Acta Geodyn. Geomater., Vol. 3, No. 4 (144), 33-39, 2006

ENVIRONMENTAL RECORD IN SOILS ON LOESS IN NORTHERN MORAVIA, CZECH REPUBLIC

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(*Received* October 2006, *accepted* November 2006)

ABSTRACT
The evolution of soil cover in the area of Litovel has been determined on the basis of grain-size distribution, mineralogy of clay fraction, chemical and micromorphological analyses. The object of the present study was a chronosequence of soils in Pleistocene sediments. Paleopedological data indicate that the area underwent environmental changes including several cycles of pedogenesis. This area provides evidence of at least two first-order warm periods. The highest degree of polygenesis can be demonstrated by Braunlehm-like Parabraunerde (PK V – Late Holstein Interglacial) and Chernozem which evolved from Haplic Luvisols (PK IV – warm period within the Riss glacial). The upper part of the profile documents different types of pedosediments which indicate erosion processes.

KEYWORDS: evolution of soil cover, micromorphological analysis, clay mineralogy, pedogenesis

INTRODUCTION

The record of soil memory is a result of pedogenic processes. It helps to understand environmental changes. The main types of soil memory were described by Targulian and Goryachkin (2004). Soil chronosequences permit to decipher soil evolution and erosion. Natural and anthropogenic processes of erosion induce transport of soil material and pedosediment formation. Only some classification systems of soils treat the problem of pedosediments (e.g. Wittmann, 1998, Němeček et al., 2001) but the understanding of the term varies widely.

The most important investigation of paleosols in the territory of Czech Republic was carried out by Smolíková (e.g., 1972a). All previous research was, however, focused on southern Moravia. A very limited attention has been paid to paleosols in northern Moravia, and this paper is the first to determine the principles of soil distribution and to discuss the evolution of soil cover in northern Moravia, Czech Republic. Its results have a considerable importance, value, and impact for the understanding of soil development on loess in other parts of the Czech Republic, especially the environs of Prague.

MATERIAL AND METHODS

The study locality is situated in northnen Moravia in a former brickyard approximately 2.5 km south of Litovel, 240 m above sea level. The locality lies in a warm temperate area with mean annual temperatures of 8 to 9 ^{o}C and mean annual precipitation of 550 to 600 mm (Syrový, 1958).

The total length of the documented exposure is 100 m. Soil cover is developed on Pleistocene sediments. The most widespread parent material in the Litovel area is loess. In other parts of this area, soils are formed on alluvial-plain deposits and sand and gravel terraces. Individual soil horizons, pedosediments and parent materials were examined on the basis of macromorphological description up to the level of artificial terraces. The recent soil on the surface these terraces is Luvic Chernozem on loess.

The soils were generally classified according to World Reference Base for Soil Resources - WRB (following Driessen et al., 2001), down to the level of soil subtype, where possible. Where the studied soil body did not correspond to any soil unit of this classification, the terminology of Smolíková (1984) was utilized. Horizon fA is preserved only partly, which means that no detailed designation can be made. Some layers of the profile are formed by redeposited soil material. This material is herein referred to as pedosediments, and the following nomenclature was adopted to fit their specific character. Ma is the designation for pedosediments having the character of pellet sands, described in detail by Kukla (1961). Mb is used for pedosediments of a different character in the sense of Kubiëna (1956). Pedosediments (Mb) are further designated I, II and III as a qualitative differentiation of their origin.

Descriptions of macromorphological and chemical properties and grain-size distribution of the individual horizons follow Catt (1990). Undisturbed samples for micromorphological analyses were studied under petrographic microscope and described

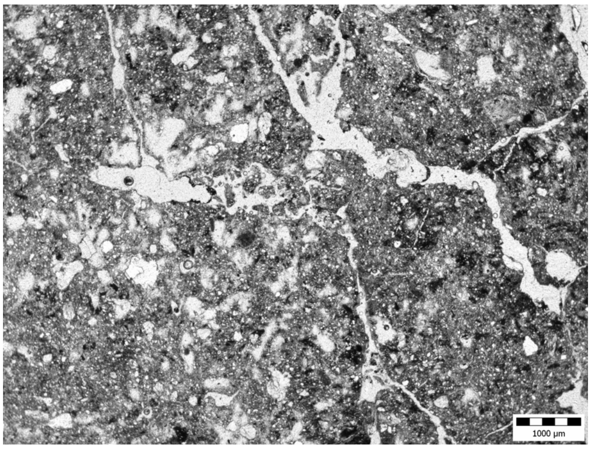

Fig. 1 638-661 cm – fBvt$_2$. Matrix consists of flocculated and peptized plasma with partial braunlehm plasma and braunlehm nodules.

