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Development and Properties of Paleosols in the Loess Section at Sandomierz (SE Poland)

Rozwój i właściwości lessowych gleb kopalnych w odsłonięciu Sandomierz (Polska SE)

Развитие и свойства ископаемых почв из разреза в г. Сандомир (ЮВ Польша)

ABSTRACT

The characteristics and properties of fossil soils in the Sandomierz exposure have been presented. Basing particularly on micromorphologic examination and on the investigation of heavy and clay minerals it has been established that the best developed soil in that exposure is the soil complex from Eemian—Early Vistulian period. It consists of destroyed forest lessivé soil, formed from Wartanian loess, and of typical chernozem occurring in its top, which is developed from the lowest Vistulian loess. Paleosols formed from younger Vistulian loesses are less developed subarctic soils and not always preserved.

Loesses and fossil soils from the vicinity of Sandomierz have been repeatedly studied (K. Straszewska 1961, K. Straszewska and E. Mycielska 1961, J. Jersak 1976, K. Konecka-Betley and K. Straszewska 1977).

Lately loess section at Sandomierz was studied — by K. Konecka-Betley et al. (1985), J. Butrym and H. Maruszczak (1985) — where the fossil soil catena * is exposed along 200 m. The stratigraphic position of the particular soil types recognized according to their pedologic properties may serve to correlate them with the fossil soils of other Polish regions.

PEDOSTRATIGRAPHY OF THE SECTION

The largest section of younger loesses, i.e. Vistulian loesses and older deposits is situated on a hill of the Cambrian Sandomierz uplift, near the road from Sandomierz to Zawichost, in an old sand-pit now partly exploited. The top of the exposure lies at 187 m a.s.l. and 42 m above the present-day bed of the Vistula River. It is separated from the neighbouring hill, where the old town is located, by a depression with a stream flowing from Gołębice. On the other side of the hill a deep loessy ravine runs from the NE.

The synthetic description of the exposure where pedologic investigations were carried out is as follows (depth in metres):

a) 0 — 5.2 Upper younger loess (younger Vistulian) capped with leached brown soil, in some parts with lessivé soil occurring on the present-day topographic surface. The thick humus horizon is degraded and decalcified from the top to the depth of 2.80 m; a great number of carbonate concretions occurs in the bottom layers.

b) 5.2— 8.0 Middle younger loess (middle Vistulian). A bipartite, poorly marked humus horizon and an equally poorly marked horizon *B* occur in the top; carbonates occur in the whole loess layer though horizon A_1 is somewhat decalcified. It is a poorly developed arctic gleyified brown soil.

c) 8.0— 9.0 Lower younger loess (older Vistulian) with a weakly marked bipartite gleyified humus horizon. In some parts of the exposure there may also be soil deluvia of a different degree of gleyization. Carbonates occur in the whole loess layer in somewhat lower quantities than in the middle younger loess. This may be an initial soil or weathered layers. It cannot be excluded that the bipartite horizons A_1, though poorly marked, represent some short warmer phases and interruptions in loess sedimentation. The initial horizon A_1 displays greater decalcification. The loess is cut by pseudomorphs of ice wedges which cut the underlying soil.

d) 9.1— 9.8 Lowest younger loess (oldest Vistulian), Chobrzany type (K. Konecka-Betley and K. Straszewska 1977), loamy dark-grey with a brown tint. The chernozem-forming process has also embraced the top of the older loess. It is fossil chernozem with "braided" structures filled with organic matter; the structures may have been formed in conditions of seasonal freezing. Carbonates occuring here are secondary.

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* The problem of fossil soils catena will be the subject of the forthcoming paper.

e) 9.8—10.5 Older loess (Saalian II=Wartanian) dark-yellow with brown interbeddings in places, slightly sanded in its floor. It is changed and transformed by denudation processes, with a slight quantity of secondary carbonates. It represents a decapitated fossil soil with a poorly preserved horizon A_1 and a well-preserved, though in some parts not very thick, horizon B_t, brown in colour with not much clay fraction; in places, particularly in its floor, contains large quantities of manganese and manganese-iron concretions; this soil is cut with younger frost wedges.

f) 10.5—13.1 Silty-sandy deposits, loamy in the top and in the bottom, slightly stratified, without carbonate. They were formed as the result of displacement of underlying till due to solifluction. They can be considered as solifluction-deluvial deposits occurring in a rather thick layer over the till. Strong gleyization may be observed in the bottom in the form of blue-grey stains with small ferruginous and iron-manganese concretions. The top of this bed constitutes a 2—5 cm thick layer of sand with prevailing fine-grained sand and less silt than in loesses; it is strongly oxidized, yellow-brown.

g) 13.1—15.0 Brown till with a small admixture of Scandinavian pebbles and with a large quantity of gravels from the local Upper Cretaceous rocks. The till was accumulated by the continental glacier of the maximum stage of Saalian I=Odranian glaciation. It was dated by J. Butrym, by the TL method, at 295 ka BP (J. Butrym and H. Maruszczak 1985).

GRANULOMETRIC AND MINERAL COMPOSITION

The granulation analysis was performed in 55 samples of Vistulian and older deposits of the studied exposure (Fig. 1B). Irrespective of age, in all loess samples the fine-silt fraction (50—20 μm) prevails, fraction <20 μm constitutes a smaller part, and the coarse-silt fraction (100—50 μm) content is the smallest. The sand content is the smallest in Vistulian loesses, while older loesses, sandy silts and till contain much more sand. Generally sandy silts have most fine sand. Till occurring in the silt floor have a varied granulation. There occur all the sand fractions and their total content reaches 30%; there is less silt than in loesses and there are various amounts of colloidal particles, sometimes reaching 70%. The soil granulation displays enrichment of illuvial horizons B_t in colloidal particles in comparison with horizons C.

Heavy minerals (Fig. 1C) were determined in five samples of Vistulian loess and in eleven samples of fossil polycyclic soil as well as in silt and till. The main part of the heavy fraction are minerals resistant and of medium resistance to weathering, such as zircon, tourmaline, rutile, epidote and garnet. Basing on the ratio of heavy minerals resistant to weathering to less and least resistant minerals it may be stated that older

