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LATE GLACIAL AND HOLOCENE STRATOTYPE PROFILE OF PALAEOSOLS IN THE WARSAW BASIN

Krystyna Konecka-Betley, Elżbieta Janowska

Department of Environmental Sciences, Division of Soil Science, Warsaw Agricultural University, Nowoursynowska Street 159, 02-776 Warsaw, Poland, e-mail: janowska@delta.sggw.waw.pl

Abstract

Palaeosols from the Warsaw Basin developed from eolian sands and aqueous deposits are distinguished as pedostratigraphic units of the Quaternary. They were typologically determined as type soils for the study area based on the succession of genetic-diagnostic horizons for the particular soil types. Two partial profiles were analysed – in Cięciwa and in Wiązowna Piekiełko, which were later considered as a composite stratotype of palaeosols in the Warsaw Basin. Both partial profiles allow recognising old aqueous processes and slightly younger eolian processes characteristic for the Oldest, Older and Younger Dryas Phase, as well as the pedogenetic processes taking place during warming stages in the terminal Late Vistulian and Holocene. Based on the analyses, five palaeosol horizons were distinguished within the Warsaw Basin. The oldest ones are represented by humus-gley soils developed from Pleistocene agueous deposits of the Epe Interphase and the initial soil from the Bölling Interphase developed from aeolian sands of the Oldest Dryas Phase. The third soil is represented by a poorly developed podzolized soil from the Alleröd developed from sands of the Older Dryas. Sands of the Younger Dryas were capped in the Holocene by a rusty soil from the Boreal Phase, which was recognised in both profiles. From the same sands undergoing continuous blowing out, or as a continuation of the rusty soil, a ferruginous podzol or ferruginous-humus podzol developed during the Atlantic Interphase. In depressions the podzol is in some cases capped by a thin peat. The stratotype profile is distinguished as a reference profile and the base for comparison with analogous horizons in Central Poland.

Key words: fossil soil, composite stratotype, Late Vistulian, Holocen, aeolian and agueous deposits

INTRODUCTION

The typological distinguishing of palaeosols in the Warsaw Basin is based on morphological, physical-chemical and partly micromorphological criteria. In turn, the age of the organic matter in palaeosols from different stratigraphic intervals is determined by radiocarbon analysis.

Several partial profiles of palaeosols were analysed on both banks of the Vistula River. After a detailed analysis, two of them were selected for a composite stratotype characterising the Warsaw Basin. They include the exposures in sand dunes in Cięciwa and in dunes and silty alluvia in Wiązowna Piekiełko. Different methods were applied to distinguish the stratigraphic units in the study area (Kobendzina 1961, Baraniecka 1982a, b, Borówko-Dłużakowa 1983, Pazdur 1983, Baraniecka & Konecka-Betley 1987, Konecka-Betley 1974, 1982, 1991, Manikowska 1985, 1992, Schild 1982, Madeyska 1995, Dzierwa & Mycielska-Dowgiałło 2003, Janowska unpubl.).

The similar succession of palaeosol types in exposures of dune sands, best preserved in Cięciwa and Wiązowna Piekiełko allows us to consider them as stratotype profiles for the vicinity of Warsaw. Based on them, the alluvial and dune-forming processes of the Oldest, Older and Younger Dryas can be recognised. They also document the pedogenetic processes taking place during the interstadials or in the particular phases of the Late Glacial and Holocene. The stratotype profiles are also the base for comparison and pedostratigraphic correlation of the entire central Poland (Konecka-Betley 2001).

The analysed data give insight into the changes within the natural environment in the Warsaw Basin in the Late Vistulian and Holocene, that is during the last 15 000 years of the Quaternary.

DUNE STRATIGRAPHY AND LITHOLOGY OF EXAMINED PROFILES

The composite stratotype profile of palaeosols in the Warsaw Basin comprises partial profiles exposed in Cięciwa and Wiązowna Piekiełko (Fig. 1).

The Cięciwa site is located in the frontal part of a dune crescent within the postglacial plateau (Nowak 1976), composed of till from the Warta Glacial of the Central Polish Glaciation. The cover of the Warta till is not continuous. Ice-dammed clays and silts separate it from the older till of the Odra Glacial. The plateau in Cięciwa is cut by small val-

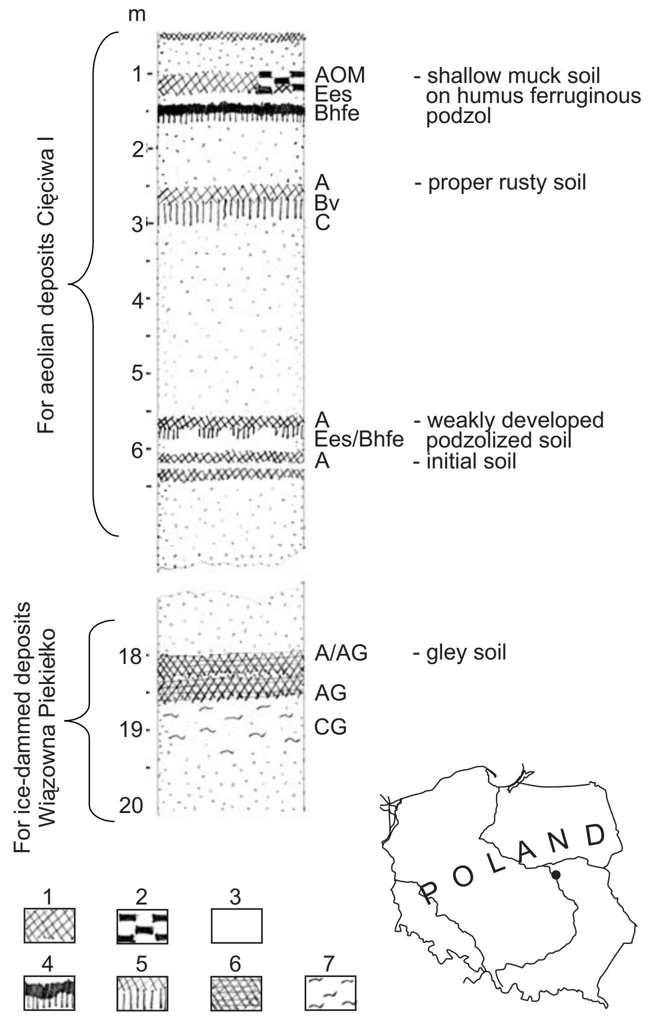


Fig. 1. Composite stratotype profile of palaeosols in the Warsaw Basin. *1* – humus horizon A; *2* – peat; *3* – elluvial horizon Ees; *4* – illuvial horizon B, with subhorizons Bh and Bfe; *5* – weathered horizon Bv and A; *6* – oldest humus horizon A; *7* – gley horizon G. The map shows location of the studied sites in Poland.

leys of the Długa River, which drain off water towards the Warsaw Basin. Dune sands of this exposure lie either on fluvial sands or directly on the till of the Warta Glacial of the Central Polish Glaciation (Figs 1, 2 A–C).

Description of the Cięciwa I site profile:

0.00–1.00 m – anthropogenic dune series with initial soil in the topmost part, partly undergoing blowing out; in some cases thickness reaches 2.00 m;

1.00–1.15 m – OM – dark grey mucky peat, with three intercalations of 1–2 mm sand beds; bottom of peat ^{14}C dated at 6155±270 BP (Lod-31); C_{org} content 27.1%, pH 3.4;

1.15–1.20 m – A – dark grey organic accumulation horizon, poorly decomposed, poorly clayey sand, C_{org} content 1.16%, pH 3.4; developed from blown out sands of the Younger Dryas or sands from the Preboreal period;

1.20–1.30 m – AEes –accumulation-elluvial horizon, grey, passing downwards into light grey, poorly clayey sand, C_{org} content 0.32%, pH 3.3;

1.30–1.40 m – Ees – white elluvial horizon, loose sand, C_{org} content 0.32%, pH 3.5;

1.40–1.50 m – Bh – brown illuvial-humus horizon, occasionally with ferruginous concretions or even ortstein with considerable content of free iron (in comparison to the overlying horizons), poorly clayey sand, C_{org} content 1.55%, pH 4.2, ^{14}C dated at 7150±350 BP (Lod-47);

1.50–1.60 m – Bfe – poorly marked illuvial horizon, light brown in colour, with low iron content, loose sand, C_{org} content 0.31%, pH 4.4;

1.60–2.50 m – C – yellow parent rock, loose sand, pH 4.5 (in some exposures of this site the Bv horizon occurs at 2.00 m);