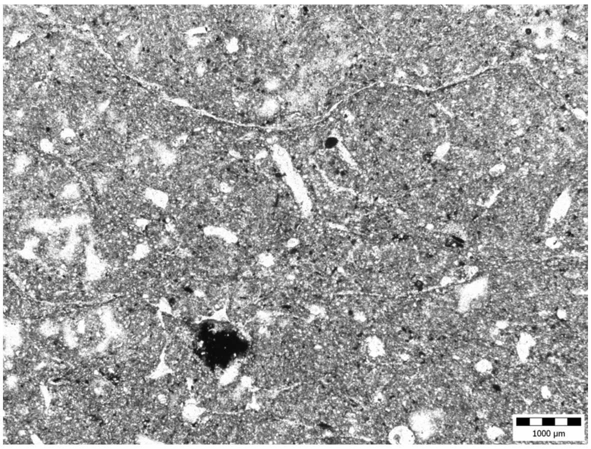

Fig. 2 529-547 cm – fBt$_3$. Flocculated matrix with partial braunlehm plasma lines some parts of channelways and braunlehm nodules.

using the nomenclature of Smolíková (1972c). A more recent nomenclature of Stoops (2003) was found to be rather applicable for recent soils.

The identification of minerals in clay fraction employed samples (<0.001 mm) separated by sedimentation from a dense suspension in distilled water, mounted on oriented slides (Jackson, 1979). All studied samples were analysed by X-ray diffraction, using the Philips PW 3710 diffractometer under the following working condition: CuKα radiation, 40 kV, 55 mA, goniometric shift 1°·min^{-1} 2Θ. The specimens were studied first air-dry , and then saturated in ethylene glycol at 80 °C for four hours and heating in a muffle furnace at 550 °C for four hours. Semiquantitative values were calculated from individual mineral basal peaks.

The latest version of chronology of the paleosol development in loess layers in central Europe was published by Němeček et al. (1990). This publication was used as a guideline for the herein presented chronostratigraphy of soil development.

RESULTS AND DISCUSION

MICROMORPHOLOGY

Results of micromorphological investigations were used for the qualitative evaluation of grain- size distribution and $CaCO_3$ content, and the genesis and stratigraphy of soil cover. The descriptions below refer to individual samples characteristic for the given horizons.

695–740 cm – C. Groundmass predominantly consists of primary components: quartz, plagioclase, muscovite, orthoclase, quartzite and other components.

661–695 cm – fBvt$_3$. Matrix is formed by flocculated and peptized plasma with high proportion of partial braunlehm plasma and frequent braunlehm nodules. Some plasmatic parts are "packed" into secondary aggregates. "Manganolimonite" coatings are sporadic. Amorphous forms of $CaCO_3$ are rare in the channelways. Microskeleton composition is: quartz, weathered amphibole, baueritized biotite, plagioclase, chlorite, muscovite, glauconite, microcline, pyroxene. quartzite and others.

638–661 cm – fBvt$_2$. It differs from fBvt$_3$ in the stronger tendency of partial braunlehm plasma toward granulation and higher frequency of braunlehm nodules (Figure 1).

602–638 cm – fBvt$_1$. "Manganolimonite" coatings in the channelways are more common than in horizon fBvt$_3$. Other features correspond to previous horizons.

585–602 cm – fABvt$_1$. Groundmass is formed by flocculated and peptized plasma. The partial braunlehm plasma has a tendency to brown earthification. Braunlehm and pseudogley nodules and secondary amorphous forms of $CaCO_3$ are rare. The composition of primary components is analogical with previous horizons.

557–585 cm – fMa$_2$. Weakly humic groundmass concentrates in curved crumbs of various sizes with minute fossil coprogenic elements of enchytraeids (Enchytraeidae), earthworms (Allolobophora), and is markedly disturbed by parallel-arranged fissures. Some parts of free spaces are filled with amorphous form of $CaCO_3$. Large-sized braunlehm nodules are sporadic. Microskeleton composition is: quartz, orthoclase, plagioclase, muscovite, biotite, chlorite and quartzite with plasmatic fillings of cracks.

