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Mineral matter composition of drained floodplain soils in north-eastern Poland

Abstract: Soils in two river valleys (Rozoga and Omulew) in north-eastern Poland were investigated. The valleys are located on a sandy outwash plain formed during the Vistulian (Weichelian) Glaciation. The soils are drained, used as meadows and classified as Fluvic Umbric Gleysol, Fluvic Mollic Gleysol, and Eutric Fluvic Histic Gleysol (IUSS Working Group WRB 2015). The aim of the study was to identify the composition of mineral matter and to determine the types of clay minerals and intermediate stages of clay minerals by means of the X-ray diffraction (XRD). The studied floodplain soils are rich in organic matter and contain considerable mineral alluvial admixtures. The content of clay fraction (< 2.0 µm) is low (0.02–5.61% of total mineral matter). Higher content of clay fraction was noted in soils with elevated content of organic matter, which can be evidence of simultaneous accumulation of both components. In deeper depressions occurring in river valleys (oxbow lakes), a specific deposit termed silty telmatic mud (16–24% TOC, 50–75% silt, 3.1–5.6% clay fraction content) was accumulated. On the other hand, in shallow depressions, a muddy deposit was accumulated (5.7–7.7% TOC, sandy texture). The main identified clay minerals were smectite, vermiculite, illite and kaolinite as well as variety of mixed-layer clays. Alluvial clay admixture in studied soil formations showed mineralogical similarity to typical floodplain mineral soils (Fluvisols). Mineral fraction of studied soils is mostly of allochthonous origin.

Keywords: river valleys, silty telmatic mud, mud soils, clay minerals, mursh forming process

INTRODUCTION

Soils rich in organic matter frequently occur in river valleys. In some river valley sections, in small depressions located on the floodplains, simultaneous accumulation of well-decomposed organic matter (of autogenous origin as well as transported by river waters) and fine-grained mineral particles takes place (Kalisz and Łachacz 2008; Devesa-Rey and Barral 2012; Gonzáles et al. 2014; Wójcicki 2015; Graf-Rosenfellner et al. 2016). Organic deposits accumulating in these places resemble well-decomposed low-moor peat (fen peat) and are termed "muds" (Okruszko 1969). These soil formations are characteristic for river valleys with a natural or semi-natural hydrological regime, i.e. with regular floods by waters relatively well saturated with oxygen (Okruszko 1969). Due to the substantial admixture of mineral particles, organic matter content in muds amounts to 20–60%, and is lower than in typical peats. Like all organic materials, they undergo the process of organic matter transformation after drainage known as the mursh-forming process (Okruszko and Ilnicki 2003). This process was described in the literature under various terms, e.g. peat ripening (Pons 1960), muck-forming process or moorsh-forming process (Łachacz and Kalisz 2016). In this paper, the authors use the term „mursh", as the qualifier „Murshic" is used in the WRB system (IUSS Working Group WRB 2015) to describe drained organic soils. During the mursh-forming process, intense mineralization and humification of the soil organic matter takes place (Piaścik and Łachacz 2001; Heller and Zeitz 2012; Łachacz and Kalisz 2016). Mursh formations lack remnants of plant tissues and have a granular, sometimes pulverized structure. Similar to mursh, but having less organic matter (3–20%), are mineral-organic soil formations called mursh-like formations. These formations are divided into postmurshic (3–10% SOM) and semimurshic (10–20% SOM) based on soil organic matter (SOM) content as proposed by Kabała et al. (2016).

These specific organic and mineral-organic soil formations occurring on the floodplains are relatively poorly described in the literature. The elucidation of their origin on the basis of the reconstruction of vegetation based on plant macrofossils was carried out by Gałka and Kalisz (2008). The studied deposits

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were accumulated in a water-swamp environment where aquatic and rush plant species were present. Floodplain soils act as a sink of chemical elements carried by river waters, and often accumulate substantial contents of nutrients (Kalembasa et al. 2009; Kalisz and Łachacz 2009; Tsheboeng et al. 2014; Sowiński et al. 2016).

Changes in organic matter of floodplain soils under influence of drainage were described by Kalisz et al. (2010). However, the mineral composition of clay fraction (ø< 2.0 μm) in organic soils has barely been studied and needs considerable attention as clay fraction stabilizes organic matter after drainage of these soils (Heller and Zeitz 2012; Graf-Rosenfellner et al. 2016). The investigations of mineral composition of floodplain soils were focused mainly on mineral soils (Dąbkowska-Naskręt and Dlugosz 1996). The composition of soil clay fraction carries information on degrees of weathering and is essential for interpreting soil genesis and soil properties.

Knowledge of the composition of river valley soil mineral matter, including types of clay minerals, will add value to the soil science by answering the following questions:

– what is the origin (alimentation zone) of the mineral part of these soils,
– what is the intensity and extent of the geomorphological processes in the catchment,
– which processes occur in soils after the sedimentation of soil material,
– what are the directions of evolution of drained soils rich in organic matter.