2.50–2.70 m – A – accumulation horizon with charcoals, developed from sand of the Younger Dryas; ^{14}C dated at 8770±110 BP (Gd-2407);

2.70–3.00 m – Bv – sideric horizon, poorly clayey sand, in some cases loose;

3.00–5.60 m – C – (in some cases down to 5.80 m) yellow parent rock, loose dune sand from the Younger Dryas, most probably blown out;

5.60–5.70 m – A – humus accumulation horizon, very poorly developed in form of grey spots and streaks, developed from sand of the Older Dryas, containing in some cases charcoal, C_{org} content 0.16%, pH 3.8; charcoals in this horizon ^{14}C dated at 11150±130 years BP (Lod-30);

5.70–5.85 m – Ees/Bhfe – poorly developed elluvial-illuvial horizons in form of discontinuous, brown-white spots in different parts of the exposure;

5.85–6.15 m – C – light yellow horizon of loose sands from the Older Dryas;

6.15–6.50 m (in some cases 6.70 m) – A – two humus horizons, 5–10 cm thick, separated by a 15 cm sand layer, ^{14}C dated at 12030±160 BP (Gd-2406) and 12150± 270 BP (Gd-2405), soils from the Bölling Interstadial developed on a dune from the Oldest Dryas.

The analysed dune in Wiązowna Piekiełko is located in the marginal part of the postglacial plateau lying adjacent the eastern part of the Warsaw Basin (Nowak 1976, Baraniecka 1973). The plateau is cut by valleys of Świder and Mienia and other smaller rivers. Plateau deposits are typically washed out and the younger ones are partly removed; in this case deposits of the older Glacial (Odra) of the Central Polish Glaciation are exposed. The described site lies in the main part of the dune crescent. The thickness of dune sands reaches here 18 m. In the basement two silty-clayey horizons lie separated by sand up to 70 cm thick. These deposits represent either the Pleistocene lake margin or old river muds. A humus horizon is developed in their upper part. A dune with a well-developed Atlantic relict podzol in its uppermost part covers this horizon (Figs 1, 2 D–F).

Description of the Wiązowna Piekiełko site profile:

0.00–0.03 m – O – ectohumus horizon, mor type, poorly decomposed;

0.03–0.20 m – AEes – humus accumulation horizon with slightly marked elluvial processes, loose sand, pH 3.1; this horizon represents the relict horizon of Atlantic podzol developed from sands of the Younger Dryas, blown out during the Preboreal;

0.20–0.35 m – Ees – light grey elluvial horizon, loose sand, pH 3.4;

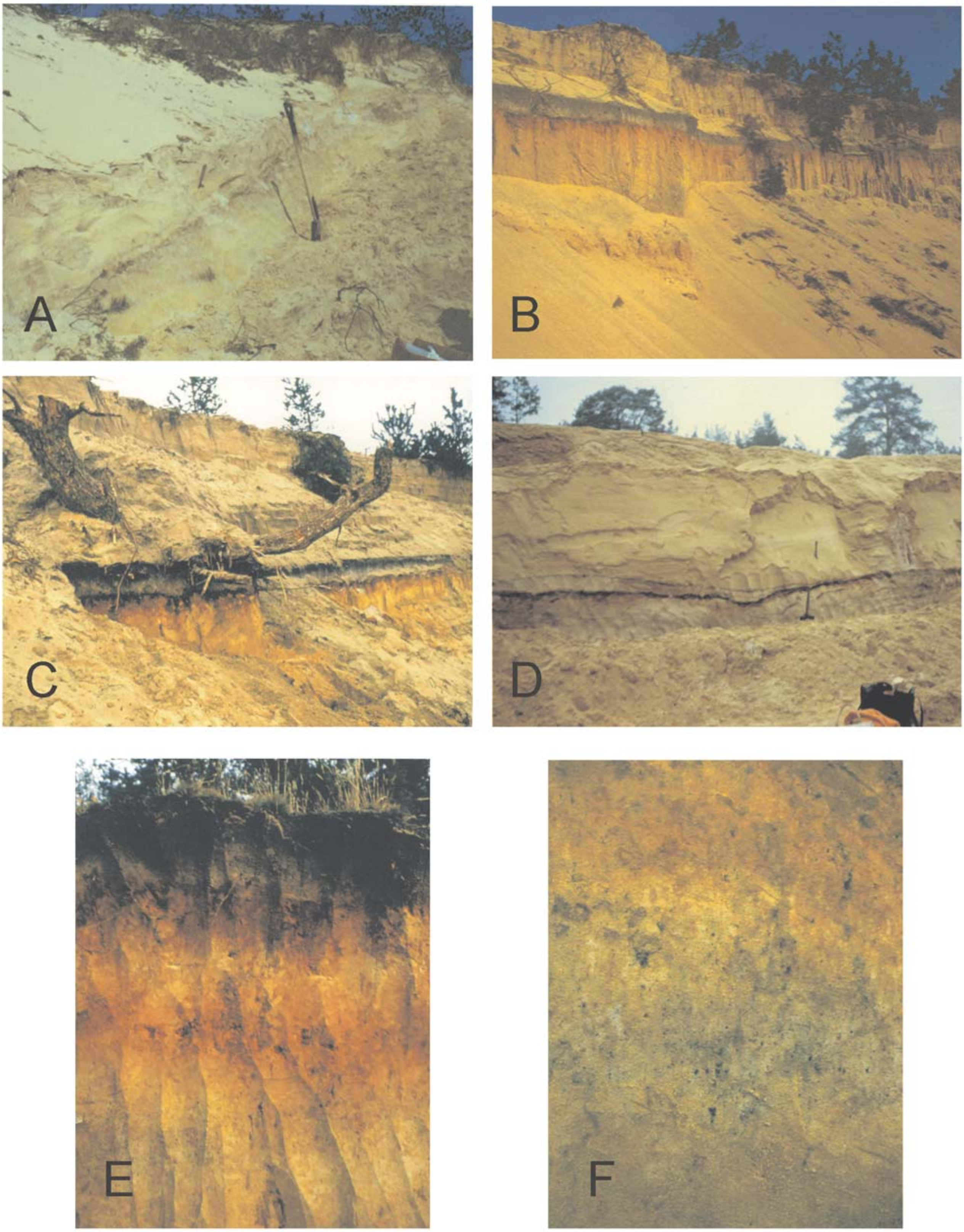


Fig. 2. Photographs of the Cięciwa and Wiązowna Piekiełko sites. **A** – Cięciwa site – weakly developed podzolized fossil soil (Alleröd); **B** – Cięciwa site – general view; humus ferruginous fossil podzol (Atlanticum); **C** – Cięciwa site – fossil podzol (Atlanticum); **D** – Wiązowna site – initial fossil soil (Bölling); **E** – Wiązowna Piekiełko site – proper rusty fossil soil (Preboreal/Boreal) and relict podzol (Atlanticum); **F** – Wiązowna Piekiełko site – fossil horizon A with charcoals (Alleröd).

Table 1

Stratigraphy, age and fossil soils types of the Warsaw Basin

Stratigraphy (Starkel 1975)		Age ^{14}C	Locality	Soils
Subatlanticum 2000	Neoholocene			continuation of podzol soils
Subboreal 5100				
Atlanticum 8400	Mezoholocene	6155±270 7150±150	Cięciwa I Cięciwa I	humus ands humus ferruginous podzols, shallow muck soil on podzols, muck and peat soil*
Boreal 9300	Eoholocene	8770±110	Cięciwa I	proper rusty soil, podzolized rusty soil, peat soil*
Preboreal 10250				
Younger Dryas 10900	Late Vistulian	10400±450	Wiązowna Piekiełko	weakly developed soil, gley soil, peat soil, black earth*
Alleröd 11800		11150±130	Cięciwa I	weakly developed podzolized soil, gley and mucky gley soil*
Older Dryas 12100		12030±170	Cięciwa I	
Bölling 12400		12150±270	Cięciwa I	initial soil
Oldest Dryas 14500		12770±130 12860±190 13200±120 13340±110	Wiązowna Piekiełko under dune	gley soil, black earth*
Epe				

* some soils are known in nearby localities (Konecka-Betley 1991, 2001, Janowska 2001)

