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STRUCTURE ASSESSMENT OF TWO AGRICULTURAL SOILS OF LOWER AUSTRIA

N. Rampazzo[1], *W.E.H. Blum*[1], *P. Strauss*[1], *J. Čurlik*[2]

[1]Institute of Soil Research, University of Agriculture, Gregor-Mendel-Strasse 33, A-118 Vienna, Austria
[2] Soil Fertility Research Institute, Gagarinova 10, 82-713 Bratislava, Slovak Republic

A b s t r a c t. The structure of two agricultural soils of different regions of Lower Austria (Cambisol in Wieselburg and Chernozem in Fuchsenbigl) was assessed using chemical, physical, mineralogical, and micromorphological investigations. The alkaline pH, the low electrical conductivity and the high calcium saturation are favourable parameters for the structure of both investigated soils, whereas the humus content is rather so high that structural stability cannot be expected. The Cambisol is more heavily textured and shows high water storage capacity but low air capacity in very wet periods, whereas in the light sandy Chernozem soil aeration is guaranteed, but little water can be availably stored in dry periods. The compaction observed under the ploughed layer led to a reduction of 'secondary-structurally-induced' coarse pores. From the hydraulic viewpoint, both investigated soils are permeable when water saturated. The k_{sat} values reflect very well the presence of a 'secondary' pore system. Expandable clay minerals absolutely do not occur in either of the soils. Moreover, because of the low weathering intensity in the investigated region, low Fe- and Al-oxide amounts occur. These mineral features, together with the low humus content, can be considered as unfavourable for soil structure stability because of their reduced CEC. The soil thin section analysis shows typical structure types such as prismatic, subangular microstructure in the loamy Cambisol and a crumby structure in the Chernozem.

K e y w o r d s: soil structure, Cambisol, Chernozem

INTRODUCTION

Soil structure can be defined as 'the physical constitution of solid soil materials as expressed by the size, shape and arrangements of soil particles and voids and its associated properties' [4]. This and similar general definitions may lead to the conclusion that soil structure should be a 'physical' soil property. In fact, almost all other soil parameters (e.g., chemical, mineralogical, biological, micromorphological) play an important role in the genesis and variability of soil structure and are therefore also to be considered as 'structural' parameters. As shown in Fig. 1, soil structural parameters can be divided into different groups, and are more or less unstable and susceptible to changes. Moreover, it is obvious that all parameters influence one another leading to a typical structural status.

The aim of this study was to assess the structural status of two typical soils of Lower Austria, using structural parameters as described and grouped during the multilateral cooperation project 'Assessment of Soil Structure in Agricultural Soils' between Austria, Czech-Republic, Hungary, Poland and the Slovak-Republic (1991-1992).

MATERIAL AND METHODS

Investigated soils

One soil is located in the western subalpine region of Lower Austria (Wieselburg)

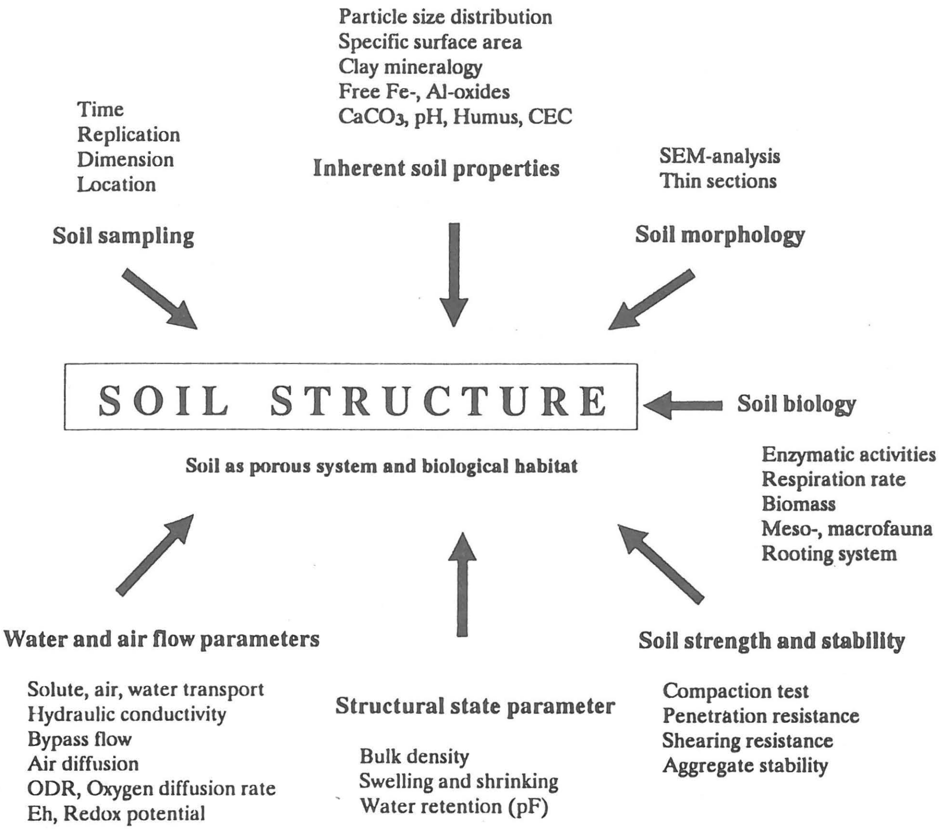

Fig. 1. Classification of soil structural parameters, 1964.

