesh size (=fine earth). For micromorphological analyses Kubiena-boxes (10 x 10 cm) were used.

Mineralogical analyses

- Semiquantitative analysis of untextured soil powder patterns by X-ray diffraction using Cukα-radiation.

- Semiquantitative analysis by X-ray diffraction of textured clay patterns pretreated with KCl, MgCl₂, dimethylsulphoxide (DMSO), glycerine and heating at 105 °C [11,18,33], using Cukα-radiation.
- Determination of Na-dithionite-citrate-bicarbonate (DCB)-soluble, NH4-oxalate-soluble and Na-pyrophosphate-soluble contents of Fe, Al, and Mn [1,4, 27,35,36].

Micromorphological analyses

Thin sections has been prepared from undisturbed soil by fixation of the samples with polyester resine (CHS-polyester 109), diluted in acetone under vacuum, according to the methods described by Jongerius-Heintzberger [20] adapted by Curlik [15].

For the preparation of thick sections vertical samples were taken in 8.5 x 9 x 4 cm metal containers. After drying in room temperature over 3 months, the samples were impregnated with a polyester resin solution. The following mixture was used:

Polyester resin POLIMAL-109	100 % (v/v)
Monostyrene	60 % (v/v) for silty and loamy samples
Cyclohexanone peroxide	0.5 % (v/v) as catalyst
Cobalt naphtenate 2 %	0.1 % (v/v) as activator

The dried samples were impregnated in series of fours in steel boxes (7 cm high, 37x11 cm at the bottom and 41.5x13 cm at the top side). The impregnation occured in vacuum device at constant vacuum (30 hPa for about 24-36 h). Following the resine polimerization (about 4-5 weeks in air temperature of 20 °C), the soil samples were cut into slices of 1 cm by means of a sawing machine with diamond impregnated blade, ground and polished. For grinding and polishing corundum powder and corundum paper were used. The opaque soil plates prepared in this manner were then photographed at 1:1 scale. The solid phase of the soil appears white on the photographs and the resine filled pores are black.

RESULTS AND DISCUSSION

AUSTRIA

Mineralogical data

Coarse mineral distribution in the fine earth

The results of the semiquantitative mineralogical analysis of the fine earth are given in Table 1. In the top horizons of the Cambisol a slight acidification led to a relative accumulation of quartz, felspars and layer silicates, whereas in the parent material also calcite and dolomite were traced. In the Chernozem the weathering intensity was lower, therefore calcite and dolomite are still present in the whole soil profile. The lower content of calcite in the C2-horizon may be due to different sedimentation processes.

Clay mineral distribution in the fine earth

Table 2 shows the clay mineral distribution of the investigated soils. The complete absence of expandable minerals of the smectite and vermiculite group has to be stressed, thus explaining the relatively low CEC and the reduced swelling and shrinking capacity. In the Cambisol of Wieselburg the weathering processes were more intensive, leading to the formation of kaolinite, which is totally absent in the Pannonian Chernozem.

Fe, Al, Mn oxide distribution in the fine earth

The amounts of oxides in the investigated soils are shown in Table 3. There is a typical vertical distribution in both soils. The climatic influence on soil genesis is evident. The Fe contents in the Chernozem are lower than in the Cambisol.

Micromorphological data

CAMBISOL-Wieselburg

Ap-horizon, (0-20 cm), Fig. 3a:
Subangular blocky (to prismatic) microstructure. The solid material is divided into subangular aggregates which are separated by planar voids, but vughs and small channels are often present. Some parallel aligned planar

T a b l e 1. Semiquantitative mineralogical composition of the fine earth of the Austrian soils in weight %

Horizon (cm)	Quartz	Layer - silicates	Felspars	Calcite	Dolomite
Cambisol					
Ap (0 - 20)	42	48	10	0	0
AB (20 - 40)	44	41	15	0	0
Bv (40 - 80)	44	39	15	0	2
BC (80 - 95)	33	32	6	12	17
C (95 +)	33	28	4	17	18
Chernozem					
Ap (0 - 15)	24	31	15	20	10
Ah (15 - 23)	30	34	8	18	10
AC (23 - 40)	20	34	6	26	14
C_1 (40 - 70)	35	23	11	13	18
C_2 (70 +)	38	18	20	8	16

T a b l e 2. Semiquantitative clay mineral distribution in the fine earth of the Austrian soils in weight %

Horizon (cm)	Illite	Vermiculite	Smectite	Chlorite	Kaolinite
Cambisol					
Ap (0 - 20)	79	0	0	16	5
AB (20 - 40)	69	0	0	20	11
Bv (40 - 80)	77	0	0	17	6
BC (80 - 95)	72	0	0	20	8
C (95 +)	70	0	0	19	11
Chernozem					
Ap (0 - 15)	70	0	0	30	0
Ah (15 - 23)	66	0	0	34	0
AC (23 - 40)	70	0	0	30	0
C_1 (40 - 70)	54	0	0	46	0
C_2 (70 +)	61	0	0	39	0

T a b l e 3. Dithionite - (d), oxalate - (o) and pyrophosphate - (p) soluble contents of Fe, Al and Mn of the Austrian soils in mg/kg fine earth

Horizon (cm)	Fe_d	Fe_o	Fe_p	Al_d	Al_o	Al_p	Mn_d	Mn_o	Mn_p
Cambisol									
Ap (0 - 20)	11195	3427	760	1858	1015	398	806	682	377
AB (20 - 40)	10310	3424	762	952	1011	400	730	679	357
Bv (40 - 80)	9730	2896	495	976	1119	454	672	648	125
BC (80 - 95)	8975	1641	90	965	846	207	477	408	29
C (95 +)	8195	738	39	863	686	374	362	312	15
Chernozem									
Ap (0 - 15)	3870	665	95	563	1321	475	270	225	53
Ah (15 - 23)	3810	683	93	573	1346	459	272	227	50
AC (23 - 40)	3385	469	44	402	653	193	128	99	12
C_1 (40 - 70)	3090	531	109	252	296	82	92	56	14
C_2 (70 +)	2945	449	150	186	236	54	95	57	17

voids give the structure a slightly prismatic appearance. Peds are fully or partially accomodated. Brown speckled and moderately impregnated typical iron nodules are randomly distributed and newly formed calcites are present.