Higher amounts of clay fraction will stabilize soil organic matter and will protect it against mineralization that leads to the formation of mollic horizons and evolution towards black earths (Mollic Gleysols). On the contrary, low amount of clay fraction with intensive long-term drainage leads to the oxidation of organic matter and evolution towards Arenosols (Kalisz and Łachacz 2008; Łabaz and Kabala 2016).

The aim of the study was to identify mineral composition of floodplain soils and determine the types of clay minerals and intermediate stages of clay minerals by means of X-ray diffraction (XRD) method. An important aspect of the paper was the description of mud soils in terms of composition and origin of soil mineral components.

STUDY AREA

The studied area is located in north-eastern Poland. According to physico-geographical division of Poland, it is situated in the mesoregion of Kurpie Plain formed by fluvioglacial sands of the Vistulian (Weichelian) Glaciation (Kondracki 2002). It is a part of the largest outwash plain in Poland with an area of approximately 5,400 km^2. The Quaternary deposits have thickness of 100–150 m, and the Miocen sands lay underneath. In the investigated area, two studied rivers – Rozoga and Omulew flow in the previous tracks of glaciofluvial waters. The northern part of the outwash plain is surrounded by the moraines of the Leszno phase of the Vistulian Glaciation. The surface of the plain is situated 100 m above sea level in the south and 150 m above sea level in the north (Kondracki 2002). The investigated rivers, Rozoga and Omulew, flow into Narew river which is right side tributary of Vistula (Wisła) river.

The river Rozoga is 82 km long. The floodplain was shaped in the early Holocene by medium and fine sands with substantial admixture of organic matter and frequently bog iron ore (Bałuk 1993; Kondracki 1972, 2002; Listkowska 1999a, 1999b). The accumulation of organic materials began in the Atlantic and Subboreal periods. The river was regulated at the very beginning of 20th century and its valley was drained.

The river Omulew is 114 km long and has numerous meanders and oxbow lakes, which affect the water regime and form the river's natural character. The floodplain was built up by medium and fine sands with admixture of plant remnants and humus (Listkowska 1999b).

MATERIALS AND METHODS

For this research, soils in two river valleys (Rozoga and Omulew) in north-eastern Poland were selected. In the 1930s and 1950s the rivers were regulated (channelized) and their valleys were drained in order to obtain more land for agricultural use. Soil samples were taken from three sites: Walery Łęg and Kapuściska sites in Rozoga river valley and Gleba site in Omulew river valley. The location of the sites is shown in Figure 1. The soils that developed on the floodplains are drained and used as meadows. The detailed description of soil profiles is presented in previous paper (Kalisz and Łachacz 2008). Five soil profiles were examined. Clay minerals were separated from selected samples numbered from 1 to 7 (Table 1).

Particle size distribution was analysed by means of the pipette method using apparatus produced by Eijkelkamp Agrisearch Equipment (ISO 13317-2: 2001). This method is based on sedimentation of soil particles in water. Solutions of 4% $(NaPO_3)_6$ and 1% Na_2CO_3 were used as a chemical dispersion agents of soil particles and then soil suspension was stirred. In the pipette method, soil material of ø< 2.0 mm was

