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FACTORS AFFECTING FOREST SOIL DISTRIBUTION AND PROPERTIES IN THE RIVER BREAKS OF THE ROZTOCZE REGION

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A b s t r a c t: Studies on the soils in forest ecosystems in breaks of the rivers Jeleń and Sopot were carried out in the years 1997-1998. Although the rivers differ in length, catchment area, amount of water carried and breadth of the valleys, the most important factors affecting soil formation and their spatial differentiation are similar: bedrock, relief, water drainage, natural type of water management, position of the ground water-table relative to the river water level, and chemistry of spring and soil waters. Steep slopes of the valleys covered with poor and highly acidic podzolic soils are usually overgrown with fir and pine phytocenoses, or rarely, with mixed oak-pine forests. The bottoms are often characterised by longitudinal duality of the flood-plain benches. In the drier area close to the river beds under ash-alder forests, there are more fertile gley soils and gley podzols. Poorer and more acidic localities are occupied by mixed forests with spruce. In permanently moist fragments of the benches at the foot of the slopes and in depressions with stagnant water weakly acidic peat-mud and peat soils occur overgrown with bog-alder forests. Peculiarities of these areas are low peat-bogs suspended even up to 4-6 m above the water-table of the river.

K e y w o r d s: river valley, forest ecosystem, mineral soil, organic soil, ground water.

INTRODUCTION

River valleys make an interesting and important element of the vegetation landscape. Their unique character results from specific habitats formed in the near and far neighbourhood of the river in the past and present geological, geomorphological and hydrological processes. The system of plant communities in the neighbourhood of a river is usually much complex and includes: (a) a diverse, usually band-like, arrangement of vegetation relative to the river current; (b) occurrence of typical valley communities together with those occurring both in a valley and beyond it; (c) large spatial refinement of habitats; d) succession processes taking place in many fragments of the valley [12].

Arrangement of habitats and vegetation, is different in the valleys of large lowland rivers than small rivers. River valleys at the break-up sections are of particular, mountainous character. Among others, these are the valleys of the rivers Tanew, Sopot, Jeleń and Szum, flowing through the escarpment zone of the Tomaszów Roztocze. Valleys of the two right Tanew tributaries: Jeleń (along its whole length) and Sopot (along a 4 km section down from Hamernia) were the subjects of an interdisciplinary study on the abiotic conditions of vegetation and its spatial differentiation. Part of the studies concerned soil characteristics and aimed at: (1) determination of spatial differentiation of the soils in the river valleys; (2) recognition of factors shaping horizontal and vertical soil distribution and their properties; (3) assessment of the habitats quality determined by the soils and waters available for forest vegetation in the river valleys.

The two studied rivers originate from large Cretaceous vaucluse springs with the yield of 70-100 l/s. The rivers differ in length (Jeleń *ca.* 5 km, Sopot *ca.* 25 km), catchment area (11 and 110 km^2, respectively), amount of carried water (160 l/s and 870 l/s, respectively), and width of the valley bottoms (25-35 and 25-150 m, respectively). In the break sections, spreading for 2.0 - 2.5 km, there are a few tens of small springs with the maximum yield of up to 5 l/s. In the break section of the river Jeleń, they drain Cretaceous and Tertiary water-bearing horizons, while in those of the river Sopot-Tertiary and Quaternary water-bearing horizons. They increase the rivers flow rate below the breaks on the average by 20% [5,6,11].

Presence of structural-geological escarpment [e.g. 1,3,9] increases a hydraulic gradient of the rivers over $6^{o}/_{oo}$ on the average. In the break sections, it reaches $11^{o}/_{oo}$ on the river Jeleń and $19^{o}/_{oo}$ on the river Sopot. A direct consequence of high flow rate in the rivers from 0.4 m/s to over 1.0 m/s [6] is enhanced deep erosion.