on loess. The other soil is situated in eastern Lower Austria (Fuchsenbigl) on sandy/silty fluviatile sediments.

Soil-Wieselburg

Ap (0-20 cm): dark brown (10 YR/4/3), silty loam, low (1 %) skeleton content, free of carbonates, spheroidal fine structure (crumbs)

AB (20-40 cm): brown (10 YR/5/3), loamy silt/silty loam, low (1 %) skeleton content, free of carbonates, prismatic fine structure (subpolyhedra)

Bv (40-80 cm): yellowish brown (10 YR/5/4), loamy silt, low (1 %) skeleton content, free of carbonates, prismatic fine structure (subpolyhedra)

BC (80-95 cm): yellowish brown (10 YR/5/4), silt, low (1 %) skeleton content, calcareous, packing coherent structure, no aggregation.

C (95+ cm): yellowish brown (10 YR/5/6), silt, low (<1 %) skeleton content, calcareous, packing coherent structure.

Soil type: Cambisol (according to FAO-system) on loess.

Soil-Fuchsenbigl

Ap (0-15 cm): very dark grey (10 YR/3/1), loam, low (1 %) skeleton content, calcareous, spheroidal fine structure (crumbs).

Ah (15-23 cm): very dark grey (10 YR/3/1), sandy loam, low (1 %) skeleton content, calcareous, spheroidal fine structure (crumbs).
AC (23-40 cm): greyish brown (10 YR/5/2), sandy loam, low (1 %) skeleton content, calcareous, single grain structure (no aggregation).
C1 (40-70 cm): olive (5 Y/5/4), loamy sand, low (1 %) skeleton content, calcareous, single grain structure (no aggregation).
C2 (70+ cm): light yellowish brown (2,5 Y/6/4), silty sand, low (1 %) skeleton content, calcareous, single grain structure (no aggregation).
Soil type: Chernozem (according to FAO-system) on fluviatile sediments.

Analytical methods

The bulk soils were air-dried and sieved at 2 mm mesh size (=fine earth). For density, porosity and hydrological properties 200 cm^3 undisturbed cylinder-samples were taken.

Chemical analysis

- pH (KCl and aqua dest.).
- Electrical conductivity (electrode conductivity meter).
- Carbonate-content (SCHEIBLER method).
- Exchangeable cations and cation exchange capacity (CEC) through unbuffered $BaCl_2$-extraction.
- Total carbon (Ct) by non-dispersive selective IR-detection.
- Organic carbon ($Ct-C_{unorg}$).

Physical analysis

- Particle size distribution (wet sieving and pipette-method).
- Bulk density (undisturbed 200 cm^3 cylinder samples).
- Total porosity (calculated from bulk and particle density).
- Pore size distribution (calculated from water retention curve).
- Saturated hydraulic conductivity [10].

Mineralogical analysis

- Semiquantitative analysis by X-ray diffraction of untextured soil powder patterns using Cuk^{α}-radiation.
- Semiquantitative analysis by X-ray diffraction of textured clay patterns pretreated with KCl, $MgCl_2$, dimethylsulphoxide (DMSO), glycerine and heating, according [5,9,13], using Cuk^{α}-radiation.
- Determination of Na-dithionite-citrate-bicarbonate (DCB)-soluble, NH_4-oxalate-soluble and Na-pyrophosphate.
- Soluble contents of Fe, and Al, Mn according to [1,2,12,14,15].

Micromorphological analysis

The soil thin sections were prepared in the Soil Fertility Research Institute of Bratislava, Slovak-Republic, according to the method published by Čurlik [6]. Polyester resin (CHS polyester 104) with acetone was used as fixing solution.

RESULTS AND DISCUSSION

Chemical data

General chemical parameters

The general chemical soil parameters are shown in Table 1. The pH of both soils is alkaline and favourable for the growth of soil organisms (bacteria and earthworms). The low electrical conductivity in both sites is typical for non-salt-affected arable soils. The content of organic carbon is also rather low in both soils and decreases with soil depth. The Chernozem is calcareous over the whole soil profile, whereas the Cambisol shows the typical loss of carbonate in the topsoil. The high calcium saturation in both soils (Table 2) is also favourable for the soil structure stability and prevents the topsoil from clay illuviation and acidification.