AB-horizon, (20-40 cm), Fig. 3b:

Intergrain channel microstructure. Closely packed mineral grains (sand and silt) between which, in addition to the normal simple packing voids, there is a system of channels. Channels mostly alongated with usually smoothed walls. Few chambers. Brown speckled iron nodules randomly distributed and many moderately impregnated typic nodules are very frequent pedofeatures in this horizon.

Bv-horizon, (40-80 cm), Fig. 3c:

Massive, coherent microstructure with no discrete peds and few voids.

C-horizon, (95+ cm), Fig. 3d:

Massive, coherent microstructure with no discrete peds and few voids.

CHERNOZEM-Fuchsenbigl

Ap-horizon, (0-15 cm), Fig. 4a:

Crumby microstructure with fully separated aggregates with large pore space. The interior of small aggregates is composed of granules which contain simple packing voids. Complex packing voids are strongly interconnected. Ca-humates and micritic calcite play an important role in the stability of microaggregates. In the interior of small aggregates opaque humus particles are found. Calcitic nodules and aggregates, admixtures of partly decomposed organic matter and humified plant residues (charcoal) are visible pedofeatures.

Ah-horizon, (15-23 cm), Fig. 4b:

Crumby microstructure with fully separated aggregates, with much pore space. Some small aggregates are distinct by higher humus content. Complex packing voids are strongly interconnected. In the interior of small aggregates, disseminated humus microaggregates are present. Calcitic nodules and aggregates are the most relevant pedofeatures.

AC-horizon, (23-40 cm), Fig. 4c:

Chamber-like microstructure, where the dominant voids are chambers. There are no discrete aggregates.

C1-horizon, (40-70 cm), Fig. 4d:

Massive, coherent microstructure with no discrete peds and few voids.

CZECH-REPUBLIC

Mineralogical data

Coarse mineral distribution in the fine earth

The distribution of the coarse minerals in the Chernozem of Tisice is shown in Table 4. Except for some traces of felspars and calcite, the soil matrix is dominated by quartz and layer silicates, the latter increasing with soil depth.

T a b l e 4. Semiquantitative mineralogical composition of the fine earth of the Czech soils in weight %

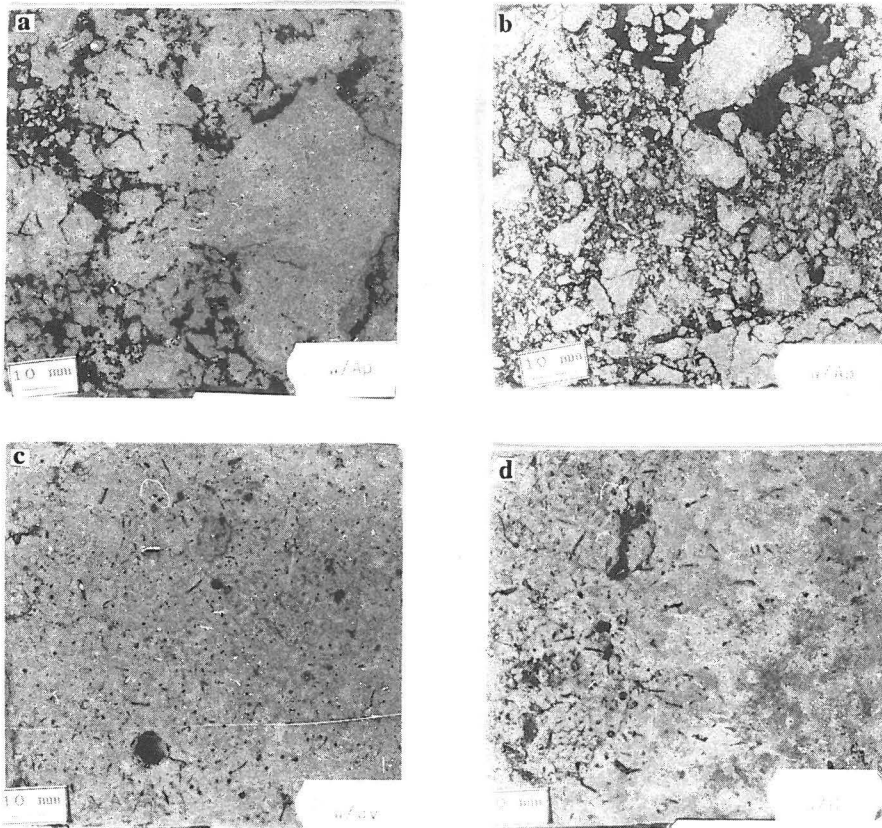| Horizon (cm)	Quartz	Layer-silicate	Feld-spars	Calcite	Dolo-mite
0-20	73	22	2	3	0
20-40	58	37	0	5	Tr.

Fig. 3. Soil thick section of the Cambisol-Austria: Ap-horizon, 0-20 cm depth (a), AB-horizon, 20-40 cm depth (b), Bv-horizon, 40-80 cm depth (c) and C-horizon, 95+ cm depth (d).

Clay mineral distribution in the fine earth

The distribution of the clay minerals is given in Table 5. The most abundant clay minerals are illite and chlorite with a low per-

centage of montmorillonite, and therefore no swelling and shrinking cracks or voids are visible,(Fig.5a).

Fe, Al, Mn oxide distribution in the fine earth

The distribution of the pedogenical oxides is shown in Table 6. The oxide contents of both soils are very low, according to the pedogenical weathering conditions of this region, comparable to the Fuchsenbigl-Chernozem in Austria and to the Phaeozem in Slovakia.