547–557 cm – fMa$_1$. Except for its higher proportion of coprogenic elements, braunlehm nodules and the occurrence of streaks of "manganolimonite", the characteristics of this horizon are the same as those of fMa$_2$.

529–547 cm – fBt$_3$. Groundmass is flocculated. Partial braunlehm plasma lines some parts of channelways. Braunlehm nodules are numerous. "Manganolimonite" coatings and amorphous $CaCO_3$ are rare. Microskeleton composition is: quartz, orthoclase, plagioclase, muscovite, chlorite, biotite, pyroxene, amphibole, muscovite and glauconite (Figure 2).

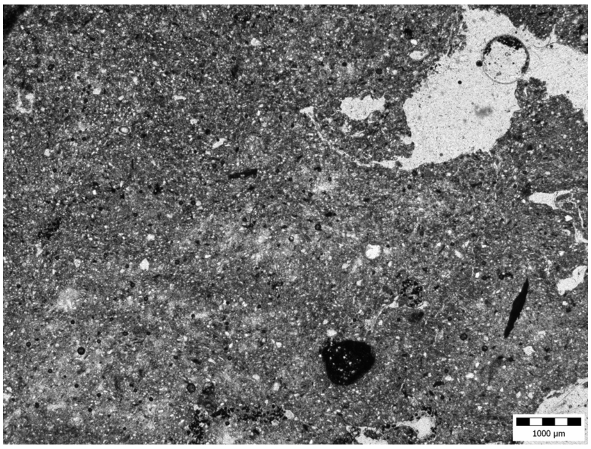

Fig. 3 412-439 cm – Ck_1. Slightly disturbed matrix by parallel-arranged fissures and a redeposited braunlehm nodule.

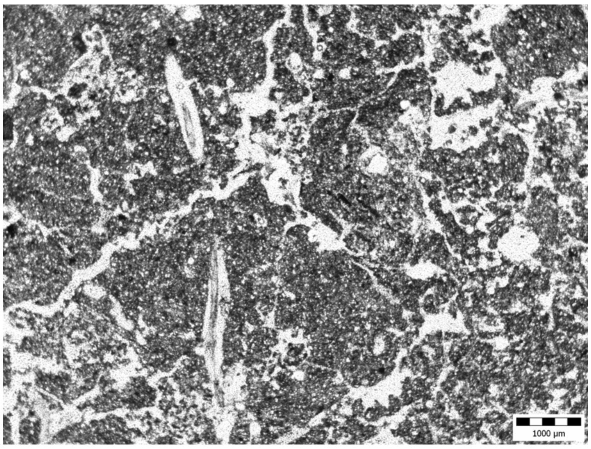

Fig. 4 0-43 cm – Mbk. Crumbs of various sizes contain humic material, plant remains and coprogenic elements.

500–529 cm – fBt_2. Same as in fBt_3 but groundmass is disturbed by parallel-arranged fissures in some parts.

477–500 cm – fBt_1. Same as in fBt_3 except for the lesser amount of "manganolimonite" coatings.

469–477 cm – fA. Humic flocculated matrix contains abundant coprogenic elements, mostly earthworms, remains of carbonized plants, opal phytoliths, minute amount of amorphous forms of $CaCO_3$, calcite rhombohedra and "manganolimonite" streaks. The channelways are locally lined with braunlehm partial plasma. Primary components are dominated by quartz, orthoclase, plagioclase, muscovite, biotite, chlorite, glauconite etc.

464–469 cm – Ck_3. Matrix is slightly disturbed by parallel-arranged fissures. Secondary $CaCO_3$ is represented by amorphous forms, calcite rhombohedra and needles. The amount of humic material, opal phytoliths, braunlehm nodules and "manganolimonite" coatings is minute. Microskeleton consists predominantly of quartz, plagioclase, biotite, muscovite and chlorite.

439–464 cm – Ck_2. Matrix as distinct from Ck_3 consists of fragments of molluscan shells and higher amount of calcite rhombohedra.

412–439 cm – Ck_1. A dominant component of groundmass is the microskeleton. Individual features are the same as in Ck_3 (Figure 3).