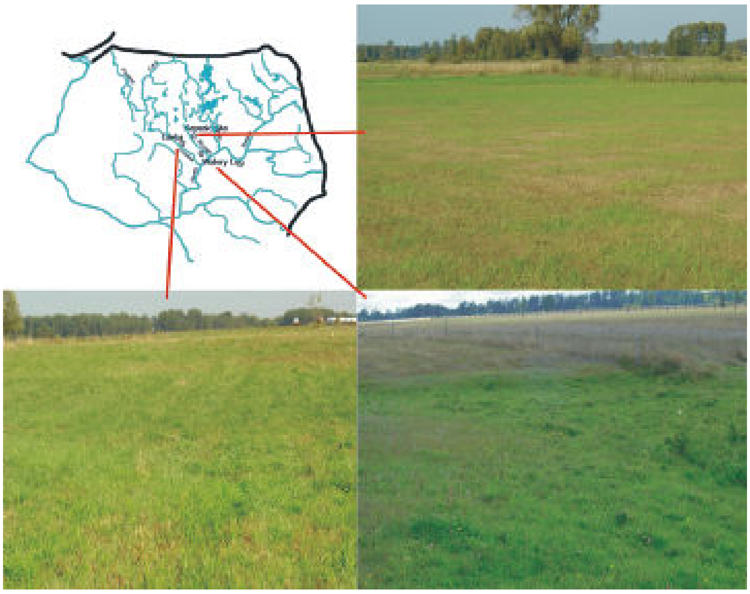


FIGURE 1. Location of the studied sites

TABLE 1. Soil morphology and soil classification

Soil horizon	Depth (cm)	Sample No.[1]	LOI (%)	Colour		Soil formation (radiocarbon age)[2]
				dry	moist	
Profile 1. Walery Łęg site in Rozoga river valley – muddy soil (gleba mułowata)[3] or semimurshic soil (gleba murszowata)[4] Fluvic Umbric Gleysol (Arenic, Drainic, Humic, Limnic)[5]						
Au	0–15	1	13.97	10YR3.5/2	10YR1.7/1	semimurshic (muddy)
Au2	15–35	2	10.75	10YR3/2	10YR1.7/1	semimurshic (muddy) (890 ± 30 BP)
Lc	35–50	–	39.23	10YR2/3	10YR1.7/1	telmatic mud
Cg	50–150	–	0.48	10YR7/4	10YR4/3	alluvial loose sand
Profile 2. Walery Łęg site in Rozoga river valley – muddy soil (gleba mułowata)[3] or typical postmurshic soil (gleba murszasta typowa)[4] Eutric Fluvic Mollic Gleysol (Arenic, Drainic, Humic, Limnic)[5]						
Au	0–20	–	8.93	10YR5/3	10YR3/3	postmurshic (muddy)
Au2	20–35	3	19.39	7.5YR3/2	7.5YR1.7/1	muddy
Cg	35–150	–	0.47	10YR7/4	10YR4/3	alluvial loose sand
Profile 3. Kapuściska site in Rozoga river valley – mud gleysol (gleba mułowo-glejowa)[4] Eutric Fluvic Mollic Gleysol (Abruptic, Endoarenic, Episiltic, Drainic, Hyperhumic, Limnic)[5]						
(M)Lc	0–18	4	41.80	10YR2.5/3	10YR2/2	murshic (mud)
Lc	18–33	5	22.38	10YR4/2	10YR2/2	telmatic mud (2260 ± 35 BP)
2Cg	33–70	–	1.75	10YR6/3	10YR3/4	alluvial loose sand
G	70–150	–	0.21	2.5Y7/4	2.5Y5/4	alluvial loose sand
Profile 4. Gleba site in Omulew river valley – mud gleysol (gleba mułowo-glejowa)[4] Eutric Fluvic Histic Gleysol (Abruptic, Endoarenic, Episiltic, Drainic, Limnic)[5]						
(M)Lc	0–25	6	51.52	10YR2.5/2	10YR2/1	murshic (mud)
Lc	25–39	–	24.30	10YR3/1	10YR1.7/1	telmatic mud
Cg	39–70	–	0.38	10YR6.5/4	10YR4/4	alluvial loose sand
G	70–150	–	0.16	2.5Y6.5/2	2.5Y4/3	alluvial loose sand
Profile 5. Gleba site in Omulew river valley – muddy soil (gleba mułowata[3] or typical postmurshic soil (gleba murszowata)[4] Fluvic Umbric Gleysol (Abruptic, Epiarenic, Episiltic, Drainic, Limnic)[5]						
Au	0–16	7	10.75	10YR3/3	10YR2/2	semimurshic (muddy) (900 ± 30 BP)
2C	16–60	–	1.00	10YR6.5/4	10YR4/4	alluvial loose sand
Lc	60–110	–	26.25	10YR3/1	7.5YR1.7/1	telmatic mud
Gc	110-150	–	0.22	2.5Y6.5/2	2.5Y4/3	alluvial loose sand

[1] number of soil sample from which clay minerals were separated (used in table 2 and 3 and on figures 2–8); [2] the lowest sub-layers 1 cm thick were analysed, [3] not included in Polish Soil Classification (2011), [4] Polish Soil Classification (2011), [5] IUSS Working Group WRB (2015).

used after sample pre-treatment, i.e. organic matter removal by oxidation with 30% H_2O_2 and removal of calcium carbonates by 20% HCl solution. Sandy fractions were determined by wet-sieving. The percentage of fractions of ø2000–50 μm (sand), 50–2 μm (silt) and < 2 μm (clay) enabled to classify soils according to USDA (United States Department of Agriculture) system (Soil Survey Division Staff 1993) and according to Soil Science Society of Poland 2008 (PTG 2009).

The amounts of biogenic and terrigenic silica were analysed according to Tobolski (2000). The raw ash obtained after dry ashing of soil samples at 550°C was treated with hydrochloric acid (concentration 10%), the solution was then filtered and dry ashed at 550°C. Clean ash which contains biogenic and terrigenic silica was obtained. After applying potassium hydroxide (concentration 10%) on clean ash, biogenic silica was measured (terrigenic silica does not react with potassium hydroxide).

Total organic carbon (TOC) content was measured with a spectrophotometer after oxidation with potassium dichromate (ISO 14235: 1998). Total nitrogen (TN) was determined by means of Kjeldahl method, pH of the soil-to-solution ratio of 1:2.5 using 1 M KCl and H_2O as the suspension medium was determined potentiometrically (van Reeuwijk 2002). Soil color was determined in air-dry and moist samples according to Munsell Soil Color Charts (Oyama and Takehara 1992). Additionally the beginning of sedimentation of studied soil formations was estimated with ^{14}C radiocarbon dating at Poznań Radiocarbon Laboratory, Poland.

