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Mineralogy and geochemistry of loesses in southern Moravia

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Abstract. Attention is paid to mineralogy and geochemistry of loesses at selected localities in southern Moravia (Czech Republic). Evaluation of samples taken from stratigraphically fixed horizons allowed to compare loess covers of different age, to draw some conclusions concerning source areas of loess, wind direction and character of weathering. Based on the studies and evaluation of "oxidizing degrees" some conclusions could be drawn on palaeoclimatic conditions during loess sedimentation, in particular with regard to inland glaciations of North European lowland.

Abstrakt. Práce se zabývá mineralogií a geochemií spraší na vybraných lokalitách jižní Moravy (Česká republika). Vyhodnocení vzorků, odebraných ze stratigraficky definovaných horizontů, umožnilo porovnání sprašových poloh různého stáří a stanovení některých závěrů o zdrojových oblastech spraší, směru větru a charakteru zvětrávání. Studium a zhodnocení „oxidačního stupně" ukázalo na paleoklimatické podmínky během sedimentace spraší, zejména ve vztahu k zalednění severoevropské nížiny.

Key words: Quaternary, loess, mineral composition, chemical composition, geochemical profile, eolian sedimentation, palaeoclimate, Quaternary of Moravian basins

Introduction

The paper presents the results of mineralogical and geochemical study of loesses in the extraglacial area of southern Moravia and is linked to the geochemical study of loesses carried out in 1995–1996 (Adamová and Havlíček 1997). The area studied is situated in the southern foreland of North European inland glaciations, which penetrated through the Moravian Gate to the main European watershed.

The study area involves the territory of southern Moravia with the cities of Znojmo, Brno and Břeclav and is characterized by stratigraphically and palaeogeographically significant aeolian sediments, frequently overlying river terraces. In the loess series, numerous palaeosols, representing significant stratigraphic markers and palaeoclimatic indicators are developed. While most papers treated stratigraphical problems, little attention was paid to the geochemistry of aeolian sediments. Now, the geochemical investigation has brought some data which not only complement the data hitherto acquired (transport direction of aeolian sediments, distance of source areas, etc.) but provide new data on the palaeoclimate of the Pleistocene period and data permitting comparison of loess accumulations in Moravia with those in other areas.

Methodology

The samples for geochemical study were taken from the localities of Brno-Červený kopec (CK), Bořetice (BOR), Sedlec near Mikulov (SM), Pavlov (PAV), Dolní Věstonice (DV), Znojmo (ZNO) and Sedlešovice (SED). Geological situation and stratigraphy were taken from papers by Havlíček et al. (1994), Havlíček and Tyráček (1996) and Adamová et al. (1997). The stratigraphic position of loess samples is based on their relation to dated soil complexes (PK in the text below, Ložek 1973, Smolíková in Němeček et al. 1990). As for magnetostratigraphy, most loess sequences were dated to the Brunhes Epoch. The Brunhes-Matuyama boundary (0.78 Ma) was established in strata underlying soil complex PK X (Brno-Červený kopec).

Spot samples (500–700 g) were taken for the study of chemical composition. All analyses were carried out in the laboratories of the Czech Geological Survey in Prague. These included complete silicate analyses, determination of

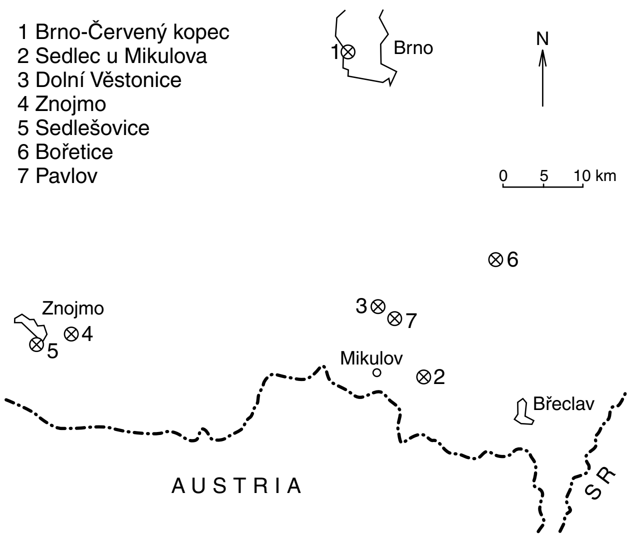
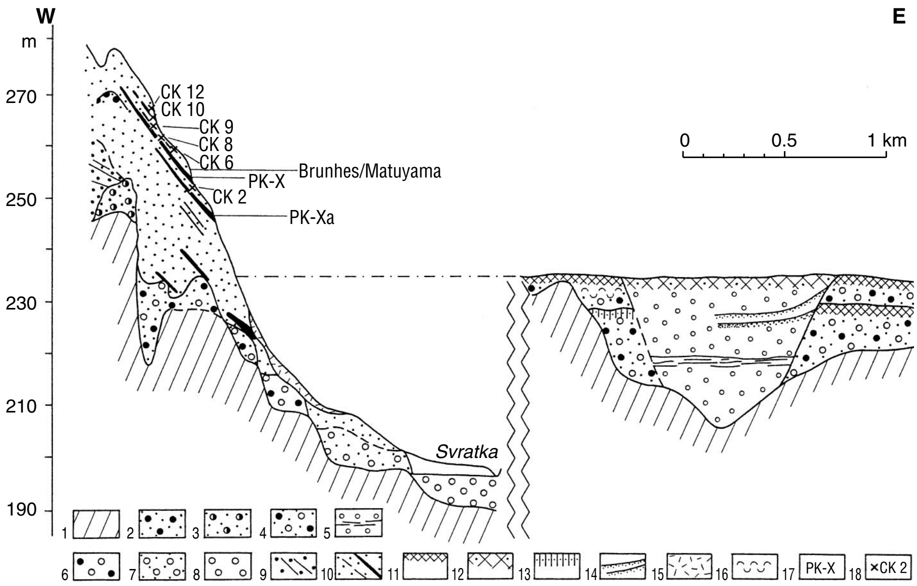


Fig. 1. A sketch of selected loess occurrences in southern Moravia, subjected to mineralogical and geochemical study.



← Fig. 2. Idealized scheme showing the Quaternary deposits at Brno-Červený kopec (Red Hill) in relation to the "Younger gravel sheet" (after Zeman 1979, 1992).
1 – pre-Quaternary rocks; 2 – fluvial terrace with the base at 70 m; 3 – older sand and gravel sheet; 4 – younger sand and gravel sheet (Tuřany terrace); 5 – fluvial sand and gravel deposited after the Brunhes/Matuyama reversal; 6 – fluvial sand and gravel (Middle Pleistocene, Mindel?); 7 – doubled Modřice terrace (Middle Pleistocene, Riss); 8 – fluvial gravel and sand (Upper Pleistocene); 9 – loess loam and paleosols developed before the Jaramillo Event; 10 – loess and fossil soils postdating the Jaramillo Event; 11 – ferreto; 12 – well-developed ferreto; 13 – semiterrestrial paleosol; 14 – well-developed semiterrestrial fossil soils; 15 – colluvial sediments; 16 – cryoturbation; 17 – pedocomplexes (PC); 18 – mineralogical and chemical analyses

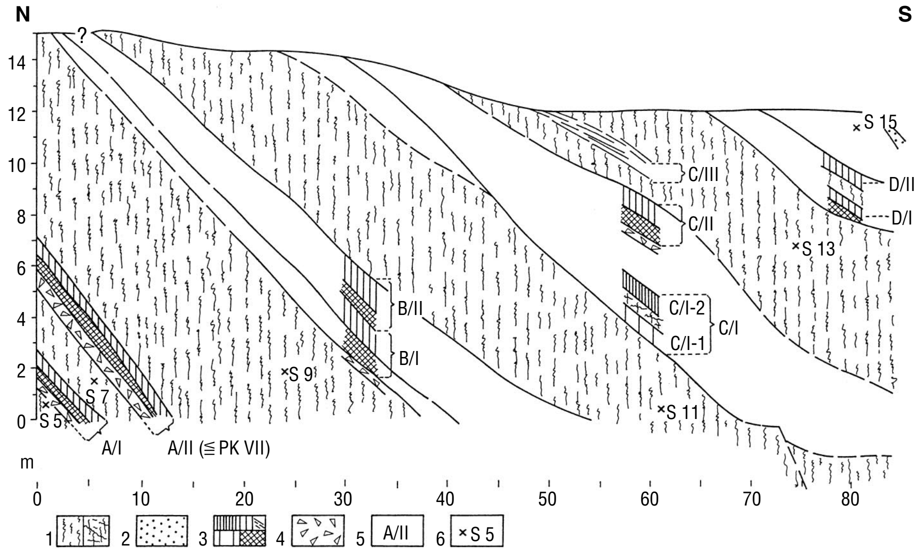


Fig. 3a. Sedlec near Mikulov. Loess sequence in a north-south-trending cut in a vineyard NE of Sedlec.
1 – loess, in places redeposited; 2 – youngest loess; 3 – fossil soil horizons A and B; 4 – carbonate horizons; 5 – pedocomplexes in sections A to D; 6 – mineralogical and chemical analyses

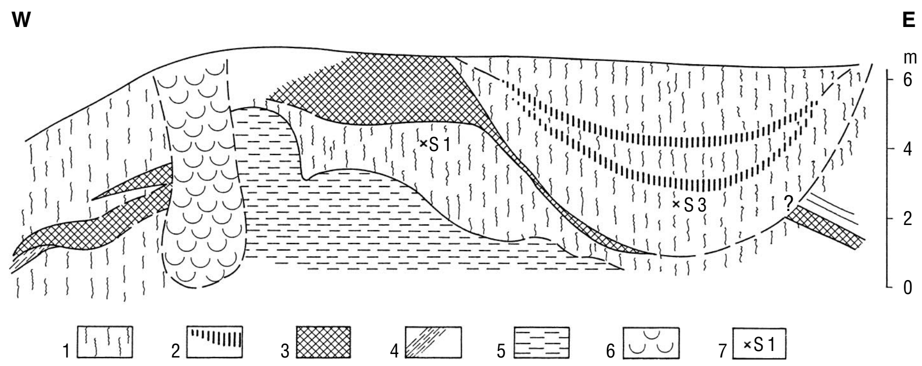


Fig. 3b. Sedlec near Mikulov. A sketch of an east-west-trending cut in a vineyard NE of Sedlec.
1 – loess; 2 – humic, initial soil horizons (Upper Pleistocene); 3 – horizon B of rubified braunlehm; 4 – soil sediments; 5 – greyish-green clays (Badenian); 6 – landslides; 7 – mineralogical and chemical analyses

a standard set of trace elements by X-ray fluorescence spectral analyses – As, Cr, Cu, Nb, Ni, Pb, Rb, Sr, Ti, U, V, Zn, Zr (M. Pelikánová) and optical emission analyses – Ag, B, Be, Bi, Cu, Co, Ga, Mo, Pb, Sn (E. Mrázová). Determination of rare earth elements (REE) was carried out by ICP method (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Y) – Perkin Elmer Plasma II (Emission spectrometer). Mineral compositions of samples were studied by X-ray diffraction phase analysis (X-ray diffractometer X Pert-System Philips – I. Haladová).