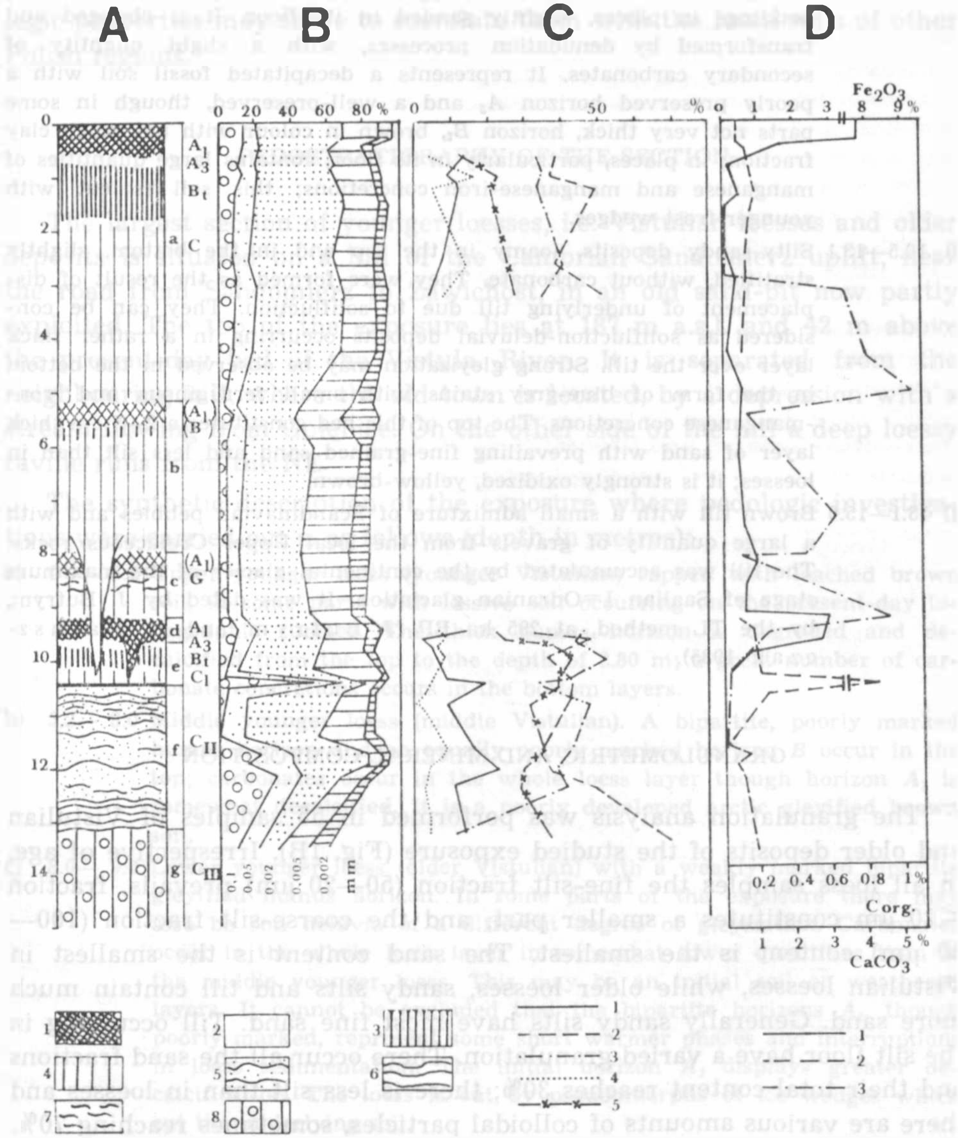


Fig. 1. Stratigraphy and properties of loess in the Sandomierz exposure

A. Pedo-lithological scheme: 1 — horizons A_1; 2 — horizons A_3; 3 — illuvial horizons; 4 — parent rock, loess; 5 — silty-sandy deposits; 6 — loamy silt; 7 — gley horizons; 8 — till. B. Grain size distribution. C. Mineral composition: 1 — amphiboles, pyroxene; 2 — epidotes, garnet, sillimanite, apatite; 3 — zircon, tourmaline, rutile, staurolite, andalusite, disthene, monacite; 4 — muscovite, biotite, chlorite; 5 — opaque minerals. D. Some physico-chemical properties: 1 — total carbon content; 2 — free iron content (Fe_2O_3); 3 — carbonate content loesses, especially in horizon B_t, are more weathered than the younger ones. The least weathered is the sand layer, separating older loesses from silt, and till.

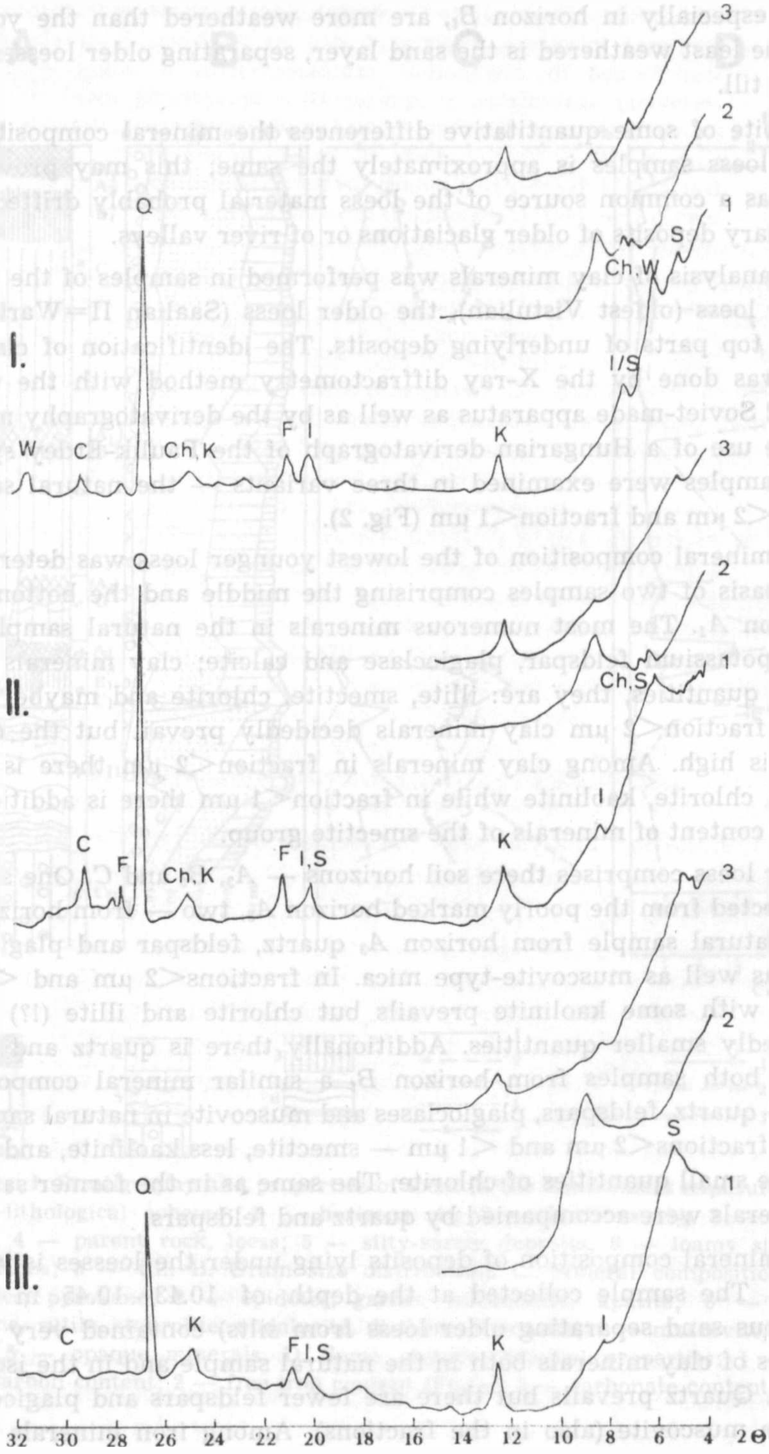
In spite of some quantitative differences the mineral composition of all the loess samples is approximately the same; this may prove that there was a common source of the loess material probably drifted from Quaternary deposits of older glaciations or of river valleys.