392–412 cm – $IfMbk_3$. Soil matrix forms curved crumbs of various sizes disturbed by parallel-arranged fissures. These crumbs consist of humic material, different coprogenic elements, braunlehm partial plasma, plant remains, and amorphous forms of $CaCO_3$ and calcite rhombohedra. The composition of primary components is: quartz, orthoclase, plagioclase, muscovite, biotite, chlorite and glauconite.

384–392 cm – $IfMbk_2$. Compared to Mbk_3, soil matrix contains fewer humic components, while amorphous forms of $CaCO_3$ and calcite rhombohedra are numerous.

361–384 cm – $IfMbk_1$. As distinct from Mbk_3 and Mbk_2, this horizon contains fragments of decayed roots with droppings of mites (Acari).

326–361 cm – Ck. Matrix is characterized by parallel-arranged fissures. All forms of secondary $CaCO_3$ are present. Fragments of molluscan concholites are few. Curved crumbs are sporadic and consist of humic material, different coprogenic elements and partial braunlehm plasma. The dominant component of matrix is the microskeleton of this composition: quartz, biotite, muscovite, chlorite, glauconite and fragments of limestone.

309–326 cm – $IIfMbk_2$. Matrix is disturbed by parallel-arranged fissures in some parts. Some voids are filled with calcite rhombohedra or amorphous forms of $CaCO_3$. Remains of carbonized wood, droppings of mites, coprogenic elements of enchytraeids and earthworms are present. Microskeleton is dominated by quartz, biotite, muscovite, chlorite, glauconite, plagioclase, orthoclase, amphibole and augite.

303–309 cm - $IIfMbk_1$. Matrix has a lower proportion of humic components, calcite rhombohedra or amorphous forms of $CaCO_3$. The proportion of primary components is lower than in $IIfMbk_2$. Other characteristics are identical.

75–303 cm – Ck_2. Matrix contains numerous voids, often filled with all forms of secondary $CaCO_3$. Microskeleton composition is: quartz, biotite, muscovite, chlorite, glauconite and fragments of limestone.

43–75 cm – Ck_1. A part of groundmass consists of humic components with fewer amounts of secondary forms $CaCO_3$ than the previous horizon. "Manganolite" knots occur in some supply channels and matrix. Other characteristics are identical with those of Ck_2.

0–43 cm – Mbk. Soil matrix consist of crumbs of various sizes which contain humic material, remains of plants, sporadic excrements of enchytraeids and earthworms, braunlehm partial plasma, redeposited

Table 1 Analytical characteristics of the Litovel profile

Depth	Horizon	$CaCO_3$	pH_{H_2O}	<0.001mm	0.001-0.01mm	<0.01mm	0.01-0.05 mm	0.05-0.25 mm	0.25-2.00 mm
cm		%		%	%	%	%	%	%
695-740	C	<0.1	7.63	10.8	15.6	26.4	14.8	26.0	32.8
661-695	$fBvt_3$	<0.1	7.55	31.9	13.9	45.8	38.4	12.7	3.2
638-661	$fBvt_2$	<0.1	7.70	33.4	17.4	50.8	36.9	10.6	1.6
602-638	$fBvt_1$	<0.1	7.71	27.9	21.5	49.0	41.6	7.7	1.6
585-602	$fABvt_1$	<0.1	7.97	22.8	17.7	40.5	49.2	6.8	3.5
557-585	fMa_2	<0.1	7.87	10.4	17.8	28.2	56.4	12.6	2.2
547-557	fMa_1	<0.1	7.81	17.5	17.8	35.3	52.3	11.4	1.1
529-547	fBt_3	<0.1	7.92	22.8	19.4	42.2	49.6	7.5	0.7
500-529	fBt_2	<0.1	7.89	22.0	18.9	40.9	29.8	28.7	0.5
477-500	fBt_1	<0.1	7.88	20.9	18.5	39.4	50.4	9.7	0.4
469-477	fA	0.3	7.99	14.5	32.6	47.1	45.5	6.7	0.7
464-469	Ck_3	3.2	8.11	21.1	18.1	39.2	50.8	9.7	0.3
439-464	Ck_2	3.6	8.20	22.5	20.8	42.8	55.1	1.8	0.2
412-439	Ck_1	3.2	8.19	19.6	25.9	45.5	47.6	6.4	0.5
392-412	$IfMbk_3$	0.5	7.92	28.0	26.1	40.8	49.6	9.3	0.3
384-392	$IfMbk_2$	4.0	8.09	21.6	13.3	34.9	55.0	9.8	0.3
361-384	$IfMbk_1$	2.2	7.80	23.7	12.8	36.5	56.9	6.2	0.4
326-361	Ck	6.4	7.96	18.8	12.9	31.7	55.4	12.6	0.3
309-326	$IIfMbk_2$	5.2	7.48	18.4	15.5	33.9	46.8	18.8	0.4
303-309	$IIfMbk_1$	3.6	6.94	15.1	19.6	34.7	28.4	36.3	0.6
75-303	Ck_2	8.2	8.08	16.7	14.0	30.7	54.7	14.4	0.2
43-75	Ck_1	4.5	7.75	18.4	14.7	33.1	57.1	9.4	0.4
0-43	IIIMbk	0.4	7.22	22.0	17.9	39.9	53.9	5.9	0.4