Localities and stratigraphical positions of samples

Locality Brno-Červený kopec (CK – see Figs 1, 2)

sample 1 (CK 2) light brown micaceous loess with molluscan fauna and big nodules
sample taken below PK X

sample 2 (CK 6) light brown loess with big fragments of mica, pebbles of red quartz, nodules 5 × 10 cm and molluscan fauna
sample taken above PK X

sample 3 (CK 8) ochreous brown to beige loess
 sample taken close below PK IX
sample 4 (CK 9) ochreous brown loess with abundant quartz detritus and abundant molluscan fauna
 sample taken 2 m above PK IX
sample 5 (CK 10) light ochreous brown strongly calcareous loess
 sample taken from the bed directly underlying PK VIII
sample 6 (CK 12) ochreous brown mica loess
 sample taken above PK VIII

Locality Sedlec near Mikulov (SM – see Fig. 3a, b)

sample 7 (S 1) ochreous brown, probably secondarily decalcified loess
 sample taken below PK VII
sample 8 (S 3) ochreous brown decalcified loess
 Upper Pleistocene
sample 9 (S 5) ochreous brown loess with big nodules
 sample taken below PK VII – Middle Pleistocene
sample 10 (S 7) light brown loess with nodules
 sample taken below PK VII
sample 11 (S 9) light brown, strongly micaceous loess
 sample taken above PK VII
sample 12 (S 11) light brown, probably secondarily decalcified loess
 Middle Pleistocene
sample 13 (S 13) light brown decalcified loess
 Middle Pleistocene
sample 14 (S 15) light brown to brown-ochreous loess with small nodules
 allochthonous position (age ?)

Locality Dolní Věstonice (DV – see Fig. 4a, b – loam pit, section "Calendar of Ages")

sample 15 (V 1) light brown, decalcified loess (carbonate content 0.86% only – mainly dolomite)
 sample taken from parabrownearth in PK III
sample 16 (V 3) light brown, weakly calcified to decalcified loess (1% dolomite)
 sample taken below the cultural layer of Pavlovian – below PK I
sample 17 (V 5) light brown to beige loess
 sample taken above the cultural layer of Pavlovian – above PK I
sample 18 (V 6) whitish beige calcareous loess
 sample taken above PK I
sample 19 (V 7) light brown loess
 sample taken above PK III
sample 20 (V 8) light brown to beige loess with whitish spots
 sample taken below PK III (Middle Pleistocene)
sample 21 (V 9) light brown to beige loess
 sample taken below the Chernozem palaeosol displaced by solifluction
sample 22 (V10) light brown to beige loess, in places with calcareous coatings

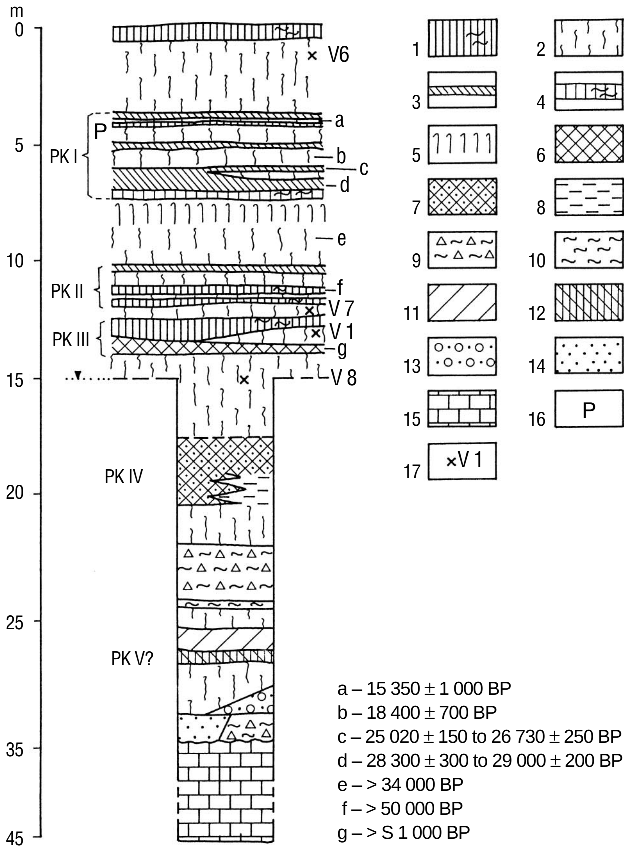
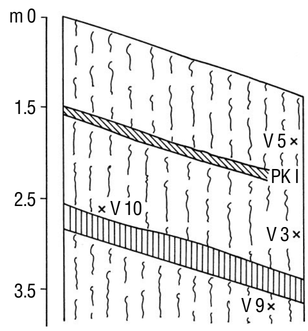


Fig. 4a. Dolní Věstonice, abandoned brickyard, main wall with "Calendar of ages".
1 – A-horizon of humic soil; 2 – loess; 3 – initial fossil soils; 4 – Chernozems; 5 – soliflucted loess; 6 – B_t-horizon of parabrownearth; 7 – gB_t-horizon of soil; 8 – soil sediments; 9 – slope (colluvial) sediments; 10 – clay-dominated slope sediment; 11 – soil sediment with limestone fragments; 12 – brown soil horizon A/B; 13 – fluvial sand and gravel (40 m terrace of the Dyje River); 14 – fluvial sand; 15 – pre-Quaternary basement; 16 – Palaeolithic artifacts; 17 – mineralogical and chemical analyses



→ Fig. 4b. Dolní Věstonice, abandoned brickyard, opposite wall (see Fig. 4a).

 sample taken above the Chernozem of PK II, strongly affected by solifluction

Locality Znojmo (ZNO – see Fig. 5)

sample 24 (ZN 1) ochreous brown, strongly calcareous loess
 sample taken below PK IV (Middle Pleistocene)

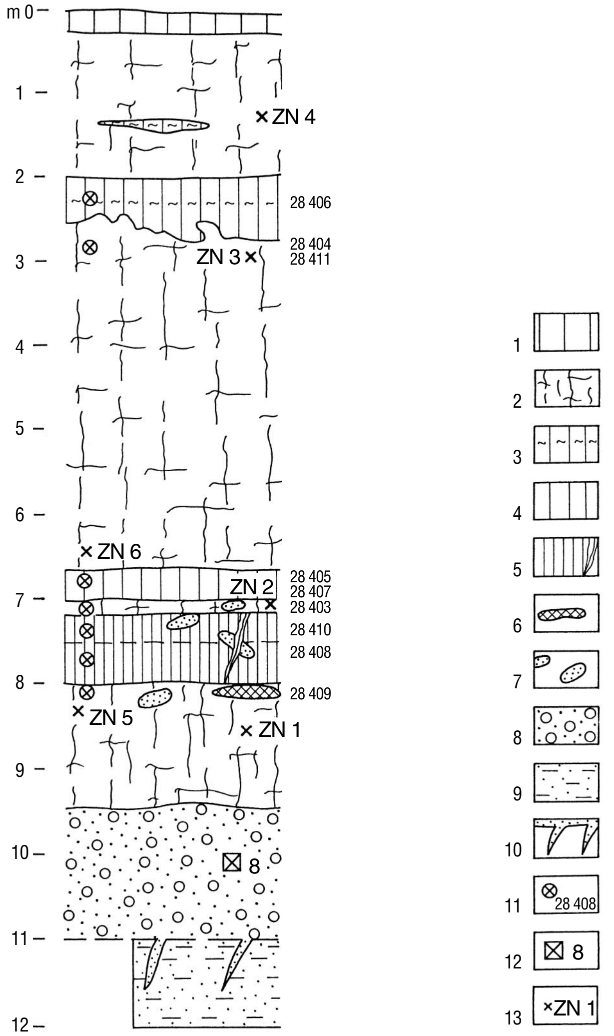


Fig. 5. Znojmo, abandoned brickyard near the crossroads of Znojmo-Brno and Vranov nad Dyjí.
1 – Chernozem of Holocene Age; 2 – loess; 3 – initial soils; 4 – palaeosols; 5 – palaeosols with infiltrations; 6 – Ca-horizon; 7 – mole-chambers; 8 – younger sand and gravel sheet (Lower Pleistocene); 9 – sandy clays (Tertiary?); 10 – infiltrations displaced by solifluction and filled with younger sands; 11 – samples for micromorphological study, numbers of their sections; 12 – analyses of lithology of pebbles; 13 – mineralogical and chemical analyses

sample 25 (ZN 2) ochreous brown, strongly calcareous loess with white coating
sample taken above PK IV
sample 26 (ZN 3) ochreous brown, disintegrated, strongly calcareous loess
sample taken below the youngest loess
sample 27 (ZN 4) light brown loess
sample taken below the youngest loess (? PK I)
sample 28 (ZN 5) ochreous brown, disintegrated sandy loess
sample taken below PK IV (Middle Pleistocene)
sample 29 (ZN 6) brown calcareous loess
sample taken above two A-horizons, over PK IV

Locality Sedlešovice (SED – see Fig. 6)

sample 30 (SE 2) ochreous brown loess
Upper Pleistocene
sample 31 (SE 1) ochreous brown, weakly calcareous loess
Middle Pleistocene

Locality Bořetice (BOR – see Fig. 7)

sample 32 (B 2) light yellow ochreous loess
sample taken below the oldest palaeosol PK VII
sample 33 (B 3) light brown to beige loess (finer in comparison with sample 32)
sample taken above PK IV (Middle Pleistocene)
sample 34 (B 4) light brown loess
Upper Pleistocene

Locality Pavlov (PAV – see Fig. 8)

sample 35 (P 1) yellowish brown, strongly calcareous sandy loess
sample taken below the palaeosol, Upper Pleistocene
sample 36 (P 2) greyish brown loess
sample taken above the palaeosol, Upper Pleistocene