The analysis of clay minerals was performed in samples of the lowest younger loess (oldest Vistulian), the older loess (Saalian II=Wartanian) and the top parts of underlying deposits. The identification of clay minerals was done by the X-ray diffractometry method with the use of DRON-2 Soviet-made apparatus as well as by the derivatography method with the use of a Hungarian derivatograph of the Paulik-Erdey system. Seven samples were examined in three variants — the natural sample, fraction<2 μm and fraction<1 μm (Fig. 2).

The mineral composition of the lowest younger loess was determined on the basis of two samples comprising the middle and the bottom part of horizon A_1. The most numerous minerals in the natural sample are: quartz, potassium feldspar, plagioclase and calcite; clay minerals occur in small quantities, they are: illite, smectite, chlorite and maybe, kaolinite. In fraction<2 μm clay minerals decidedly prevail but the quartz content is high. Among clay minerals in fraction<2 μm there is illite, smectite, chlorite, kaolinite while in fraction<1 μm there is additionally a higher content of minerals of the smectite group.

Older loess comprises there soil horizons — A_3, B_t and C. One sample was collected from the poorly marked horizon A_3, two — from horizon B_t. In the natural sample from horizon A_3 quartz, feldspar and plagioclase prevail as well as muscovite-type mica. In fractions<2 μm and <1 μm smectite with some kaolinite prevails but chlorite and illite (!?) occur in decidedly smaller quantities. Additionally there is quartz and feldspars. In both samples from horizon B_t a similar mineral composition occurs — quartz, feldspars, plagioclases and muscovite in natural samples, while in fractions<2 μm and <1 μm — smectite, less kaolinite, and illite. There are small quantities of chlorite. The same as in the former samples clay minerals were accompanied by quartz and feldspars.

The mineral composition of deposits lying under the loesses is visibly different. The sample collected at the depth of 10.43—10.45 m (silty ferruginous sand separating older loess from silts) contained very small quantities of clay minerals both in the natural sample and in the isolated fractions. Quartz prevails but there are fewer feldspars and plagioclases and more muscovite (also in the fractions). Among iron minerals there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is mainly goethite and lepidocrocite, there also occur small quantities of siderite.

A sample from 10.60—10.70 m of depth represents a loamy interbedding within the silty sand. In its natural form it contains — beside clay minerals — large quantities of quartz, feldspars and plagioclase as well as of muscovite. Besides, there occurs hematite and manganese minerals — braunite and, maybe, psilomelane (?). Illite prevails in the clay fractions, there is also much smectite and kaolinite. No chlorite was found.

MICROMORPHOLOGICAL PROPERTIES OF THE PALEOSOL

Micromorphologic investigations were carried out in the middle part of the exposure in horizons A_1, B_t and C of the polycyclic paleosol. In horizon A_1 a silt deposit occurs containing much mullicol and small quantities of silasepic plasma. In the upper part of this horizon large calcite crystals were found in pores (Photo 1). In the lower part of horizon A_1 there occur small spherical iron concretions in the mullicol. Washing of the horizon is also marked. Horizon B_t contains small but numerous agglomerations of vosepictype plasma. There are also iron concretions in the form of (star-like) aggregates (Photo 2). The lower part of horizon B_t contains much crystic plasma (Photo 3) which was formed owing to intensive accumulation of calcium carbonate washed out of younger loesses and deposited in spaces left by roots and pores. The concentric arrangement of silt grains in the concretions (Photo 4) proves that the displacement concerned also carbonates from silt fractions. There can also be observed "flow" structures of saturation of the basic substratum with iron compounds (Photo 5).

The upper part of horizon C, and maybe also horizon BC, contains numerous iron-manganese concretions, while in the lower part there occurs strong saturation with iron compounds. Anisotropic packets of ferruginous-clay plasma can be observed in this layer (Photo 6). They are relicts of vosepic plasma, they underwent subsequent recrystallization which obliterated the primary "stratification" found in that type of plasma. Those packets display a strong tendency to combine with

Fig. 2. X-ray diffractograms of <2 μm fraction (oriented specimens); I — horizon of interstadial soil; II — horizon A_1 of interglacial soil; III — horizon B_t of interglacial soil
1 — natural specimen; 2 — specimen heated at 555°C; 3 — specimen saturated with ethylene glycol; S — smectite, J — illite, K — kaolinite, Ch — chlorite, Q — quartz, F — feldspar, C — calcite, W — vermiculite, J/S — illite/smectite

compounds of iron and manganese displaced from the upper part of the profile. These complex processes lead to the loss of transparence of the packet and the formation of isotic plasma (Photo 7). The accumulation of this plasma may also occur in the surroundings of agglomerations of the ferruginous-clay substance, which results in the formation of irregularly-shaped concretions (Photo 8). Another characteristic of this horizon is the occurrence of single calcite macrocrystals, or even of their agglomerations. They were formed most probably as the result of recrystallization of single calcite microcrystals.

SOME PHYSICO-CHEMICAL PROPERTIES OF SOILS

The sorption capacity of the studied soils and loess deposits shows differences according to granulation, organic substance content and the leaching degree of carbonates. The pH in the whole exposure is strictly correlated with the calcium carbonate content (Fig. 1D, Table 1).

The sorption capacity ranges between 7.1 and 39.4 me/100 g of soil (Table 1). The lowest values are characteristic of older sandy interbeddings, while the highest values occur in humus horizons and layers of a higher content of colloidal particles and carbonates.

The saturation degree with alkalies is very high, it amounts to over 95% and it exceeds 99% in horizons containing more carbonate. Calcium decidedly prevails among basic cations, its content in the soil sorption complex exceeds 60% and in less leached horizons it reaches 88%. The part of exchangeable Mg in the sorption complex is much smaller and ranges from 7 to 32%; there is frequently more Mg in horizons containing less calcium. Exchangeable Na and K occur in small quantities rarely exceeding 0.5 me/100 g of soil, i.e. 2.5% in the sorption complex.

In conditions of neutral pH in decalcified horizons or of slightly basic pH in the other ones exchangeable H occurs in small quantities. Soil-forming processes brought about the acidification of the upper soil horizons which can be best observed in the Holocene soil. In the middle part of the exposure secondary carbonates displaced from the overlying younger loesses caused the deacidification of the soil horizons.