For mineralogical analysis, soil samples were sieved through 1.0 mm mesh and prepared according to the Jackson's procedure (Cieśla 1976), in which unwanted components (carbonates, organic matter and free oxides) were removed. The mineralogical composition of clay was assessed by XRD method using HZG4 (Carl Zeiss) instrument. Samples of clay fraction were saturated with Mg^{2+} ions, then solvated with ethylene glycol (Mg^{2+} + GE), K^+ ions and the samples were heated to 300 °C and 550 °C (K^+ specimens).

The soils were classified according to the Polish Soils Classification (PSC 2011) and WRB classification system (IUSS Working Group WRB 2015).

RESULTS

The soil profiles 1, 2 and 5 were described as muddy soils (Table 1), which are not included in the PSC (2011). They were classified as Fluvic Umbric Gleysols (soil profile 1), Fluvic Mollic Gleysols (soil profile 2), Fluvic Umbric Gleysols (soil profile 5) according to WRB system (IUSS Working Group WRB 2015). The soil profiles 3 and 4 were classified as mud gleysols (PSC 2011) and as Eutric Fluvic Mollic Gleysols (soil profile 3), Eutric Fluvic Histic Gleysols (IUSS Working Group WRB 2015).

The investigated soils contain 107.5–515.2 g kg^{-1} of organic matter and 43.8–240.3 g kg^{-1} of organic carbon. The soil C/N ratio in Rozoga river valley (Walery Łęg and Kapuściska) amounted to approximately 10–11, irrespective of the depth in the soil profile. However, the soil C/N ratio in Omulew river valley amounted from 8.8 to 12.0 (Table 2). The accumulation of surface organic deposit (mud) in Rozoga valley started 2260 ± 35 ^{14}C years BP (Kapuściska site, soil profile No. 3), and mineral-organic deposit (muddy formation) started 890 ± 30 ^{14}C years

TABLE 2. Basic properties of the studied soils

Sample No.	Depth (cm)	TOC	TN	C/N	pH	pH	Percentage of mineral fraction (μm)			Texture class (PTG 2009)	Texture class (USDA)
		g·kg^{-1}			KCl	H_2O	2000–50	50–2	<2		
Walery Łęg site in Rozoga river valley											
1	0–15	77.4	7.1	10.9	5.2	6.0	83.8	14.6	1.6	pg	Loamy sand
2	15–35	57.9	5.3	10.9	5.0	5.7	95.2	4.6	0.2	pl	Sand
3	20–35	72.1	7.2	10.0	6.1	6.9	92.9	7.0	0.0	pl	Sand
Kapuściska site in Rozoga river valley											
4	0–18	164.4	15.6	10.5	5.0	5.9	43.9	51.6	4.5	pyg	Silt loam
5	18–33	90.3	8.4	10.7	5.3	6.3	41.1	55.8	3.1	pyg	Silt loam
Gleba site in Omulew river valley											
6	0–25	240.3	20.0	12.0	5.3	6.0	35.8	58.5	5.6	pyg	Silt loam
7	0–16	43.8	5.0	8.8	5.9	7.0	20.3	75.0	4.6	pyg	Silt loam

pg – loamy sand, pl – sand, pyg – silt loam.

BP (Walery Łęg site, soil profile No. 1). The age of surface deposit (muddy formation) in Omulew river valley (soil profile No. 5) is 900 ± 30 ^{14}C years BP.

The research showed that the analysed soil samples differ in the content of sand, silt and clay fractions and have sandy, loamy sandy and silty loamy texture (Table 2). The highest content of clay fraction was found in soils at Kapuścicka and Gleba sites, which also have enhanced content of organic carbon.

The investigated soil formations contain from 48 to 89% of raw ash (Table 3). The main component of raw ash is quartz particles of sand and silt size. The further constituents of raw ash are compounds soluble in hydrochloric acid, mostly iron oxides. It should be noted that their content is enhanced in soil formations rich in organic matter, i.e. mursh formations at Kapuściska and Gleba sites (soil profiles No. 3 and 4). When clean ash is considered, it should be noted that the studied soil formations contain more quartz (terrigenic silica) than biogenic silica. The total content of biogenic silica is below 2% of clean ash. Its higher content (1.69–1.77% of clean ash) was found in soils accumulated in a shallow lake occurring in Rozoga river valley (Kapuściska site, soil profile No. 3).

Clay fraction (< 0.002 mm) of analyzed soils contains clay minerals that occur in both discrete and mixed-layer forms. Smectite was found in all samples based on occurrence of the broad 1.4 nm peak (Mg^{2+} saturated specimens), which moved to 1.68–1.70 nm after solvation with ethylene glycol (Mg^{2+} + GE) (Fig. 2–8). Furthermore, vermiculite (a peak 1.4 nm after EG treatment) occurs in some samples (Fig. 4 and 5). The studied clay fractions may also contain swelling chlorite and/or chlorite-vermiculite. Moreover, illite (the 001 peak at ~1.0 nm which does not change its position neither after GE treatment) and kaolinite (the peaks 0.720 and 0.356 nm which does not shift after GE treatment) was identified. Additionally, quartz (peaks 0.426 nm and 0.334 nm), amphibole (peak 0.85 nm) and feldspars (peaks 0.330–0.315 nm and 0.430–0.410 nm) were present in the studied clay fraction.