T a b l e 5. Semiquantitative clay mineral distribution in the fine earth of the Czech soils in weight %

Horizon (cm)	Illite	Chlo-rite	Smec-tite	Vermi-culite	Kao-linite
0-20	48	41	11	0	0
20-40	53	36	11	0	0

T a b l e 6. Dithionite - (d), oxalate - (o) and pyrophosphate - (p) soluble contents of Fe, Al and Mn in the Czech soils in mg/kg fine earth

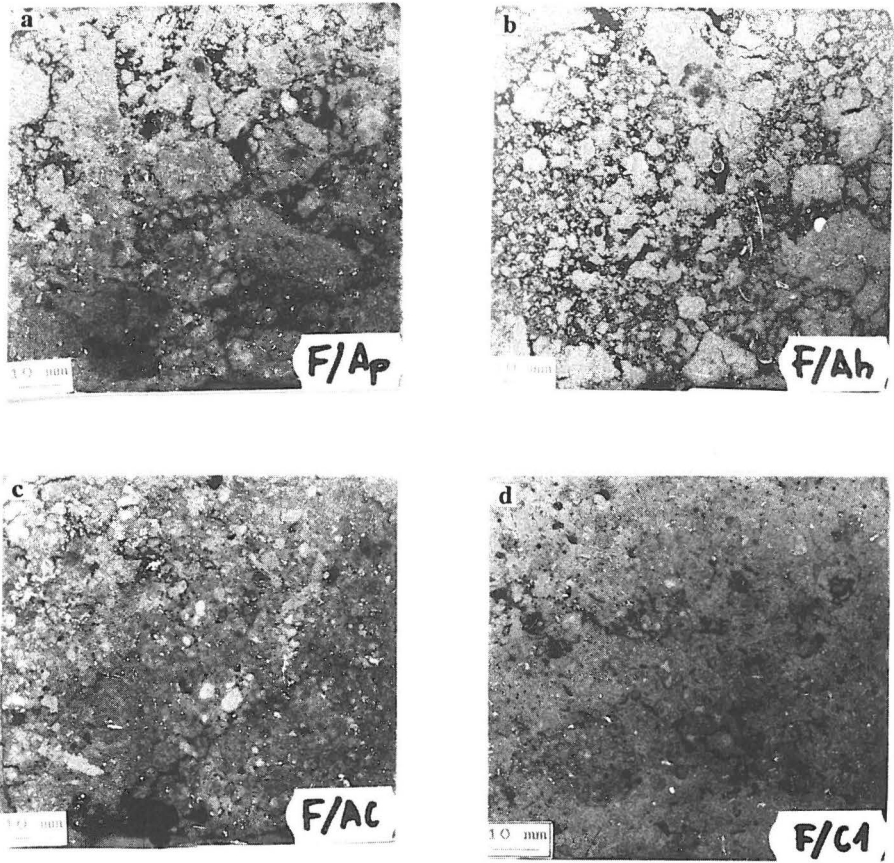| Horizon (cm)	Fe$_d$	Fe$_o$	Fe$_p$	Al$_d$	Al$_o$	Al$_p$	Mn$_d$	Mn$_o$	Mn$_p$
0 - 20	2970	763	259	307	1223	257	286	276	204
20 - 40	3280	653	229	301	893	166	559	590	138

Fig. 4. Soil thick section of the Chernozem-Austria: Ap-horizon, 0-15 cm depth (a), Ah-horizon, 15-23 cm depth (b), AC-horizon, 23-40 cm depth (c) and C1-horizon, 40-70 cm depth (d).
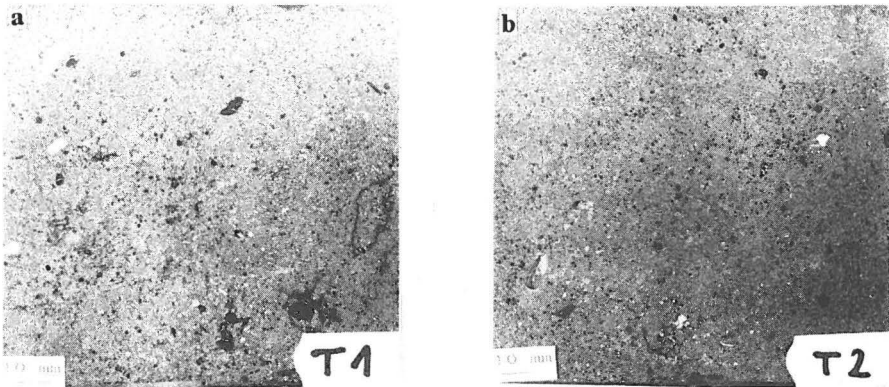

Fig. 5. Soil thick section of the Chernozem - Czech-Republic: Chernozem - T1, A-horizon, 0-20 cm depth (a) and Chernozem - T2, A-horizon, 20-40 cm depth (b).

Micromorphological data

CHERNOZEM-Tišice

A-horizon, (0-30 cm), Fig. 5a:
Massive, compact microstructure with no discrete peds and few voids.

Ak-horizon, (22-35 cm), Fig. 5b:
Massive, compact microstructure with no discrete peds and few voids.

HUNGARY

Mineralogical data

The mineralogical data of the Hungarian soils are unfortunately missing. However, the salt-affected, ameliorated Solonetz described below, has a very high clay content (50 %) and very strongly developed swelling/shrinking properties.

Micromorphological data

SOLONETZ-Kargacpuszta

AB1-horizon, (0-20 cm), Fig. 6a:
Subangular blocky microstructure. The solid material is divided into subangular aggregates separated by short planar voids on all or most sides. Vughs and channels occur within the aggregates. The aggregate faces largely accomodate each other.

B2-horizon, (20-60 cm), Fig. 6b:
Prismatic microstructure. The solid material is divided into prisms separated by vertically aligned planar voids. The faces of the aggregates normally accomodate each other.

BC-horizon, (60-70 cm), Fig. 6c:
Prismatic structure. The solid material is divided into prisms separated by vertically aligned planar voids. The faces of the aggregates normally accomodate each other. Iron mottles and iron concretions, white lime spots, lime concretions are present as pedofeatures.

C-horizon, (70+ cm), Fig. 6d:
Subangular blocky microstructure. The solid material is divided into subangular aggregates separated by short planar voids on all or most sides. Vughs and channels occur within the aggregates. The aggregate faces largely accomodate each other. White lime mottles and lime concretions are present.

POLAND

Mineralogical data

Coarse mineral distribution in the fine earth

The distribution of the coarse minerals in the Orthic Luvisol is shown in Table 7 and shows very clearly the dynamic of clay illuviation due to pH variation. In the topsoil only quartz and feldspars are present, whereas in the Bt-horizon phyllosilicates accumulate. This is also confirmed through the particle size distribution of this soil (see [18a]).