MATERIALS AND METHODS

In the course of geobotanical mapping carried out in the vegetation seasons of 1997-1998, basic types of habitats in the valleys of the rivers Jeleń and Sopot were delimited (Fig. 1). In late autumn, a total number of 45 soil pits were made in the valleys: 17 and 28, respectively. They were drilled in the bottoms of the valleys to the depth of 2.5-4.0 m. Physical and chemical soil properties were determined for 87 and 130 samples, from the respective valleys, of mineral and organic formations. In the strict zone of breaks of the Jeleń and Sopot rivers, 7 and 12 soil profiles were analysed. The following characteristics were determined using the commonly accepted methods [7,13]; content of organic matter, granulometric composition of formations,

active acidity, content of CaO, K_2O, Na_2O, MgO, Fe_2O_3, P_2O_5 and nitrogen in the form of ammonia and nitrate compounds. This work reports the most representative data from the soil profiles for the forest ecosystems of the break zones (Fig. 1).

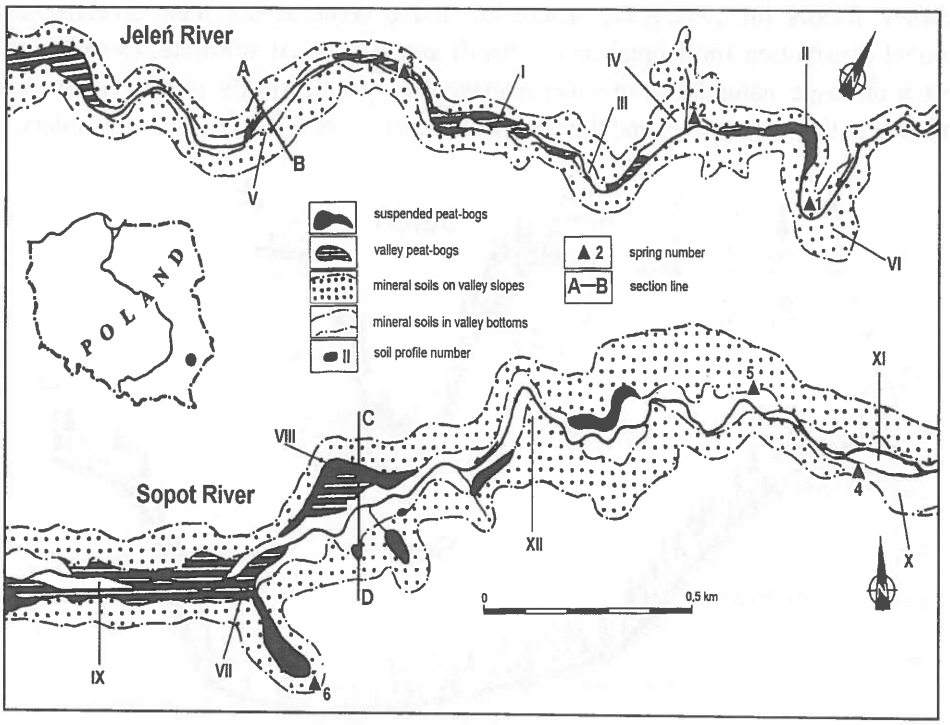

Fig. 1. Localization of selected soil profiles (I-XII) and springs (1-6) on the background of spatial soil complexes in the breaks of the rivers Jeleń and Sopot. For section lines A-B and C-D see Fig. 2.

Quality of the river water was determined from the analyses of 9 (the river Jeleń) and 15 (the river Sopot) samples from hydrological drills, 49 samples of spring water; 73 samples in total. The parameters determined were: pH, hardness (total, carbonate and non-carbonate), ionic composition, specific conductivity and mineralisation degree [4,8,10].

RESULTS AND DISCUSSION

In the studied areas, erosion processes led to cracks in the substrate and formation of valleys of the mountain ravine type. In the Jeleń river valley, the crack in

the substrate reaches 15 m down, whereas in the Sopot river valley it is deeper than 25 m (Fig. 2). A characteristic feature of both valleys is frequent asymmetry of slopes and terraces and bipartite inundate terrace over large sections of the rivers, i.e. the drier part near the river-bed and the wetter near the slope. The most important factors influencing characteristics in the break zones, their diversity and spatial distribution (horizontal and vertical) are: geological substrate, terrain relief, water drainage, natural type of water management, position of the ground water-table relative to that of the river, and the chemical properties of the spring and soil waters.