0.35–0.55 m – Bhfe – humus-ferruginous illuvial horizon, dark brown in colour, with poorly developed ortstein, loose sand, pH 4.3;
0.55–0.90 m – C – light yellow parent rock, loose sand, pH 4.4;
0.90–1.10 m – ABv – rusty horizon with charcoal horizon (at 90–100 cm), loose sand, pH 4.5; soil developed from sands of the Younger Dryas, Preboreal–Boreal in age;
1.10–1.20 m – A – rather distinctly marked horizon with charcoals, loose sand with large admixture of coarse sand;
1.20–1.35 m – Ees/Bh – poorly marked, in form of spots, eluvial and illuvial horizon of soil probably from the Alleröd, loose sand from the Older Dryas;
1.35–17.80 m – C – light yellow loose dune sand;
17.80–18.00 m – bottom of dune, light yellow loose sand (with the prevalence of fine-grained sand) from the Older Dryas, pH 6.4; most probably lack of deposits from the Oldest Dryas, and if present – usually of small thickness;
18.00–18.10 m – A – laminated horizon of organic matter accumulation, dark grey, with visible ferruginous compounds, fine-grained sand and silty deposit of alluvial silt, C_{org} content in topmost part 2.09%, decreasing inwards, pH 6.5; ^{14}C dated at 12770±130 BP (Gd-1327);
18.10–18.27 m – AG – horizon developed from silts and clays of the Epe Interphase (without ferruginous compounds), poorly marked, grey-blue in colour, sand with up to 20% silt; C_{org} content in topmost part 0.42%; ^{14}C dated at 12860±190 BP (Gd-1375);
18.27–18.50 m – fine-grained, light grey sand, in topmost part with silty intercalations, pH 6.2;
18.50–18.69 m – AG – second horizon, dark grey, silty, with sand in the topmost part, in bottom passing into clay gley horizon, C_{org} content 0.78%, pH 6.5; ^{14}C dated at 13200±120 years BP (Gd-1376) and at 13340±110 BP (Gd-1377);
18.69–18.74 m – CG – intercalation of laminated silty-sandy deposit, cut by a rusty stripe developed most probably due to iron infiltration and oxidation processes;
18.74–19.00 m – light grey sand, in topmost part yellow;
19.00–19.58 m – grey-white silty-clayey deposit, with strongly marked oxidation processes resulting in ferruginous stripes, pH 6.7;
19.58–19.80 m – light grey loose, fluvial sand with prevalence of medium-grained sand, with small admixture of coarse-grained sand, pH 6.4.

The presented data for sites representing the composite stratotype in the Warsaw Basin allow for distinguishing five palaeosol horizons in the analysed area. The oldest type profile for ice-dammed deposits, or the oldest muds, in Wiązowna Piekiełko has the ^{14}C dated humus horizon lying below the 18-m dune from the Older Dryas. Most probably that soil started to develop in the Epe Interphase (the oldest dates in Table 1), referred to in some cases as Agard-Bölling (Mörner 1976, Konecka-Betley 1982, Żarski 1990).

It is worth noting that the high dune of the Older Dryas in Wiązowna Piekiełko is capped by a palaeosol from the Alleröd Interphase and blown out sands of the Younger Dryas, from which two younger palaeosols developed: rusty palaeosol (Konecka-Betley 1991, Janowska 2001, Nowaczyk 1986) and podzol of Atlantic age, recognised only morphologically.

The second partial profile is represented by the dune in Cięciwa, where dune sands of the Oldest Dryas are capped by a poorly developed soil from the Bölling Interphase *sensu stricto*, and dune sands of the Older Dryas – by soil from the Alleröd Interphase. In frequently blown out sands of the youngest Dryas developed a Preboreal–Boreal and Atlantic soil. These two youngest palaeosols often overlap one another (Baraniecka & Konecka-Betley 1987, Konecka-Betley 1982, Baraniecka 1982a, b).

ANALYSES AND INTERPRETATION OF THEIR RESULTS

In the composite stratotype palaeosol profile (Wiązowna Piekiełko – Cięciwa) of the late Pleistocene and Holocene in the Warsaw Basin, a gley soil was determined under a 18-m high dune from the Older Dryas in Wiązowna Piekiełko. This is the oldest soil characterising this interval in the study area, developed from fluvial deposits: silty and silty-sandy (old muds) or from deposits of the marginal part of the ice-dammed lake. This soil, comprising two horizons of humus silts, separated by a sand bed, was ^{14}C dated at between 13340±110 and 12770±130 BP (Table 1). The latter date refers to the moment when the soil was buried.

In the petrographic composition of the oldest gley soil in the study area, the large content of silt fragments (Table 2) and small quartz content, mainly of the medium fraction (0.5–0.25 mm) are worth noting. The mineral content of the heavy fraction (0.06–0.2 mm) differs considerably from the mineral content of dune sands. The non-transparent minerals (Table 3a, b) are rather sparse, whereas within the transparent minerals garnets and amphiboles dominate. The granulometric composition (Table 4) indicates a silty, in some cases clayey deposit. The degree of base saturation is very high (Table 5), in the entire profile the pH is around 7.0; cations of calcium and magnesium prevail. A larger differentiation of the content of particular components is present at the depth of 19 m. The degree of free iron translocation index is below 1 (Table 6). The organic matter fractionation analysis (Tables 7, 8) indicates the large content of humines – organic compounds strictly linked with the mineral part of soils, particularly with their bounded fraction (Table 7, 8). The high degree of organic matter humification was also noted. The content of the residuum or non-soluble organic matter is very low in the free fraction. In the surficial soil horizons fulvic acids prevail, whereas the lower horizons are dominated by humic acids. The ratio between the humic and fulvic acids is below 1, also in the surficial horizons (Konecka-Betley 1982).

Micromorphological analysis was carried out within the oldest palaeosol of the Wiązowna Piekiełko partial profile (below the Older Dryas dune). This palaeosol was developed from ice-dammed of the lake deposits.

A silty skeleton with single quartz grains (Fig. 3A) represents horizon A (topmost part) at the depth 18.00–18.10 m. The silty mass is often saturated by iron compounds along the pressed organic matter laminas; part of the organic matter from this horizon, mainly in the topmost part, is well humified, the small pores in the silty mass are typically empty. The entire horizon underwent diagenesis caused by the weight of the dune, developed by the end of the Pleistocene and most probably blown out in the Holocene.

At the depth 18.10–18.27 m horizon A is characterised by a silty skeleton with some clay fraction and maybe dispersed clay minerals (Fig. 3B); varied disturbed organic matter laminas are common, flattened due to the dune weight. This might represent some type of organic matter diagenesis, which in some cases is better humified, although remains of roots or plant stalks may also be present (Fig. 3C). The accumulation of iron takes place typically at the silt/clay/sand boundary. Rare oval pores are typically empty, and the longitudinal pores are filled sometimes with largely humified organic matter.

At the depth 18.50–18.69 m, horizon AC comprises a sandy-silty skeleton, with large iron accumulation within the clay fraction, represented by little ferruginous or ferruginous-humus concretions lying parallel to the soil surface. Longitudinal pores are empty (Fig. 3D), thus they are probably younger, of secondary origin. In the mineral mass, the oval small pores are typically empty. A larger iron accumulation occurs in form of ferruginous zones (Fig. 3E).

Horizon CG at the depth 18.69–18.90 m is characterised by a skeleton of different fractions (Figs 3F, 3G) comprising sand grains of variable diameter as well as pseudo-laminated silt and clay. Small admixture of iron is present in the silt material, mainly at the passage into the horizon with a slightly different granulometric composition, where small ferruginous concretions, pointing to gley processes, occur (Fig. 3H).