In all three closely studied sites (Fig. 1D) the so-called free iron was determined using Jackson's method. The mobilization, displacement and accumulation of this component characterise the genetic horizons and indicate a soil-forming process. The greatest displacement of iron in the Sandomierz exposure, from the upper horizons to horizons B_t takes place in profile 1, the least — in profile 3. Profile 6, where the studied soil occurs on the present-day surface, shows intermediate values. The dis-

Table 1. Some physico-chemical properties of soils in the loess section at Sandomierz

Genetic horizon	Depth acc. to synthetic description	pH		Hydrolytic acidity H_h	Exchangeable cations				Alkali sum $Ca^{2+}+Mg^{2+}+K^{+}+Na^{+}$	Sorption capacity $T = S+H_h$	Base saturation degree $V_s=\frac{S}{T}\cdot 100$
		H_2O	KCl		Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}			
	cm			me / 100 g of soil							%
A_1	5 - 30	6.56	5.86	1.20	13.00	1.63	0.25	0.19	15.07	16.27	92.62
A_3	40 - 60	7.81	6.78	0.64	16.20	1.64	0.35	0.25	18.44	19.08	96.64
B_t	60 - 90	7.98	7.29	0.45	13.40	1.26	0.26	0.19	15.11	15.56	97.11
B_t	90 - 100	7.80	7.20	0.52	13.50	1.41	0.28	0.21	15.40	15.92	96.73
C	120 - 135	7.64	6.98	0.60	11.00	1.31	0.25	0.21	12.77	13.37	95.51
	150 - 160	8.04	7.20	0.41	9.50	1.16	0.19	0.18	11.03	11.44	96.42
	250 - 260	7.63	7.00	0.56	9.50	1.67	0.29	0.18	11.64	12.20	95.41
	300 - 320	7.95	7.40	0.45	27.90	4.90	0.35	0.42	33.57	34.02	98.68
	400 - 450	7.92	7.49	0.41	27.90	3.92	0.45	0.47	32.74	33.15	98.76
A_1	510 - 530	8.28	7.65	0.37	31.00	3.57	0.27	0.51	35.35	35.72	98.96
(B)	540 - 580	8.20	7.41	0.34	31.70	4.44	0.32	0.50	36.96	37.30	99.09
	600 - 620	8.24	7.61	0.26	27.10	4.41	0.25	0.40	32.16	32.42	99.20
$(A_1)G$	810 - 815	8.31	7.60	0.22	17.20	6.82	0.26	0.48	24.76	24.98	99.12
A_1	910 - 920	7.94	7.00	0.52	32.80	5.00	0.39	0.68	38.87	39.39	98.68
A_1	925 - 935	8.05	7.01	0.45	25.45	5.25	0.39	0.54	31.63	32.08	98.60
A_1	937 - 950	8.02	7.03	0.45	20.00	5.41	0.36	0.46	26.24	26.69	98.31
A_3	955 - 965	7.85	6.90	0.49	19.15	6.40	0.46	0.47	26.48	26.97	98.18
B_t	980 - 990	7.96	6.97	0.45	17.90	6.07	0.43	0.42	24.82	25.27	98.22
C	1020 - 1030	8.04	7.14	0.49	10.15	3.61	0.28	0.16	14.19	14.68	96.66
	1035 - 1050	8.04	7.20	0.37	6.00	2.46	0.17	0.07	8.70	9.07	95.92
	1050 - 1052	8.00	7.41	0.49	7.60	2.30	0.13	0.09	10.12	10.61	95.38
	1067 - 1077	7.96	7.01	0.37	8.65	3.94	0.26	0.11	12.96	13.33	97.22
	1120 - 1130	8.02	7.02	0.45	11.50	4.51	0.35	0.16	16.52	16.97	97.35
	1150 - 1160	8.00	6.96	0.37	7.50	3.69	0.28	0.10	11.56	11.93	96.90
	1165 - 1175	8.00	7.09	0.37	5.40	3.03	0.19	0.06	8.68	9.05	95.91
	1190 - 1200	7.97	7.09	0.41	4.50	1.97	0.18	0.05	6.70	7.11	94.23
	1250 - 1260	7.92	7.01	0.49	9.50	3.94	0.31	0.12	13.86	14.35	96.59
	1315 - 1340	7.71	6.60	0.56	16.70	8.61	0.78	0.26	26.35	26.91	97.92

placement of colloidal fractions from top horizons to horizons B_t proceeds in the same way in the studied profiles.

The fractionation analysis of organic matter was carried out in the genetic horizons of the soil complex, in profiles 1 and 3. Fossil horizon A_1 is covered by one meter of younger loesses in profile 1 (southwesternmost part of the section) and by several meters in profile 3 (middle part of the section). Duchaufour and Jacquin's method was used to isolate the organic fractions and Tiurin's method — to determine the content of organic carbon in the particular fractions. The results of the fractionation analysis of organic matter show a spatial differentiation of the soil due to varying conditions of its formation in the studied catena (profile 1 is situated higher on the fossil slope) as well as to different conditions created by the overlaying loess layer of various thickness.

In all the studied horizons of both soils the organic matter consists

Table 2. Carbon content in different fractions of organic matter of fossil soil complex at Sandomierz: chernozem (A_1) and truncated lessivé soil (A_1 and B_t)

Profile No	Genetic horizon	Depth cm	Weight per cent in relation to total C		Total C %	Per cent of carbon in relation to soil		In per cent of total C	
			light fraction	heavy fraction		light fraction	heavy fraction	light fraction	heavy fraction
1	A_1	70 - 110	0.38	99.62	0.377	0.105	0.272	27.9	72.1
	B_t	120 - 170	0.11	99.89	0.157	0.024	0.133	15.3	84.7
3	A_1	910 - 920	0.23	99.77	0.600	0.069	0.531	11.5	88.5
	A_1	925 - 935	0.32	99.68	0.550	0.086	0.464	15.6	84.4
	A_1	937 - 950	0.26	99.74	0.436	0.037	0.399	8.5	91.5
	A_3	955 - 965	0.24	99.76	0.283	0.034	0.249	12.0	88.0
	B_t	980 - 990	0.11	99.89	0.145	0.002	0.143	1.4	98.6

mainly of the heavy fraction (Table 2) which contains humified organic compounds. The content of the light fraction is then very small and amounts to ca 0.5%, its content is higher in horizons A_1 and lower in horizons B_t. In the heavy fraction of horizon A_1 there is a total of 72% of C in profile 1 and 84–91% in profile 3. The same tendency could be observed in horizons B_t. The humification process is less advanced in profile 1 because some more C occurs in the light fraction than in the corresponding horizons of profile 3. Those small differences may result from changes of the local conditions in which the soil of both sites

Table 3. Content of different forms of organic compounds in fossil soil complex at Sandomierz: chernozem (A_1) and truncated lessivé soil (A_1 and B_t) by the method of Ph. Duchaufour and F. Jacquin

Profile No	Genetic horizon	Depth cm	Total C %	Distribution in % of total carbon											
				light fraction					heavy fraction						
				I-st extr.		II-nd extr.			I-st extr.		II-nd extr.		III-rd extr.		humines
				F_1	H_1	F_2	H_2	R	F_3	H_3	F_4	H_4	F_5	H_5	H
1	A_1	70-110	0.377	-	-	-	-	27.9	8.2	2.9	1.3	12.2	0.5	6.1	40.9
	B_t	120-170	0.157	-	-	-	-	15.3	16.5	0.0	0.6	5.2	1.3	3.2	57.9
3	A_1	910-920	0.600	-	-	-	-	11.5	19.3	5.7	7.8	12.0	4.5	7.7	31.5
	A_1	925-935	0.550	-	-	-	-	15.6	20.4	7.3	6.7	19.5	0.2	9.4	29.9
	A_1	937-950	0.436	-	-	-	-	8.5	25.5	11.2	17.0	22.9	0.5	6.4	8.0
	A_3	955-965	0.283	-	-	-	-	12.0	33.6	2.5	1.4	8.5	3.5	6.7	31.8
	B_t	980-990	0.145	-	-	-	-	1.4	46.2	5.5	5.5	9.7	1.4	13.1	17.2