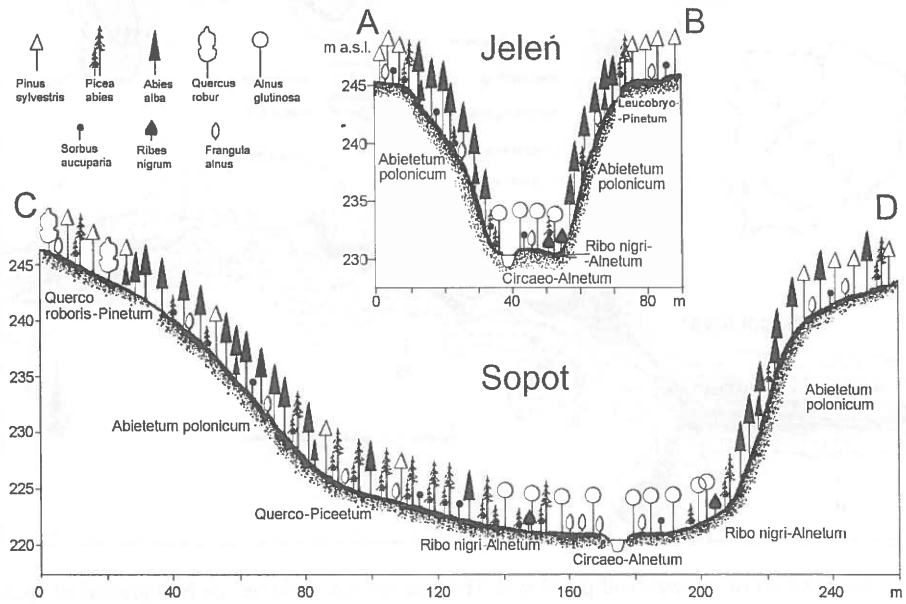

Fig. 2. Distribution of forest ecosystems in the breaks of the rivers Jeleń and Sopot

In the two valleys, a few spatial soil complexes can be distinguished: (1) organic soils occurring in the permanently wet parts of terraces and depressions without outflow filled with stagnant water; (2) organic soils related to the presence of the water-bearing horizon perched with respect to the water-table in the rivers; (3) mineral soils occurring in the valley bottoms in parts of the inundate terrace where river draining is well visible; (4) mineral soils occurring on the valley slopes (Fig. 1).

The soils of the first complex represent hydrogenic swamp soils [15]. Most often they are peaty soils typical of low peats. A far smaller area is taken by peat-mud soils.

Beds of low-valley peats are formed mainly in the lower sections of the river breaks, where Quaternary hypogeal waters cross the topographic surface on the level of terraces; their contribution increases along the river courses [5].

The valley peats vary in their thickness from 110 cm to 200 cm (in the Jeleń river valley) and from 50 to 270 cm (in the Sopot river valley), and usually include mineral interbeddings of different thickness (profile I, Fig. 3, Table 1, profile VII, Fig. 4, Tables 2 and 3). Granulometric composition of the interbeddings and underlying rock varies from loose sand and poor-clayey sand to common silt. Relative to other Polish peat-bogs, they should be classified as shallow to medium-deep [2,14,16]. The pH values of the organic formations in the two valleys vary from strongly acidic (the lowest value was 3.46) to weakly acidic (the highest value was 6.96), however, most often pH values were close to 5. In the upper peat layers, contribution of organic matter is usually significant, but in the lower layers, under mineral formations, their contribution is reduced to 13-33 wt%. The content of CaO is rarely higher than 2-3 g/100 g of peat mass. Because of the presence of such components as phosphorus, potassium, magnesium