TABLE 3. Ash composition of the studied soils

Sample No.	Depth	Raw ash	Clean ash	Components easily soluble in hydrochloric acid	Terrigenic silica	Biogenic silica
	(cm)	(% DM)			(%)*	
Walery Łęg site in Rozoga river valley						
1	0–15	86.03	83.31	2.72	98.75	1.25
2	15–35	89.25	87.43	1.82	99.23	0.77
3	20–35	80.61	76.17	4.44	99.14	0.86
Kapuściska site in Rozoga river valley						
4	0–18	58.20	50.14	8.06	98.31	1.69
5	18–33	77.62	72.14	5.48	98.23	1.77
Gleba site in Omulew river valley						
6	0–25	48.48	42.20	6.28	98.95	1.05
7	0–16	89.25	86.35	2.90	99.37	0.63

DM – dry matter; * in relation to clean ash.

Certain differences in the type of clay minerals occurring in soils were found. The mineral alluvial admixture of studied soils at Walery Łęg in Rozoga river valley had loamy sandy and sandy texture (Table 2) and contained very low concentration of clay. The mineralogical composition of fraction < 2.0 μm showed that predominant swelling clay mineral was smectite as expressed by the peak of 1.700 nm of magnesium-ethylene glycol specimen and 1.280–1.200 nm of K^+ specimen (Fig. 2–4). The analyzed clay fraction may also contain some vermiculite or kaolinite minerals shown by the peaks of 1.100, 0.356 nm in K^+ specimen and illite minerals expressed by the peaks of 1.000, 0.500, 0.334 nm also in K^+ specimen.

On the floodplain of Rozoga river at Kapuściska site, mursh contained alluvial admixture of silty loamy texture. The analysed soils contained 3–4% of clay (Table 2). In soil sample from the layer of 18–33 cm, typical smectite minerals prevailed, which was demonstrated by the peaks of 1.680 nm of magnesium-ethylene glycol specimen (Fig. 5 and 6).

In Omulew river valley, studied soils contained alluvial admixture of silt loam texture. These soils contained more clay and silt than the soils at Walery and Kapuściska sites in Rozoga river valley (Table 2).

DISCUSSION

Classification of soils occurring in river valleys is difficult due to overlapping of various processes of accumulation of soil materials and their further pedogenesis. River valley habitats are heterogenous, with land depressions formed during accumulation of fluvioglacial sediments and during activity of the river, i.e. oxbow lakes (Kittel et al. 2016). The soil profiles 1 and 5 were classified as semimurshic subtype and the soil profile 2 as typical postmurshic soil (PSC 2011). However, the systematic position, emphasizing the occurring mursh-forming process, does not fully reflect the identity of soil formation and its alluvial-telmatic origin. Therefore, it is suggested to include the muddy soil sub-type in postmurshic soil type or muddy gleysols subtype in gleysols type (Roj-Rojewski 2003, 2009; Kalisz and Łachacz 2008; Mendyk et al. 2015; Glina et al. 2016).

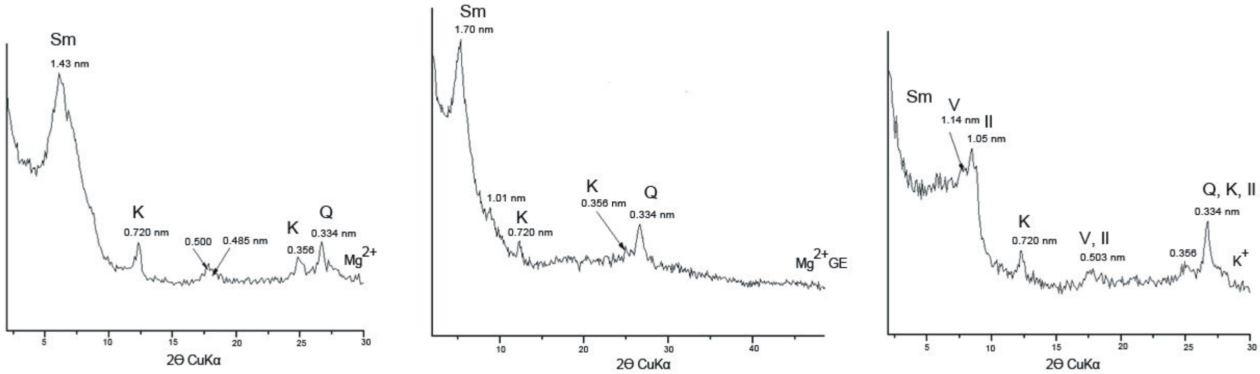
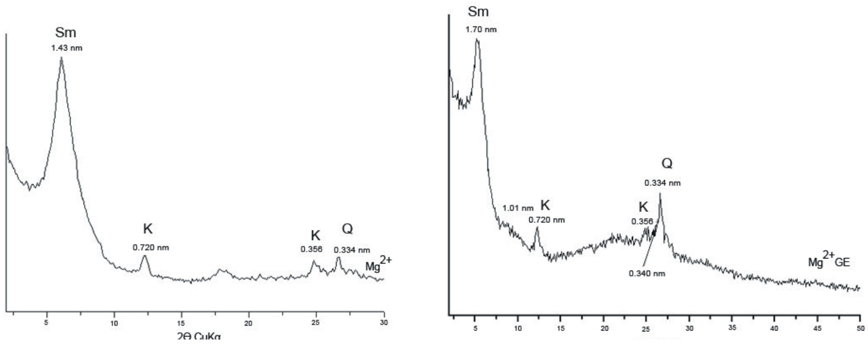