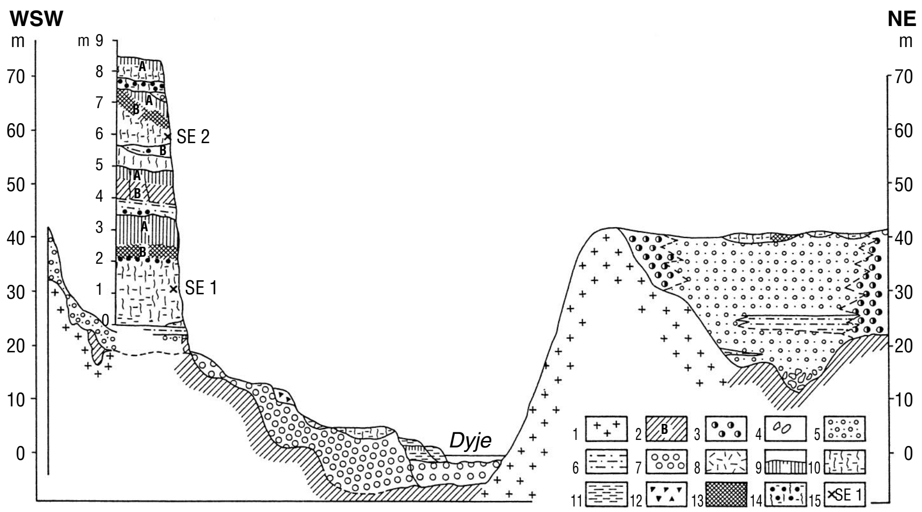


Fig. 6. Sedlešovice, loess cut behind garages (after Smolíková and Zeman 1982).
1 – granodiorites; 2 – clays (Miocene); 3 – younger sand and gravel sheet (Lower Pleistocene); 4 – blocks of rock; 5 – coarse-grained fluvial sand and gravel; 6 – fluviolacustrine clays and silts; 7 – fluvial sandy gravel; 8 – colluvial sediments; 9 – soil sediment and subfossil soils; 10 – loess; 11 – sands and gravels mixed with anthropogenic material; 12 – talus; 13 – ferreto; 14 – carbonate horizons; 15 – mineralogical and chemical analyses

Mineral composition of loesses

Generally higher contents of carbonates, attaining the values of 16 to 40%, were found in loesses from the surroundings of the cities of Znojmo and Pavlov (Table 1). The presence of dolomite in the carbonate admixture is characteristic for the loess from Znojmo, for some samples from DV (samples 19 and 21) and BOR (in particular sample 32 loess < PK VII). Dolomite is practically absent from the carbonate component of Pavlov loesses. Minimum contents of dolomites were established in loesses of SM and SED. Higher amount of plagioclases was found in loesses from DV (samples 16, 17, 19 and 22), SM (samples 12 and 13) and ZNO (samples 27 and 29). K-feldspar is almost absent from loesses from PAV and ZNO or present only in traces. Kaolinite in small amount was established in loesses from DV (samples 18 and 19) and, in small to medium amounts, in loesses from PAV. Smectite generally appears in small or trace amounts only. The relatively highest content of smectite has been found in loesses from SM (samples 7, 8, 9, 12), SED (sample 31) and PAV (samples 35 and 36). The lowest contents were found in loesses from CK (except sample 6), DV (except samples 18 and 19) and ZNO (except samples 24 and 25). The contents of mica minerals are generally small, exceptionally medium (this concerns mostly very young, Upper Pleistocene loesses – samples 10, 22, 27 and 34). Flysch sediments or even Karpatian rocks can be considered the source rocks of illite.

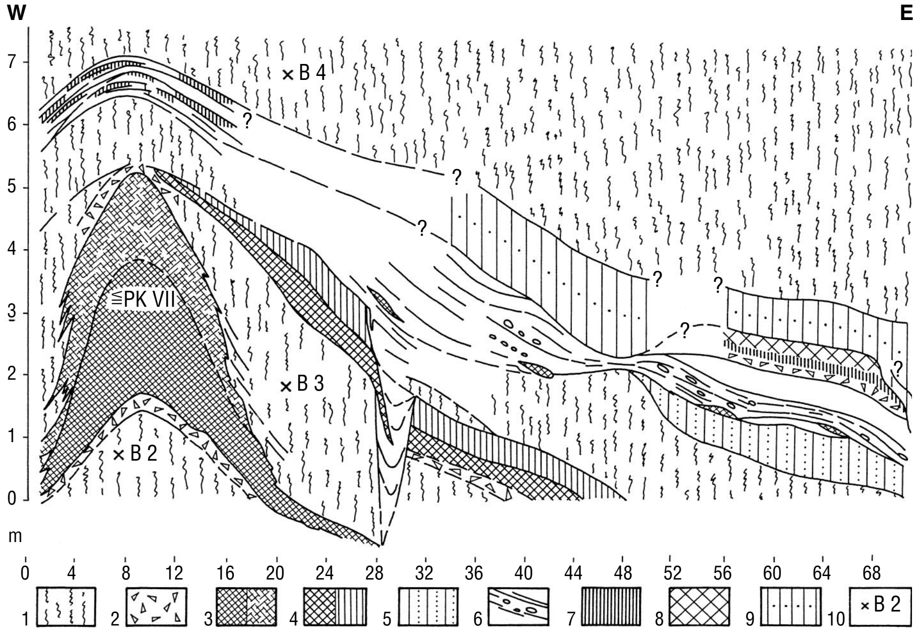


Fig. 7. Bořetice, reclamation cut on a field.
1 – loess; 2 – carbonate rocks; 3 – soil horizon of loamy rotlehm; 4 – soil horizons of loamy braunlehm; 5 – soil horizons affected by solifluction; 6 – clays and fragments of rotlehms redeposited by solifluction; 7 – humic soil sediments; 8 – reddish-brown soil horizons; 9 – humic soil horizon; 10 – mineralogical and chemical analyses

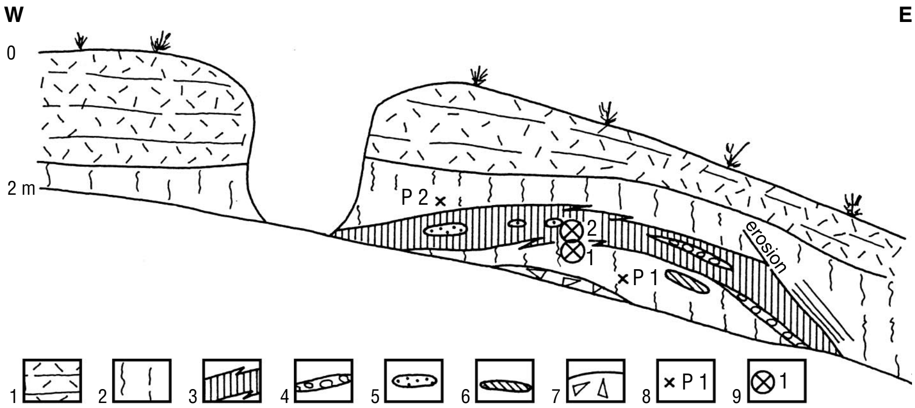


Fig. 8. Pavlov, road cut, direction to Klentnice.
1 – colluvio-eolian sediments and loess with debris of Jurassic carbonate rocks; 2 – loess; 3 – Chernozems; 4 – talus; 5 – mole-chambers filled with loess; 6 – mole-chambers filled with Chernozem; 7 – colluvial stony-loamy sediments; 8 – mineralogical and chemical analyses; 9 – micromorphological determination of paleosols

The presence of haematite was established in loesses from CK, DV, BOR and in older loesses from SM. Besides haematite, goethite is also present (Frechen et al. 1999, Wen et al. 1997). Anatase was found only in loesses from ZNO, PAV and DV (samples 19, 20, 21, 22). Amphibole is present in loesses from PAV, ZNO, DV and CK (except sample 1). The mineral composition of heavy fraction was determined in two samples from DV (samples 20 and 21) and four samples from ZNO (samples 26–29). Loesses from the two localities differ in particular in higher proportion of magnetite and titanite in the Znojmo samples. The Znojmo loesses (samples 26–29) contain chlorite and, with the exception of sample 26, no K-feldspar was found. No K-feldspar is present in the loesses from DV; nevertheless, chlorite is present in very low amounts or only in traces (Tab. 2).

Geochemical characteristics of loesses

Besides mineralogical studies, the attention was also given to the bulk chemical compositions of the loesses studied. The results of chemical analyses are given in

Table 1. Mineral composition of loesses.

Sample No.	Locality	Code	Quartz %	Plagioclase %	Feldspar	Mica	Smectite	Chlorite	Kaolinite	Carbonate %	Calcite	Dolomite	Haematite	Amphibole	Anatase
1	Brno-Červ. kopec	CK 2	55–60	~10	+	+	(+)	+		1.5	+	tr	tr		
2	Brno-Červ. kopec	CK 6	45–48	11-12	+	+	(+)	+		10	+	+		tr	
3	Brno-Červ. kopec	CK 8	39–41	~10	+	+	(+)	+		19.1	++	+	tr	(+)	
4	Brno-Červ. kopec	CK 9	48–50	12-14	+(+)	(+)	tr	+(+)		13.2	+(+)	+			
5	Brno-Červ. kopec	CK 10	~40	~10	+	+	(+)	(+)		25.6	+++	(+)		tr	
6	Brno-Červ. kopec	CK 12	42–45	13-15	+	+	+	+(+)		9.5	+(+)	+	tr	tr	
7	Sedlec u Mikulova	S 1	45–47	10-11	+	+	+	++		0.2			tr		
8	Sedlec u Mikulova	S 3	52–55	12–14	+(+)	+	+	+		0.2			tr		
9	Sedlec u Mikulova	S 5	51–53	10–11	+	+	+	+(+)		3	+	tr	(+)		
10	Sedlec u Mikulova	S 7	42–44	~10–11	+	(+)	(+)	++		15.1	++	+	tr		
11	Sedlec u Mikulova	S 9	~35	~10	(+)	+	(+)	(+)		24.5	+++	(+)			
12	Sedlec u Mikulova	S 11	48–50	13–15	+	+	+(+)	+(+)		0.4					
13	Sedlec u Mikulova	S 13	40–42	12–13	+	+	tr – (+)	+		10.9	++	tr			
14	Sedlec u Mikulova	S 15	41–43	12–13	+	+	(+)	+(+)		11.1	+(+)	+	tr	tr	
15	Dolní Věstonice	V 1	~60	12–14	+	(+)	(+)	+		0.9		+	tr		
16	Dolní Věstonice	V 3	~50	15–17	+	+(+)	(+)	+(+)		1		+	tr	tr	
17	Dolní Věstonice	V 5	50–52	15–17	+	+	(+)	+		8.6	+(+)	+	tr	tr	
18	Dolní Věstonice	V 6	42–44	12–13	+	+	+		(+)	18.1	++	+(+)		(+)	
19	Dolní Věstonice	V 7	50–53	12–14	+	+	+		+	8.2	++	(+)		tr	(+)
20	Dolní Věstonice	V 8	44–47	11–13	+	+	(+)	+		14.8	++	+		tr	tr
21	Dolní Věstonice	V 9	45–48	~13	+	+	(+)	tr		15.5	++	+(+)			tr
22	Dolní Věstonice	V 10	45–47	13–15	tr	+(+)	(+)	(+)		10.6	++	st		tr	tr
24	Znojmo brickyard	ZN 1	28–30	8–9	tr	+	+			32.8	+++	++		tr	
25	Znojmo brickyard	ZN 2	24–27	10–11	(+)	+	+			29.1	+++	+(+)			
26	Znojmo brickyard	ZN 3	30–33	12–13	+	+	(+)	(+)	tr	20.5	++	++		tr	tr
27	Zbnojmo brickyard	ZN 4	31–33	13–15		+(+)	(+)	+		14.7	+(+)	+(+)		tr	+
28	Znojmo factory	ZN 5	34–36	10–12		+	(+)	+		18.2	+(+)	++			(+)
29	Znojmo factory	ZN 6	30–33	13–15	tr	+	(+)	+		16.2	+(+)	++		tr	(+)
30	Sedlešovice	SE 2	35–36	12–13	+	+	(+)	st		15.6	++	+			
31	Sedlešovice	SE 1	50–52	12–14	+	+	+(+)	st		1.4					
32	Bořetice	B 2	45–47	9–10	+	+	+	+		13	+(+)	+(+)			
33	Bořetice	B 3	48–50	12–13	+	+	(+)	+		10.2	+(+)	+	tr		
34	Bořetice	B 4	45–48	11–12	+	+(+)	(+)	+		13.2	++	+			
35	Pavlov	P 1	25–28	7–8		(+)	+		+(+)	40.3	+++++			tr	tr
36	Pavlov	P 2	36–38	10–11		+	+(+)		+(+)	16.3	+++	tr		tr	tr