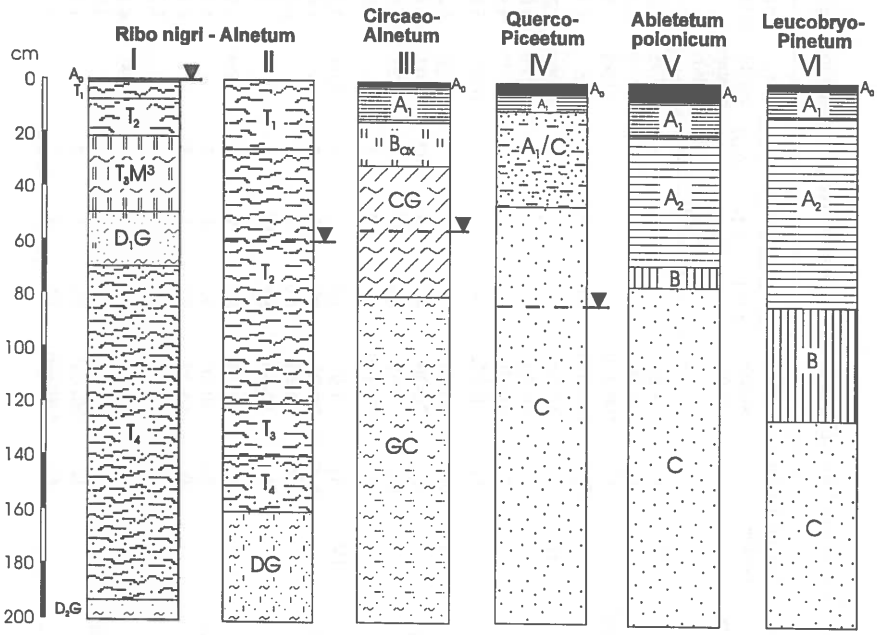

Fig. 3. Outlines of selected soil profiles representative of forest ecosystems in the break of the Jeleń river. For location see Fig. 1. Explanations of symbols for Figs. 3 and 4: A_o - litter, A_1 - humus horizon, A_2 - elluvial horizon, B - illuvial horizon, (B) - browning horizon, C - non-massive parent rock, D - underlying rock, G - ground gley, T - peat horizon, TMł - peat-mud horizon. The broken line with triangle means stabilized ground water table. See also Tables 1 and 3.

Table 1. Properties of the selected soils representative of forest ecosystems in the break of the Jeleń river

Forest ecosystem and soil type	No. of profile	Horizon	Depth of horizon (cm)	Earth parts (%)			Org. matter content (%)	pH in H_2O	Content (mg/100 g soil)							
				1-0.1	0.1-0.02	<0.02			N-NO_3^-	N-NH_4^+	P_2O_5	K_2O	CaO	Na_2O	MgO	Fe_2O_3
				(mm)												
Peat-slime soil *Ribo nigri-Alnetum* peat soil	I	T_1	5-8	-	-	-	77.75	6.20	7	9	10	19	3230	279	7	150
		T_2	10-20	-	-	-	48.99	5.52	4	18	9	17	2280	182	12	260
		T_4	100-110	-	-	-	36.88	6.96	1	0	4	6	1740	134	23	30
		D_2G	200-210	91	5	4	-	7.13	1	0	0	1	77	8	5	10
	II	T_1	10-20	-	-	-	81.96	6.64	3	6	7	21	4350	310	10	140
		T_2	40-50	-	-	-	88.60	5.88	1	3	3	10	3730	252	8	150
		T_2	80-110	-	-	-	76.72	6.55	1	2	2	11	4470	320	4	50
		T_3	120-140	-	-	-	69.81	6.60	1	1	1	7	4570	260	5	30
Circaeo-Alnetum ground-gley soil	III	A_1	10-16	-	-	-	7.28	4.41	9	6	2	3	67	7	6	260
		B_{ox}	20-30	47	42	11	2.92	5.80	8	3	4	1	119	12	4	300
		CG	35-45	65	27	8	2.23	6.62	1	1	2	3	74	13	4	30
		GC	100-110	79	17	4	-	6.65	1	1	0	1	40	5	3	30
Querco-Piceetum allucial soil	IV	A_1	5-9	80	12	8	5.06	3.80	1	0	4	3	30	5	4	40
		A_1C	20-30	92	5	3	-	5.40	1	0	1	1	8	3	3	20
		A_1C	35-40	65	28	7	-	6.44	1	4	2	4	32	5	7	10
		C	50-60	82	15	3	-	6.58	1	3	0	2	20	3	5	20
Abietetum polonicum podzolic soil	V	A_1	10-15	89	5	6	5.09	3.92	1	0	0	2	2	1	2	50
		A_2	30-40	97	2	1	-	4.70	1	1	0	1	0	1	1	20
		B	65-75	91	4	5	-	4.15	7	6	15	1	0	2	6	90
		C	80-90	94	2	4	-	4.52	3	4	8	1	0	1	2	40
Leucobryo-Pinetum podzolic soil	VI	A_1	5-10	88	5	7	3.93	4.15	1	0	0	1	2	2	2	30
		A_2	50-60	95	3	2		4.65	0	1	1	1	2	2	2	10
		B	90-100	96	2	2		4.45	1	1	8	1	0	2	5	80
		C	130-140	94	4	2		5.00	1	1	4	1	0	1	4	90