$F_{1 \ldots 5}$ - fulvic acids; $H_{1 \ldots 5}$ - humic acids; R - "residuum" constituting a non-extracted part of the light fraction; humines - non-extracted part of the heavy fraction; I-st extraction - $Na_4P_2O_7$ + Na_2SO_4 solution with pH = 7; II-nd extraction - $Na_4P_2O_7$ solution with pH = 9.8; III-rd extraction - 0.1N NaOH solution

Table 4. Total content of different humus compound forms and the values characteristic for humification in fossil soil complex at Sandomierz: chernozem (A_1) and truncated lessivé soil (A_2 and B_t)

Profile, No	Genetic horizon	Depth cm	Total C %	C of fulvic and humic acids, humines and residuum in % of total C				Ration $C_h : C_f$	Humification degree
				fulvic acids C_f	humic acids C_h	R	humines		
1	A_1	70 - 110	0.377	10.0	21.2	27.9	40.9	2.12	72.1
	B_t	120 - 170	0.157	20.4	6.4	15.3	57.9	0.31	84.7
3	A_1	910 - 920	0.600	31.6	25.4	11.5	31.5	0.80	88.5
	A_1	925 - 935	0.550	27.3	36.2	15.6	20.9	1.33	84.4
	A_1	937 - 950	0.436	43.0	40.5	8.5	8.0	0.94	91.5
	A_3	955 - 965	0.263	38.5	17.7	12.0	31.8	0.46	88.0
	B_t	980 - 990	0.145	53.1	28.3	1.4	17.2	0.53	98.6

remained during the whole Vistulian. It cannot be excluded that the thin layer of younger loesses overyling profile 1 facilitated the inflow of a certain quantity of fresh, less humified organic matter. The ratio of humic acids to fulvic acids in horizon A_1 profile 1 is much higher than in horizon A_1 profile 3, which indicates a somewhat higher polymerization of humic acids in profile 1 (Table 3 and 4). Stronger leaching (connected with a more intensive migration of fulvic acids) in profile 1 is manifested by a lower ratio of humic acids to fulvic acids in horizon B_t as compared with horizon B_t of profile 3.

It should be noticed that horizon A_1 in the soil of profile 3 is tripartite. The succesive layer of this horizon differ in the ratio of humic to fulvic acids and in the humification degree (Table 4), and this fact seems to confirm the suggestion that this horizon was formed in rather differentiated circumstances.

The varying quantity of humines — organic compounds bound with the mineral part of the soil — proves that horizons A_1 are heterogenous.

RECAPITULATION

The pedostratigraphy of fossil soils has been based, in the first place, on the formation and occurence of diagnostic soil horizons. The features of indicator horizons of selected soil types were defined precisely with biological, physico-chemical and micromorphologic numerical indices in a wide range, including fractionation of organic matter (K. Konecka-

-Betley 1974). Investigations on the distribution and transformations of organic matter have allowed to state precisely the whole of ecologic conditions which occurred during the formation of ecosystems of that time. Other authors characterize fossil soils of loess areas in a similar way (W. Chmielewski et al. 1977, K. Konecka-Betley and H. Maruszczak 1976, K. Konecka-Betley and K. Straszewska 1977, K. Konecka-Betley — in press, A. Bronger 1979, S. Uziak 1979).

The prevailing and best analysed soil in the Sandomierz section is the fossil soil complex: destroyed lessivé forest soil or brown leached forest soil formed from older loess and typical chernozem occurring in its top, formed from the lowest younger loess with a large admixture of weathered and redeposited older loess. The physico-chemical properties indicate an Eemian Interglacial, lessivé or brown leached forest soil, according to the microrelief, with a well developed argillic or cambic diagnostic horizon. A characteristic feature of this soil is the enrichment of horizon B_t in free iron and colloidal fractions as compared with the overlying horizons. Minerals of the smectite group and, in smaller quantities, illite and kaolinite prevail in this horizon. The similar results were obtained for Eemian soils by A. Bronger (1979), S. Uziak (1977, 1979), L. Stoch et al. (1982).

Chernozem constitutes the overlying younger soil in the complex; the layer undergoing the chernozem process is bipartite or even tripartite. The different fractions in the humus of three layers of horizon A_1 suggest the connection with warmer periods of early Vistulian (Amersfoort—Brörup) or with the last interglacial period sensu lato interpreted. The interglacial character of this horizon may be proved by the large quantity of the clay fraction and a three times as large quantity of humines in its top as in its lowest part. The accumulation of humus was due to steppe or meadow-steppe vegetation. Horizon A_1 of the profile 1 and the middle part of horizon A_1 of the profile 3 have the C_h:C_f ratio$>$1 with a prevalence of humic acids over fulvic acids which is typical of chernozem (F. Kuźnicki and P. Skłodowski 1970). There are also more humines, organic compounds strongly bound with the mineral part of the soil and with alkaline reaction. The lower part of horizon A_1 of the profile 3 has similar properties but three times less humines. It may be a horizon partially developed on deluvia of the horizon A_1 of destroyed lessivé forest soil. The transformation process of organic matter is more advanced than in the other, formerly studied loessy paleosols of similar age (K. Konecka-Betley 1974).

Soils formed from middle and lower younger loesses are less developed in the investigated exposure and have not always been preserved.

Their characteristic feature is the occurrence of small quantities of carbon, the declacification of humus horizons, poorly or not at all developed illuvial horizons, pseudogleyization and a lower degree of weathering of primary minerals. Generally their horizon A_1 is bipartite. Those are interstadial soils: younger — brown subarctic soil and older — gley soil. The holocen soils developed from upper younger loess are represented by lessivé and brown leached soils.

Micromorphologic properties show that there were several developmental phases of the studied fossil soil complex. The process of lessivage, with vosepic-type plasma, began after the climatic optimum of the Eemian period. While the climate was growing cooler there occurred a process of pseudogleyization with iron-manganese-clay concretions. The displaced iron and manganese gradually saturated packets of vosepic plasma which resulted in the formation of recrystallized vosepic plasma with iron and manganese components occurred probably in cold climate, maybe even in conditions of permafrost. A continuous loamy layer favouring the periodic stagnation of water has played an important role in the formation of iron-manganese concretions in the profile. It intensified the process of pseudogleyization. The secondary displacement of carbonates took place in the horizons of the destroyed lessivé forest soil, capped by younger chernozem soil developed from the lowest younger loess. This secondary process contributed to the formation, in horizon B_t, of crystic-type plasma and large calcite crystals found mainly in the mullicol horizon. This is horizon A_1 of chernozem overlaid much later on the destroyed upper horizons of lessivé soil and on the newly-drifted lowest younger loess.

Thermoluminescence dating of some horizons of the studied exposure (J. Butrym and H. Maruszczak 1985) allowed to state the age of the mineral material of soils. The upper part of horizon A_1 of chernozem was dated in ka BP at 128.0 ± 19.0 (Lub—665) and its lower part — at 142.0 ± 21.0 (Lub—666). Instead, the illuvial-argillic horizon B_t — at 171.0 ± 25 (Lub—667).