The soil from beneath the dune in Wiązowna Piekiełko was subject to pollen analysis (Borówko-Dłużakowa 1983) – in three samples from the humus horizon in the topmost part and four samples in the lower horizon (Fig. 1). Most of the analysed samples are contaminated by pollen of Tertiary plants, mainly from Miocene deposits. The determined pollen is characteristic of plants from a temperate-cold climate. The trees and bushes include *Pinus*, *Betula*, *Larix* and *Hippophae rhamnoides*, *Salix* and Ericaceae. Herbaceous plants include those from non-forest areas as well as Cyperaceae and Gramineae. The topmost humus horizon is dominated by pollen of herbaceous plants, mainly grasses and sedges. The presence of woody plants reaches only up to 26%, *Pinus sylvestris* and *Betula nana* are present here. The content of pollen of grasses and sedges reaches up to 75%. Pollen of photophilous plants indicates a steppe environment in a mod-

Table 2

Petrographic composition of soils in per cent*

Locality Profile no	Depth m	Sum = 100%										Plant residues	
		Mineral grains**				Rock fragments**							
		Quartz		Feldspars		Crystalline		Sandy lumps		Silt fragments			
		a	b	a	b	a	b	a	b	a	b	a	b
Cięciwa Profile 3	1.15-1.20	95	96	3	2	2	2	+	+	-	-	3	2
	1.30-1.40	91	92	4	4	5	4	-	-	-	-	2	1
	1.40-1.50	73	84	2	3	3	3	22	10	-	-	1	1
	1.50-1.60	91	93	4	5	5	2	-	-	-	-	+	+
	2.20-2.30	88	91	6	5	6	4	-	-	-	-	+	+
	2.50-2.60	88	90	6	7	6	3	+	+	-	-	-	-
Cięciwa Profile 4	5.60-5.70	88	93	5	5	7	2	-	-	-	-	-	-
	5.70-5.85	90	95	4	3	4	2	2	+	-	-	-	-
	5.85-6.00	90	95	5	3	5	2	-	-	-	-	-	-
Wiązowna Soil under the dune Profile 1	18.00-18.10	-	-	-	-	-	-	-	-	100	100	-	-
	18.10-18.27	-	7	-	-	-	-	-	-	100	93	-	-
	18.27-18.50	-	50	-	2	-	-	-	34	-	14	-	-
	18.50-18.69	-	-	-	-	-	-	-	-	100	100	-	-
	18.69-18.90	72	96	4	4	4	+	20	-	-	-	-	-

*according to Konecka-Betley 1982; analysed by Anna Maliszewska; **Grains of biotite, magnetite and siliceous rock fragments are rare and in trace amounts; a – fraction of grains of diameter: 0.5-0.8 mm; b – fraction of grains of diameter: 0.25-0.50 mm; + trace; - no occurrence.

Table 3a

Mineral composition of heavy fraction of 0.06–0.20 mm in diameter*

Locality Profile no	Depth m	Weight %	Non transparent minerals			Transparent minerals (sum 100%)															
			%	Magnetite	Leukoxene	Andalusite	Amphibole	Apatite	Biotite	Chlorite	Zirkon	Disten	Epidote	Glauconite	Garnet	Clinozoisite	Pyroxene	Rutile	Staurolite	Sylimanite	Tourmaline
Cięciwa Profile 3	1.15-1.20	0.33	31	27	4	3	17	-	+	+	6	2	5	-	48	2	7	2	3	+	5
	1.30-1.40	0.36	23	19	4	5	17	-	-	-	2	1	4	-	60	1	3	1	2	1	3
	1.40-1.50	0.51	22	18	4	1	20	-	+	+	1	1	5	-	61	+	5	1	4	-	1
	1.50-1.60	0.53	28	26	2	2	13	-	-	-	3	+	3	-	65	1	6	+	4	1	2
	2.20-2.30	0.31	33	31	2	3	36	-	+	-	3	+	5	-	36	+	5	-	5	1	6
	2.50-2.60	0.73	28	25	3	2	21	-	-	-	2	+	6	-	59	+	4	+	3	2	1
Cięciwa Profile 4	5.60-5.70	1.21	29	27	2	2	20	-	-	-	6	+	11	-	44	1	6	6	2	-	2
	5.70-5.85	1.06	24	22	2	1	22	1	-	-	10	+	7	-	45	1	4	4	3	1	1
	5.85-6.00	0.63	20	18	2	2	25	+	-	-	7	+	6	-	39	2	7	1	7	1	3
Wią-zowna Profile 1	18.00-18.10	0.18	15	13	2	2	25	+	+	+	8	2	10	-	35	1	8	2	2	-	5
	18.10-18.27	0.36	10	9	1	2	22	+	+	+	4	1	11	-	46	2	1	1	2	+	9
	18.27-18.50	0.07	11	7	4	2	36	+	+	+	2	2	21	+	27	3	1	+	3	1	2
	18.50-18.69	0.30	15	13	2	2	27	-	+	-	2	+	12	+	47	2	4	-	3	+	1
	18.69-18.90	0.27	19	16	3	3	28	+	-	-	+	+	15	+	40	3	4	+	2	3	2

*according to Konecka-Betley 1982; analysed by Anna Maliszewska; + trace; - no occurrence

erately dry and cool climate. The lower horizon with organic matter is characterised by a larger content of tree pollen in comparison to other plants. The content of pine and birch pollen reaches 70%. Larch pollen is present. The content of grass and sedge pollen is two times smaller in comparison to the topmost part of the profiles. The recognised sporomorphs in the bottom part of the profile indicate the possible occurrence of a forest-tundra plant assemblage.

Based on all analyses and ^{14}C dates, the analysed profile is older than the Bölling phase. It should be linked with a slight warming before the Bölling, during which the presence of trees and plants of temperate cool climate were deter-

Table 3b

Mineral composition of heavy fraction

Locality Profile no	Depth m	Composition indices of transparent minerals						
		N	S	O	O/N+S	N/O	S/O	N/S
Cięciwa Profile 3	1.15-1.20	24	55	21	0.27	1.14	2.61	0.43
	1.30-1.40	20	66	14	0.17	1.42	4.71	0.30
	1.40-1.50	25	66	9	0.10	2.77	7.33	0.38
	1.50-1.60	19	70	11	0.12	1.72	6.35	0.28
	2.20-2.30	41	42	17	0.20	2.41	2.47	0.93
	2.50-2.60	25	67	8	0.08	3.12	8.37	0.37
Cięciwa Profile 4	5.60-5.70	26	56	18	0.22	1.44	3.11	0.47
	5.70-5.85	26	55	19	0.23	1.36	2.89	0.47
	5.85-6.00	32	48	20	0.25	1.60	2.40	0.66
Wiązowna Soil under the dune Profile 1	18.00-18.10	33	46	21	0.27	1.57	2.19	0.71
	18.10-18.27	23	59	18	0.22	1.25	3.26	0.38
	18.27-18.50	37	52	11	0.12	3.36	4.72	0.72
	18.50-18.69	31	61	8	0.08	3.86	7.62	0.50
	18.69-18.90	32	61	7	0.08	4.58	8.71	0.52

*according to Konecka-Betley 1982; analysed by Anna Maliszewska. Transparent minerals after L.B. Ruchina: N – susceptible to mechanical weathering: amphibol, pyroxene; S – medium susceptible to mechanical and chemical weatheting: apatite, biotite, chlorite, common epidote, clinozoisite, garnet, sylimanite, no occurrence of monacite; O – resistant to mechanical and chemical weathering: andalusite, zircon, disten, rutyl, staurolite, tourmaline.

Table 4

Grain composition of fossil soils of the Warsaw Basin*

Locality Profile no	Depth m	Percentage of particular fractions in conversion to particles smaller than 1 mm in diameter										
		1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	0.05-0.02	0.02-0.005	0.005-0.002	<0.002	Total		
										1-0.1	0.1-0.02	<0.02
Cięciwa Profile 2	1.18-1.28	8.0	60.5	26.5	1	1	3	0	0	95	2	3
	1.30-1.40	5.5	59.2	30.3	2	0	3	0	0	95	2	3
	1.45-1.55	6.9	57.0	33.1	1	1	1	0	0	97	2	1
	1.70-1.80	10.5	59.5	28.0	1	0	1	0	0	98	1	1
	2.00-2.10	1.7	29.5	51.8	12	2	1	0	2	83	14	3
	2.50-2.60	10.7	58.7	24.6	2	1	3	0	1	94	3	3
Cięciwa Profile 3	1.15-1.20	9.6	59.0	26.4	1	1	3	0	0	95	2	3
	1.20-1.30	8.7	61.0	26.3	1	1	2	0	0	96	2	2
	1.30-1.40	5.7	53.5	35.8	1	2	2	0	0	95	3	2
	1.40-1.50	6.2	56.7	32.1	2	2	0	0	1	95	4	1
	1.50-1.60	2.2	45.0	46.8	5	1	0	0	0	94	6	0
	2.20-2.30	11.7	59.0	24.3	2	2	1	0	0	95	4	1
Wiązowna Piekiełko Soil under the dune Profile 2	17.80-18.00	0.25	36.0	58.7	2	2	1	0	0	95	4	1
	18.00-18.10	0.0	0.75	68.2	22	4	2	0	3	69	26	5
	18.10-18.27	0.0	1.5	26.5	45	12	6	2	7	28	57	15
	18.27-18.50	0.0	0.5	25.5	8	23	17	9	17	26	31	43
	18.50-18.69	0.0	0.25	16.7	10	14	22	7	30	17	24	59
	18.69-18.74	0.6	2.4	14.0	8	9	19	18	29	17	17	66
	18.74-19.00	0.0	0.4	34.6	47	8	4	2	4	35	55	10
	19.00-19.58	0.25	5.0	19.7	9	18	18	12	18	25	27	48
	19.58-19.80	0.7	23.1	59.2	17	0	0	0	0	83	17	0