FIGURE 2. XRD patterns for clay fraction from 0–15 cm soil layer (sample No. 1) at Walery Łęg in Rozoga river valley. Mineral symbols: Il – illite, K – kaolinite, Q – quartz, Sm – smectite, V – vermiculite

FIGURE 3. XRD patterns for clay fraction from 15–35 cm soil layer (sample No. 2) at Walery Łęg in Rozoga river valley. Mineral symbols: K – kaolinite, Q – quartz, Sm –



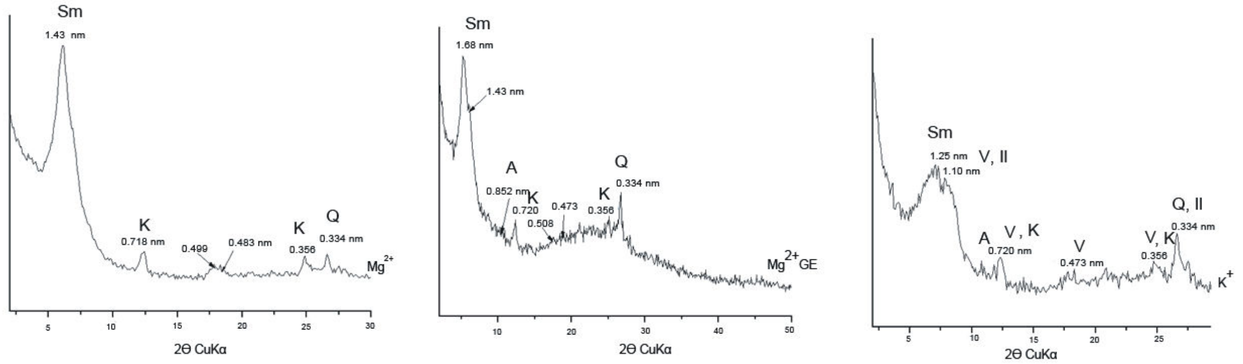


FIGURE 4. XRD patterns for clay fraction from 20–35 cm soil layer (sample No. 3) at Walery Łęg in Rozoga river valley. Mineral symbols: A – amphibolite, Il – illite, K – kaolinite, Q – quartz, Sm – smectite, V – vermiculite

Soil profiles 3 and 4 were classified as mud gleysols in the gley soil type (PSC 2011), which is consistent with the character of surface soil formation, but the information about murshing is however lost.

According to the WRB system (IUSS Working Group WRB 2015) all soils studied were included in Gleysols Reference Soil Group. The existing principal and supplementary qualifiers describe well the specificity of the soils. However, it should be noted that the WRB system includes the studied soil formations in the limnic material, accenting their lake origin. In fact it is specific soil formations termed silty telmatic mud.

In biogenic deposits, especially in those of lacustrine origin, the content of biogenic silica (opal), which is a component of so-called raw ash, is important (Tobolski 2000). In lacustrine basins, terrigenic and biogenic sedimentation, as well as chemogenous sedimentations of amorphous and crystalline matter take place. It is generally assumed that in fluvial systems terrigenic matter is of allochthonous origin and biogenic matter is mostly of autogenic origin (e.g. Tobolski 2000). This consists of diatom and other phytolith fragments, amorphous organic matter, mollusks, ostracods (Goldman and Horne 1983; Lerman et al. 1995; Borówka 2007). The wide range of raw ash content in the investigated soils is a result of local differences in accumulation as well as further oxidation of organic matter after drainage. Considering the analysis of terrigenic and biogenic silica, it should be stated that the prevalence of terrigenic silica in mineral fraction proves that this mat-