braunlehm nodules, amorphous forms of $CaCO_3$ and calcite rhombohedra. The composition of primary components is: quartz, muscovite, biotite, orthoclase, plagioclase, chlorite, pyroxene, amphibole and glauconite (Figure 4).

pH AND $CaCO_3$

These values are only approximate in their character because the buried soils of the loess sequences are subjected to alteration due to diagenetic processes after their burial. The values of pH correspond with the content of $CaCO_3$ (Table 1), and are predominantly neutral. Higher pH is characteristic for the upper part of the profile. The character of parent material plays a significant role in the occurrence and amount of $CaCO_3$. The highest content of $CaCO_3$ in the profile corresponds to Ck horizons. The fA horizon shows an increased amount of carbonates. This horizon was buried by redeposited loess, which is reflected in the content of $CaCO_3$. As revealed by micromorphological research, all types of secondary carbonates are represented only in the Ck horizons. The amount and character of secondary forms of carbonate in pedosediments depend on their composition.

GRAIN-SIZE DISTRIBUTION

The grain-size distribution (Table 1) is a function of parent material and pedogenic processes. Particle size analyses indicate that the development of different parts of the profile is probably a result of different types of erosion. Quantitative composition of pedosediments has a different character. The stage of soil development at a depth of 477–547 cm and 585–695 cm, as shown by the distribution of fraction <0.001 mm, is indicative of the processes of argilluviation.

MINERALOGY OF THE CLAY FRACTION

From the viewpoint of soil genesis, a high significance is given to the compositional changes of clay fraction within the soil profile. The distribution of individual minerals in the soil profile is shown in Figure 5.

Horizon C (695–740 cm) contains a high proportion of illite, quartz and a small amount of plagioclase, kaolinite and cacoxenite.

The fBvt horizons with the oldest stage of soil development (585–695 cm) are mainly composed of illite and quartz whereas other minerals are minor (chlorite) or missing (feldspars). Furthermore, gypsum was identified as a secondary mineral.

Series of pedosediments in the fMa horizon (547–585 cm) are characterized by the predominance of quartz and plagioclase.

An elevated proportion of clay minerals with dominant illite were observed in horizon fBt (477–547 cm). This horizon also shows a decreasing feldspar content, which correlates with increasing kaolinite content, both being an indicator of the higher weathering grade. A relatively high proportion of smectite is typical for horizon Bt (Sirový, 1966).

The above outlined horizon fA (469–477 cm) proves two remarkable parameters – the lowest illite content in the whole profile, and an elevated quartz content.

Horizon Ck above (412–469 cm) contains higher proportions of quartz and illite, all indicating rather redeposited loess.

Series of pedosediments in horizon IfMbk (361-412 cm) are dominated by illite.

Horizon Ck (326–361 cm) corresponds to redeposited loess with a high proportion of illite and quartz.

Horizon IIfMbk (303–326 cm) is characterized by a high proportion of kaolinite, a product of feldspar alteration. Totally altered feldspars were not detected. An elevated weathering intensity is evidenced also by very high contents of smectites.

Horizon Ck (43–303 cm) most probably represents redeposited loess, as indicated by the content of illite. Kaolinite is totally missing but chlorite reaches the highest content compared to other horizons.

The uppermost horizon IIIMbk (0–43 cm) has the character of pedosediment equal to that in horizon IfMbk (361–412 cm).

As suggested by the mineral composition, the soils are derived from loess. The types of pedogenesis on loess were described by Sirový (1973).

The absence of carbonate in some horizons indicates specific conditions of pedogenesis.

