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Genesis and classification of the soils developed from the sediments of the former Oleszek mill pond basin (the Chełmińskie Lakeland, N Poland)

Abstract: Construction and operation of water mills had influenced the transformation of the relief and water conditions, as well as the soil cover around them. The study area includes the former Oleszek mill pond basin, located near the Borówno village, western part of the Chełmińskie Lakeland, about 20 km northeast of Toruń. The objective of the study was to determine the genesis of the soils developed from the Oleszek mill pond basin sediments. Five soil profiles were selected in the basin of the former mill pond, within the 550 m transect located along the Struga Rychnowska river. All of the analysed soils developed from the sediments filling the former mill pond basin. They have been developed as a result of a number of overlapping processes such as mud-forming, alluvial, colluvial and gleyic process. According to the Polish classification system (Classification of Polish Soils 2011) (CPS) two of the soils (profiles 3 and 4) derived from organo-mineral and organic materials are typical organic limnic soils. Systematic position of another two soils (2 and 5) was proposed as muddy soils. Due to the problems of classification of such soils, implementation of the muddy soils or muddy-gleyic soils subtypes (in Polish: gleby mułowate lub mułowato-glejowe) should be considered during developing of the next update of Classification of Polish Soils. These four profiles were classified as Histosols (profiles 3 and 4) and Gleysols (profiles 2 and 5) in WRB (2014). Pedons developed from alluvial materials (alluvial soils in CPS 2011 or Fluvic Phaeozems in WRB 2014) occurred in the proximal part of the basin.

Key words: mill pond sediments, mud soils, organic soils, Gleysols, paralimnic environment

INTRODUCTION

Water mills are one of the first hydro-technological constructions in Poland. They appeared at the turn of the 11th and 12th century and became common in the 13th century (Dembińska 1973). The energy of the water was not used for grinding grain only, but also in fulleries, granaries, oil mills, tanneries, sawmills and hammermills (Baranowski 1977; Podgórski 2004). Construction and operation of water mills had influenced the transformation of the natural environment around them. Relief and water conditions are characterized by the major changes (Podgórski 2004). In addition to the above mentioned, soil cover is another element of the environment that is characterized by the fast reaction on the anthropic pressure. Natural soils around the mill ponds have been transformed (i.e. enriched with material from the basin). On the other hand, completely new ones have been developed from the materials accumulated in the former mill pond basins.

Mill pond sediments are studied mainly by geomorphologists and sedimentologists. They use these deposits as an indicator of anthropogenic environmental changes (e.g. Kocel 1997; Michalska and Szpikowski 1999; Klimek et. al. 2003; Szwarczewski 2003; Sypka et. al. 2007). These sediments are also studied due to their agricultural use after dredging (e.g. Madeyski and Tarnawski 2006; Tarnawski and Michalec 2006).

Apart from a few exceptions (e.g. Jonczak and Forek 2013), there is a lack of the soil science studies on mill pond sediments. For this reason, inter alia, the presented research was carried out. The objective of the study was to determine the genesis of soils developed from the Oleszek mill pond basin sediments.

MATERIAL AND METHODS

The study area includes the former Oleszek mill pond basin, located near the Borówno village, western part of the Chełmińskie Lakeland, northern Poland. It was located on the eastern branch of the Struga Rychnowska river. The river flows in the bottom of subglacial channel in the western part of the Chełmińskie Lake District, approximately 20 km northeast of Toruń (Figure). This part of the channel is bordering a morainic plateau of the east and outwash plain of the west.