Table 1. General chemical soil parameters

Horizon (cm)	pH		Electrical conduct. (µS/cm)	Carbonate (%)	Ct (%)	Corg (%)
	KCl	H_2O				
Cambisol						
Ap (0 - 20)	6.9	7.4	136	1.4	1.3	0.6
AB (20 - 40)	6.8	7.5	121	1.3	1.2	0.3
Bv (40 - 80)	7.2	8.0	245	1.0	0.7	2.4
BC (80 - 95)	7.4	8.5	251	2.7	0.4	19.2
C (95 +)	7.4	8.7	246	3.9	0.3	29.8
Chernozem						
Ap (0 - 15)	7.3	8.5	266	4.1	4.1	21.6
Ah (15 - 23)	7.5	8.5	284	4.0	4.0	20.2
AC (23 - 40)	7.7	8.6	297	4.9	4.9	35.0
C1 (40 - 70)	7.8	8.9	288	3.6	3.6	27.5
C2 (70 +)	7.8	9.1	254	3.3	3.3	23.0

Table 2. CEC of the fine earth and exchangeable cations in % of CEC

Horizon (cm)	CEC (meq n^{-1}/kg)	Ca (%)	Mg (%)	K (%)	Na (%)	Fe (%)	Al (%)	Mn (%)
Cambisol								
Ap (0 - 20)	173	78	16	4	1.1	<0.1	<0.1	<0.1
AB (20 - 40)	164	80	15	4	1.0	<0.1	<0.1	<0.1
Bv (40 - 80)	161	80	17	1	1.2	<0.1	<0.1	<0.1
BC (80 - 95)	154	82	15	1	1.3	<0.1	<0.1	<0.1
C (95 +)	129	81	16	1	1.5	<0.1	<0.1	<0.1
Chernozem								
Ap (0 - 15)	205	88	10	1	0.9	<0.1	<0.1	<0.1
Ah (15 - 23)	204	88	10	1	1.0	<0.1	<0.1	<0.1
AC (23 - 40)	134	84	14	0.6	1.7	<0.1	0.1	<0.1
C1 (40 - 70)	104	75	22	0.5	2.5	<0.1	0.1	<0.1
C2 (70 +)	85	76	20	0.6	2.3	<0.1	0.1	<0.1

CEC and exchangeable cations

Table 2 shows the cation exchange capacity and the distribution of exchangeable cations in the fine earth. The degree of CEC depends mainly upon the organic matter content as well as on clay mineral distribution. The CEC of both soils is rather low because of the low content of organic matter and the complete absence of expandable clay minerals of the smectite and vermiculite group. The amount and the quality of exchangeable cations influence the stability of soil structure through flocculation and peptization phenomena. Ca, which is the dominant cation in both soils, advances aggregation processes.

Physical data

Particle size distribution

The results of the texture analysis are shown in Fig. 2. The Cambisol shows the typical high silt content of a loess soil, which decreases at the soil surface, where weathering processes have led to clay formation. Because of the high Ca-saturation no clay illuviation to the Bv-horizon can be observed. The Chernozem shows a high percentage of sand and silt.

Density and porosity parameters

The physical soil parameters are given in Table 3. Bulk density and total porosity are two descriptive structure parameters,

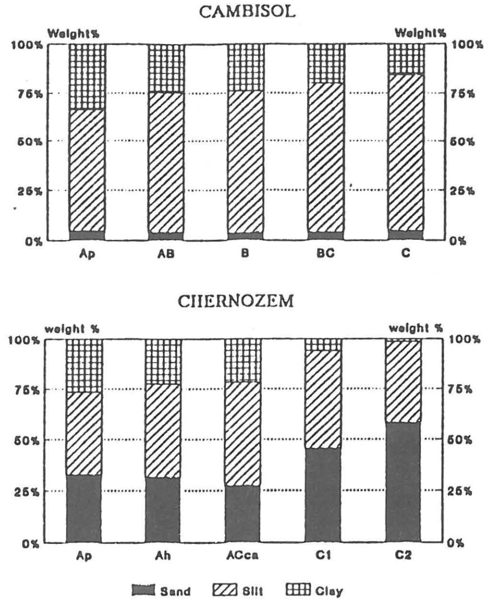

Fig. 2. Particle size distribution of the investigated soils.

but they give no information about the geometry and the continuity of the pore system. The loamy Cambisol shows a compaction in the depth of 20-40 cm, indicated by the higher bulk density and the decrease of porosity. Ehlers [7] indicates a maximum of 1.55 g/cm^3 for bulk density as critical level for plant growth, which is also reached in the Cambisol. On the other hand, Beckmann

Table 3. Bulk density (dB), particle density (dP), and total porosity (TP)