The course and intensity of pedogenetic processes in the considered fossil soils depended on the macro- and mainly microrelief, the exposition, the occurrence of ground water and its movements, the destruction of the soil surface horizons in cold periods. The above named factors brought about the differentiation of vegetation, mainly of the undergrowth and thus caused typologic differences of soils. Further transformation of the soil was also due to secondary carbonates the displacement of which from younger to older loesses occurred after the deposition of lower Vistulian loesses. This took place when the polycyclic Eem/Amersfoort/Brörup soil was already well developed.

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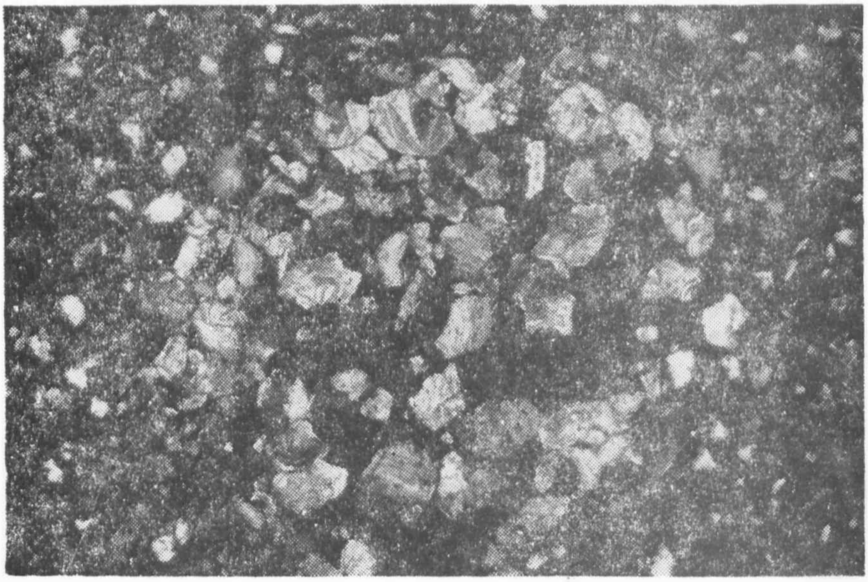

Photo 1. Calcite crystals in large pores, formed through recrystallization of carbonate; magn. 72×, crossed nicols. Horizon A_1 of profile 3

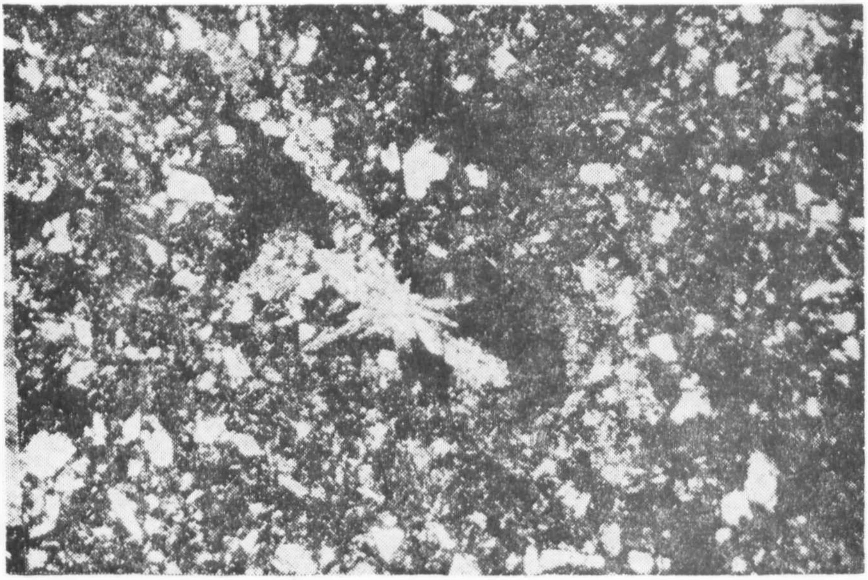

Photo 2. Carbonate in the form of radiate aggregates; magn. 72×, crossed nicols. Horizon A_1 of profile 3

K. Konecka-Betley, D. Czępińska-Kamińska, Z. Zagórski

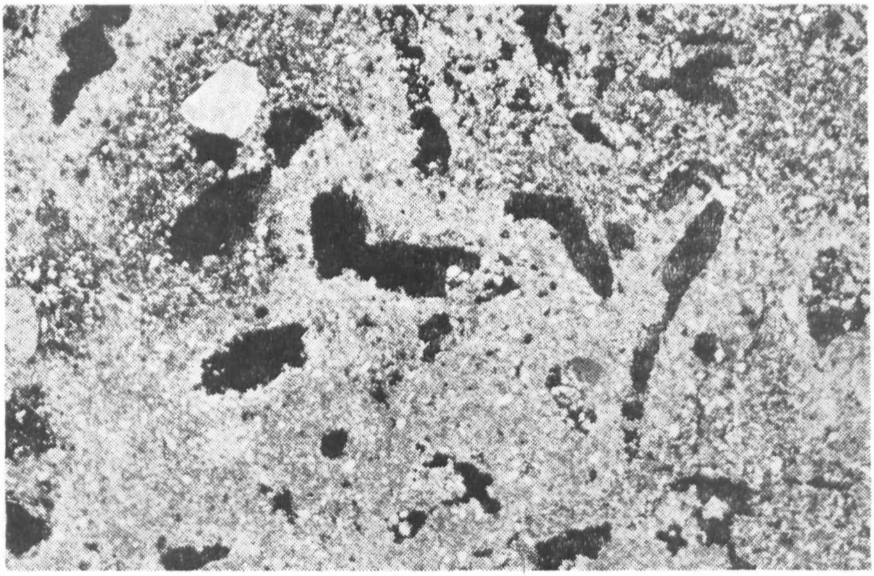

Photo 3. Crystic-type plasma developed as result of intensive accumulation of carbonates in spaces; magn. 24×, crossed nicols. Horizon B_t of profile 3

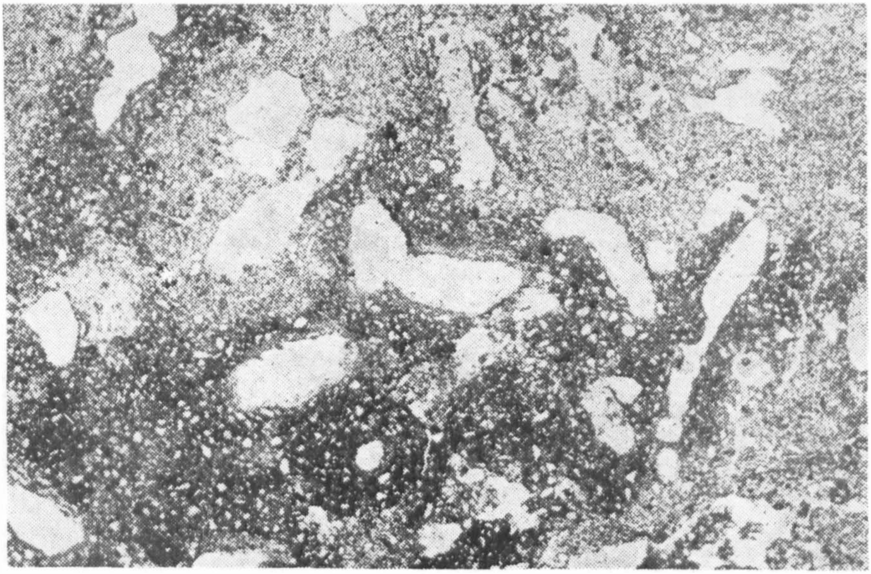

Photo 4. Concentric arrangement of silt grains in concretions; magn. 24×, parallel nicols. Horizon B_t of profile 3