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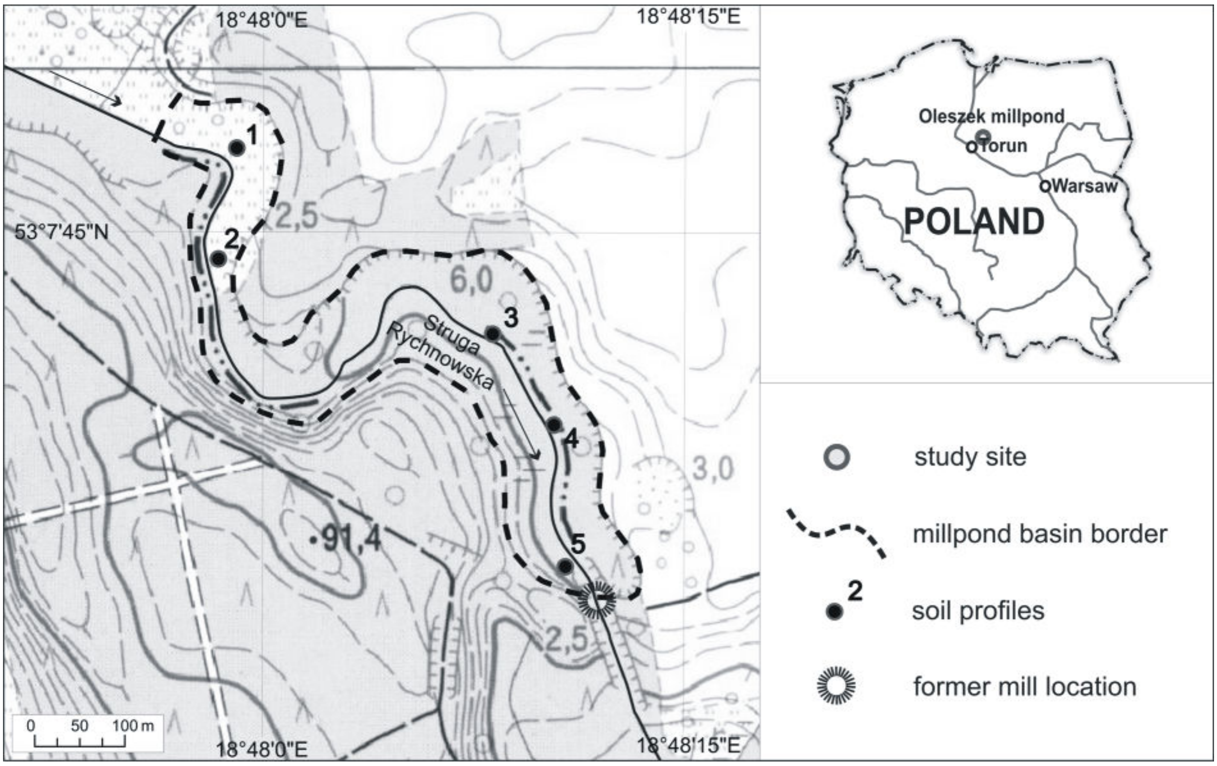

FIGURE. Location of the study area

Landscape around the study area is affected by the Scandinavian ice-sheet of the Vistulian Glaciation, mainly by the recession of the continental glacier of the Krajna-Wąbrzeźno subphase, as well as stagnation and recession of the Kujawy-Dobrzyń subphase, about 17–16 thousand years BP (Niewiarowski 1984). Characteristic feature of the subglacial channels in this region are common depressions separated by thresholds (Niewiarowski 1968). One of these thresholds was used for setting the mill pond dam.

Podgórski (2004) showed that the history of the bottom sediments of the basin begins with a natural body of water existing since approximately 10 700 years BP until the XVI century. The river mill was located in 18^{th} century and worked until the 1920s. After this period, the mill pond basin was used as a storage reservoir for about 30 years and later drained. In 1924, the pond covered the area of 2.60 ha and was 615 meters long (Podgórski 2004).

Five soil profiles were selected within the 550 m transect located along the Struga Rychnowska river which is the longitudinal axis of the basin (Figure). Transect was delineated from the proximal part of the basin (profile 1) to the dam that is closing the former pond (profile 5).