Horizon (cm)	dB (g/cm^3)	dP (g/cm^3)	TP (cm^3/100 cm^3)
Cambisol			
Ap (0 - 20)	1.46	2.65	44.7
AB (20 - 40)	1.55	2.70	42.5
Bv (40 - 80)	1.49	2.69	44.7
BC (80 - 95)	1.53	2.74	44.4
C (95 +)	1.54	2.74	43.8
Chernozem			
Ap (0 - 15)	1.34	2.69	50.2
Ah (15 - 23)	1.45	2.69	46.1
AC (23 - 40)	1.41	2.76	49.0
C1 (40 - 70)	1.42	2.78	48.9
C2 (70 +)	1.43	2.78	48.6

and Altemüller [3] showed that bulk density of topsoils can vary from 1.3 to 1.6 g/cm^3. The Chernozem also shows the effect of tillage, with the lowest bulk density in the Ap-horizon and the maximum compaction in the Ah-horizon.

Soil pore distribution

The equation of capillarity allows the calculation of soil pore distribution (Fig. 3) from the volumetric water contents of the pF-curve. Because of its silty texture, the Cambisol shows a relatively high amount of medium pores (0.2-10 μm diameter), indicating a higher available field capacity of water for plant roots. The content of fine pores (<0.2 μm diameter), which retain the unavailable soil water, decreases like the clay fraction with soil depth. The coarse pores (>10 μm diameter), responsible for aeration, water and solute transport, are rather low. Therefore soil aeration is endangered after persistent precipitations or thawing of snow in spring.

In the Chernozem sufficient amounts of medium and fine pores are found, due to the clay and organic matter contents. In the parent material (C2-horizon), no fine pores could be measured, following the decrease

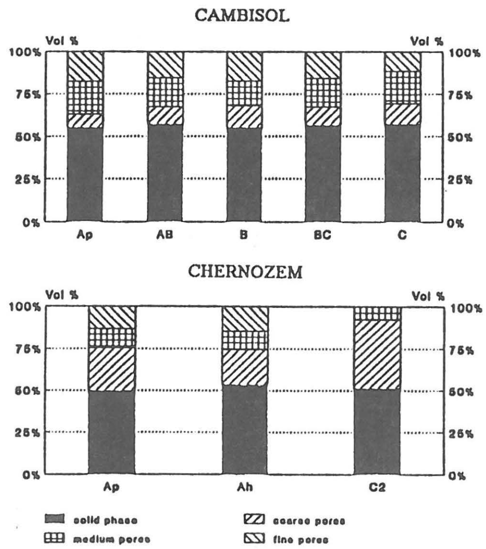

Fig. 3. Pore size distribution of the investigated soils.

of the clay fraction. The mechanical stress through tillage practices becomes evident by the slight decrease of coarse pores in the Ah-horizon, whereas the medium pores are not influenced [8]. From an agricultural viewpoint, the Chernozem is favourable concerning air permeability, but the low content of medium pores can be a disadvantage in summer periods with little precipitation.

Saturated hydraulic conductivity

The hydraulic conductivity under water saturated conditions plays an important role in matters of drainage, irrigation, etc., and is a very sensitive soil structure parameter which sometimes may give better information about the status of soil structure than pore distribution [10,11].

Table 4 shows the K_{sat}-values, which were measured in the top soils of both investigated sites. Due to the influence of different pore size systems (the 'primary' pore system as a result of particle size distribution and the 'secondary' pore system as a result of aggregation), the variability of this parameter can be very high, with differences in the same horizon of one order of magnitude. Therefore at least 5 repetitions should be collected for that purpose. Since the saturated hydraulic conductivity in not a normal distributed parameter, it is not convenient to calculate its average value but rather the frequency of distribution, which shows much better amplitude of deviation due to different pore systems.

The hydraulic conductivity is primarily influenced by soil texture. Soil aggregation, genesis of the 'secondary' pore system and the pricking of pores through illuviation of fine particles cause a deviation from the rather theoretical values of K_{sat}, as shown in Fig. 4. In the case of the investigated topsoils, the influence of aggregation-induced 'secondary' pores is evident.