Table 2. Properties of the selected soils representative of forest ecosystems in the break of the Sopot river

Forest-ecosystem and soil type	No. of profile	Horizon	Depth of horizon (cm)	Earth parts (%)			Org. matter content (%)	pH in H_2O	Content (mg/100 g soil)							
				1-0.1	0.1-0.02	<0.02			N-NO_3^-	N-NH_4^+	P_2O_5	K_2O	CaO	Na_2O	MgO	Fe_2O_3
					(mm)											
Ribo nigri-Alnetum peat soil	VII	T_1	15-25	-	-	-	39.92	5.80	23	27	20	5	964	77	11	900
		T_2	130-150	-	-	-	75.31	6.43	23	12	16	7	2320	160	6	990
		T_2	240-260	-	-	-	27.12	7.13	3	11	9	8	910	940	7	415
		D_2	275-285	91	3	4	-	7.26	0	0	0	1	38	3	0	25
Querco-Piceetum peat soil	VIII	T_1	10-15	-	-	-	85.36	4.04	2	15	24	22	876	77	29	150
		T_1	30-40	-	-	-	90.99	4.42	2	10	5	6	1660	150	38	125
		T_2	70-80	-	-	-	71.71	4.76	1	16	7	7	2170	140	19	225
		D_2	100-110	83	9	8	2.30	5.56	0	0	3	1	123	10	0	10
Circaeo-Alnetum alluvial soil	IX	A_1	10-20	71	20	9	0.26	5.53	1	3	3	2	134	11	1	315
		A_1C	30-40	94	4	2	-	7.00	0	0	1	2	27	6	0	20
		C	60-70	95	5	0	-	6.84	0	2	0	1	11	2	0	0
		T_2	160-180	-	-	-	49.73	6.46	0	16	5	4	1840	160	24	470
		D_2G	260-280	73	22	5	-	7.11	0	0	0	2	73	6	1	125
Circaeo-Alnetum gley podzolic soil	X	A_1	20-30	76	12	12	0.27	6.42	8	3	7	2	222	19	0	140
		B_{ox}	70-80	86	7	7	-	4.46	0	0	3	1	77	7	0	25
		CG_2	150-180	54	21	25	-	7.57	2	0	43	11	289	23	3	150
		D	185-210	78	8	14	-	7.89	1	3	38	12	-	595	36	80
Circaeo-Alnetum rendzina soil	XI	A_1	10-20	72	12	16	-	7.57	4	5	130	19	-	275	4	155
		B(C)	50-55	37	24	39	-	7.98	4	3	110	35	-	600	13	260
		C	65-75	8	43	49	-	8.18	1	1	84	30	-	720	17	65
Abietetum polonicum podzolic soil	XII	A_1	10-15	93	2	5	0.16	3.87	3	0	5	1	4	2	0	25
		A_2	20-30	95	3	2	-	4.54	0	2	0	1	7	2	0	10
		B	50-60	95	1	4	-	4.45	3	3	36	1	2	2	1	105
		C	145-160	96	2	2	-	5.32	0	0	5	1	2	2	0	20