Analysed soil profiles were described and samples were collected from the soil horizons. The following soil properties were determined in collected samples: bulk density by the oven-dry method, particle size distribution by the sieve method and the hydrometer (the Bouyoucos aerometric, modified by Cassagrande and Prószyński) method, the names of the texture classes were given according to the Polish Soil Science Society classification (Polskie Towarzystwo Gleboznawcze 2009), pH of the soil-to-solution ratio of 1:2.5 using 1M KCl and H_2O as the suspension medium, content of total organic carbon (TOC) by sample oxidation in the mixture of $K_2Cr_2O_7$ and H_2SO_4, content of total nitrogen (Nt) by the Kjeldahl method, content of carbonates by the Scheibler volumetric method, colour has been described in the dry and the wet samples according to Munsell (Munsell Soil Colour Charts, 2000). The soils were classified according to the Classification of Polish Soil (2011) (CPS) and WRB classification system (IUSS Working Group WRB 2014).

RESULTS AND DISCUSSION

Morphology and properties of the studied soils

All of the analysed soils were developed from the sediments filling the former mill pond basin. These sediments can be divided into three lithological-chronological types: (I) mineral sediments of the subglacial channel bed, (II) organo-mineral materials accumulated in natural reservoir, and (III) organo-mineral and mineral materials accumulated in the former mill pond. Due to the flow-through nature of both the natural reservoir and the mill pond, sediments of the types II and III should be considered as the paralimnic ones, in opposite to the typical limnic sediments of the still water reservoirs. The sequence of the sediments in analysed profiles corresponds to the one described by Podgórski (2004).

Mineral sediments of the subglacial channel bed (I) are characterized by the diverse particle size distribution of clay and clay loams (profiles 1 and 2), as well as sands and loamy sands (profiles 3–5). It