Mineralogical data

Mineralogical composition of the fine earth

The results of the semiquantitative mineralogical analysis of the fine earth are given in Table 5. In the upper 3 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 are found. In the Chernozem the weathering intensity is commonly lower, therefore calcite and dolomite are present over the whole

Table 4. Saturated hydraulic conductivity

Horizon (cm)	Replication	K_{sat}-value (cm s^{-1})	K_{sat} - value (m d^{-1})
Cambisol			
Ap (0 - 20)	Ap/1	4.4 x 10-3	3.7
	Ap/2	4.9 x 10-3	4.2
	Ap/3	5.9 x 10-2	51.0
AB (20 - 40)	AB/1	3.5 x 10-2	30.6
	AB/2	1.2 x 10-3	1.1
	AB/3	5.1 x 10-3	4.4
Chernozem			
Ap (0 - 15)	Ap/1	1.0 x 10-3	0.9
	Ap/2	5.7 x 10-4	0.5
	Ap/3	1.4 x 10-3	1.2
Ah (15 - 23)	Ah/1	6.3 x 10-3	5.5
	Ah/2	3.5 x 10-3	3.0
	Ah/3	1.8 x 10-3	1.6

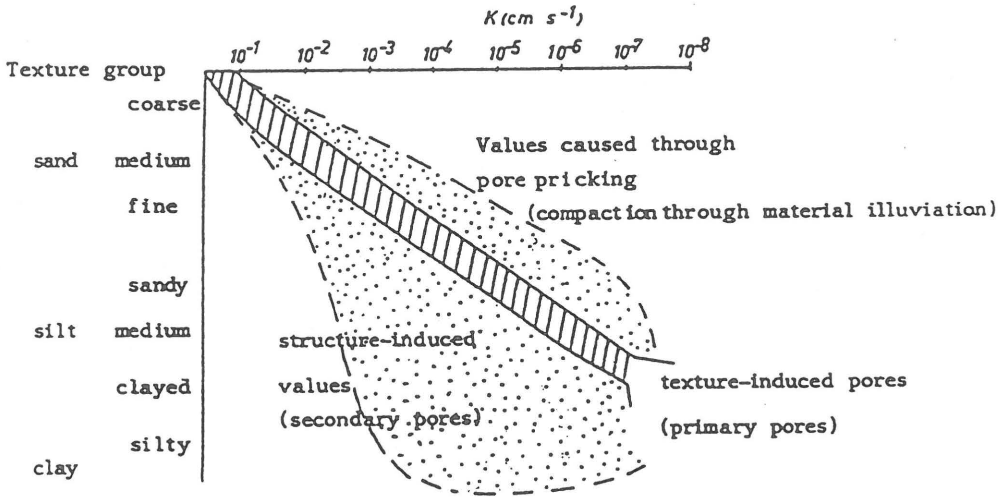

Fig. 4. Variability of K_{sat}-values in soils (according to [11]).

Table 5. Semiquantitative mineralogical composition of the fine earth

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
C1 (40 - 70)	35	23	11	13	18
C2 (70 +)	38	18	20	8	16

soil profile. The decrease of calcite in the C2-horizon may be a consequence of different sedimentation and transport phases.

Clay mineral distribution in the fine earth

Clay minerals play a multiple role in the genesis of soil structure :

a) Their swelling and shrinking behaviour influences the 'secondary' pore system and the bypass flow.

b) Clay-humic complexes stabilize soil structure.

c) The negative layer charge and charge density of clay minerals directly influence the CEC and therefore also the soil structure.

Table 6 shows the clay mineral distribution of the investigated soils. One important fact is the complete absence of expandable minerals of the smectite and vermiculite group, thus explaining the relatively low CEC and reduced swelling and shrinking processes.

Table 6. Semiquantitative clay mineral distribution in the fine earth

Horizon (cm)	Kaolinite	Illite	Vermiculite	Montmorillonite	Chlorite
	(%)				
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	-	-	30	-
Ah (15 - 23)	66	-	-	34	-
AC (23 - 40)	70	-	-	30	-
C1 (40 - 70)	54	-	-	46	-
C2 (70 +)	61	-	-	39	-

Oxides and hydroxides

'Free' Fe-, Al- and Mn-oxides and hydroxides are typical weathering neoformations which are often used for the explanation of soil weathering and genesis processes.

Fe- and Al-oxides increase the structure stability by cementing small-sized particles or by binding negatively charged minerals through electrostatical forces. In fact, it is still difficult to quantify this function of 'free' oxides.

The amounts of oxides in the investigated soils are shown in Table 7. There is a typical vertical distribution in both soils. The climatic influence on soil genesis is very evident, where the Fe-contents of the Chernozem are much lower than in the Cambisol.

Micromorphological data

Soil thin sections allow to classify different microstructure types and pedogenetical processes. The upper horizons of the investigated soils were analysed, as shown in Figs 5-7.