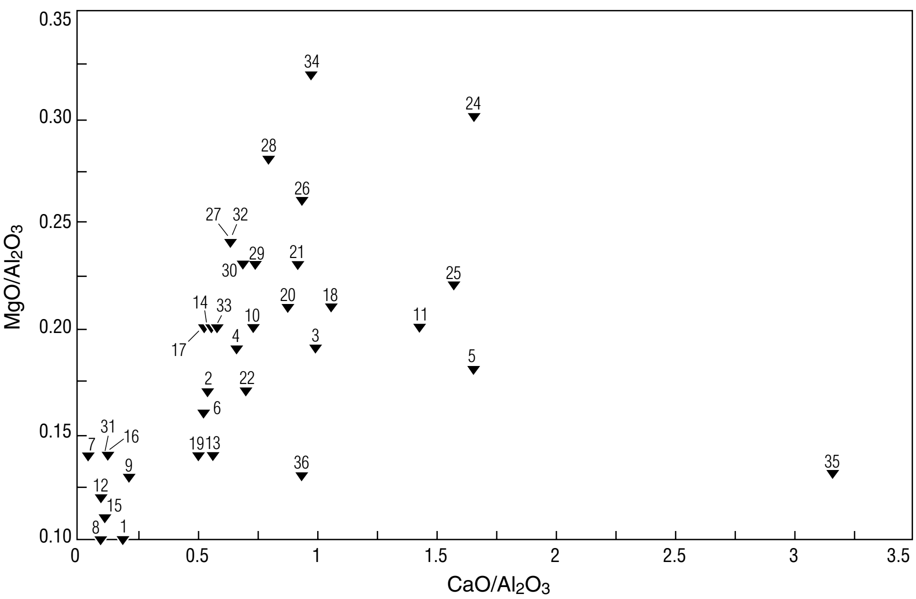


Fig. 9. CaO/Al_2O_3 vs. MgO/Al_2O_3 diagram.

Table 3 and their diagrammatic interpretation in Figs 9–15. As indicated by the contents of CaO, MgO, Al_2O_3 and the proportions CaO/Al_2O_3 vs. MgO/Al_2O_3 (Fig. 9), loesses from ZNO, BOR and partly from DV have a relatively higher content of dolomite in their carbonate admixture. Loesses from CK and SM show lower dolomite contents, the carbonates in loesses from PAV are represented only by calcite. A distinctive difference in the contents and composition of carbonate admixture can be observed even in the Upper Pleistocene loesses. The loesses from SM (sample 8) and DV (sample 15) are probably secondarily decalcified; in con-

Table 2. Mineral composition of the heavy fraction of selected loesses.

magnetic fraction										non-magnetic fraction						
Sample No.	Locality	Code	Magnetite	Amphibole	Haematite	Ilmenite	Mica	Chlorite	Zeolite	Code	F-apatite	Titanite	Sillimanite	Amphibole	Mica	Anatase
20	Dolní Věstonice	V 8	+	+	(+)	(+)	tr	tr		V 8	+	+	(+)		(+)	(+)
21	Dolní Věstonice	V 9	+	+	(+)	(+)	tr	tr		V 9	+(+)	+	(+)		(+)	(+)
26	Znojmo brickyard	ZN 3	+(+)	+	tr	(+)	tr			ZN 3	+	+(+)	(+)		(+)	(+)
27	Znojmo brickyard	ZN 4	++	+	(+)	(+)	tr	tr		ZN 4	+(+)	++	(+)		(+)	+
28	Znojmo factory	ZN 5	+(+)	+	tr	tr	tr	tr	(+)	ZN 5	+(+)	+(+)	(+)	tr	(+)	(+)
29	Znojmo factory	ZN 6	+(+)	+	(+)	(+)	tr	tr		ZN 6	+(+)	+(+)	(+)	tr	(+)	(+)

tr – traces, (+) – very low content, + – low content, ++ – medium content, +++ (and more) – high content

trast, loesses from BOR (sample 34) and DV (sample 19) are strongly calcareous with considerable dolomite content. The Middle Pleistocene loesses taken from the horizon below PK III in DV (sample 20), from the over- and underlying strata of PK IV in ZNO (samples 24. 25, 28, and 29) and loesses from the same localities sampled above and below PK I are more calcareous with considerable dolomite content.

According to the SiO_2 and alkali content – SiO_2 vs. $K_2O + Na_2O/Al_2O_3$ diagram (Fig. 10) – the most similar are Upper Pleistocene loesses from DV (sample 15) and SM (sample 8). The Upper Pleistocene loess from BOR (sample 34) has a higher alkali content as well but the SiO_2 content is lower. Except for sample 19 the loesses from DV have generally a higher content of alkalies. A relatively higher SiO_2 content was proved in the oldest loesses from CK and SM.

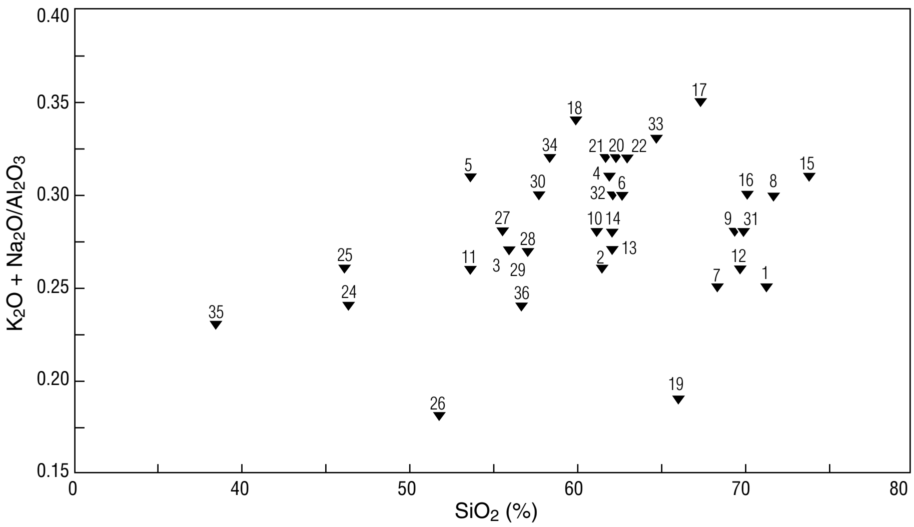


Fig. 10. SiO_2 vs. $K_2O + Na_2O/Al_2O_3$ diagram.

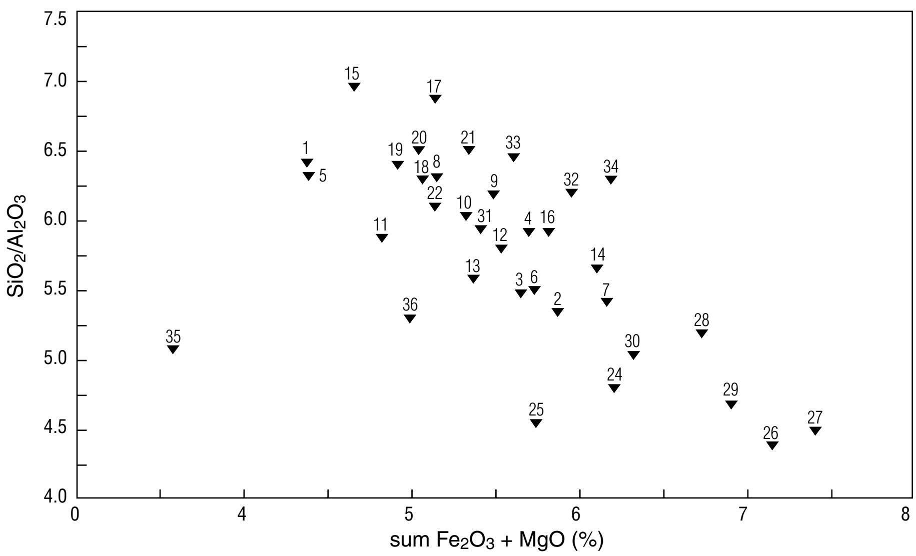


Fig. 11. $Fe_2O_3 + MgO$ vs. SiO_2/Al_2O_3 diagram.