T a b l e 7. Semiquantitative mineralogical composition of the fine earth of the Polish soil in weight %

Horizon (cm)	Quartz	Layer-silicates	Fels-pars	Calcite	Dolo-mite
Orthic Luvisol					
A_h	68	0	32	0	0
E	71	0	29	0	0
B_{t1}	58	39	3	0	0
B_{t2}	71	22	7	0	0
BC	61	31	8	0	0
C_k	59	20	10	7	4

Clay mineral distribution in the fine earth

The distribution of the clay minerals is given in Table 8. A distinct accumulation of smectite in the Bt-horizon is visible, where the contents of illite and chlorite are much lower. Smectite clay minerals are generally known to be illuviated because of their capacity of dispersion in the soil solution and their small particle size.

T a b l e 8. Semiquantitative clay mineral distribution in the fine earth of the Polish soil in weight %

Horizon (cm)	Illite	Chlo-rite	Smec-tite	Vermi-culite	Kao-linite
Orthic Luvisol					
A_h	38	44	18	0	0
E	46	54	Tr.	0	0
B_{t1}	24	30	46	0	0
B_{t2}	31	17	52	0	0
BC	58	18	24	0	0
C_k	54	13	33	0	0

Fe, Al, Mn oxide distribution in the fine earth

The distribution of the pedogenical oxides is shown in Table 9. The illuviation process also
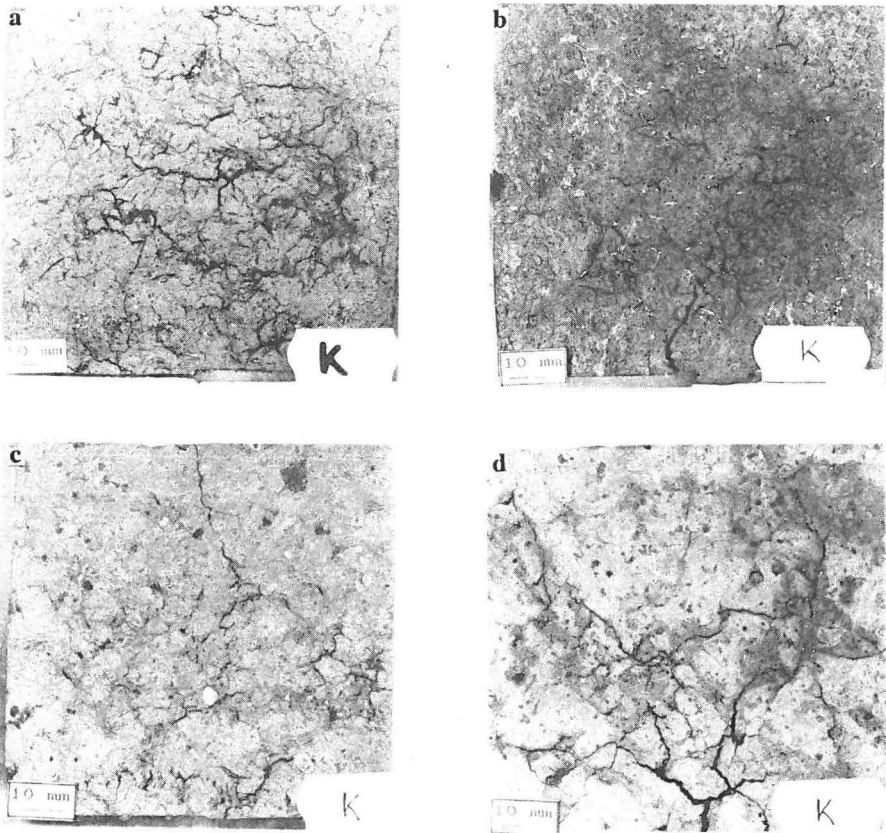
Fig. 6. Soil thick section of the ameliorated Solonetz-Hungary: AB1-horizon, 0-20 cm depth (a), B2-horizon, 20-60 cm depth (b), BC-horizon, 0-20 cm depth (c) and C-horizon, 78+ cm depth (d).

T a b l e 9. Dithionite - (d), oxalate - (o) and pyrophosphate - (p) soluble contents of Fe, Al and Mn of the Polish soils in mg/kg fine earth

Horizon (cm)	Fe_d	Fe_o	Fe_p	Al_d	Al_o	Al_p	Mn_d	Mn_o	Mn_p
Orthic Luvisol									
Ah	3520	1895	1660	939	1235	1190	202	220	205
E	3500	1795	1290	1020	1203	1170	364	364	231
B_{t1}	6810	1848	589	1493	1611	985	217	203	47
B_{t2}	3430	1298	336	597	727	382	215	213	47
BC	3930	1210	347	481	625	255	231	221	84
C_k	2010	685	93	272	458	59	137	130	21

regards Fe oxides, which are accumulated in the Bt-horizon, as well. Moreover, the Bt-horizon of Luvisols is called a 'weathering' - horizon. This explains the lower Fe_o/Fe_d-ratio of the Bt1-horizon (Table 10). The vertical transport and distribution of Fe is also very well expressed by the MUNSELL-colors, as shown in Table 11.

Micromorphological data

Orthic LUVISOL

Ah-horizon, (0-6 cm), Fig. 7a:

The upper 3 cm are leaves and twigs, partly decomposed. The rest of the section shows a massive, coherent structure with no peds, but visible root channels and voids.

T a b l e 10. Weathering indices of the Polish soil in the fine earth

Horizon (cm)	Fe_t	(Fe_d/Fe_t)	$(Fe_d\text{-}Fe_o)/Fe_t$	(Fe_o/Fe_d)
Orthic Luvisol				
A_h	9825	35.8	16.5	53.8
E	9375	37.3	18.2	51.3
B_{t1}	19875	34.2	25.0	27.1
B_{t2}	13275	25.8	16.0	37.8
BC	13450	29.2	20.2	30.8
C_k	10325	19.5	12.8	34.1

T a b l e 11. MUNSELL-colors of the Orthic Luvisol under forest in Poland

Horizon (cm)	Hue/value/chroma	Name
Orthic Luvisol		
Ah (0 - 6)	10 YR/6/2	light brownish gray
E (6 - 27)	10 YR/7/2	light gray
Bt1 (27 - 57)	10 YR/6/6	brownish yellow
Bt2 (57 - 103)	10 YR/6/6	brownish yellow
BC (105 - 136)	10 YR/7/3	very pale brown
Ck (136+)	10 YR/7/3	very pale brown

E-horizon, (6-27 cm), Fig. 7b:

Massive, coherent microstructure with no peds and few voids.