Table 7. Dithionite- (d), oxalate- (o) and pyrophosphate- (p) soluble contents of Fe, Al and Mn fine earth

Horizon (cm)	Fe_d	Fe_o	Fe_p	Al_d	Al_o	Al_p	Mn_d	Mn_o	Mn_p
	(mg/kg)								
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
C1 (40 - 70)	3090	531	109	252	296	82	92	56	14
C2 (70 +)	2945	449	150	186	236	54	95	57	17

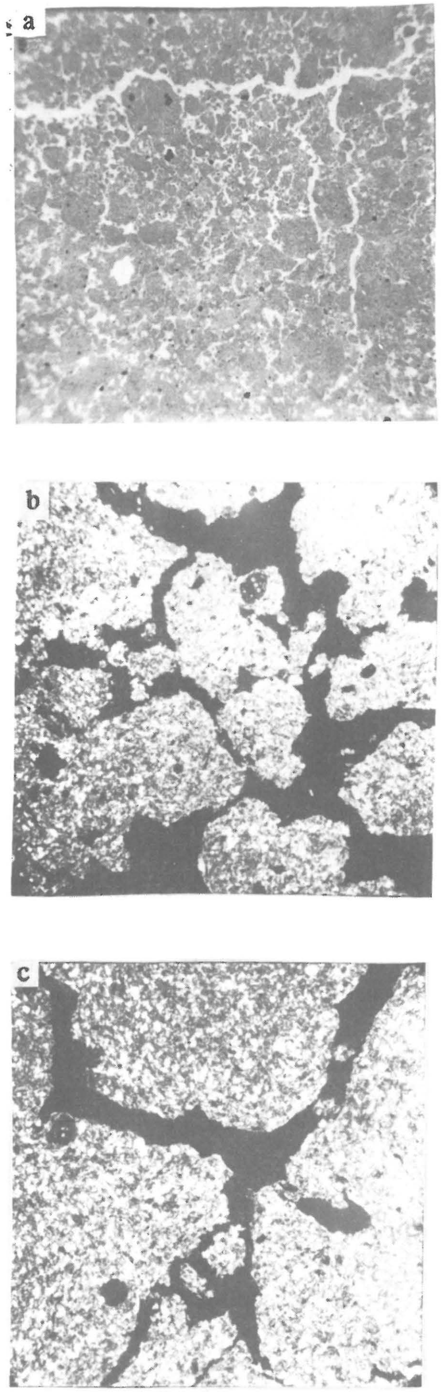

Fig. 5. Soil thin section of the Cambisol: a - Ap-horizon, 0-20 cm, 3.3 x magnification, PPL; b - Ap-horizon, 0-20 cm, 30 x magnification, XPL; c - Ap-horizon, 0-20 cm, 30 x magnification, XPL.

Cambisol

Ap-horizon (0-20 cm)

Microstructure

Subangular blocky (to prismatic) structure. 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 voids give the structure a slightly-prismatic appearance. Peds are fully or partially accomodated (Fig. 5a).

Coarse minerals

Quartz, micas, few felspars, some chlorites and opaque minerals.

Fine material

The fine material consists of speckled and dotted clay with fine micaceous silt and iron oxides. The fine material shows some parallel orientation of micaceous particles. C/f ratio limit 10 μm 70:30. Complex C/f related distribution: open porphyric (Figs 5b and 5c).

Pedofeatures

Brown speckled and moderately impregnated typical iron nodules (Figs 5b and 5c) are randomly distributed. Newly formed calcites are present.

Chernozem

AB-horizon (20-40 cm)

Microstructure

Intergrain channel structure (Fig. 6a). 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 elongated, usually smoothed walls. Few chambers.

Coarse minerals

Quartz, micas, few felspars, calcite, some amphiboles and chlorite.