TABLE 1. Selected physical properties of the soils investigated

Type of sediment*	Genetic horizon		Depth	Colour		Bulk density [g·cm^{-3}]	Percentage share of fraction [mm]			Textural class
	CPS (2011)	WRB (2014)		dry sample	wet sample		2–0.05	0.05–0.002	<0.002	
Profile 1 – mada czarnoziemna typowa (typical chernozemic alluvial soil)** – Greyzemic Orthofluvic Gleyic Phaeozem (Geoabruptic, Epiloamic, Nechic) *** – ground water level: 88 cm										
III	A(p)	A(p)	0–27	10YR 4/2	10YR 2/1	1.06	67	28	5	sandy loam
III	A	A	27–42	10YR 4/2	10YR 3/2	1.16	42	46	12	loam
III	A/C	A/C	42–65	2.5Y 6/2	2.5Y 3/2	1.65	84	11	5	loamy sand
III	Cg1	Cl1	65–78	2.5Y 6/1	2.5Y 3/2	0.90	35	48	17	loam
III	Cg2	Cl2	78–88	10YR 5/3	10YR 3/3	1.26	89	7	4	sand
II	Oe	Oe	88–100	10YR 3/1	10YR 2/1	n.d.	n.d.	n.d.	n.d.	n.d.
I	Cg3	Cl3	100–128	2.5Y 5/1	2.5Y 3/1	n.d.	79	16	5	loamy sand
I	Cg4	Cl4	>128	2.5Y 6/1	2.5Y 4/2	n.d.	16	31	53	clay
Profile 2 – gleba mułowata (muddy soil)**** – Endocalcaric Gleysol (Epiloamic, Colluvic, Humic, Limnic)*** – ground water level: 125 cm										
III	A	A	0–38	10YR 4/2	10YR 2/2	1.22	74	21	5	sandy loam
III	LA	LA	38–53	2.5Y 4/2	2.5Y 3/1	0.62	70	27	3	sandy loam
II	Lc	Lc	53–100	2.5Y 3/2	2.5Y 2.5/1	0.56	n.d.	n.d.	n.d.	n.d.
II	GL	CL	100–122	2.5Y 4/1	2.5Y 2.5/1	1.13	81	15	4	loamy sand
I	G	Cl	>122	2.5Y 6/2	2.5Y 4/2	1.64	33	34	33	clay loam
Profile 3 – gleba organiczna limnowa typowa (typical limnic organic soil) ** – Rheic Sapric Histosol (Calcaric, Epifluvic, Limnic, Orthomineralic, Loaminovic)*** – ground water level: 92 cm										
III	(M)L	AL.	0–14	10YR 4/2	10YR 2/2	0.44	51	42	7	sandy loam
III	(M)Lc	Lc	14–33	10YR 4/2	10YR 3/1	0.51	59	36	5	sandy loam
III	Lcm	Lcm	33–56	2.5Y 3/1	2.5Y 2.5/1	0.31	n.d.	n.d.	n.d.	n.d.
III	Lc2	Lc2	56–74	2.5Y 2/1	2.5Y 2/1	0.20	n.d.	n.d.	n.d.	n.d.
II	Lcm2	Lcm2	74–94	2.5Y 4/1	2.5Y 3/2	0.84	n.d.	n.d.	n.d.	n.d.
II	GL	CL	94–105	2.5Y 3/1	2.5Y 2.5/1	n.d.	n.d.	n.d.	n.d.	n.d.
I	G1	Cl1	105–120	5Y 6/3	5Y 4/4	n.d.	86	12	2	loamy sand
I	G2	Cl2	>120	5Y 6/3	5Y 4/4	n.d.	96	1	3	sand
Profile 4 – gleba organiczna limnowa typowa (typical limnic organic soil)**– Epicalcaric Endofluvic Gleysol (Epiloamic, Endoarenic, Hyperhumic, Epilimnic)*** – ground water level: 75 cm										
III	(M)Lc	AL	0–47	10YR 4/3	10YR 2/2	0.42	53	40	7	sandy loam
III	GL	CL	47–54	2.5Y 4/1	2.5Y 2.5/1	n.d.	80	17	3	loamy sand
I	G1	Cl1	54–65	2.5Y 5/1	2.5Y 3/1	1.31	95	4	1	sand
I	G2	Cl2	>65	10YR 6/4	10YR 3/4	1.55	97	3	0	sand
Profile 5 – gleba mułowata (muddy soil)**** -– Calcaric Gleysol (Loamic, Hyperhumic, Limnic)*** – ground water level: 80 cm										
III	(M)L	AL.	0–14	10YR 4/2	10YR 3/2	1.16	89	8	3	loamy sand
III	L1	L1	14–34	10YR 4/3	10YR 2/2	0.93	74	20	6	sandy loam
III	L2	L2	34–68	2.5Y 5/4	2.5Y 3/2	0.58	73	22	5	sandy loam
III/II	Lc	Lc	68–210	2.5Y 3/3	2.5Y 2.5/1	0.27	n.d.	n.d.	n.d.	n.d.
I	G	Cl	>210	2.5Y 6/1	2.5Y 3/2	n.d.	96	3	1	sand

n.d. – not determined, * lithological-chronological type of sediment, ** Classification of Polish Soils (2011), *** IUSS Working Group WRB (2014), **** not included in CPS (2011).

could be a result of a specific location of the basin within the part of the channel on the border between fine morainic tills and the outwash sands. Roof of these materials starts in studied soils on different depths from 54 (profile 4) to 210 cm (profile 5).

Organo-mineral deposits accumulated in natural reservoir (II) and later mill pond (III) in profiles 2–5 are characterized by the particle size distribution of sandy loams and loamy sands. The exceptions is the profile 1, which consists of fluvic material characterized by alternate layers of variable particle size distribution (Table 1).

Contents of organic carbon in analysed soils depended on the type of the material from which individual horizons are composed. Mineral channel bed sediments (I) in the bottom of each profile and the alluvium (III) building the profile 1 contained the least amounts of organic carbon (up to 31 $g \cdot kg^{-1}$), whereas the organo-mineral and organic deposits of natural reservoir and the mill pond are characterized by much higher content of TOC (29–412 $g \cdot kg^{-1}$). Carbonates are distributed in a very irregular way, from 2 $g \cdot kg^{-1}$ in sandy channel sediments to 411 $g \cdot kg^{-1}$ in paralimnic materials. Reaction of all analysed samples