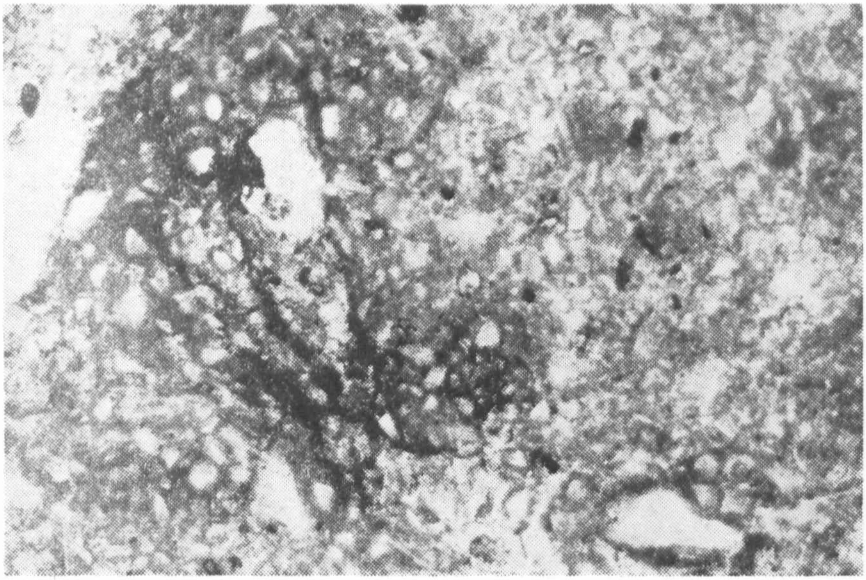

Photo 5. Flow structures of saturation with compounds of iron and, maybe, of manganese; magn. 72×, parallel nicols. Horizon B_tC of profile 3

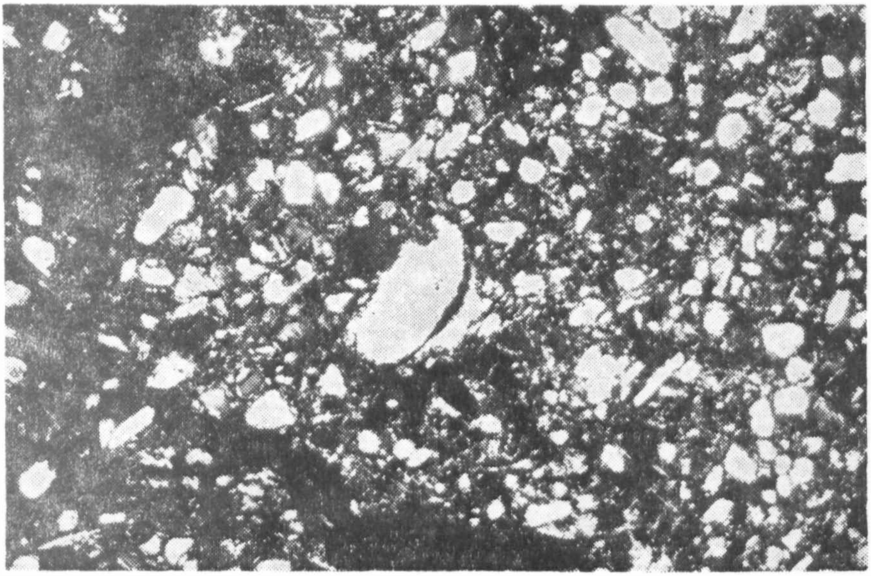

Photo 6. Relicts of vosepic plasma, recrystallized; magn. 72×, crossed nicols. Horizon B_tC of profile 3

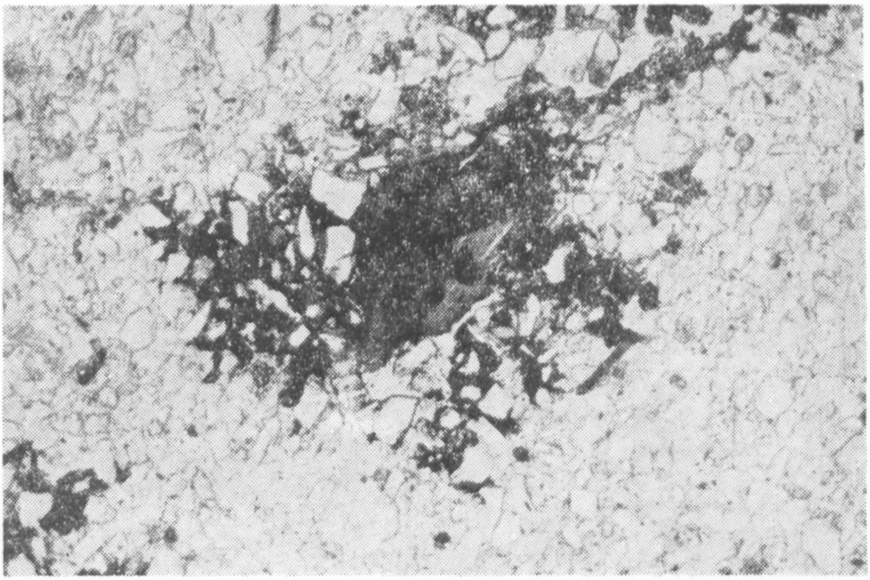

Photo 7. Opaque, isotic-type plasma; magn. 72×, parallel nicols. Horizon C of profile 3

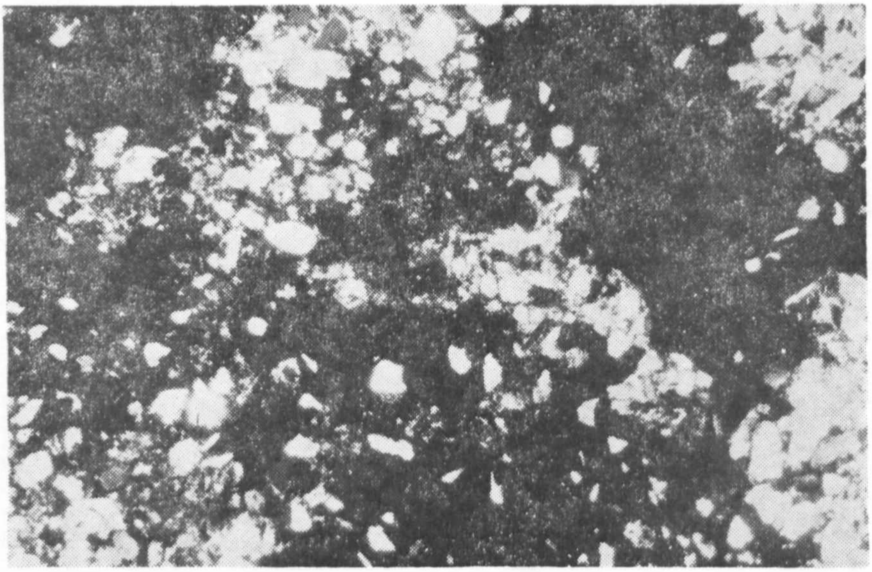

Photo 8. Accumulation of isotic plasma near agglomerations of ferruginous-clayey substance; magn. 72×, parallel nicols. Horizon C of profile 3