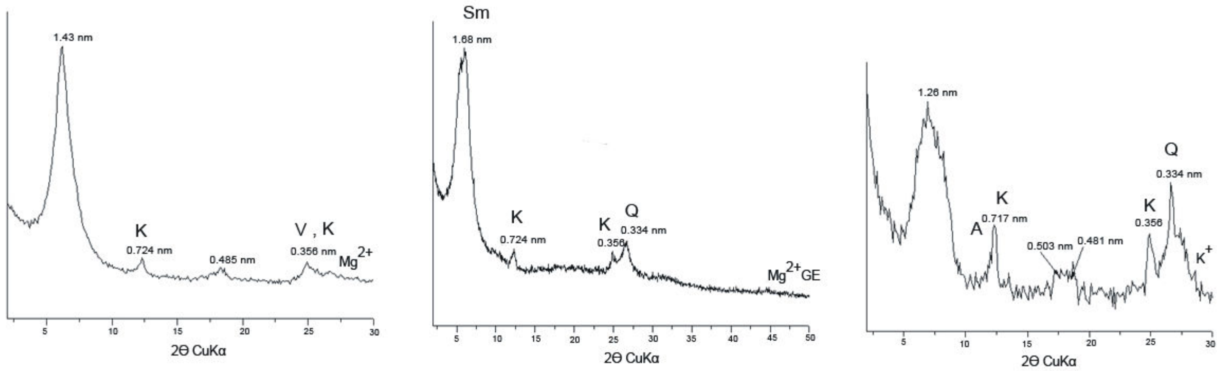


FIGURE 5. XRD patterns for clay fraction from 0–18 cm soil layer (sample No. 4) at Kapuściska in Rozoga river valley. Mineral symbols: A – amphibolite, K – kaolinite, Q – quartz, Sm – smectite, V – vermiculite

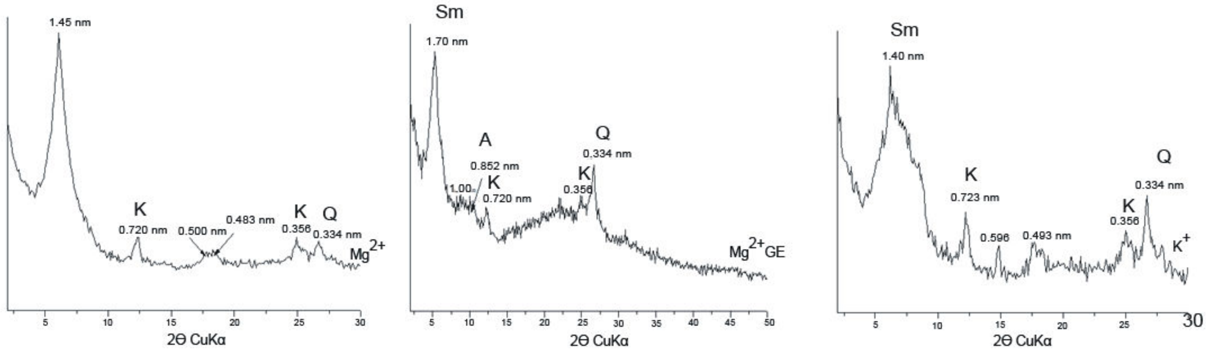


FIGURE 6. XRD patterns for clay fraction from 18–33 cm soil layer (sample No. 5) at Kapuściska in Rozoga river valley. Mineral symbols: A – amphibolite, K – kaolinite, Q – quartz, Sm – smectite

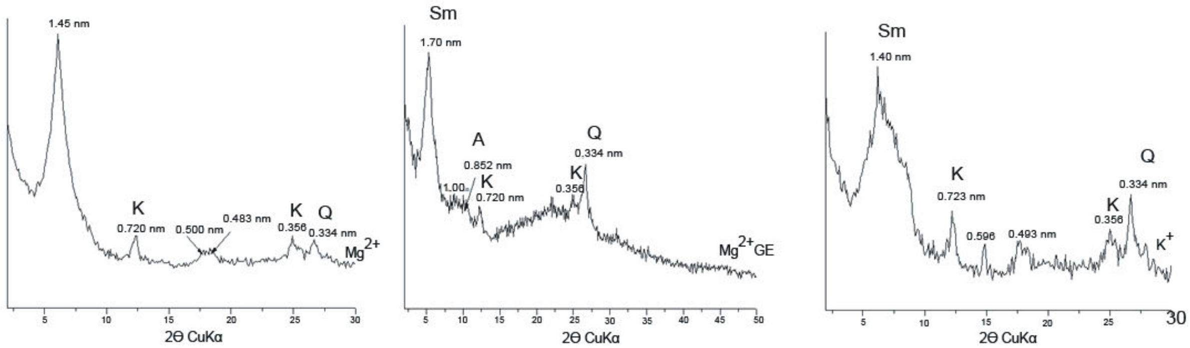


FIGURE 7. XRD patterns for clay fraction from 0–25 cm soil layer (sample No. 6) at Gleba in Omulew river valley. Mineral symbols: A – amphibolite, K – kaolinite, Q – quartz, Sm – smectite