TABLE 2. Selected chemical properties of the soils investigated

Type of sediment*	Genetic horizon		Depth	Corg	Nt	C:N	pH		$CaCO_3$
	CPS (2011)	WRB (2014)		[$g \cdot kg^{-1}$]			H_2O	KCl	[$g \cdot kg^{-1}$]
Profile 1 – mada czarnoziemna typowa (typical chernozemic alluvial soil)** Greyzemic Orthofluvic Gleyic Phaeozem (Geoabruptic, Epiloamic, Nechic) **									
III	A(p)	A(p)	0–27	30.97	3.29	9.4	7.8	7.3	18
III	A	A	27–42	23.75	2.52	9.4	8.3	7.5	37
III	A/C	A/C	42–65	6.95	0.58	11.9	8.5	8.0	18
III	Cg1	Cl1	65–78	24.84	2.65	9.4	8.0	7.5	54
III	Cg2	Cl2	78–88	10.14	0.90	11.2	7.9	7.7	12
II	Oe	Oe	88–100	141.89	10.36	13.7	n.d.	n.d.	9
I	Cg3	Cl3	100–128	20.29	1.85	11.0	8.0	7.7	41
I	Cg4	Cl4	>128	6.08	0.55	11.1	8.4	7.5	94
Profile 2 – gleba mułowata (muddy soil)**** Endocalcaric Gleysol (Epiloamic, Colluvic, Humic, Limnic)**									
III	A	A	0–38	17.33	1.68	10.3	7.8	7.1	1
III	LA	LA	38–53	108.87	8.79	12.4	7.9	7.4	102
II	Lc	Lc	53–100	155.80	11.45	13.6	7.4	7.0	39
II	GL	CL	100–122	28.22	1.73	16.3	8.0	7.7	14
I	G	Cl	>122	4.69	0.39	12.1	8.4	7.7	111
Profile 3 – gleba organiczna limnowa typowa (typical limnic organic soil) ** Rheic Sapric Histosol (Calcaric, Epifluvic, Limnic, Orthomineralic, Loaminovic)***									
III	(M)L	AL.	0–14	117.92	11.61	10.2	8.1	7.4	143
III	(M)Lc	Lc	14–33	124.06	11.06	11.2	8.1	7.5	173
III	Lcm	Lcm	33–56	271.44	20.12	13.5	7.8	7.5	214
III	Lc2	Lc2	56–74	412.44	27.08	15.2	7.2	6.9	32
II	Lcm2	Lcm2	74–94	136.34	10.41	13.1	7.9	7.9	411
II	GL	CL	94–105	29.05	2.05	14.2	7.9	7.5	44
I	G1	Cl1	105–120	1.60	0.14	11.4	8.5	8.1	5
I	G2	Cl2	>120	6.84	0.49	13.9	8.1	7.6	38
Profile 4 – gleba organiczna limnowa typowa (typical limnic organic soil)** Epicalcaric Endofluvic Gleysol (Epiloamic, Endoarenic, Hyperhumic, Epilimnic)**									
III	(M)Lc	AL	0–47	128.94	11.90	10.8	8.0	7.3	120
III	GL	CL	47–54	29.73	2.16	13.8	7.8	7.6	59
I	G1	Cl1	54–65	9.01	0.64	14.1	8.5	8.2	24
I	G2	Cl2	>65	1.20	0.10	12.0	8.7	8.5	2
Profile 5 – gleba mułowata (muddy soil)**** – Calcaric Gleysol (Loamic, Hyperhumic, Limnic)***									
III	(M)L	AL	0–14	33.60	2.83	12	7.9	7.5	19
III	L1	L1	14–34	37.79	3.84	10	8.3	7.7	51
III	L2	L2	34–68	87.17	7.18	12	8.1	7.6	169
III/II	Lc	Lc	68–210	136.69	8.83	16	7.3	7.0	43
I	G	Cl	>210	8.93	0.44	20	8.3	8.1	18

n.d. – not determined, * lithological-chronological type of sediment, ** Classification of Polish Soils (2011), *** IUSS Working Group WRB (2014), **** not included in CPS (2011).

is near-neutral or slightly alkaline with the pH_{H2O} values ranging from 7.2 to 8.7 (Table 2).