*according to Konecka-Betley 1982

Table 5

Physico-chemical properties of fossil soils*

Locality Profile no	Depth m	Genetic horizon**	pH		H_h	S	T	V_s %	Percentage of exchangeable cations in the soil sorption complex				
			H_2O	KCl	cmol$^+$/kg				Ca	Mg	K	Na	H
Cięciwa Profile 2	peat												
	1.18-1.28	AEes	4.8	3.7	2.21	0.147	2.36	6.24	4.24	0.43	0.43	1.14	93.76
	1.30-1.40	Bh	4.4	3.9	4.54	0.104	4.64	2.24	1.61	0.17	0.22	0.24	97.76
	1.45-1.55	Bfe	4.4	4.3	2.51	0.057	2.57	2.22	0.78	0.19	0.39	0.86	97.78
	1.70-1.80	C	4.8	4.4	1.31	0.069	1.38	5.00	2.17	0.14	0.73	1.96	95.00
	2.00-2.10	Bv	4.7	4.4	1.35	0.101	1.45	6.96	3.45	0.14	0.89	2.48	93.04
	2.50-2.60	C	5.0	4.6	0.90	0.042	0.94	4.46	2.12	0.22	0.53	1.59	95.54
Cięciwa Profile 3	peat												
	1.15-1.20	AEes	4.3	3.4	5.40	0.032	5.43	0.59	0.09	0.09	0.09	0.32	99.41
	1.20-1.30	AEes	4.0	3.2	7.16	0.059	7.22	0.82	0.56	0.07	0.07	0.12	99.18
	1.30-1.40	Ees	4.7	3.5	2.59	0.082	2.67	3.07	0.94	0.11	0.19	1.83	96.93
	1.40-1.50	Bh	4.4	3.9	6.15	0.073	6.22	1.17	0.24	0.06	0.08	0.79	98.83
	1.50-1.60	Bfe	4.8	4.2	2.77	0.117	2.89	4.05	1.73	0.28	0.17	1.87	95.95
	2.20-2.30	C	4.9	4.3	1.16	0.093	1.25	7.42	2.79	0.24	0.64	3.75	92.58
Wiązowna Piekiełko under the dune Profile 2	17.80-18.00	Sand	7.0	6.4	0.37	0.900	1.27	70.87	35.43	33.54	1.02	0.87	29.13
	18.00-18.10	A	7.3	6.5	0.49	2.105	2.60	81.12	65.51	13.91	1.12	0.58	18.88
	18.10-18.27	AG	7.1	6.4	0.94	8.794	9.73	90.34	74.48	14.66	0.72	0.48	9.66
	18.27-18.50	AG	6.9	6.2	1.84	29.097	30.94	94.05	72.73	19.72	0.87	0.73	5.95
	18.50-18.69	AG	7.5	6.4	0.67	25.210	25.88	97.41	76.70	18.00	1.90	0.81	2.59
	18.69-18.74	CG	7.3	6.5	0.90	38.434	39.33	97.71	82.62	12.80	1.19	1.09	2.29
	18.74-19.00	CG	7.8	6.7	0.45	25.184	25.63	98.24	90.70	6.53	0.21	0.80	1.76
	19.00-19.58	CG	7.4	6.7	0.75	21.639	22.29	96.65	83.19	11.79	0.95	0.72	3.35
	19.58-19.80	CG	7.6	6.7	0.34	1.027	1.37	75.13	64.01	9.95	0.36	0.80	24.87

*according to Konecka-Betley 1982; **Systematics of Polish Soils 1989; Hh – hydrolitic acidity; S – sum of bases; T– cation exchange capacity; Vs – base saturation.

mined. Mörner (1976) referred to this interval in Sweden as the Agard–Bölling phase. At present, the palaeosol should be included to the Epe Interphase, although ^{14}C dates show that Wiązowna Piekiełko was buried much later in comparison to the soil from Epe Interphase in Kamion (Manikowska 1985).

On a flat area, at the foot of the dune covering the older palaeosols, a poorly developed palaeosol was also recognised. Its organic matter was ^{14}C dated at 10400±450 BP (Lod-32), that is at the terminal part of the Younger Dryas (Baraniecka 1982b, Konecka-Betley 1982, 1991). The palaeosol development may be linked with the Alleröd Interphase. The water conditions influencing the soil development were completely different here than on the dunes, therefore the palaeosol resembles morphologically black-earth or poorly developed gley soil, while on the dune it is a poorly developed podzolized soil. The ^{14}C date indicates its burial.

In order to characterise the sand material composing the Cięciwa dune, petrographic analysis was carried out, along with the determination of heavy minerals, similarly as in the case of analyses carried out for Wiązowna Piekiełko. The analysed fraction of several sand samples from Cięciwa (Table 2) indicates the prevalence of quartz and the subordinate content of feldspars and crystalline rock fragments. Traces of eolian transport can be observed on the quartz grains. The percentage of heavy minerals is much higher that in the case of Wiązowna Piekiełko. Non-transparent minerals are dominated by magnetite. Thus, in Cięciwa there is a prevalence of minerals resistant to weathering (Table 3a, b). In the granulometric composition (Table 4) the 0.25–0.5 mm sand fraction prevails, and a slightly higher coarse sand content in comparison to Wiązowna Piekiełko. The pH and alkaline cations contents are low, and the saturation degree does not exceed 10% (Table 5). Free iron occurs in this locality in higher quantities in fossil horizons A of soils capped with peat and in the spodic horizons of podzols. The iron translocation index varies between 9 and 6 (Table 6). In rusty soils, which in the analysed sites typically have a poorly preserved humus accumulation horizon, the accumulation of different components can be observed in horizons Bv (sideric). In comparison with horizon C all values are slightly higher.

The transformations of organic compounds in palaeosols of different ages developed from dune sands in Cięciwa depend mainly on the intensity of pedogenetic processes. Generally, both the free and bounded fraction of podzols and poorly developed podzolized soils there is a prevalence of humic acids in relation to the fulvic acids (Table 7, 8), mainly

Table 6

Free iron and organic carbon ratio and the iron translocation index*

Locality Profile no	Depth m	Horizon**	Free-Fe g/kg	C organic g/kg	Fe/C	Free-Fe translocation index	Name of soil
Cięciwa Profile 2	1.00-1.15	Peat	1.75	201.96			humus-ferrugineous podzol
	1.18-1.28	AEes	0.11	5.02			
	1.30-1.40	Bh	1.01	5.94			
	1.45-1.55	Bfe	0.45	n.o.			
	1.70-1.80	C	0.18	1.65	0.17	9.8	
	2.00-2.10	Bv	0.42	n.o.			
	2.50-2.60	C	0.18	n.o.			
Cięciwa Profile 3	1.00-1.15	Peat	1.21	271.00			hunus podzol
	1.15-1.20	AEes	0.14	11.63			
	1.20-1.30	AEes	0.45	11.32			
	1.30-1.40	Ees	0.18	3.15			
	1.40-1.50	Bh	1.12	11.48	0.072	6.4	
	1.40-1.50	concretions	2.17	n.o.			
	1.50-1.60	Bfe	0.35	3.09			
	2.20-2.30	C	0.18	n.o.			
Wiązowna Piekiełko Profile 1	18.00-18.10	A	2.5	20.93			gley soil
	18.10-18.27	AG	1.5	4.21	n.o.	0.6	
	18.50-18.69	AG	1.2	7.83			

*according to Konecka-Betley 1982; ** Systematics of Polish Soils 1989; n.o. – no occurrence; translocation index – content of free iron in B/content of free iron in Ees or AEes.