STRESZCZENIE

Badano kopalną katenę glebową w odsłonięciu lessów w Sandomierzu. Pedostratygrafię ustalono na podstawie analizy wykształcenia poziomów gleb kopalnych różnego wieku. Cechy poziomów przewodnich poszczególnych gleb uściślono wskaźnikami fizyczno-chemicznymi i mikromorfologicznymi, łącznie z oznaczaniem minerałów ilastych i ciężkich. W odsłonięciu zwraca uwagę przede wszystkim kompleks glebowy z Eemianu i wczesnego Vistulianu. Reprezentowany on jest przez ogłowioną glebę płową leśną lub miejscami brunatną wyługowaną, wytworzoną z lessu starszego (prawdopodobnie ze zlodowacenia Wartanian) oraz przez występujący w jej stropie typowy czarnoziem wytworzony z lessu młodszego najniższego (najwcześniejszy Vistulian). Właściwości fizyczno-chemiczne i mikromorfologiczne wskazują, że gleba leśna powstała w warunkach interglacjalnych. Jest ona wykształcona przeważnie jako płowa z poziomem diagnostycznym argillic lub poziomem wietrzenia cambic. Cechą charakterystyczną tej kopalnej, ogłowionej gleby płowej jest wzbogacenie poziomu B_t w żelazo wolne i frakcję koloidalną oraz występowanie minerałów ilastych z grupy smektytów. Młodszy od gleby leśnej, nadległy czarnoziem rozwijał się pod roślinnością stepową lub łąkowo-stepową. Różny skład frakcyjny próchnicy w poziomie A_1 tej gleby sugeruje trzy lub dwie fazy jej powstawania. W południowo-zachodniej części odsłonięcia (profil 1) próbka z poziomu A_1, a w centralnej części (profil 3) środkowa próbka z tego poziomu wykazuje stosunek $C_h : C_f$ powyżej 1, świadczący o przewadze kwasów huminowych nad fulwowymi, który jest typowy dla czarnoziemów. Górna próbka z poziomu A_1 w profilu 3 wykazuje także duże nagromadzenie humin, części organicznych związanych z mineralnymi — głównie z minerałami ilastymi. Proces transformacji substancji organicznej jest bardziej zaawansowany niż w analogicznych glebach zbadanych w innych profilach lessowych.

Właściwości mikromorfologiczne uściślają obraz następstwa procesów glebotwórczych w okresie powstawania kompleksu glebowego. Proces lessivage zaznacza się w poziomie B_t dobrze wykształconą plazmą vosepic, która w okresie późniejszym przeobraziła się w nieprzezroczystą plazmę typu isotic w wyniku przemieszczenia żelaza i manganu. Po osadzeniu się lessów młodszych najniższych i powstaniu czarnoziemu nastąpiło wtórne przemieszczenie węglanów do poziomów niższych. Powstała w nich wtedy plazma typu cristic. Datowanie metodą termoluminescencyjną wybranych poziomów glebowych (J. Butrym i H. Maruszczak 1985) określa wiek substratu mineralnego gleb. Dla poziomu A_1 czarnoziemu, dla próbki z górnej jego części uzyskano tą metodą wiek 128 ka, a dla próbki z części dolnej 142 ka. Wiek próbki z poziomu B_t gleby leśnej wynosi 171 ka.

Gleby młodsze wytworzone z lessów vistuliańskich w badanym odsłonięciu są słabiej wykształcone i nie zawsze dobrze zachowane. Charakteryzuje je odwapnienie, słabe wykształcenie lub brak poziomów iluwialnych, odgórne oglejenie i słabe oznaki wietrzenia minerałów pierwotnych. Są to gleby interstadialne typu subarktycznego, rozdzielające lessy młodsze dolne, środkowe i górne.

РЕЗЮМЕ

Исследовались ископаемые почвы в разрезе лёссов в г. Сандомир. На основании анализа почвенных горизонтов разработанная педостратиграфическая схема этого разреза. Свойства основных горизонтов отдельных почв определено на основании результатов анализа физико-химических и микроморфологических свойств, а также состава глинистых и тяжелых минералов. В разрезе выделяется прежде всего почвенный комплекс из времени эемского межледниковия и ранних этапов последнего, значит вислинского оледенения. Составляют его две почвы: псевдоподзолистая с эродированными верхними горизонтами или бура лесная выщелоченная — развиты из древнего лёсса (вероятно из оледенения Варты=Москвы) и прикрывающая их с верху черноземная, сформированная на слоях самого нижнего молодого лёсса (из раннего времени оледенения Вислы = Валдайского). Физико-химические и микроморфологические свойства свидетельствуют, что лесная почва образовалась в межледниковых условиях. Это главным образом псевдоподзолистая почва с диагностическим горизонтом B_t с плазмой типа argillic или горизоном выветривания типа cambic. Для этой псевдоподзолистой почвы характерно обогащение горизонта B_t свободным железом и коллоидами, а тоже присутствие глинистых минералов типа смектитов. Верхнюю, моложе лесной почвы, часть комплекса составляет чернозем образованный под степной или лугово-степной растительностью. Различия группового состава гумуса в горизонте A_1 этой почвы свидетельствуют о трех или двух фазах ее развития. В найболее юго-западной части разреза (профиль 1) образец из горизонта A_1, а в центральной части (профиль 3) образец из средней части этого горизонта отличаются соотношением $C_h : C_f$ выше 1, свидетельствующим о преобладании гуминовых кислот над фульвокислотами, характерным для черноземов. Образец из верхней части горизонта A_1 в профиле 3 отличается значительным накоплением гумин, значит органического вещества связанного с минеральным, главным образом с глинистыми минералами. Степень трансформации органического вещества более высокий чем в сходных почвах исследованных в других лёссовых разрезах.

Микроморфологические свойства использовались для более детального определения последовательности явлений во время образования почвенного комплекса. О развитии процесса лёссиважа в горизонте B_t свидетельствует хорошо развита плазма типа vosepic, которая последовательно преобразовывалась — в следствие перемещений железа и марганца в непрозрачную плазму типа isotic. После накопления самых нижних слоев молодых лёссов и с образованием чернозема наступало вторичное перемещение карбонатов в нижние горизонты почвенного комплекса. Тогда образовалась в них плазма типа cristic. Термолюминисцентные датировки образцов из некоторых горизонтов (J. Butrym и H. Maruszczak 1985) определяют возраст минеральной основы почв. Из горизонта A_1 чернозема образец верхний имеет возраст 128 тыс. лет, а нижний 142 тыс. лет.

Более молодые почвы среди лёссов вислинского оледенения в исследованном разрезе развитые плохо и всегда хорошо сохраненные. Отличаются они декарбонатизацией, слабым развитием или отсутствием иллювиальных горизонтов, верхним оглеением и слабыми признаками выветривания первичных минералов. Это интерстадиальные почвы субарктического типа, разделяющие лёссы молодые нижние, средние и верхние.