Taking under consideration physical and chemical features, analysed soils are very similar to ones described by Jonczak and Florek (2013) from the mill pond basin located in the Jarosławianka river valley (Sławno Plain). Low values of bulk density are distinctive feature of paralimnic sediments in both basins. Bulk densities were 0.20–0.84 $g \cdot cm^{-3}$ in the Oleszek and 0.42–1.32 $g \cdot cm^{-3}$ in the Jarosławianka river valley (Jonczak and Florek 2013). The main difference between soils of this two sites is the layering which is much less accented in sediments in Oleszek what is clearly visible when comparing the soils morphology. It is probably connected with much more stable sedimentation conditions in the Oleszek mill pond.

Genesis and classification of the studied soils

Soils of described basin has been developed as a result of a number of overlapping processes. The basic one, having the strongest influence on the morphology and characteristics of studied soils was the mud-forming process. It is defined as a process of organo-mineral and organic materials sedimentation within the consistent or periodic reservoirs in conditions of stagnant water which is relatively well saturated with oxygen (Okruszko 1969). The evidence for mud genesis of organo-mineral and organic paralimnic materials building the middle parts of profiles 2–5 is their similarity to the typical limnetic muds forming e.g. in the oxbow lakes (Okruszko 1969). Organo-mineral surface horizons created due to overlapping of the mud-forming and the alluvial processes. Features of these layers are similar to the typical telmatic muds (Okruszko 1969). Their accumulation led to developing of mud soils and muddy soils. Nowadays it takes place at the flood plains of semi-natural rivers like for example Biebrza and Narew (Roj-Rojewski 2003, 2009; Roj-Rojewski and Walasek 2013) or Omulew (Kalisz and Łachacz 2008). Due to the small thickness (less than 40 cm) of surface organo-mineral sediments, two of the analysed soil profiles (3 and 4) meet the criteria of typical limnic organic solis (in Polish: gleby organiczne limnowe typowe). Profiles 2 and 5 cannot be classified as limnic organic soils because of the presence of thick (more than 40 cm) organo-mineral surface horizons. This is a result of aforementioned alluvial process and also the colluvium deposition.

It should be considered to implement the sub-type of muddy soils or muddy-gleyic soils (in Polish: gleby mułowate lub mułowato-glejowe) within the type of the gleyic soils in the next update of CPS. This classification unit could include soils developed from organo-mineral materials with content of organic matter between 10 and 20% accumulated in mud-forming process. The need to create such a taxonomic units was noticed already (Kalisz and Łachacz 2008; Roj-Rojewski 2009), also in relation to soils derived from the mill pond sediments (Jonczak and Florek 2013).

According to WRB classification system (IUSS Working Group WRB 2014), three profiles among of the soils developed from mud and muddy materials (profiles 2, 4, and 5) were classified as Gleysols. The basis for this classification was the presence of features associated with gleyic process as ferruginous precipitations around the living and dead roots. Colours that indicates the domination of the reducing conditions are partially hidden by the lithogenic features of the deposits e.g. dark colour due to high organic matter content. In case of the profile 3, classified as Rheic Sapric Histosol, the main feature is the domination of organic material within the profile (IUSS Working Group WRB 2014). Classification discrepancies between used systems are caused by different quantitative criteria in the terms of soil organic material characterization (12–18% of TOC in the PSC 2011, >20% TOC in WRB 2014).

Profile 1 has different genesis when compared to profiles 2–5. It developed as a result of alluvial process, that dominates in the proximal part of the basin (Podgórski 2004). Systematic position of the soil in profile 1 is the reflection of this process. Domination of *fluvic* material within the whole profile and the presence of *mollic* horizon allowed to classify the soil as a typical chernozemic alluvial soil (in polish: mada czarnoziemna typowa) according to CPS (2011), whereas according to the WRB (IUSS Working Group WRB 2014) it is Greyzemic Orthofluvic Gleyic Phaeozem.