The variation in the composition of clay minerals between the individual horizons results from of several factors, such as variations in source-rock mineralogy during and after the weathering process, or the type of pedogenesis. Lower chlorite contents correlate with elevated weathering intensity. Nevertheless, chlorite contents also show negative correlation with grain-size distribution.

Mineral composition of the individual horizons of the profile corresponds with the type of pedogenesis and results of micromorphological analysis.

STAGES OF SOIL EVOLUTION

The preservation of soils in the most characteristic part of the profile allows determining soil types and individual stages of soil development. The oldest stage of soil development (585–695 cm) corresponds to Braunlehm-like Parabraunerde. This paleosol has a high degree of polygenesis and develops on forested land under warm and humid climate. It was followed by slight brown earthification (partial braunlehm plasma has a stronger tendency toward granulation) due to moisture changes, particularly dry conditions. After the granulation, the subsequent more humid oscillation was terminated by a slight pseudogleyization ("manganolimonite" coatings) of the soil. The final stage of pedogenesis was completed by a slight recalcification (amorphous forms of $CaCO_3$). Then, in consequence of rainwash sedimentation, the territory was covered by pedosediments fMa (547–585 cm) having the character of pellet sands. In this period, eolian and solifluction activity rhythmically alternated. Horizon fBt is a preserved Haplic Luvisol (477–547 cm). The development of this soil proceeded under forest steppe conditions. In the next stage of development, the soil was affected by a slight pseudogleyization, followed by cryogenic disturbation (parallel-arranged fissures) and finally recalcification. The trend in the soil cover evolution was changed after the accession of steppe vegetation. Horizon fBt gave rise to horizon fA of Chernozem (469–477 cm) but preserved some features of the previous stage (braunlehm partial plasma). Horizon Ck (412–469 cm) has probably the character of redeposited loess (braunlehm nodules). Fossil pedosediments of IfMbk (361–412 cm) are composed of material of Luvic Chernozems (coprogenic elements and partial braunlehm plasma). These sediments correspond to erosion of soil cover. Horizon Ck (326–361 cm) consists of redeposited loess with small relics of pedosediments (humic material and partial braunlehm plasma). In the next stage, the locality was covered by pedosediments of IIfMbk (303–326 cm) with a high proportion of humic material. The character of these pedosediments probably corresponds to redeposited A horizon of Chernozems. The above lying parts of the profile (43–303 cm) are composed of loess. The topmost horizon IIIMbk (0–43 cm) is formed by pedosediments of Luvic Chernozems (crumbs containing humic material, coprogenic elements and braunlehm partial plasma).

Soil development on loess is characterized by high illite contents of 55–75 % (Kalm et al., 1996), but sometimes also about 20 % of illite (Šťastný, 1997). Illite contents in the individual horizons of the studied profile are highly variable. This variability results from climatic variations in the past, namely an alternation of arid and humid climatic periods.

CONCLUSION

This is probably the first time that paleopedological data on the evolution of soil cover were obtained from northern Moravia, Czech Republic. Grain-size distribution, mineralogy of clay fraction, chemical and micromorphogical analyses indicate that this area underwent environmental history in which several cycles can be distinguished. The oldest cycle of soil formation can be related to Braunlehm-like Parabraunerde with high degree of polygenesis. Based on micromorphologicagal studies, this paleosol can be probably paralleled with PK V from Late Holstein Interglacial. Later, at the beginning of the glacial, the area was covered by pedosediments having the character of pellet sands. The next stage of soil development is represented by Haplic Luvisol and Chernozem horizon fA which evolved from the underlying horizon fBt. By analogy it can be expected that these two paleosols correspond to PK IV from the warm period within the Riss glacial. Small thickness of horizon fA is probably a result of erosion. The next period is characterized by increasing intensity of erosion processes and by several hiatuses. For this reason chronostratigraphy cannot be used for the evaluation of the overlying part of the profile. The paleosols of PK IV were covered by redeposited loess which is overlain by fossil pedosediments from the material of Luvic Chernozem. Fossil pedosediments IfMbk probably come from PK II (Stillfried A) because this soil complex does not occur in an autochtonous position at many localities (cf. Smolíková, 1972b). In the next stage, the redeposited loess was covered by fossil pedosediments of IIfMbk. The character of these pedosediments probably corresponds to the redeposited horizon A of Chernozem. Horizon IIIMbk (0–43 cm) of pedosediments of Luvic Chernozems above loess may be a product of the formation of artificial terraces.