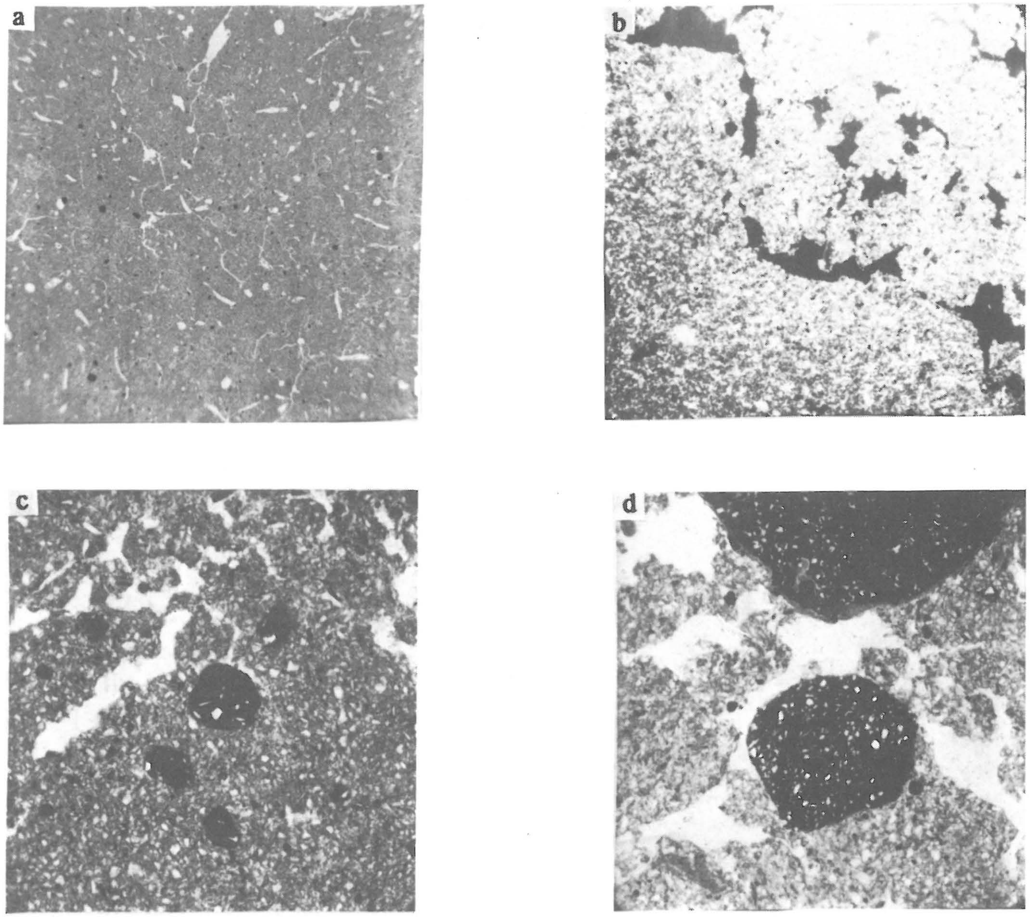

Fig. 6. Soil thin section of the Cambisol a - AB-horizon, 20-40 cm, 3.3 x magnification, PPL; b - AB-horizon, 20-40 cm, 30 x magnification, XPL; c - AB-horizon, 20-40 cm, 48 x magnification, PPL; d - AB-horizon, 20-40 cm, 48 x magnification, PPL.

The fine material consists of speckled and dotted clay with fine micaceous silt and iron oxides. The fine material shows some signs of poro-striated pattern. C/f ratio limit 10 μm 70:30. Complex C/f related distribution: open porphyric related distribution (Fig. 6b).

Pedofeatures

Brown speckled iron nodules randomly distributed and many moderately impregnated typical nodules are very often present (Figs 6c and 6d).

Chernozem

Ap-horizon (0-15 cm)

Microstructure

Crumb structure. Fully separated aggregates with much pore space. The interior of small aggregates is composed by granules which contain simple packing voids (Fig. 7a). 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 (see Fig. 7b).