Bt1-horizon, (27-57 cm), Fig. 7c:

Cracky microstructure with no fully separated aggregates. The matrix material is dense, but with enough chambers and voids.

BC-horizon, (105-136 cm), Fig. 7d:

This horizon shows a transition between cracky and coherent microstructure, with few, but strongly developed cracks.

Ck-horizon, (136+ cm), Fig. 7e:

Massive, dense, coherent microstructure with few, if any, voids.

SLOVAK-REPUBLIC

Mineralogical data

Coarse mineral distribution in the fine earth

The fluviatile coarse fraction is composed mainly of quartz, micas (muscovite, biotite), felspars, calcite, dolomite, and chlorite, (Table 12). Newly formed carbonates (neocalcitans, nodules, cement) are also very important constituents of this soil.

Clay mineral distribution in the fine earth

The distribution of the clay minerals is given in Table 13. The non-swelling character of the main constituents, illite and chlorite, the low content of swelling smectite and the high carbonate content have a strong influence on the soil structure formation. Fe, Al, Mn oxide distribution in the fine earth.

Fe, Al, Mn oxide distribution in the fine earth

The distribution of the pedogenical oxides is shown in Table 14. The contents of Fe, Al and Mn are rather low (0.4-0.5 % Fe in the fine earth) and typical for these Pannonian regions, (see also the Chernozem in Fuchsenbigl-Austria).

Micromorphological data

Calcaro-haplic-PHAEOZEM-Macov 1

Akp-horizon, (0-38 cm), Fig. 8a:

Coarse angular to subangular blocky weak grade microstructure.

Ak-horizon, (38-48 cm), Fig. 8b:

Fine angular to subangular blocky weak grade microstructure.

A/Ck-horizon, (48-65 cm), Fig. 8c:

Fine angular to subangular blocky weak grade microstructure.

Ck-horizon, (65-85 cm), Fig. 8d:

Massive coherent microstructure, with no peds and few voids.

Cgk-horizon, (85+ cm), Fig. 8e:

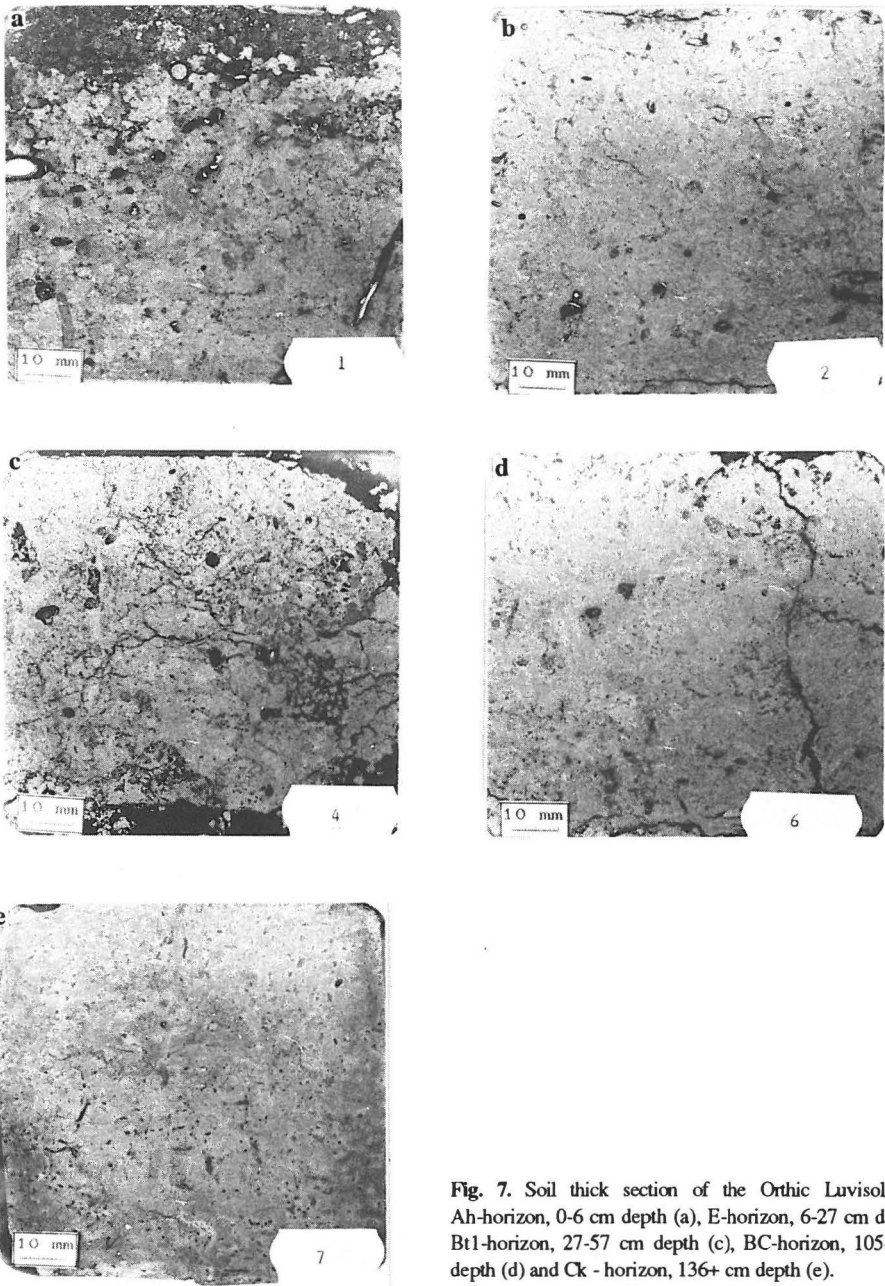Massive coherent microstructure, with no peds and few voids.

Fig. 7. Soil thick section of the Orthic Luvisol-Poland: Ah-horizon, 0-6 cm depth (a), E-horizon, 6-27 cm depth (b), Bt1-horizon, 27-57 cm depth (c), BC-horizon, 105-136 cm depth (d) and Ck - horizon, 136+ cm depth (e).