Table 3. Physical and chemical water properties of the selected soil profiles (I-IV, VII-X) and springs (1-6) in the breaks of the rivers Jeleń and Sopot

Object No. in Fig. 1	pH	Hardness (meq/1)			Ions (mg/l)						Total mineraliz. M (mg/l)
		Total	Carbonate	Noncarbonate	Ca^{2+}	Mg^{2+}	$Na^{+}+K^{+}$	HCO_3^-	Cl^-	SO_4^{2-}	
I	6.57	1.80	1.30	0.50	34.1	1.2	2.5	79	10.3	14.9	112
II	6.90	5.08	3.15	1.93	96.2	3.4	1.2	192	41.8	38.4	362
III	6.24	2.48	2.00	0.48	46.1	1.7	2.5	122	7.1	18.3	155
IV	6.13	1.30	0.70	0.60	24.0	1.2	0.5	43	9.2	17.3	81
VII	6.19	1.26	0.85	0.41	19.4	3.5	0.0	52	5.3	12.5	80
VIII	4.33	0.86	0.22	0.66	14.8	1.5	0.0	13	7.4	20.7	64
IX	6.72	3.12	2.90	0.22	55.7	4.1	1.0	177	6.0	4.8	216
X	6.52	3.60	2.90	0.70	65.3	4.1	0.0	177	12.8	16.3	218
1 Cr	7.25	4.66	3.90	0.76	92.0	3.4	0.0	207	12.8	22.0	312
2 Cr	7.12	5.12	4.70	0.42	94.8	4.7	8.5	287	10.3	11.5	348
3 Q	7.18	1.50	1.30	0.20	25.7	2.7	5.2	79	8.5	8.2	129
4 Tr	7.06	3.22	3.02	0.20	57.3	4.4	6.7	184	8.9	10.6	247
5 Tr	7.35	4.40	3.90	0.50	84.6	2.2	2.5	238	11.7	13.0	340
6 Q	6.27	1.24	0.80	0.44	20.8	2.4	1.0	49	71.0	12.5	113

Explanations for stratigraphy of water-bearing rocks: Cr - Cretaceous, Tr - Tertiary, Q - Quarternary.

and nitrogen in the form of nitrates, important for vegetation, these habitats are classified as mezotrophic and sometimes eutrophic.

Peaty soils are covered with phytocenoses of *Ribo nigri-Alnetum* (Fig. 2) and *Salicetum pentandro-cinereae*, less often with those of *Sphagnosquarrosi-Alnetum*. Peat deposits are usually formed of sedges and alder litter, sometimes with high contribution of reed and peat mosses. The most abundant species in the moss layer are *Sphagnum palustre, S. angustifolium* and *S. squarrosum.*

At many sites, in the breaks of the two rivers, the water-bearing horizon is perched with respect to the river water-table. The reasons for the differences in the underground water-table are tectonic deformations of the substrate and its lithological diversity. Presence of perched horizons in the river Sopot valley is related to the occurrence of Tertiary (Sarmatian) clays beneath Pleistocene sand. In the river Jeleń, break section, that cause a local lift of the Cretaceous and Quaternary water-bearing horizons, were recognised [5] that gave rise to the so-called suspended low peat-bogs (Fig. 1).

Thickness of the perched peat bogs varies. In the river Sopot valley, it most often is between 50 and 90 cm. Peat usually lies on loose sand, or less often on poor-clayey sand (Tables 2 and 3, profile VIII). Acidic hydrogenic soils at the foot of the slopes where the ground water-table is 1-1.5 m higher than the river table, and supplied with poorly mineralised Quaternary waters, are usually covered with moist mixed coniferous forest with spruce *Querco-Piceetum* (Fig. 4, profile VIII). In the branch valleys, on the left bank of the river Sopot (Fig. 1), the springs are perched even up to 4-6 m. Water in these springs and gravitation flows and effluences is richer in alkaline components. Hence, more demanding vegetation cover appeared there. The peat-forming vegetation at the low-perched peat bogs is mainly composed of mezophilous vascular species and bryophytes, with a very small contribution of species from the genus *Sphagnum* [6]. An interesting observation is that the peat thickness in the branch valleys is the smallest at their heads and increases towards their mouths. It can be expected that the age gradient of these formations is the same [5].