Loesses from ZNO differ markedly from those with a higher Mg content and lower proportion of free SiO_2 (quartz) – see the sum Fe_2O_3 +MgO vs. SiO_2/Al_2O_3 diagram (Fig. 11). Loess from SED (sample 30) belongs to these loesses as well. The loess exposed in the lateral section of SM (sample 7) differs considerably from the oldest loess of the main section (sample 9). All loesses exposed in the main exposure except for the redeposited loess (sample 14) are characterized by lower Fe and Mg contents and by higher amount of quartz. Similar are the DV loesses with lower Fe and Mg contents and a higher proportion of quartz (except for loess samples taken below the cultural layer of Pavlovian). Loesses from CK can be subdivided into two groups – the oldest loess (sample 1 below PK X) and the loess below PK VIII (sample 5) contain the lowest amounts of Fe and Mg and a higher amount of quartz;

Table 3. Chemical composition of loesses (contents of principal components in %, concentration of trace elements and REE in ppm)

Sample No.	Locality	Code	Depth (m) from	to	SiO_2	TiO_2	Al_2O_3	Fe_{TOT}	Fe_2O_3	FeO	MnO	MgO	CaO	SrO	BaO	Li_2O	Na_2O	K_2O	P_2O_5	CO_2	C	H_2O^+	F	S	H_2O^-	Ba
1	Brno-Červ. kopec	CK 2	2.5	2.7	71.28	0.84	11.11	3.32	3.31	0.10	0.123	1.08	1.99	0.013	0.051	0.008	0.88	1.85	0.06	0.77	0.20	3.41	0.03	0.03	2.49	457
2	Brno-Červ. kopec	CK 6	6.1	6.2	61.51	0.64	11.52	3.90	3.54	0.32	0.056	2.00	6.17	0.020	0.045	0.008	0.95	2.09	0.11	4.51	0.10	3.60	0.05	0.02	2.00	403
3	Brno-Červ. kopec	CK 8	4.2	4.3	55.99	0.64	10.22	3.74	3.55	0.17	0.079	1.94	10.12	0.022	0.043	0.008	0.88	1.92	0.14	8.03	0.09	3.28	0.05	0.02	2.24	385
4	Brno-Červ. kopec	CK 9	3.9	4.05	61.95	0.71	10.46	3.70	3.48	0.20	0.065	2.03	6.90	0.022	0.043	0.007	1.02	2.19	0.13	5.82	0.10	2.94	0.04	0.04	1.79	386
5	Brno-Červ. kopec	CK 10	2.8	2.9	53.62	0.51	8.49	2.91	2.83	0.07	0.045	1.51	14.02	0.030	0.109	0.005	0.84	1.80	0.09	11.25	0.21	2.41	0.04	0.02	1.77	977
6	Brno-Červ. kopec	CK 12	2.2	2.3	62.62	0.68	11.34	3.98	3.51	0.42	0.061	1.78	5.86	0.021	0.043	0.008	1.17	2.19	0.10	4.15	0.27	3.14	0.04	0.04	2.26	386
7	Sedlec u Mikulova	S 1	4.2	4.4	68.45	0.74	12.62	4.42	4.19	0.21	0.053	1.77	0.51	0.011	0.043	0.009	0.98	2.16	0.10	0.10	0.15	3.81	0.04	0.03	3.62	386
8	Sedlec u Mikulova	S 3	0.9	1	71.88	0.76	11.39	3.99	3.78	0.19	0.065	1.16	1.08	0.011	0.044	0.007	1.18	2.22	0.11	0.09	0.18	2.94	0.05	0.02	2.80	394
9	Sedlec u Mikulova	S 5	14.2	14.3	69.60	0.72	11.25	4.01	3.82	0.17	0.062	1.50	2.31	0.013	0.045	0.006	0.96	2.18	0.12	1.32	0.10	3.31	0.05	0.02	2.77	403
10	Sedlec u Mikulova	S 7	12.3	12.4	61.26	0.56	10.16	3.38	2.98	0.36	0.065	1.98	7.37	0.021	0.042	0.006	0.92	1.96	0.11	6.62	0.08	2.89	0.04	0.02	2.13	376
11	Sedlec u Mikulova	S 9	11.45	11.55	53.64	0.51	9.14	3.04	2.52	0.47	0.055	1.81	13.07	0.020	0.034	0.005	0.84	1.56	0.10	10.75	0.12	2.93	0.04	0.02	1.73	305
12	Sedlec u Mikulova	S 11	8.5	8.6	69.83	0.82	12.04	4.15	4.03	0.11	0.091	1.41	1.07	0.013	0.093	0.007	1.19	1.99	0.10	0.18	0.12	3.52	0.04	0.01	2.72	833
13	Sedlec u Mikulova	S 13	3.9	4.05	62.21	0.67	11.15	3.85	3.60	0.22	0.073	1.55	6.26	0.017	0.094	0.007	1.11	1.93	0.10	4.52	0.27	3.29	0.05	0.02	2.34	842
14	Sedlec u Mikulova	S 15	0.75	0.85	62.18	0.73	10.98	3.99	3.32	0.60	0.081	2.14	6.15	0.019	0.141	0.007	1.12	1.95	0.11	4.87	0.37	3.32	0.02	0.03	1.92	1263
15	Dolní Věstonice	V 1	12.9	13.1	73.93	0.80	10.62	4.69	3.35	0.19	0.080	1.13	1.18	0.013	0.048	0.006	1.14	2.18	0.06	0.38	0.23	2.87	0.04	0.04	1.83	430
16	Dolní Věstonice	V 3	1.95	2.15	70.16	0.69	11.86	4.15	3.49	0.59	0.059	1.69	1.37	0.016	0.127	0.007	1.37	2.20	0.09	0.42	0.49	3.64	0.04	0.06	1.87	1138
17	Dolní Věstonice	V 5	0.7	0.85	67.44	0.51	9.79	3.27	2.67	0.54	0.065	1.89	5.15	0.019	0.041	0.006	1.34	2.07	0.13	3.80	0.43	2.46	0.06	0.04	0.96	368
18	Dolní Věstonice	V 6	0.5	0.6	59.93	0.54	9.48	3.07	2.16	0.82	0.060	2.03	10.07	0.020	0.039	0.005	1.16	2.04	0.09	7.83	0.16	2.64	0.06	0.20	1.24	350
19	Dolní Věstonice	V 7	12.1	12.2	66.02	0.66	10.35	3.45	2.75	0.63	0.079	1.49	5.45	0.015	0.040	0.005	1.16	1.84	0.09	3.54	0.33	3.22	0.04	0.05	1.88	359
20	Dolní Věstonice	V 8	14.8	15	62.42	0.57	9.44	3.14	2.30	0.76	0.061	1.94	8.34	0.019	0.038	0.005	1.10	1.94	0.09	6.50	0.08	2.72	0.05	0.07	1.24	341
21	Dolní Věstonice	V 9			61.69	0.58	9.55	3.15	2.26	0.80	0.066	2.22	8.75	0.021	0.037	0.005	1.13	1.93	0.10	6.89	0.07	2.65	0.08	0.02	1.14	332
22	Dolní Věstonice	V 10			63.05	0.59	10.35	3.46	2.47	0.89	0.066	1.71	7.09	0.020	0.041	0.005	1.27	2.00	0.08	4.69	0.35	3.20	0.05	0.02	1.32	368
24	Znojmo brickyard	ZN 1			46.36	0.44	9.69	3.32	2.65	0.60	0.055	2.91	16.12	0.035	0.037	0.006	0.73	1.55	0.09	14.43	0.03	2.93	0.05	0.02	1.88	331
25	Znojmo brickyard	ZN 2			46.08	0.49	10.16	3.52	2.85	0.60	0.063	2.25	15.94	0.039	0.084	0.006	0.95	1.67	0.07	12.81	0.15	3.19	0.05	0.03	1.88	753
26	Znojmo brickyard	ZN 3			51.75	0.63	11.68	4.11	2.98	1.02	0.076	3.06	10.98	0.023	0.039	0.007	1.13	1.96	0.09	9.00	0.13	3.77	0.04	0.02	1.51	350
27	Znojmo brickyard	ZN 4			55.59	0.74	12.25	4.47	3.08	1.25	0.084	2.95	7.85	0.020	0.090	0.007	1.24	2.13	0.12	6.48	0.33	3.87	0.05	0.02	1.37	807
28	Znojmo factory	ZN 5			56.99	0.64	10.96	3.69	2.62	0.96	0.073	3.07	8.82	0.016	0.037	0.006	0.99	1.94	0.12	7.93	0.13	3.35	0.05	0.06	1.34	332
29	Znojmo factory	ZN 6			55.95	0.66	12.02	4.11	3.02	0.99	0.078	2.82	8.90	0.018	0.040	0.007	1.24	2.00	0.12	7.12	0.29	3.84	0.05	0.03	1.34	359
30	Sedlešovice	SE 2			57.68	0.56	11.41	3.76	3.17	0.53	0.056	2.59	7.87	0.029	0.048	0.007	1.14	2.23	0.09	6.85	0.14	3.00	0.05	0.03	1.83	430
31	Sedlešovice	SE 1			69.87	0.67	11.76	3.81	3.57	0.22	0.045	1.63	1.41	0.014	0.086	0.006	1.16	2.18	0.11	0.63	0.10	3.42	0.05	0.06	2.28	770
32	Bořetice	B 2			62.21	0.58	9.99	3.62	3.30	0.29	0.070	2.36	6.38	0.015	0.051	0.007	0.89	2.09	0.09	5.75	0.08	3.08	0.05	0.02	2.25	457
33	Bořetice	B 3			64.77	0.63	10.02	3.66	3.24	0.38	0.081	1.97	5.72	0.016	0.042	0.007	1.10	2.17	0.12	4.50	0.11	2.66	0.06	0.01	1.75	377
34	Bořetice	B 4			58.42	0.50	9.28	3.22	2.82	0.36	0.070	3.00	9.08	0.022	0.037	0.007	1.02	1.92	0.10	5.81	0.83	4.45	0.05	0.02	1.59	332
35	Pavlov	P 1			38.48	0.41	7.58	2.62	2.06	0.50	0.076	0.98	23.93	0.015	0.028	0.005	0.63	1.12	0.09	17.69	0.30	3.58	0.06	0.03	1.97	251
36	Pavlov	P 2			56.65	0.57	10.71	3.58	2.65	0.84	0.068	1.44	10.00	0.014	0.037	0.006	1.01	1.56	0.08	7.14	0.42	3.63	0.07	0.03	2.36	332

Table 3. cont.