Table 7

Content of various forms of organic compounds in free and bounded fractions, method of Duchaufour and Jacquin*

Locality Profile no	Depth m	Genetic horizon**	Organic carbon %	C of fulvic and humic acids and humines in % of organic C					H:F ratio
				Free fraction		Bounded fraction			
				F_1+F_2	H_1+H_2	$F_3+F_4+F_5$	$H_3+H_4+H_5$	H-humines	
Cięciwa I Profile 2 Atlanticum	1.00-1.15	Peat	20.20	5.1	14.1	0.7	0.6	0.2	2.54
	1.18-1.28	AEes	0.50	2.2	5.4	20.2	28.4	6.0	1.52
	1.30-1.40	Bh	0.59	2.3	3.7	43.4	17.6	11.1	0.47
	1.45-1.55	Bfe	0.16	1.8	6.0	19.9	20.2	44.8	1.19
Cięciwa I Profile 3 Atlanticum	1.00-1.15	Peat	27.10	10.3	12.0	8.8	1.7	2.3	1.24
	1.15-1.20	A	1.16	5.8	8.0	9.0	10.9	5.8	1.25
	1.20-1.30	AEes	1.13	9.4	11.8	13.3	12.8	5.6	1.06
	1.30-1.40	Ees	0.31	10.2	15.8	14.6	27.0	10.5	1.73
	1.40-1.50	Bh	1.55	11.7	9.3	42.7	14.9	4.0	0.44
	1.50-1.60	Bfe	0.31	0.3	0.9	21.2	29.4	43.4	1.42
Wiązowna Piekiełko Soil under the dune, Profile 1	18.00-18.10	A	2.09	11.9	10.4	23.8	13.8	38.1	0.67
	18.10-18.27	AG	0.42	0.7	1.0	26.5	20.5	50.6	0.77
	18.50-18.69	AG	0.78	1.2	0.2	13.8	20.5	65.8	1.60

*according to Konecka-Betley 1982 , **Systematics of Polish Soils; F_1 – fulvic acids in the free fraction; H_1 – humic acids in the free fraction (Ist extraction $Na_4P_2O_7$+ Na_2SO_4, pH 7); F_2 – fulvic acids in the free fraction; H_2 – humic acids in the free fraction (IInd extraction $Na_4P_2O_7$, pH 9.8); F_3 – fulvic acids in the bounded fraction; H_3 – humic acids in the bounded fraction (Ist extraction $Na_4P_2O_7$+ Na_2SO_4, pH 7); H – humins insoluble part of bounded fraction of organic matter, remained after three consecutive extractions; F_4 – fulvic acids in the bounded fraction; H_4 – humic acids in the bounded fraction (IInd extraction $Na_4P_2O_7$, pH 9.8); F_5 – fulvic acids in the bounded fraction; H_5 – humic acids in the bounded fraction (IIIrd extraction 0.1 N NaOH); R – residuum, non extracted part of free fraction of organic matter.

Table 8

Per cent of carbon in particular fractions in relation to soil, method of Duchaufour and Jacquin*

Locality Profile no	Depth m	Genetic horizon**	Humification degree	C per cent in particular fractions in relation to soil					
				Free fraction			Bounded fraction		
				R	F_1+F_2	H_1+H_2	$F_3+F_4+F_5$	$H_3+H_4+H_5$	H-humines
Cięciwa I Profile 2 Atlanticum	1.00-1.15	Peat	20.7	16.013	1.030	2.844	0.140	0.122	0.048
	1.18-1.28	AEes	62.2	0.190	0.011	0.027	0.100	0.143	0.030
	1.30-1.40	Bh	78.1	0.130	0.014	0.022	0.256	0.106	0.066
	1.45-1.55	Bfe	92.7	0.012	0.030	0.010	0.033	0.033	0.074
Cięciwa I Profile 3 Atlanticum	1.00-1.15	Peat	27.1	24.370	1.036	1.210	0.082	0.174	0.230
	1.15-1.20	A	39.5	0.704	0.070	0.093	0.105	0.125	0.067
	1.20-1.30	AEes	52.9	0.533	0.110	0.134	0.150	0.140	0.064
	1.30-1.40	Ees	78.1	0.070	0.032	0.050	0.046	0.085	0.033
	1.40-1.50	Bh	82.6	0.270	0.180	0.144	0.662	0.230	0.062
	1.50-1.60	Bfe	95.2	0.015	0.001	0.003	0.065	0.090	0.134
Wiązowna Piekiełko Soil under the dune, Profile 1	18.00-18.10	A	98.0	0.041	0.250	0.220	0.500	0.285	0.800
	18.10-18.27	AG	99.3	0.003	0.004	0.003	0.112	0.086	0.213
	18.50-18.69	AG	99.6	0.003	0.010	0.002	0.092	0.161	0.515

*according to Konecka-Betley 1982; Explanations as in Table 6

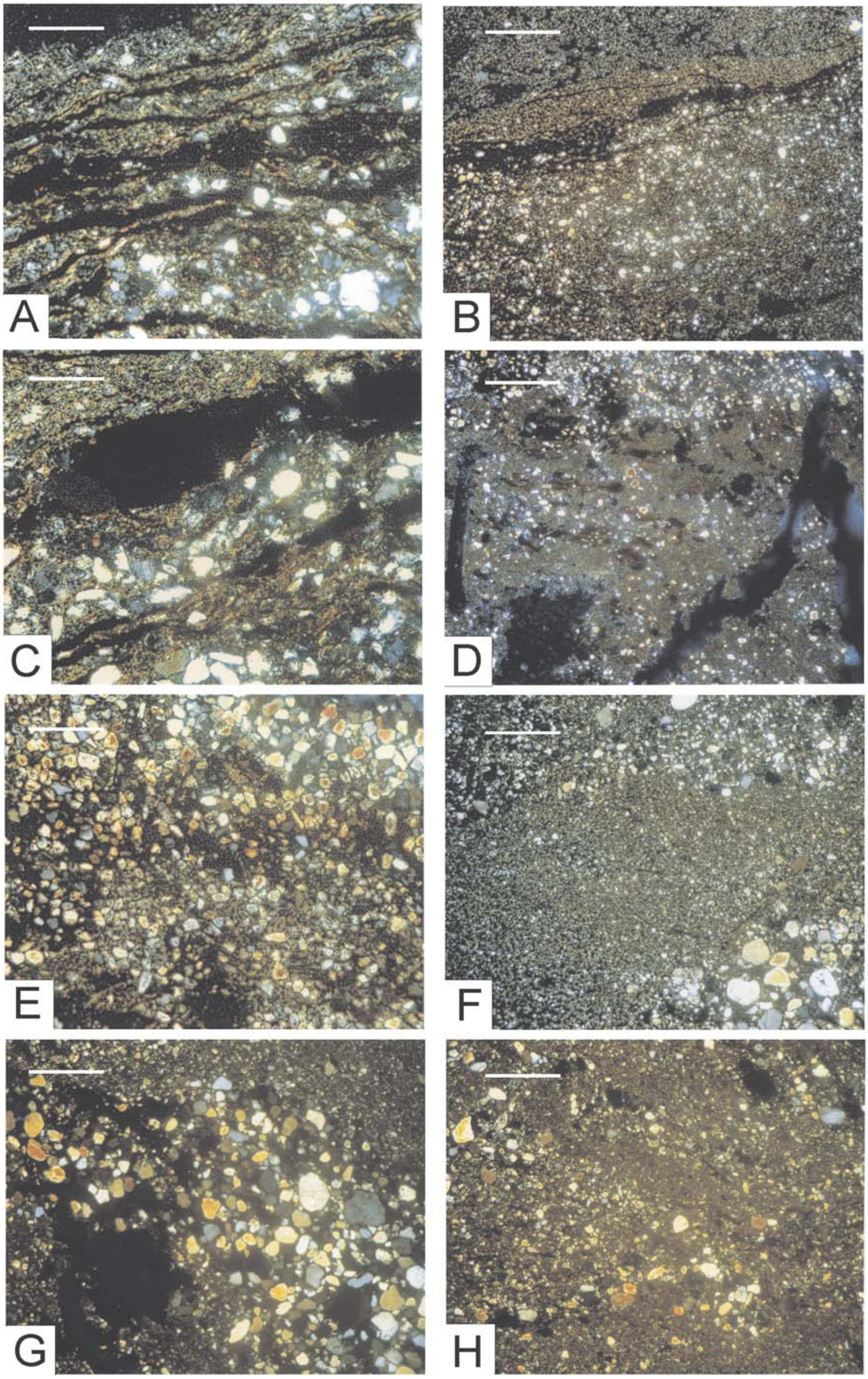
Table 9

Content of soluble phosphorus (mg/100g of soil)