In the break section of the Jeleń river valley there is a single suspended peat deposit of the spring type and mountainous character, which is rarely met in lowlands [*cf.* 2]. Its structure and physical and chemical properties are illustrated in the profile II (Fig. 3, Tables 1, 3). It is grown with a patch of fertile bog-alder forest *Ribo nigri-Alnetum*. A specific character of this carbonaceous peat site (the content of CaO in the profile varies from 3.7 to 4.5 g/100 g of peat mass) was described in earlier reports [5,6,11].

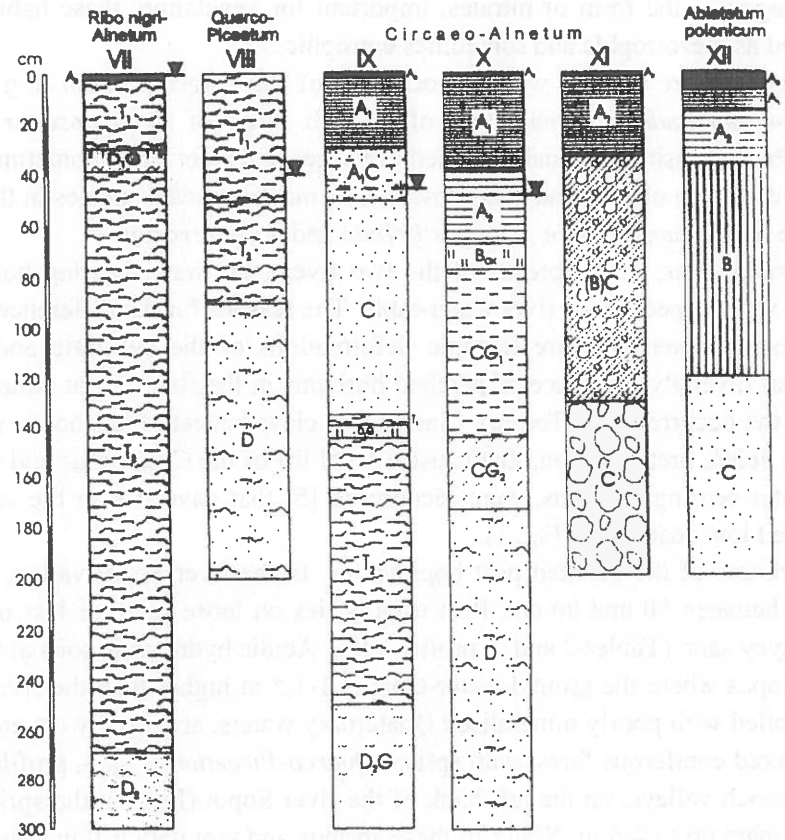

Fig. 4. Outlines of the selected soil profiles representative of forest ecosystems in the break of the Sopot river. Explanations as in Fig. 3. See also Tables 2 and 3.

Mineral profiles at the bottoms of the valleys differ from the complexes described earlier not only in lithology but also in the chemical composition of the analysed horizons (Tables 1 and 2). These soils are markedly distinguished by almost all the parameters describing water quality. Differences arise from the fact that particular formations are supplied with water from different water-bearing horizons (Table 3).

The soils formed in drier parts of inundate terraces in both valleys, favour, first of all, phytocenoses of stream-line ash-alder forest *Circaeo-Alnetum* (Figs 1, 2). These soils are alluvial formations with highly diversified granulometric composition (Tables 1, 2), from loose and poorly-clayey sands to heavy clays and silty clay, probably "Krakowiec" clays [see 6]. Depending on the relation between ground waters and precipitate, quality of the former and geochemistry of their substrates, different semihydrogenic and alluvial soils developed in the area [15].