T a b l e 12. Semiquantitative mineralogical composition of the fine earth of the Slovakian soil in weight %

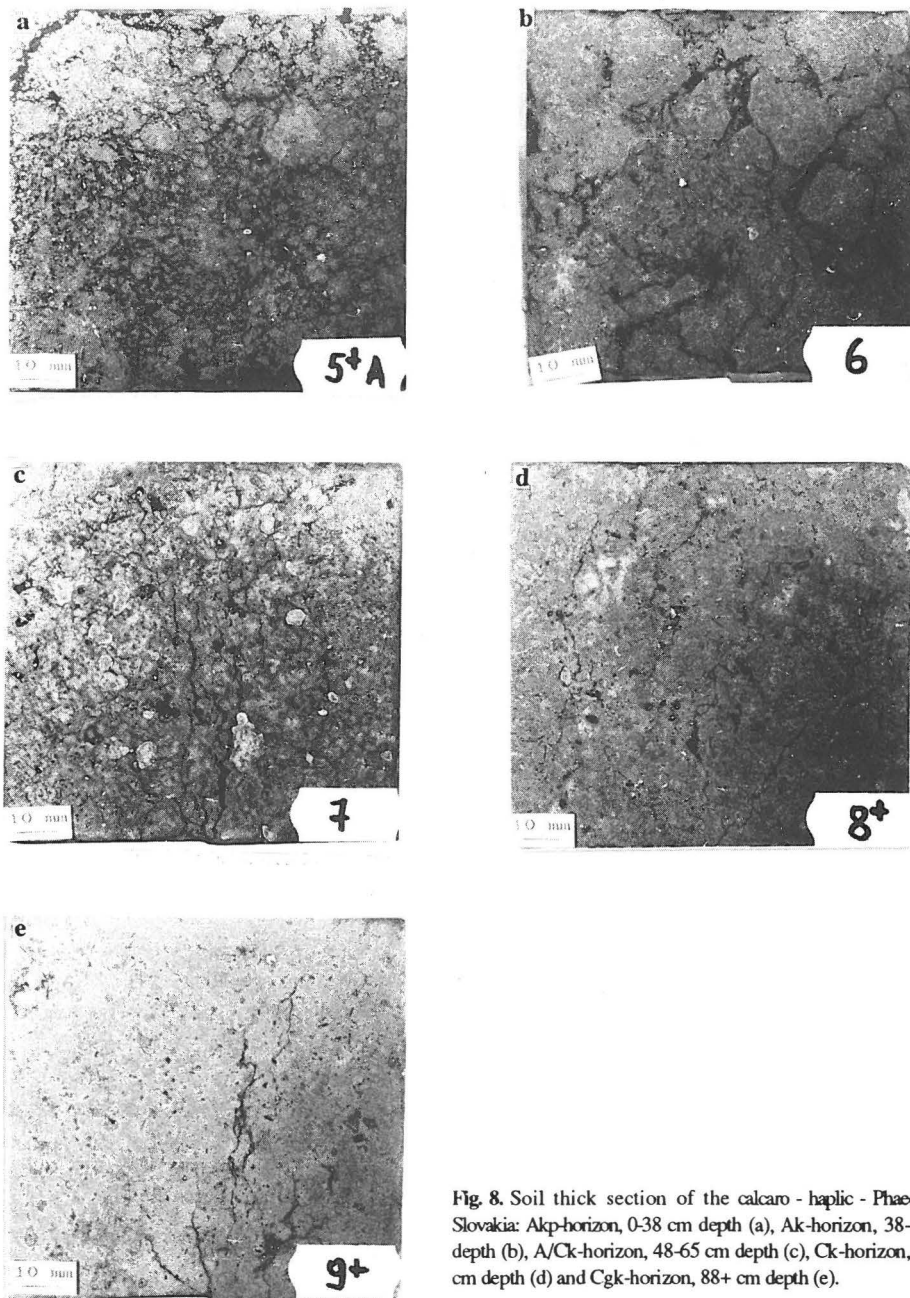| Horizon	Quartz	Layer-silicates	Feldspars	Calcite	Dolomite
Macov 1					
Akp	30	34	18	5	13
Ak	29	39	12	6	14
A/Ck	22	40	3	19	16
Ck	19	29	5	28	19

Fig. 8. Soil thick section of the calcaro - haplic - Phaeozem - Slovakia: Akp-horizon, 0-38 cm depth (a), Ak-horizon, 38-48 cm depth (b), A/Ck-horizon, 48-65 cm depth (c), Ck-horizon, 65-85 cm depth (d) and Cgk-horizon, 88+ cm depth (e).

T a b l e 13. Semiquantitative clay mineral distribution in the fine earth of the Slovakian soil in weight %

Horizon	Illite	Chlorite	Smectite	Vermiculite	Kaolinite
Macov 1					
Akp	74	23	3	0	0
Ak	66	28	6	0	0
A/Ck	42	36	22	0	0
Ck	55	36	9	0	0

T a b l e 14. Dithionite- (d), oxalate- (o) and pyrophosphate- (p) soluble contents of Fe, Al and Mn of the Slovakian soil in mg/kg fine earth

Horizon	Fe_d	Fe_o	Fe_p	Al_d	Al_o	Al_p	Mn_d	Mn_o	Mn_p
Macov 1									
Akp	3890	670	16	492	973	331	386	301	174
Ak	3940	735	153	501	1140	399	376	337	175
A/Ck	4930	958	93	653	1118	476	250	197	24
Ck	4460	1143	64	516	1270	271	206	164	14

CONCLUSIONS

Interactions between soil mineralogy, soil micromorphology and soil macrostructure.

The coarse 'primary' soil minerals accumulate mostly in the sand and silt fraction. Besides their influence on chemical soil parameters (pH, cation release, CEC, etc.), their size, shape and arrangement seems to characterize particular types of soil macrostructures. As an example, soil horizons with massive, coherent structure are mostly sandy/silty loessial horizons, with few non-swelling clay minerals (e.g., the C-horizon of the Cambisol in Austria, the eluvial E-horizon of the Orthic Luvisol in Poland). These horizons possess few voids, if any, and become very compact and dense when moistened. On the contrary, soils with abundant amounts of clay minerals, especially of the swelling type (smectite, randomly interstratified illite), have a very pronounced swelling/shrinking behaviour. This leads mostly to a typical cracky, prismatic macrostructure, as shown for example in the heavy-textured Solonetz of Hungary.