Soil type Soil age Locality	Depth m	Genetic horizon	Soluble P_2O_5				Sum of soluble P_2O_5	Insoluble P_2O_5		P_2O_5 Total
			in 0.5N $(COOH)_2$		in 4% NH_4OH			Mineral	Organic	
			Mineral	Organic	Mineral	Organic				
Ferruginous humus podzol Cięciwa I Atlanticum	1.00-1.20	A	3.5	8.0	-	2.4	13.9	2.0	8.1	24.0
	1.25-1.30	Ees	0.5	1.0	-	-	1.5	0.5	-	2.0
	1.35-1.45	Bh	392.0	34.0	-	3.2	429.0	20.0	8.0	458.0
	1.45-1.55	Bfe	32.0	3.0	-	1.6	36.6	0.5	0.9	38.0
	1.5-1.70	C	9.0	1.5	+	+	10.5	0.9	9.5	20.9
Rusty soil Preboreal/ Boreal Cięciwa I	2.10-2.30	A	20.0	-	0.3	-	20.3	1.2	-	21.5
	2.30-2.50	Bv	39.0	5.0	+	+	44.0	1.0	3.0	48.0
	2.50-2.60	C	14.0	3.5	+	+	17.5	0.1	5.5	23.1
Weakly developed podzolized soil Alleröd Cięciwa I	2.70-2.90	AEes	11.0	1.5	+	-	12.5	1.5	-	14.0
	2.90-3.10	Ees/B	9.0	0.5	+		9.5	0.5	-	10.0
	3.10-3.30	B/C	8.5	2.5	-	-	11.0	0.5	0.5	12.0
	3.30-3.50	C	3.5	2.5	-	-	6.0	0.5	1.5	8.0

- no occurrence; + trace

Fig. 3. Micromorphology of sediments from the Wiązowna-Piekiełko site (microscopic views in crossed nicols, white bars represent 1 mm). **A** – Topmost part of horizon A, depth 18.00–18.10 m, silt skeleton with single rounded quartz grains and pressed organic matter remains, variably decomposed, within the mineral material; **B** – Bottom of horizon A, depth 18.10–18.27 m, silt skeleton with small content of clay, zones of horizontal lamines of organic matter; **C** – Bottom of horizon A, pressed remains of roots and concentrations of iron at boundaries of granulometric content changes; **D** – Horizon AG, depth 18.50–18.69 m, silt skeleton, small concentration of humified organic matter in the clay material, elongated pores empty, not coated with clay; **E** – Horizon AG, zonal concentration of iron in silt material; **F, G** – Horizon CG, depth <18.69 m, sand-silt skeleton of different fractions, transition sharp; **H** – Horizon CG, skeleton with slightly higher iron content.


A
B
C
D
E
F
G
H

in surficial mineral and organic horizons (organic matter was not analysed in the rusty soil). The content of humines is low or very low, it increases in horizon Bfe, contrary to older soils, where the content of these compounds is the highest (Wiązowna Piekiełko). The ratio of humic acids to fulvic acids, apart from horizons Bh of podzols, is above 1. The degree of humification of the organic matter is low in surficial parts of podzols, and increases from horizon Bh downwards. In soil from the Alleröd phase this ratio is high and more similar to older soils from the late Vistulian. The data indicate that transformations of organic matter in fossil podzols are very similar to transformations of such soils occurring on the surface. The only difference lies in the fact that in fossil soils the content of humines increases distinctly in horizons Bhfe, mainly Bfe. Humines as soluble compounds and the large content of iron and aluminium favour the development of washed out ortstein. The podzolization process in Atlantic soil is confirmed by analyses of the phosphorus content (Gigel method modified by Brogowski), which is transported along with the organic matter from the surficial horizons to horizon Bfe (Table 9) of podzol in Cięciwa (Konecka-Betley 1982).

Four ^{14}C dates were obtained for four soils of different degree of development in the Cięciwa site. The oldest date for charcoals of the initial soil poorly developed on a small dune of the Oldest Dryas is 12030±170 BP (Gd-2406) and 12150±270 BP (Gd-2405). This is the palaeosol from the Bölling Interphase developed from horizontally laminated sands. The younger series of sands from the Older Dryas, composed of fine grained, cross-laminated sands, is capped by a poorly developed podzolized soil from the Alleröd Interphase. This soil thins away at the present-day dune margins and lies on a surface inclined at up to 24°. The dune from the Older Dryas is up to 10 m high. ^{14}C date of the soil is 11150±130 BP. In other exposures at the base of the dunes this soil occurs often as a gley soil (Schild 1982, Konecka-Betley 1982), or even muck-gley soil. In Wiązowna Piekiełko, as mentioned above, a soil with a higher content of humus occurs at the base of the dune, the development of which started during the Alleröd Interphase. The ^{14}C date at 10400±450 BP (Lod-30) indicates its burial in the Younger Dryas.

The charcoals of the rusty soil developed from the dune of the younger Dryas were ^{14}C dated for the Boreal at 8770±110 years BP (Gd-2407). In some cases, a later podzolization process, taking place when the blowing out of sands of the younger Dryas took place in the analysed area, overlaps horizon Bv. With the change of water conditions, shallow peats covered the podzol. A preliminary pollen analysis of peat in the topmost part of the podzol (Janczyk-Kopikowa 1980) shows that of tree pollen AP – *Pinus* is 58%, *Betula* 14% and the remaining pollen of such trees as *Alnus*, *Picea*, *Tilia*, *Abies*, *Carpinus*, *Quercus*, *Corylus* and *Fagus* – is only several percent. Graminae, Cyperaceae, Compositeae and Cereales dominate pollen of other NAP. Their content varies from 2 to 4%. Up to 2% of *Sphagnum*, *Typha*, *Plantago* and *Urtica* were also noted. The analysed spectrum was determined as the younger Holocene, and the presence of crop and synanthropic plants indicates the presence of human beings in the study area in this interval (Janczyk-Kopikowa 1980). The peat horizon was ^{14}C dated at 6155±270 BP (Lod-31), and the ferruginous-humus horizon Bh at 7150±150 BP (Lod-47). All physical-chemical analyses of the soil, fractionation analysis of the organic matter, pollen analysis and ^{14}C datings allow to recognise the course of pedogenetic events in the Late Glacial and Holocene in the composite stratotype of palaeosols from the Warsaw Basin. Authors studying other regions (Manikowska 1985, Nowaczyk 1986) also obtained similar dates.

DISCUSSION

The composite stratotype profile of palaeosols in the Warsaw Basin allows recognising the development of its deposits and the pedogenetic processes in detail. Material older than the Oldest Dryas is represented by an aqueous substrate, either old muds (silt, sand) or silty deposits of the marginal part of the ice-dammed lake. The micromorphological method confirms their aqueous rather than eolian origin. Gley or mucky-gley soil developed most probably from alluvial silty deposits of the Epe Interphase, referred to in older papers as Agard-Bölling (Mörner 1976, Konecka-Betley 1982, Żarski 1990), is covered by an eolian sandy substrate from the Oldest, Older and Younger Dryas, separated by several palaeosol horizons. Such recognition of the eolian and aqueous mineral material forming the soils is confirmed by other authors (Czępińska-Kamińska 1986, Konecka-Betley 1982, 1991, Konecka-Betley *et al*. 1999, Starkel 2001, Żarski 1990).

Manikowska (1985, 1992) described palaeosols from the Epe phase, as well as from the Bölling and Alleröd, in the Kamion-Młodzieszynek site on the left bank of the Bzura River. This site is considered a type exposure, and the dates correspond well with dates obtained by other authors (Baraniecka, Konecka-Betley 1987, Konecka-Betley 1991, Żarski 1990). The oldest palaeosol in Kamion developed from a silty deposit, which according to its ^{14}C date of 14590±270 BP (Lod-85) is linked with the Epe Interphase. Manikowska (1985) recognised it as a tundra palaeosol. A gley soil developed from silty and clayey deposits from the Epe Interphase was distinguished by Żarski (1990) in Stężyca near Dęblin. The ^{14}C date for this burial soil is 12940±110 BP (Gd-1986).

In some cases the oldest soils bear permafrost structures developed in a cold climate (Goździk 1992) as well as fragipan zones, typically linked with the development of ground ice. These structures point to the presence of permafrost in central Poland during the development of the oldest soils in the Late Vistulian.