Sam. No.	As	Cr	Cu	Nb	Ni	Rb	Sr	Ti	V	Y	Zn	Zr	B	Be	Co	Cu	Ga	Mo	Pb	Sn	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Y
1	4	88	20	16	25	97	119	6500	68	47	63	486	70.0	2.0	13.0	28.0	13.0	1.0	22.0	3.0	41.07	95.99	10.71	37.68	6.78	1.21	5.88	–0.90	5.90	1.09	3.72	0.55	3.78	0.54	32.67
2	4	90	22	14	30	97	177	5100	70	46	62	395	48.0	1.0	14.0	18.0	10.0	2.0	15.0	5.0	37.68	73.37	8.20	36.95	6.43	1.14	5.75	0.97	5.55	0.89	3.13	0.50	3.47	0.48	30.05
3	4	82	20	12	29	89	187	4500	69	41	59	354	40.0	1.0	15.0	18.0	10.0	2.0	14.0	4.0	32.47	73.77	7.61	31.15	4.59	1.05	4.64	–0.90	4.86	0.85	3.26	–0.40	2.89	0.45	26.41
4	4	81	19	14	26	93	183	4700	67	43	53	455	50.0	1.0	16.0	15.0	10.0	2.0	16.0	5.0	35.01	71.66	7.28	32.44	6.46	0.98	5.43	0.99	5.20	0.89	3.39	0.50	3.27	0.51	29.85
5	4	77	16	9	17	77	227	3800	53	38	43	400	39.0	1.0	14.0	11.0	8.0	2.0	11.0	4.0	29.22	60.15	6.98	28.42	5.20	0.88	4.37	–0.90	4.85	0.85	2.59	–0.40	2.87	0.40	24.62
6	4	87	29	16	30	94	179	4800	67	44	65	382	43.0	1.0	14.0	10.0	9.0	2.0	13.0	5.0	37.60	75.40	7.44	14.63	5.09	1.12	4.85	1.47	5.09	1.16	3.40	–0.40	3.19	0.47	29.05
7	4	92	14	14	37	101	102	5100	70	42	72	356	72.0	2.0	13.0	10.0	13.0	1.0	19.0	4.0	37.91	77.29	8.96	37.79	6.66	1.19	6.20	–0.90	5.66	1.10	2.72	0.45	3.27	0.46	29.64

8	4	85	14	12	24	87	100	5100	66	45	58	408	58.0	1.0	12.0	6.0	8.0	1.0	13.0	4.0	37.95	76.76	7.33	37.39	6.83	1.16	6.00	1.02	5.22	0.87	3.51	−0.40	3.26	0.50	28.71
9	4	89	17	16	34	88	116	5300	69	44	67	477	60.0	2.0	17.0	26.0	7.0	2.0	12.0	5.0	36.86	81.86	6.51	35.15	6.90	1.05	5.38	−0.90	5.40	1.09	3.44	−0.40	3.27	0.49	29.78
10	4	88	11	13	21	87	175	4300	58	39	56	367	60.0	2.0	16.0	25.0	10.0	2.0	14.0	5.0	33.86	72.40	7.39	31.92	5.64	1.02	4.77	−0.90	4.85	0.93	2.54	−0.40	2.81	0.41	25.67
11	4	70	19	12	25	66	172	3700	59	32	44	347	33.0	1.0	14.0	14.0	8.0	0.6	10.0	6.0	30.61	63.82	5.20	30.01	5.97	0.95	4.59	−0.90	4.35	0.79	2.42	0.51	2.75	0.39	25.32
12	4	93	13	16	35	89	113	5500	65	47	64	472	70.0	2.0	14.0	16.0	14.0	1.0	13.0	4.0	41.57	86.09	10.54	40.09	6.39	1.31	6.62	0.96	6.27	1.24	3.62	0.45	3.54	0.54	32.42
13	4	86	14	13	24	88	133	4600	62	40	58	363	39.0	1.0	17.0	14.0	8.0	2.0	10.0	5.0	35.92	74.34	9.38	33.17	6.13	1.04	5.22	−0.90	5.14	0.70	3.02	−0.40	3.07	0.40	27.36
14	4	84	26	12	32	87	138	4700	66	45	64	364	47.0	1.0	14.0	10.0	9.0	1.0	8.0	4.0	35.98	79.31	10.78	34.56	6.17	1.22	5.50	−0.90	5.38	0.94	3.01	−0.40	3.15	0.43	28.58
15	4	77	5	15	17	101	113	5200	58	42	57	457	56.0	1.0	12.0	5.0	7.0	1.0	9.0	3.0	44.25	77.30	10.14	32.70	6.10	1.03	5.15	−0.90	5.03	0.95	2.66	−0.40	3.03	0.45	27.88
16	4	95	18	14	31	102	130	4900	66	44	66	378	50.0	2.0	13.0	8.0	8.0	1.0	9.0	3.0	37.47	77.59	9.98	33.32	6.83	1.10	5.86	−0.90	5.50	1.00	3.41	−0.40	3.25	0.49	29.14
17	4	70	5	8	26	86	157	4300	49	37	50	306	45.0	1.0	12.0	8.0	5.0	1.0	9.0	3.0	32.13	66.31	6.77	29.42	5.26	0.93	4.78	−0.90	4.56	0.85	2.63	−0.40	2.62	0.40	24.07
18	5	62	16	13	22	78	197	3300	51	29	46	327	74.0	2.0	12.0	10.0	9.0	1.0	18.0	5.0	25.83	61.14	7.27	29.46	5.56	0.92	5.18	−0.90	5.14	1.10	2.88	−0.40	2.88	0.42	28.54
19	5	80	15	14	20	84	150	4000	54	35	58	439	100.0	2.0	13.0	13.0	10.0	1.0	17.0	4.0	33.61	76.82	8.51	37.08	7.27	1.06	6.40	1.19	6.38	1.21	3.18	0.42	3.50	0.51	34.26
20	4	67	13	14	21	85	187	3500	48	32	47	381	74.0	2.0	13.0	13.0	9.0	0.6	17.0	5.0	24.12	63.30	6.98	32.55	6.14	1.00	5.62	−0.90	5.86	1.14	3.07	0.41	3.30	0.48	31.97
21	5	72	15	14	19	80	196	3500	51	32	48	380	80.0	2.0	13.0	11.0	9.0	2.0	19.0	4.0	24.72	55.12	7.11	31.63	6.11	0.97	5.65	1.16	6.16	1.10	3.23	0.43	3.27	0.50	32.12
22	5	63	15	6	25	87	186	3600	56	33	53	355	90.0	2.0	13.0	14.0	10.0	2.0	17.0	4.0	32.42	74.92	8.60	35.07	6.60	1.06	6.46	−0.90	6.00	1.21	3.18	0.42	3.39	0.48	32.95
24	4	68	17	9	32	71	265	3500	58	21	58	269	22.0	1.0	14.0	6.0	6.0	0.6	7.0	4.0	31.09	61.02	11.86	27.24	4.64	0.84	5.53	3.79	3.95	1.06	2.25	0.86	2.48	0.35	22.09
25	4	65	13	9	30	81	286	4000	51	23	55	268	30.0	1.0	14.0	5.0	7.0	0.6	5.0	3.0	34.83	77.20	11.90	37.15	5.88	1.09	5.87	3.45	4.00	1.54	3.46	0.89	2.61	0.42	24.17
26	9	67	17	14	28	87	225	3800	69	32	66	281	62.0	2.0	18.0	17.0	9.0	0.6	16.0	4.0	32.86	72.99	8.13	35.03	6.40	1.16	6.34	−0.90	6.01	1.10	2.94	−0.40	3.14	0.45	31.50
27	8	81	23	14	35	94	183	4500	76	36	72	341	100.0	2.0	16.0	21.0	13.0	1.0	18.0	5.0	31.06	79.22	9.33	38.96	7.50	1.30	6.81	1.48	6.57	1.20	3.59	0.41	3.53	0.51	35.32
28	7	78	22	8	22	91	160	3900	39	40	60	365	82.0	2.0	14.0	19.0	11.0	1.0	17.0	3.0	34.24	85.78	8.93	42.02	8.42	1.38	7.36	1.36	7.42	1.39	3.91	0.53	4.08	0.60	39.45
29	8	67	22	13	26	96	177	4000	69	45	67	318	80.0	2.0	18.0	18.0	11.0	1.0	17.0	5.0	41.39	82.59	10.05	38.18	6.67	1.25	6.75	1.24	8.08	1.54	3.94	0.48	4.10	0.57	44.63
30	4	77	19	14	26	93	231	4400	58	25	64	333	29.0	1.0	16.0	6.0	8.0	0.6	8.0	3.0	36.50	77.18	14.01	35.62	7.02	0.89	6.46	2.26	4.75	1.60	3.29	1.04	3.06	0.45	29.20
31	4	67	12	11	18	100	111	5000	53	25	59	446	50.0	2.0	10.0	6.0	9.0	2.0	14.0	5.0	48.23	101.82	10.72	45.40	9.03	1.38	7.23	1.25	6.07	1.39	3.59	1.05	3.62	0.52	31.58
32	4	77	20	14	20	91	145	3500	62	29	56	387	62.0	2.0	16.0	28.0	9.0	2.0	15.0	4.0	35.80	71.87	8.73	32.96	5.52	1.02	5.49	1.30	5.07	1.02	2.97	0.20	3.87	0.46	28.95
33	4	87	22	14	25	92	159	3800	65	34	56	488	70.0	2.0	20.0	24.0	11.0	2.0	21.0	4.0	76.93	93.06	10.80	40.97	7.24	1.16	6.94	1.53	5.96	1.14	3.37	0.47	3.72	0.53	33.66
34	4	69	10	12	27	79	206	3000	54	28	56	369	58.0	1.0	20.0	20.0	8.0	2.0	17.0	4.0	64.18	71.87	7.82	32.12	5.83	1.00	5.40	0.99	4.88	0.91	2.96	0.25	3.03	0.43	27.64
35	6	42	6	8	23	59	144	2500	40	23	35	199	35.0	1.0	15.0	6.0	8.0	0.6	11.0	1.2	20.76	47.21	6.11	22.37	4.37	0.74	4.34	0.50	4.12	0.81	2.33	0.20	2.31	0.34	22.40
36	6	64	16	13	25	86	136	3500	56	25	58	311	80.0	2.0	16.0	20.0	11.0	1.0	16.0	4.0	22.90	45.70	4.90	24.14	5.08	0.87	4.82	0.50	4.84	0.85	2.57	0.20	2.54	0.37	25.51

other loesses exposed at this locality have higherand similar Fe and Mg contents. A relatively high basicity of the source material of the studied loesses corresponds with loesses from ZNO and SED (sample 30). The most acid character of the source material was observed in loesses from DV and CK (samples 1 and 5).

Al_2O_3/Na_2O vs. K_2O/Na_2O ratios (Fig. 12) indicate chemical and mineralogical “maturity” of the sediment (Pettijohn 1957). The far lowest maturity values were observed in loesses from DV. A higher maturity degree was established in older loesses from CK and SM. Both localities, as well as BOR, indicate a distinctive decline of maturity towards the overlying strata and younger loess. Older loesses of the main section in SM (samples 9 and 10) generally correspond to the position between PK IX and PK VIII in loesses from CK. The Znojmo loesses were, with the exception of one sample, taken below PK IV (sample 24) chemically and mineralogically less mature than loesses from the localities of CK, SM, BOR and SED. Similarity of some Upper Pleistocene loesses (samples 8, 15 and 34) is clearly shown in Fig. 12.

Low TiO_2/Al_2O_3 ratios and especially Zr/Al_2O_3 ratios – see TiO_2/Al_2O_3 vs. Zr/Al_2O_3 diagram (Fig. 13) – differentiate loesses from ZNO and PAV from the other samples. Generally more basic character of ZNO loesses may be influenced by the presence of basic and ultrabasic rocks in the source area (besides schists and gneisses, basic and ultrabasic rocks from the surroundings of Znojmo and Moravský Krumlov are also present in the source material). The Bořetice loesses indicate higher values of the Zr/Al_2O_3 ratio. No substantial difference in the values of this ratio can be found between the youngest loess from CK (sample 6 – over PK VIII) and the oldest loess from BOR (sample 32 – below PK VII). Higher values are evidenced in some loesses from CK (samples 1, 4 and 5) and in the oldest loess in the main section at Sedlec (sample 9). A different situation was observed in the Upper Pleistocene loesses. The highest values of this ratio were established in DV (sample 15). A comparison of the oldest loesses in SM (sample 7 – lateral section, and sample 9 – main section) showed mutual differences between the two loesses. The loess from the lateral section has a considerably more basic source than that of the main section.