ACKNOWLEDGMENT

The contribution was supported by project A300130504 of the Grant Agency AS CR and performed within Research Plan AV0Z30130516 and Research Plan AV0Z30460519. My great thanks are due to Prof. RNDr. L. Smolíková, DrSc. from the Faculty of Science, Charles University in Prague, for consulting the issues of micromorphological studies.

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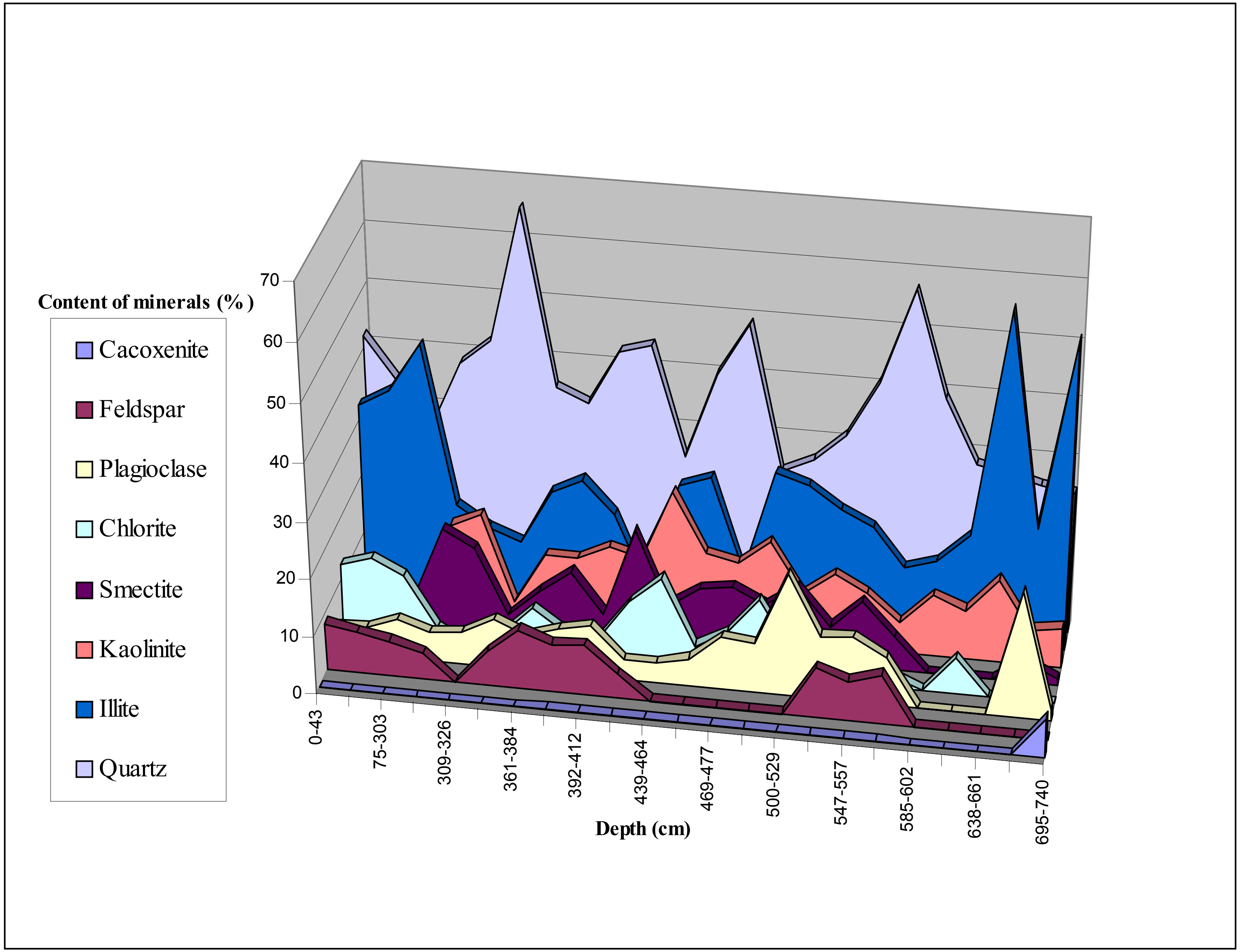

Fig. 5 Mineralogy of the clay fraction.