Based on some properties of soils the hydrological regime of the study area can be recognised. Changes in water conditions may be linked with the general moistening of climate or with water fluctuations within rivers flowing in the valley. It seems that the dune development in the Warsaw Basin was linked with climatic and hydrological conditions as well as the deep erosion of the river, that influenced the appearance of various plant communities before 15,000 years BP. Lack of the changes in the plant communities point to the stability of forest ecosystems, mainly in the Holocene, when well-developed mature soils appear, characterised by genetic horizons O-A-E-B-C (climax soils). The duration of the pedogenetic process also influences the development of mature soils. Palaeosol from the composite stratotype profile for the Warsaw Basin was developed from older – aqueous and younger – aeolian deposits. Their typological recognition and properties are linked with the climate and the changing water regime as well as the composition of the parent rock. Artefacts were not encountered in the investigated exposures, although the pollen data of Janczyk-Kopikowa (1980) indicate the presence of pollen of synanthropic plants in the podzol Cięciwa I. Probably with the larger number of analyses it will be possible to determine anthropostratigraphic units as one of the methods of dating mineral deposits for the Late Quaternary and Holocene in the Warsaw Basin. At present it seems that human activity is marked in soils younger than 5000 years BP, when anthropogenic blowing out of dunes and destruction of older soils took place.

CONCLUSIONS

The following conclusions can be drawn based on analyses of palaeosols from the Warsaw Basin:

1. The composite stratotype profile in the Warsaw Basin for ^{14}C dated palaeosols of the Late Glacial and Holocene comprises two partial profiles: Wiązowna Piekiełko and Cięciwa.

2. Five palaeosols were distinguished in the stratotype profile: oldest gley soil developed from ice-dammed lake deposits of the Epe Interphase, initial soil from the Bölling Interphase (*sensu stricto*), poorly developed podzolized soil from the Alleröd Interphase, Preboreal–Boreal rusty soil and well-developed podzol, in some places ferruginous or ferruginous-humus, from the Atlantic Interphase; the four latter soils were developed from aeolian sands.

3. If not buried, the rusty soil and podzol occur on the surface of the study area.

4. Micromorphological analysis carried out for the oldest soil in Wiązowna Piekiełko confirms the petrographic analyses indicating the aqueous and not eolian origin of the parent rock.

REFERENCES

Baraniecka M.D. 1973. Detailed Geological Map of Poland, sheet Otwock, 1:50000 (original: Szczegółowa Mapa Geologiczna Polski, arkusz Otwock). Instytut Geologiczny, Warszawa (in Polish).

Baraniecka M.D. 1982a. Dunes from the vicinity of Otwock in relation to the geological setting. Investigations in the Quaternary of Poland. *Biuletyn Instytutu Geologicznego* 337, 1–32 (in Polish with English Summary).

Baraniecka M.D. 1982b. Geological setting and distribution of dunes in the vicinity of Warsaw. *Roczniki Gleboznawcze* 53, 33–57 (in Polish with English Summary).

Baraniecka M.D., Konecka-Betley K. 1987. Fluvial sediments of the Vistulian and Holocene in the Warsaw Basin. In: Evolution of the Vistula river valley during the last 15 000 years. *Geographical studies. Special issue* 4, 151–171.

Borówko-Dłużakowa Z.1983. Palinologic analysis of organic matter samples from the fossil profile in Wiązowna-Piekiełko (original: Analiza palinologiczna próbek z substancją organiczną profilu kopalnego w Wiązownej Piekiełku) *Unpublished archival paper, Soil Science Faculty SGGW* (in Polish).

Czępińska-Kamińska D. 1986. Relationship between the morphology and soil types from the dune areas of the Kampinos Forest. In: *Influence of anthropogenic activity on the soil environment in the Kampinos National Park.* Wydawnictwo SGGW, 5–72 (in Polish with English Summary).

Dzierwa K., Mycielska-Dowgiałło E. 2003. Reconstruction of the dynamics of aeolian processes in relation to their duration based on selected textural features of the dune at Cięciwa. *Przegląd Geologiczny* 51, 163–167 (in Polish with English Summary).

Goździk J. 1992. Evolution of permafrost and its influence of deposition conditions and development of some features of sediments between 20 000 and 8 000 years BP (original: Ewolucja wieloletniej zmarzliny i jej wpływ na warunki depozycji i kształtowania się niektórych osadów w okresie 20 000 – 8 000 lat BP w Polsce). *Przegląd Geologiczny* 10, 601–603 (in Polish).

Janowska E. 2001. Origin and properties of rusty soils in the area of the Central Polish Glaciation. Wydawnictwo Fundacja "Rozwój SGGW" Warszawa, 75pp (in Polish with English Summary).

Janowska E. unpublished. Palaeosols developed from dune sands – Cięciwa II (original: Gleby kopalne wytworzone z piasków wydmowych – Cięciwa II). Department of Environmental Sciences, Warsaw Agricultural University (in Polish).

Janczyk-Kopikowa Z. 1980. Pollen analysis of peat from the Cięciwa profile (original: Analiza pyłkowa torfu z profilu Cięciwa). *Unpublished archival paper, Soil Science Faculty SGGW* (in Polish).

Kobendzina J. 1961. Tentative datings of the dunes from the Kampinos Forest. (original: Próba datowania wydm z Puszczy Kampinoskiej). *Przegląd Geograficzny* 33, 383–399 (in Polish).

Konecka-Betley K. 1974. Late pleistocenic and holocenic fossile soils and relict soils in the vicinity of Otwock. *Roczniki Gleboznawcze* 25, 101–118 (in Polish with English Summary).

Konecka-Betley K. 1982. Fossil and relict soils in dunes of Warsaw environs. *Roczniki Gleboznawcze* 33, 81–112 (in Polish with English Summary).

Konecka-Betley K. 1991. Late Vistulian and Holocene fossil soils developed from aeolian and alluvial sediments of the Warsaw Basin. *Zeitschrift für Geomorphologie N. F.* Berlin, Supplement, 90, 90–105.

Konecka-Betley K. 2001. Reconstruction of Late Pleistocene and Holocene pedological processes in central Poland. *Roczniki Gleboznawcze* 52, 99–118 (in Polish with English Summary).

Konecka-Betley K., Brogowski Z., Okołowicz M. 1982. Distribution of phosphorus compounds in fossil soils developed from Late Pleistocene dune sands in Cięciwa. *Roczniki Gleboznawcze* 36, 75–84 (in Polish with English Summary).

Konecka-Betley K., Czępińska-Kamińska D., Janowska E. 1999. The alteration trends in the soil cover of Kampinos National Park (1991-1994). *Roczniki Gleboznawcze* 50, 5–29, (in Polish with English Summary).

Madeyska T. 1995. Late Vistulian vegetation in Poland. *Przegląd Geologiczny* 43, 595–599 (in Polish with English Summary).

Manikowska B. 1985. On fossil soils, stratigraphy and lithology of dunes in central Poland. *Acta Geographica Lodzensia* 52, 137 (in Polish with English Summary).

Manikowska B. 1992. Fossil soils in sediments between 20 000 and 8 000 years BP in Poland, (original: Gleby kopalne w osadach z okresu 20 000 – 8 000 lat BP w Polsce). *Przegląd Geologiczny* 10, 588–600 (in Polish).

Mörner N.A. 1976. Paleoclimatic records from south Scandinavia global correlations origin and cyclicity. In Horie S. (ed.) *Paleolimnology of Lake Biwa and Japanese Pleistocene*, Japan, 4, 499–528.

Nowaczyk B. 1986. Age of the dunes in Poland. *Seria Geografia* 28, 245 pp. Adam Mickiewicz University, Poznań (in Polish with English Summary).

Nowak J. 1976. Detailed Geological Map of Poland, sheet Okuniew, 1:50000 (original: Szczegółowa Mapa Geologiczna Polski, arkusz Okuniew). Państwowy Instytut Geologiczny, Warszawa (in Polish).

Pazdur M. 1983. ^{14}C dating of organogenic deposits. Scientific Report. (original: Datowanie metodą ^{14}C osadów organogenicznych. Sprawozdanie z badań naukowych). Committee on Quaternary Research of the Polish Academy of Science, Section V, 95–104 (in Polish).

Schild R. 1982. Archaeological stratigraphy of inland dunes in Mazowsze. *Roczniki Glebozawcze* 33, 59–79 (in Polish with English Summary).

Starkel L. 2001. History of the Vistula River valley from the last glaciation till present. *Monographies* 2, Polska Akademia Nauk, IGiPG, 263 pp. (in Polish with English Summary).

Systematics of Polish Soils (IVth edition) 1989. *Roczniki Gleboznawcze* 40, 1–150 (in Polish with English Summary).

Żarski M. 1990. New site of fossil soils in Stężyca in relation to the geological setting. *Geological Quarterly* 35, 503–510 (in Polish with English Summary).