The most distinctive predominance of Fe and Al over alkalies (Fig. 14) – values of the $(Al_2O_3 + Fe_2O_3\,T)/(Na_2O + K_2O)$ ratio – the so-called weathering index, was found in the loesses from the PAV locality (5.83 and 5.56 for

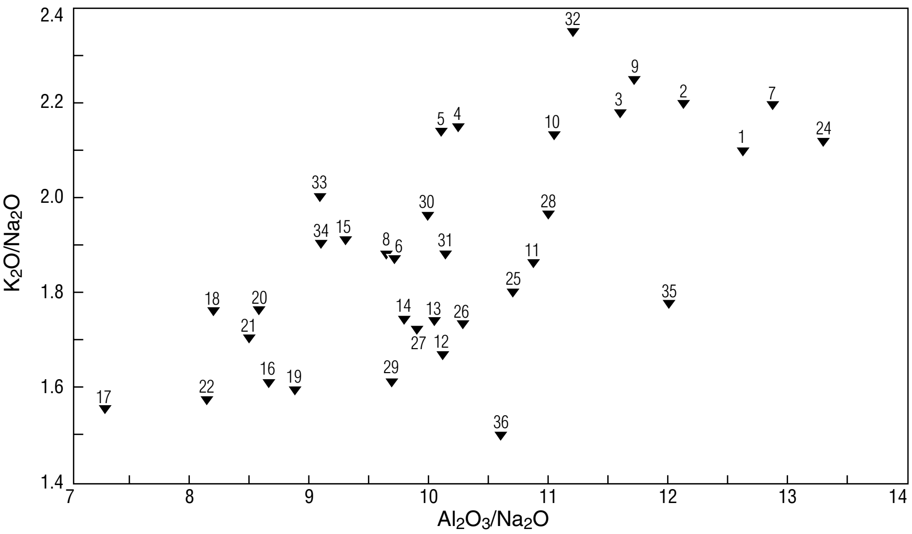


Fig. 12. Al_2O_3/Na_2O vs. K_2O/Na_2O diagram.

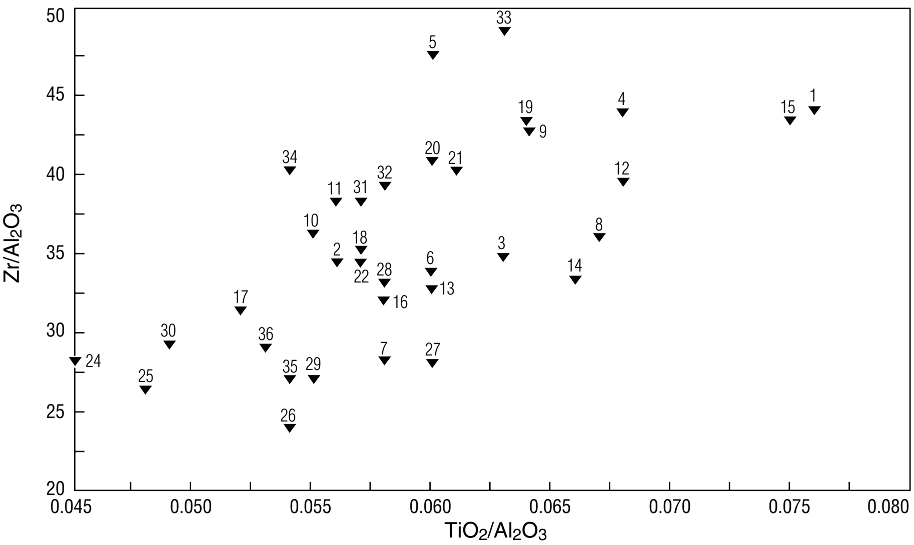


Fig. 13. TiO_2/Al_2O_3 vs. Zr/Al_2O_3 diagram.

samples 35 and 36), in the oldest loesses from CK (5.29 and 5.08 for samples 1 and 2), SM (5.43, sample 7) and loesses from ZNO (5.71, 5.22, 5.11 for samples 24, 25, 26). Weathering index of the Upper Pleistocene loesses ranges mostly between 4.25 and 4.6. Generally, the lowest degree of weathering was found in loesses from DV (3.83–4.6) and in young loesses from CK taken from the horizon overlying PK IX (4.18–4.56). The value of 3.5 is given in literature for entirely non-weathered loess (Pye 1987). As the alkalies are concerned, no considerable relation to the carbonates or SiO_2 was found.

Loesses from DV (except sample 17) and SED are characterized by higher values of negative Eu anomaly (Tab. 4). Loesses from localities SM (samples 9 and 11) and CK (sample 4 – below PK VIII) can be attributed to this group as well. It is evident in general that the loess samples taken below PK III (DV – sample 20) and over PK III (DV – samples 15 and 19, SM – sample 8, BOR – sample 34) have a more prominent negative Eu anomaly. An expressive Eu anomaly corresponds to a more acid character of the source material.

As stated above, the most basic source material is represented by loesses from PAV and ZNO (Fig. 15). Sample 28 taken below PK IV represents an exception, much like samples 20 and 21 from DV. They belong to loesses with the most acid source material. Loesses of Upper Pleistocene age from the localities of DV (samples 15 and 19), SM (sample 8) and BOR (sample 34) are characterized by relatively more acid material as well. Loesses of the main section in SM manifest an increase in basicity towards the overlying strata (sample 9 to sample 14). In the exposure at Červený kopec, the basicity of material increases towards the overlying strata as well (loesses below PK X, above PK X and above PK IX – samples 1–3). This is followed by a change in loesses sampled 2 m above PK IX and below PK VIII (sample 4 and sample 5 – more acid material) and finally by a more expressive shift towards higher basicity of source material observed in the loess cover sampled above PK VIII (sample 6).

The FeO/Fe_2O_3 ratio reflects redox conditions at the time of the origin of loesses and palaeosols (Lukachev 1961). Wen et al. (1985, 1997) applied an inverse approach – they called the Fe_2O_3/FeO ratio the "oxidizing degree" where a higher value corresponds to a warmer climate and a lower value to a colder one (high temperature causes decomposition of organic material and formation of Fe_2O_3). Values of this ratio in the loesses studied (Tab. 4) indicate that a relatively warmer fluctuation corresponded to the period of loess formation in CK with the exception of loess sampled above PK VIII. This loess cover is similar to that of BOR, sampled below PK VII (sample 32) and to that of SM (sample 10), sampled also below PK VII. Values of the Fe_2O_3/FeO ratio range between 8.3 and 11.5 here. In Sedlec, the oldest loesses could have formed during a relatively warmer period (samples 7 and 9), much like loess sampled between B/II and CI (sample 12) with Fe_2O_3/FeO values of 20–36. A relatively cooler temperature fluctuation corresponds to the period of loess formation in ZNO, PAV and DV, i.e. to loesses sampled below and above PK IV, below and above PK III and below and above PK I. Fe_2O_3/FeO values in these loesses mostly range from 2.5 to 5, reaching a maximum of 5.9. An exception is the Upper Pleistocene loess in DV (sample 15) sampled inside PK III with the value of 17.6. Similarly, a high Fe_2O_3/FeO value (19.9) was found in the Upper Pleistocene loess from SM (sample 8).

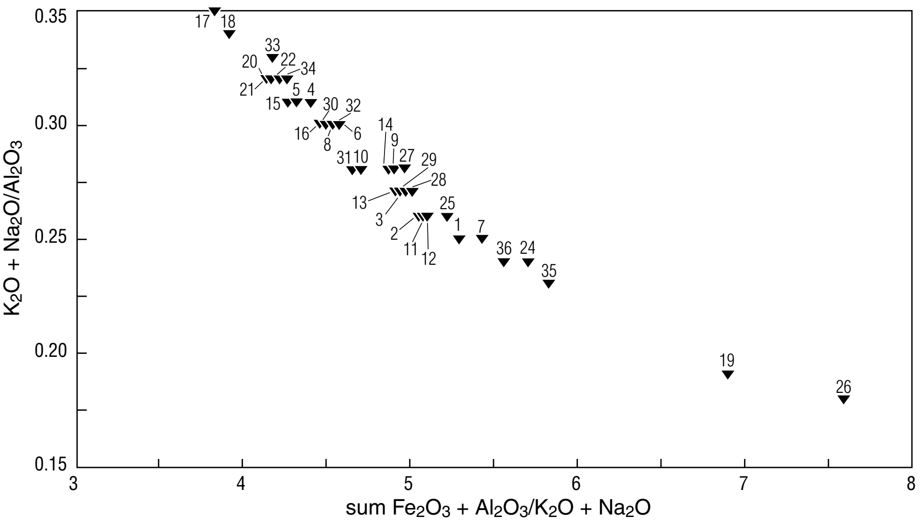


Fig. 14. (Fe_2O_3T+ Al_2O_3/)/(K_2O + Na_2O) vs. (K_2O + Na_2O)/Al_2O_3 diagram.

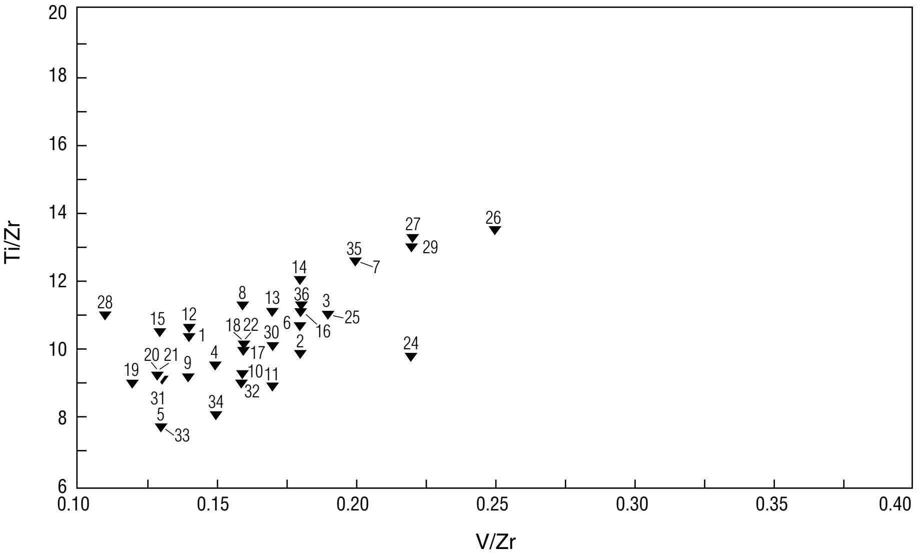


Fig. 15. V/Zr vs. Ti/Zr diagram.