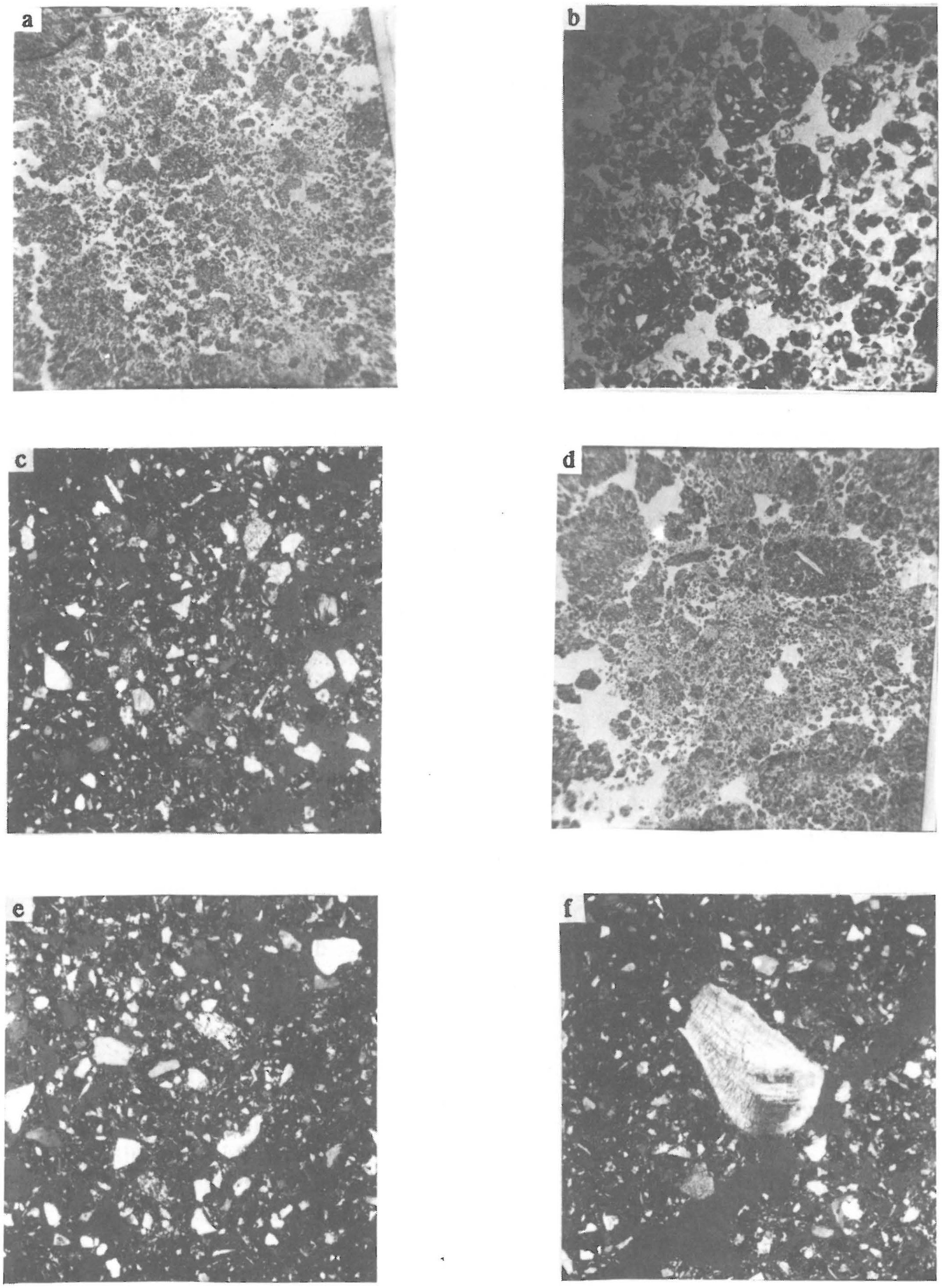

Fig. 7. Soil thin section of the Chernozem a - Ap- horizon, 0-15 cm, 3.3 x magnification, PPL; b - Ap-horizon, 0-15 cm, 30 x magnification, PPL; c - Ap-horizon, 0-15 cm, 48 x magnification, XPL; d - Ah-horizon, 15-23 cm, 3.3 x magnification, PPL; e - Ah-horizon, 15-23 cm, 48 x magnification, XPL; f - Ah-horizon, 15-23 cm, 48 x magnification, XPL.

Coarse minerals

Quartz, felspars, micas (biotite, muscovite), clastogene calcite, rock fragments, chlorite, rutile and some accessories.

Clay-humus fine material with undifferentiated b-fabric masked by humus, which corresponds to the asepic fabric of Brewer [4]. Strong features of crystallitic b-fabric are due to the presence of small birefringent crystallites of newly formed (micritic) calcite (Fig. 7c).

Pedofeatures

Calcitic nodules and aggregates. Admixtures of partly decomposed organic matter and humified plant residues (charcoal).

Note: This is a typical Calcaric Chernozem, but developed on terrace material or alluvial sediments and not on typical loess. The coarse (sandy) material is not well sorted, subangular to angular with rock fragments.

Chernozem

Ah-horizon (15-23 cm)

Microstructure

Crumb structure. 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 (Fig. 7d).

Coarse minerals

Quartz, felspars, micas (biotite, muscovite), clastogene calcite, rock fragments, shell fragments (Fig. 7e).

Fine material

Clay-humus ground mass with some silty micaceous particles and with micritic calcite. Undifferentiated b-fabric for clay-humus complexes but in whole strong features of crystallitic b-fabric because of the presence of micritic calcites.

Pedofeatures

Calcitic nodules, aggregates (Fig. 7f).

CONCLUSIONS

Considering soil structure as a dynamic status which is influenced by different soil parameters, chemical, physical, mineralogical, and micromorphological investigations were carried out on two typical soils of Lower Austria.

The alkaline pH, the low electrical conductivity and the high calcium saturation are favourable parameters for the structure of both investigated soils, whereas the humus content is rather low so that a high structural stability cannot be expected. The Cambisol is free of carbonates in the top horizons, as a consequence of weathering processes.

The particle size distribution allows a clear distinction between the loamy-textured Cambisol and the light sandy Chernozem. The mechanical soil compaction under the ploughed layer is visible from the bulk density and total porosity. The storage of available soil water is favourable for plant roots in the Cambisol, but because of the low air capacity, oxygen diffusion can be handicapped under very wet conditions. The contrary is true for the Chernozem, where soil aeration is guaranteed, but little water can be availably stored in dry periods. Moreover, the mechanical tillage compaction destroyes mainly the 'secondary' pore system.

From the hydraulic viewpoint, both investigated soils are permeable when saturated. The K_{sat}-values reflect the presence of secondary pore systems very well.

The mineralogical composition of the soils is not favourable for soil structure stability because of the total absence of expandable clay minerals and low Fe-oxide amounts.

The micromorphological thin section analysis shows typical structure types such as prismatic, subangular structure in the loamy Cambisol and crumby structure in the Chernozem.

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