The class of semihydrogenic soils is represented by proper gley soils (profile III, Fig. 3), peat-like gley soils, and proper gley podzols (profile X, Fig. 4). Properties of semihydrogenic soils and waters supplying them indicate that they create mesotrophic habitats (Tables 1-3). Under riverside ash-alder forests, there are also alluvial soils - humous and proper (profile IX, Fig. 4). The former are, however, poorer in the components easily available for plants, because of strong acidification. They are grown with mixed coniferous forest with spruce, similar to the *Querco-Piceetum* association from the phytosociological point of view (see Tables 1,2).

In the profiles of certain semihydrogenic and alluvial soils in the Sopot river valley, buried peats were found. They are characterised by the pH level varying from 5.62 to 7.73, organic matter content of 13 to 56%, CaO content of 0-2.5 g/100 g soil, thickness from 5 to 120 cm and deposition depth of 135 cm (profile IX, Fig. 4) to 380 cm in the break section of this river. Up the break, such peats were found on the level of the current river table, and farther up, near Nowiny, at the level of 90 cm above the river water-table [6]. The enhanced level of calcium (to 1-2.5 g/100 g peat mass) and magnesium, sometimes also phosphorus and nitrate nitrogen (Table 2) can be used by deeper rooting perennials, and, first of all, trees and shrubs.

In the river Sopot valley, at the sites of erosion scars uncovering Cretaceous and Miocene formations, under drier fragments of *Circaeo-Alnetum,* there are also relatively small patches of lithogenic soils-Cretaceous and Tertiary rendzinas (profile XI, Fig. 4) and autogenic ones-leached brown soils.

The poorest and most acidic habitats developed on the autogenic podzol soils (profiles V and VI, Fig. 3, profile XII, Fig. 4, Tables 1, 2), less often on the podzolized rusty soils, developed on steep, sometimes abrupt slopes with an inclination from 30^{o} to 60^{o}. The parent rocks of these soils are loose or poor-clayey sands, which are permeable and supplied with precipitate waters; hence poor in nutrients (M *ca.* 10-15 mg/l). The podzol soils show great diversity of thickness in individual horizons (mainly alluvial and illuvial) as well as organic matter content in the humus accumulation horizon (0.10-4.42%). In lower horizons, the content of nutrients falls almost to zero. Similar oligotrophic habitats are formed on the brown-podzolic soils. Thus, the slopes of the valleys are most often covered with coniferous forest phytocenoses: upland mixed coniferous forest with fir *Abietum polonicum*, pine forest *Leucobryo-Pinetum* and in the river Sopot valley also mixed forest with oak and pine *Querco roboris-Pinetum* (Fig. 2). Parts of the slopes from which fir stands were removed, are occupied by secondary communities with planted Scotch pine.

CONCLUSIONS

1. Specific features of the studied river valleys are the soils, which developed and function under the influence of a combination of the following factors: bedrock, geochemistry, relief, drainage of underground waters, hydrogeochemical zonation and stratigraphy, plant communities and biochemical processes therein.

2. Complexes of mineral soils in the fragments of the valleys in which rivers play a draining role. The condition necessary for the formation of hydrogenic soils (valley and suspended peats) is an appropriate stagnant water or perched water-bearing horizon in the form of springs, gravitation flows and effluences at the foot of the slopes and in the branch valleys.

3. Determination of the extent of gravitation flows and effluences, as well as the character of the waters, significantly facilitates delimitation of soil complexes and the corresponding types of vegetation in the bottoms of the valleys, and is particularly useful for the riverside ash-alder and bog-alder forests, which show significant floristic and ecological similarities.

4. The soil studies in the area raised some new questions concerning the presence of buried peats and stratigraphic status of "Krakowiec" clays. It is expected that investigations of these problems may revise ideas on the geology and tectonics of this part of the escarpment zone of the Tomaszów Roztocze.

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