The degree of crystallinity of the Fe oxides varies widely among different soils. The large variation in crystallinity reflects the conditions under which Fe-oxide crystals develop, and may therefore be regarded as an indicator of the pedoenviroment. The most relevant reaction inducing the formation of Fe(III)-oxides is the hydrolytic and oxidative weathering of Fe (II)-containing 'primary' minerals (Fe(II)-silicates). The degree to which this irreversible reaction has taken place is used for characterizing the degree of weathering of parent material, measured by the ratio of DCB-soluble-Fe to total Fe (Fe_d / Fe_t). The ratio oxalate-soluble-Fe to dithionite-soluble Fe (Fe_o / Fe_d), moreover, gives an indication of the 'pedogenical' wheathering intensity [35,36].

In cemented horizons, the Fe oxides fill significant proportions of the pores between matrix particles, as can be seen from thin sections of nodules, concretions, ferricretes, etc. Aggregation, on the other hand, is understood as the association of soil matrix particles into aggregates by particles of Fe oxides. This is probably less due to crystall growth but more to the attraction between positively charged Fe oxide particles and negatively charged matrix particles, particularly clay silicates. Because the charge of Fe oxide particles is pH-dependent, their aggregation effect is also pH-dependent.

The aggregation effect of Fe oxides has been demonstrated in various ways:
a) By a significant correlation between the percentage of water-stable aggregates or related structural properties and the content of Fe oxides [2,21,28].
b) By the dispersion of aggregated soils after removal of Fe oxides with a reducing agent [30].
c) By the aggregating effect of added synthetic Fe oxides [7,25,34].

These data indicate that Fe oxides are the more effective in aggregating silty, e.g., loessial soils, the lower their crystallinity and the higher their oxalate solubility (i.e., the higher their Fe_o / Fe_d ratio). Therefore, very small, highly charged Fe-oxide-Polymers were found to be particularly effective in binding soil particles together [32]. It is also well known that certain microorganisms are able to oxidize Fe(II) in aqueous solutions and have therefore been grouped collectively and called iron bacteria. The Fe-oxide formed by microbial oxidation usually is ferryhdrite [14], which often covers the bacterial or algal cells with 0.5 to 2.0 m-sized spherical aggregates.

The soil structure is the dynamic result of the activity of abiotic and biotic factors and

processes. Usually texture, mineral composition and organic matter are the main structure-forming factors, together with human activities [22]. They mediate the activity of soil organisms and plants according to the climatic and hydrological conditions. Structure-forming processes, instead, determine types, size, grade, porosity, packing and stability of soil structure.

Soil structure, together with soil organisms and plants, playes a main role in transport of water, gas and heat, which are structure-following factors and processes [22].

Microscopical soil analyses (using light microscope and submicroscopic techniques) are very useful in studying natural peds, crumbs, aggregates and associated voids. With these procedures voids and aggregates produced by soil fauna and due to tillage, root and faunal channels, can be distinguished. Soil micromorphology gives the possibility to identify the coagulating and cementing effect of components, the properties and occurance of peds. Some of these components can be quantified in a global (porosity, volume fraction of homogeneous zones) as well as in the feature-specific sense (informations about individual objects). All observed facts can be presented and documented as graphs, pictures and descriptions.

Methodological approaches

Determination of coarse and clay minerals (qualitative and quantitative)

- Differential Thermal Analysis (DTA);
- Differential Thermal Gravimetry (DTG);
- Infrared (IR) spectroscopy;
- X-ray fluorescence (XRF);
- X-ray diffraction (XRD);
- Chemical analysis;
- Scanning electrone microscopy (SEM);
- Transmission electrone microscopy (TEM).

Determination of Fe oxides (qualitative and quantitative)

- MUNSELL color in the range of 10YR to 5R;
- Dissolution by DCB [31];
- Dissolution by ammonium oxalate in the dark [13,29,35,36,37,39];

- X-ray diffraction (XRD);
- Differential Thermal Analysis (DTA);
- Infrared (IR) spectroscopy;
- Mössbauer (gamma resonance) spectroscopy;
- Scanning electrone microscopy (SEM);
- Transmission electrone microscopy (TEM).

Micromorphological analyses

- Binocular microscope, [38];
- Scanning electron microscope (SEM);
- Polarizing microscope;
- Transmission electrone microscope (TEM);
- Computed Tomography (CT);
- Magnetic Resonance Imaging (MRI).

Applicability of the methods for different soils

As a conclusion, it can be stated that the mineralogical composition of coarse and clay minerals as well as the content of Fe-, Al-, Mn-oxides can easily be determined in any kind of soil, whereas the preparation of thin and thick sections from heavy soils is limited because of impregnation problems. Quantitative microscopic obsevations in soil structure are not videly applied exept for soil porosity studies [20]. The use of soil micromorphology in soil structure studies is limited, due to difficulties associated with the prevention of shinkage of organic material and clays in soil samples, with staining techniques and preparation of images [6,23].

REFERENCES

1. **Aguilera N.H., Jackson M.L.:** Iron oxide removal from soils and clays. Soil Sci. Soc. Amer. Proc., 17, 359-364, 1959.
2. **Arca M.N., Weed S.B.:** Soil aggregation and porosity in relation to contents of free iron oxide and clay. Soil Sci., 101, 164-170, 1966.
3. **Bal L.:** Micromorphological analysis of soils. Soil Survey Papers, 6, Netherlands Soil Survey Institute, Wageningen, 170, 1973.
4. **Bascomb C.L.:** Distribution of pyrophosphate-extractable iron and organic carbon in soils of various groups. J. Soil Sci.,19, 251-268, 1968.
5. **Bisdom E.B.A., Schononderbeek D.:** The characterization of the shape of mineral grains in thin sections of soils by Quantimet and BESI. Geoderma, 30, 303-322, 1983.
6. **Bisdom E.B.A., Tessier D., Schoute J.F.Th.:** Micromorphological techniques in research and training

(submicroscopy). In: Soil Micromorphology: a Basic and Applied Science (Ed. L.A. Douglas). Developments in Soil Sci., 19, 581-605, 1990.