Principal results
of geochemical studies

Mineral composition of the loesses studied corresponds with their chemical composition, particularly in their principal components.

Loesses from the localities of Znojmo, Bořetice and partly Dolní Věstonice contain a relatively higher proportion of dolomite in their carbonate component. The appearance of dolomite in the investigated loesses may be related to its presence in pre-Quaternary sediments of the Karpatian and of the Ždánice-Hustopeče Formation of the Ždánice Unit.

Loesses from Znojmo differ distinctly from other loesses in higher contents of Fe and Mg and a lower proportion of quartz. Loesses from Dolní Věstonice contain less Fe and Mg and have a higher quartz content.

The definitely lowest degree of mineralogical and chemical maturity was found in loesses from Dolní Věstonice. Higher maturity was established for the Middle Pleistocene loesses from Červený kopec and Sedlec. Loess sections at both these localities, much like at Bořetice, clearly show an upwards decreasing degree of maturity.

Generally the lowest degree of weathering (weathering index) was found in loesses from Dolní Věstonice and younger loesses from Červený kopec and Bořetice. The highest values of weathering index were established in loesses from the localities of Pavlov and Znojmo, in the oldest loesses from Červený kopec (samples 1 and 2) and Sedlec near Mikulov (sample 7).

Loesses sampled at Dolní Věstonice, Sedlešovice, Bořetice (sample 33) and Upper Pleistocene loesses (Dolní Věstonice – samples 15 and 19, Sedlec – sample 8, Bořetice – sample 34) show a prominent negative Eu anomaly.

Loesses from Znojmo and Pavlov indicate the highest basicity of source material. Exceptional in this respect is sample 28 (taken below PK IV), belonging among loesses with a more acid character of source material, such as those from Bořetice and Sedlešovice. A relatively more acid material was also found in the Upper Pleistocene loesses from Dolní Věstonice (samples 15 and 19), Sedlec (sample 8) and Bořetice (sample 34). The character of material in loesses near Znojmo may be influenced by occurrences of metabasites in the area of Znojmo, Vranov, Moravský Krumlov and Ivančice (implying a direction from the W, NW, NE). This concerns particularly serpentinite bodies, amphibolites and eclogites.

A relatively warmer climatic fluctuation corresponds to the period of loess formation at the locality of Brno-Červený kopec, with the exception of the loess cover sampled above PK VIII (sample 6). This sample was similar

Table 4. Values of ratios of selected elements in the loesses studied.

Sample	SiO_2/Al_2O_3	Fe_2O_3/FeO	(La/Yb)N	Eu/Eu*
1	6.42	33.1	7.32	0.59
2	5.34	11.1	7.32	0.58
3	5.48	21.0	7.57	0.70
4	5.93	17.4	7.22	0.51
5	6.32	40.4	6.87	0.56
6	5.52	9.0	7.95	0.69
7	5.43	20.0	7.81	0.57
8	6.31	19.9	7.85	0.55
9	6.19	22.5	7.60	0.53
10	6.03	8.3	8.13	0.61
11	5.87	5.5	7.50	0.56
12	5.82	36.6	7.92	0.62
13	5.59	16.5	7.89	0.57
14	5.66	5.5	7.70	0.64
15	6.96	17.6	9.84	0.54
16	5.92	5.9	7.77	0.54
17	6.89	5.0	8.27	0.57
18	6.32	2.7	6.05	0.53
19	6.38	4.4	6.50	0.48
20	6.61	3.0	4.93	0.52
21	6.46	2.9	5.09	0.51
22	6.10	2.8	6.45	0.50
24	4.78	4.4	8.45	0.53
25	4.53	4.8	9.0	0.57
26	4.43	2.9	7.06	0.56
27	4.54	2.5	5.90	0.56
28	5.19	2.7	5.66	0.54
29	4.65	3.1	6.81	0.57
30	5.05	6.0	8.04	0.47
31	5.94	16.3	8.98	0.53
32	6.23	11.5	6.24	0.57
33	6.43	8.5	13.94	0.50
34	6.24	8.0	14.28	0.54
35	5.07	4.2	6.06	0.53
36	5.28	3.2	6.08	0.56

N = chondrite-normalized

to loesses from Bořetice (sample 32) and Sedlec near Mikulov (sample 10). The oldest loesses from Sedlec near Mikulov (samples 7 and 9) and those sampled between B/II and C/I (sample 12) were deposited under relatively warm climatic conditions. A relatively colder oscillation corresponds to the period of loess formation at the localities of Znojmo, Pavlov and Dolní Věstonice with the exception of loess sampled within PK III (sample 15).

Discussion and conclusions

The most basic material was found in loesses from Znojmo. The composition of these loesses may be influenced by the presence of metabasites in the area of Znojmo, Vranov, Moravský Krumlov and Ivančice (implying a direction from the W, NW and SW). The Middle Pleistocene loesses from Bořetice (loess overlying PK VII) and Sedlešovice, loesses sampled below PK III (Dolní Věstonice – sample 20 and Znojmo – sample 28) and – to some extent – the Upper Pleistocene loesses from the localities of Dolní Věstonice (samples 15 and 19), Sedlec near Mikulov (sample 8) and Bořetice (sample 34) belong to loesses with a more acid character of source material. At the Brno-Červený kopec locality, the increase in basicity upwards was observed at the beginning; then, between PK VIII and PK IX, the character of the material changes and becomes more acid. The loess cover overlying PK VIII shows again a higher proportion of basic components. This loess is very similar to that from the localities of Sedlec near Mikulov sampled below PK VII (sample 10) and to some extent to the loess below PK VII at Bořetice (sample 32). A certain parallel can be drawn between the loess cover underlying PK VIII at Sedlec near Mikulov and loesses sampled below PK VIII from Červený kopec (samples 4 and 5). The above mentioned differences in the character of source material indicate pronounced changes in prevailing wind directions.

A comparison of the principal studied components of Moravian loesses as described by Galet et al. (1998), namely SiO_2, Al_2O_3, K_2O, Na_2O and P_2O_5, shows a high similarity with other European loesses (France, Great Britain). If compared with the composition of the upper continental crust (Taylor et al. 1983, McLennan 1989) and of loesses from China, Argentina and Siberia, the European loesses including those from southern Moravia have lower contents of Al, Na and K. The $(La/Yb)_N$ values range between 5 and 10 (mostly between 6 and 8) and correspond to those given by Galet at al. (1998) for French loesses. The Eu/Eu* ratio (calculated values of Eu anomaly) oscillating between 0.47 and 0.69 (with prevailing values 0.52–0.59) in Moravian loesses corresponds to the data given for European loesses as well.

The present research permitted to draw some conclusions on the palaeoclimatic development of the area studied. The area itself is situated in the extraglacial zone south of the outermost limits of inland glaciation, which reached the main European watershed (between the Baltic Sea and the Black Sea) near the town of Hranice during the Elster and Saale glaciations. Climatic changes during the Pleistocene period substantially affected the chemical composition of loesses.

Palaeoclimatic conclusions are based on the study of the index Fe_2O_3/FeO representing the "oxidizing degree" introduced by Wen et al. (1997). The samples were taken both from loesses deposited in the periods of inland glaciations and those deposited at the time when the central European area was ice-free. The results so far achieved pointed to a surprising coincidence of climatic changes and glaciations with "oxidizing degree" values.

In the sections studied, low values of oxidizing degree were found in the Upper and partly in Middle Pleistocene loesses. The lowest values (2.7–5.9) were established below and above soil complex PK 1, where the horizon with the value of 2.7 corresponds to loesses with prevailing Collumela fauna, characteristic of the uppermost part of the pleniglacial of the Last Glacial Stage. This corresponds to the maximum of the last, Vistulian glaciation of the North European lowland. During this glaciation the inland ice reached about 50 km south of Berlin. A higher value of oxidizing degree found in the loess sample from the basal part of the Last Glacial Stage (19.9) shows a relatively warmer climate, as also indicated by molluscan fauna with Helicopsis strata ("warm" loess facies, cf. Ložek 1973), when loess was deposited during a transitional period between the Interglacial and Glacial Stage. Higher values of the oxidizing degree (17.6) were encountered also in the sample taken from a thin loess horizon separating two palaeosols of the Last Interglacial. Here, an analogy was found with the finds of thermophile fauna in comparable horizons described from several European localities (Obermaier 1935, Wernert 1949, Pelíšek 1954), which even led to a discussion on the interglacial origin of loesses (cf. Ložek 1973). However, this horizon originated in a relatively short period of loess sedimentation between two periods of soil-forming processes in a non-glaciated area.

The values of Fe_2O_3/FeO decrease again below the palaeosol complex of the Last Interglacial, ranging between 2.7–4.8. No samples were acquired from the interval between PK V and PK VI. Nevertheless, from PK VII downwards the oxidizing degree values substantially increase towards the Brunhes-Matuyama boundary, most probably indicating the warming of climate. As a result, values of 8.3–11 were established between soil complexes PK VII and PK VIII (Brno-Červený kopec, Sedlec near Mikulov and Bořetice localities) and reached 22.5 below PK VIII (sample 9, Sedlec near Mikulov). The highest value so far detected comes from below PK VIII: 40.4 (sample 5, Brno-Červený kopec). Rather warm conditions during loess sedimentation are indicated by oxidizing degree values separated by the oldest soil complexes PK IX – PK X: from 17.4 below PK IX to 33.1 below PK X. The lowermost horizon, highly probably, belongs to the Matuyama Chron.

Results of the geochemical research so far achieved are in agreement with climatic oscillations palaeontologically dated in the Upper Pleistocene. Palaeoclimatically, loesses showing low oxidizing degree values are related to inland glaciations of the European lowland. Higher values were found in loesses deposited in glacial stages preceding these glaciations and the highest values are referred to the time span close to the Brunhes/Matuyama boundary or to the immediately preceding period. According to Obruchev (1948) loesses deposited in the periglacial zone of a glacier belong to the so-called "cold loesses". "Warm loesses" were brought from desert areas during relatively warm but not interglacial periods. We presume that loess formation in southern Moravia was influenced rather by the aridity of the region than by classical glacial conditions, although their sedimentary environment has to be further studied.

The present study has demonstrated the agreement of geochemical data with some palaeontologically evidenced climatic oscillations in the Upper Pleistocene, and pointed out the differences between glaciated and non-glaciated areas in the Middle and Lower Pleistocene. In the future, attention should be paid to the study of palaeoclimatic conditions in the period preceding inland glaciations of the North European lowland, particularly within the palaeomagnetic Matuyama Epoch. The conformity of results of geochemical study with palaeontological data and inland ice advances opens the possibility of using geochemical methods for the study of palaeoclimatic conditions even where other methods usually fail.

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