In parallel with all the above mentioned, the gleyic process occurs in the all described soils, due to a high ground water level in the basin (Table 1 and 2). Morphological features caused by this process are often masked by dark colour of horizons resulting from high content of organic matter (Table 2). Probably the progressive process of decomposition and mineralization of organic matter (mursh-forming process) which is evidenced in tiny cracks occurring in the surface horizons derived from mud and muddy materials will have a significant impact on these soils in the future.

CONCLUSIONS

1. Mud-forming process had the strongest impact on the characteristic of soil cover of the Oleszek mill pond basin. On the other hand it is overlapped by alluvial and colluvial processes that modifies features of surface horizons mainly in the middle and the distal parts of the basin.
2. As a result of aforementioned processes specific organic and organo-mineral sediments have been developed. According to the Polish classification system (CPS 2011) typical limnic organic soils and muddy soils (in Polish: gleby organiczne limnowe typowe i gleby mułowate) have derived from these sediments. They were classified as Histosols and Gleysols in WRB (2014). Alluvial soils (CPS 2011) or Fluvic Phaeozems (WRB 2014) developed from alluvial materials occurred only in the proximal part of the basin.
3. Implementation of muddy soils or muddy-gleyic soils subtypes (in Polish: gleby mułowate lub mułowato-glejowe) within the type of gleyic soils that include soils derived from organo-mineral alluvial-muddy materials should be considered during developing of the next Classification of Polish Soils update.

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Geneza i pozycja systematyczna gleb wykształconych z osadów niecki dawnego stawu młyńskiego Oleszek (Pojezierze Chełmińskie)

Streszczenie: Budowa i funkcjonowanie młynów wodnych znacznie wpłynęły na przekształcenie środowiska przyrodniczego w ich otoczeniu, przede wszystkim na zmiany rzeźby terenu i warunków wodnych. Obszar badań obejmuje nieckę dawnego stawu młyńskiego Oleszek w okolicach wsi Borówno, w zachodniej części Pojezierza Chełmińskiego, około 20 km na północny wschód od Torunia. Celem badań było określenie genezy gleb wykształconych z osadów zakumulowanych w niecce dawnego stawu młyńskiego Oleszek. Pięć profili glebowych w transekcie o długości około 550 m zlokalizowanym wzdłuż Strugi Rychnowskiej stanowiącej oś podłużną niecki. Wszystkie przeanalizowane gleby zbudowane są z osadów wypełniających nieckę dawnego stawu młyńskiego. Gleby w opisywanej niecce powstały w wyniku wielu nakładających się procesów, takich jak: proces mułotwórczy, aluwialny, koluwialny oraz glejowy. Dwa z analizowanych profili glebowych (profile 3 i 4) spełniają kryteria wydzielania gleb organicznych limnowych typowych (Systematyka gleb Polski 2011). Jako pozycję systematyczną kolejnych dwóch gleb (profile 2 i 5) zaproponowano gleby mułowate. W związku z problemami klasyfikacyjnymi dotyczącymi tego typu gleb, przy opracowaniu aktualizacji Systematyki gleb Polski należałoby wprowadzić w typie gleb glejowych podtyp gleb mułowatych lub mułowato-glejowych, obejmujący gleby wytworzone z mineralno-organicznych utworów aluwialno-mułowych. Cztery wymienione powyżej profile zostały zaklasyfikowane jako Histosols (3 i 4) i Gleysols (2 i 5) według klasyfikacji WRB (2014). Jednostki glebowe wykształcone z osadów aluwialnych (mady wg SgP 2011 lub Fluvic Phaeozems wg WRB 2014) występują w proksymalnej części stawu (cofce).

Słowa kluczowe: osady stawów młyńskich, gleby mułowe, gleby organiczne, gleby glejowe, środowisko paralimniczne