7. **Blackmore A.V.**: Aggregation of clay by the products of iron (III) hydrolysis. Aust. J. Soil Res., 11, 75-78, 1973.

8. **Bonneau M., Souchier B.**: Constituents and Properties of Soils. Acad. Press, London. New York, 496, 1992.

9. **Brewer R.**: Fabric and mineral analysis of soils. J. Wiley, New York, 470, 1964.

10. **Brewer R.**: Fabric and mineral analysis of soils. Robert E. Kreiger, New York, 1976.

11. **Brindley G.W., Brown G.**: Crystal structures of clay minerals and their X-ray identification. Min. Soc., London, 1980.

12. **Bullock P., Fedoroff N., Jongerius A., Stoops G., Tursina T., Babel U.**: Handbook of Soil Thin Section Description. Waine Res. Publ., 152, 1985.

13. **Campbell A.S., Schwertmann U.**: Iron oxide mineralogy of placic horizons. J. Soil Sci., 35, 569-582, 1984.

14. **Chukhrov F.V., Zvyagin B.B., Gorshkov A.I., Ermilova L.P., Balashova V.V.**: Ferrihydrite. Izv. Akad. Nauk. SSSR, Ser. Geol., 4, 23-33, 1973.

15. **Čurlik J.**: Pedographical-microscopical and mineralogical study of Slovakian soils. Unpublished Ph. D. Thesis. Natural Science Faculty of Comenius University, Bratislava, 05, 1977.

16. **FAO-UNESCO**: Soil map of the world - Revised legend. Food and Agriculture Organization of the United Nations, Rome, 1988.

17. **Fitzpatrick E.A.**: Micromorphology of Soil. Chapman Hall, London, 1984.

18. **Garcia S.G., Camazano M.S.**: Differentiation of kaolinite from chlorite by treatment with dimethylsulphoxide. Clay Min., 7, 447-450, 1968.

19. **Gliński J.**: General characteristics of soils included to the multilateral programme. Int. Agrophysics, 7(2-3), 99-116, 1993.

20. **Jongerius A.**: Recent developments in soil micromorphometry. In: Soil Microscopy. Proc. 4th Int. Working Meeting on Soil Micromorphology, Kingston (Ed. G.K. Rutherford). The Limestone Press, Kingston, Ont., 67-83, 1973.

21. **Kemper W.D.**: Aggregate stability of soils from western United States and Canada. SDA Tech. Bull. 1355, U.S. Gov. Print Office, Washington, D.C., 1966.

22. **Kooistra M.J.**: A micromorphological approach to the interactions between soil structure and soil biota. Agriculture, Ecosystem and Environment, 34, 315-328, 1991.

23. **Kooistra M.J., Bouma J., Boersma O.H., Jageger A.**: Physical and morphological characterization of undisturbed and disturbed ploughpans in a sandy loam soil.

Soil Tillage Res., 4, 1984.

24. **Kooistra M.J., Bouma J., Boersma O.H., Jageger A.**: Soil structure differences and associated physical properties of some loamy typic Fluvaquent in the Netherlands. Geoderma, 36, 215-228, 1985.

25. **Kuron H., Walter B.**: Ber die Bildung und Bindung von Mikroaggregaten in Boden. Z. Pflanzen. Bodenkd., 104, 12-24, 1964.

26. **Letey J.**: The study of soil structure: Science or art. Austr. J. Soil Res., 29, 699-707, 1991.

27. **Mackenzie R.C.**: Free iron oxide removal from soils. J. Soil Sci., 5, 167-172, 1954.

28. **McIntyre D.S.**: The effect of free ferric oxide on the structure of some Terra Rossa and Rendzina soils. J. Soil Sci., 7, 302-306, 1956.

29. **McKeague J.A., Day J.H.**: Dithionite- and oxalate extractable Fe and Al as aids in differentiating various classes of soils. Can. J. Soil Sci., 43, 83-96, 1966.

30. **McNeal B.L., Layfield D.A., Norwell W.A., Rhoades J.D.**: Factors influencing hydraulic conductivity of soils in the presence of mixed salt solution. Soil Sci. Soc. Am. Proc., 32, 187-190, 1968.

31. **Mehra O.P., Jackson M.L.**: Iron oxide removal from soils and clays by a dithionite - citrate system buffered with sodium bicarbonare. Clays Clay Miner., 7, 317-327, 1960.

32. **Rengesamy P., Oades J.M.**: Interaction of monomeric and polymeric species of metal ions with clay surfaces. II. Changes in surface properties of clays after addition of iron (III). Aust. J. Soil Res., 15, 235-242, 1977.

33. **Riedmüller G.**: Neoformations and transformations of clay minerals in tectonic shear zones. TMPM Tschermaks Min. Petr. Mitt., 25, 219-242, 1978.

34. **Schahabi S., Schwertmann U.**: Der Einfluss von synthetischen Eisenoxiden auf die Aggregation zweier Lössbödenhorizonte. Z. Pflanzen. Bodenkd., 125, 193-204, 1970.

35. **Schwertmann U.**: Die fraktionierte Extraktion der freien Eisenoxide in Böden, ihre mineralogischen Formen und ihre Entstehungsweisen. Z. Pflanzen. Bodenkd., 84, 194-204, 1959.

36. **Schwertmann U.**: Differenzierung der Eisenoxide des Bodens durch Extraktion mit Ammoniumoxalat-Lösung. Z. Pflanzen. Bodenkd., 105, 194-201, 1964.

37. **Schwertmann U., Murad E., Schulze D.G.**: Is there Holocene reddening (hematite formation) in soils of axeric temperate areas? Geoderma, 27, 209-223, 1982.

38. **Stoops G.**: Optical and electron microscopy. A comparison of their principles. In: Soil Microscopy. Proc. 4th Int. Working Meeting on Soil Micromorphology, Kingston (Ed. G.K. Rutherford). The Limestone Press, Kingston, Ont., 101-119, 1973.

39. **Tamm O.**: Um bestämning of de oorganiska komponenterna i markens gelkomplex. Medd. Statens Skogsfrslanst. (Swed.), 19, 385-404, 1922.