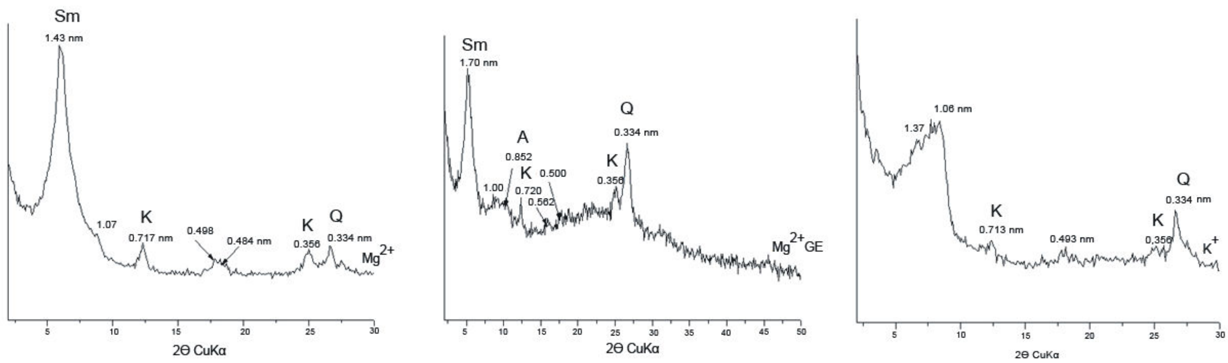


FIGURE 8. XRD patterns for clay fraction from 0–16 cm soil layer (sample No. 7) at Gleba in Omulew river valley.
Mineral symbols: A – amphibolite, K – kaolinite, Q – quartz, Sm – smectite

ter is of allochthonous origin. Only a small proportion of silica is of autochthonous origin (living organisms). It is assumed that biogenic silica is mostly of autogenous origin (Bengtsson and Enell 1986; Tobolski 2000; Borówka 2007). Occurrence of biogenic silica suggests that the investigated formations were accumulated under water (long-lasting floods or oxbow lakes) which enabled development of aquatic organisms, which later constitute the biogenic silica (Gałka and Kalisz 2008).

All studied soils contained low amounts of mineral fraction of ø< 2.0 μm. However, it should be noted that the content of clay fraction is much higher than in the surrounding soils which were formed from fluvioglacial sands and which frequently contain less than 1.0% of clay (usually less than 0.1%) (Kalisz and Łachacz 2008). This also proves the thesis about allochthonous origin of clay fraction of studied soils. Clay fraction transported by river waters may be partly derived from morainic soils occurring in the upper river course.

Mineral fraction of soils at Kapuściska and Gleba sites (profiles No. 3, 4, 5) is composed mostly of silt fraction (51.6%–75.0%), and substantial amounts of clay (3.1%–5.6%) in comparison to soils at Walery Łęg (profiles No. 1 and 2). The coexistence of humified organic matter and fine-textured mineral matter is termed "mud" in the Polish literature (Okruszko 1969). Higher amounts of clay and silt will determine the evolution of these soils towards black earths (Mollic Gleysols) after drainage. Narrower C:N ratio (8.8–12.0) indicates high mineralization and humification of SOM (the amount of organic carbon is decreased), which is related to the accumulation of soil materials in oxygenated waters and then in conditions of variable moisture.

The mineralogical composition of clay components from the floodplains of Rozoga (Fig. 2–6) and Omulew (Fig. 7 and 8) rivers show some similarities. The identified minerals were smectite and vermiculite (there might be also swelling chlorite and/or hydroxy-interlayer vermiculites) as well as certain mixed-layer minerals. The clay components of the studied soils at Walery Łęg in Rozoga river valley (Fig. 2–4) originated from the riverine sediments as they contained more smectite minerals than other soils studied.

Similarly to the investigated alluvial sediments, occurring as an admixture in organic and mineral-organic formation, smectite minerals and swelling minerals prevailed in Fluvisols of Vistula river valley in Poland (Dąbkowska-Naskręt and Dlugosz 1996). The floodplains of other parts of the world had similar mineral composition (Abe et al. 2006; Nguyen et al. 2006). Clay fractions in soils located in floodplains are subjected to transformations associated with floods and fluctuations of groundwater level (Urushadze et al. 2006).

CONCLUSIONS

The following conclusions can be drawn from the obtained results:

1. The studied floodplain soils are rich in organic matter and contain considerable amounts of alluvial mineral fraction.
2. The amount of clay is not high (3–6% in the investigated muds) but substantially affects the soil properties and direct evolution of soils after drainage.
3. Studied soils had sandy, loamy sandy and silty loamy textures.
4. Studied soils contained more terrygenic than biogenic silica.
5. Mineral components of studied soils are mostly of allochthonous origin.
6. The major clay minerals identified in the investigated soils are smectite, vermiculite, illite and kaolinite.

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Skład masy mineralnej odwodnionych gleb w dolinach rzecznych północno-wschodniej Polski

Streszczenie: Badano gleby w dolinach rzek Rozoga i Omulew w północno-wschodniej Polsce. Badane doliny położone są na równinie sandrowej uformowanej podczas zlodowacenia wisły (Vistulian). Badane gleby są odwodnione, użytkowane jako łąki i zaklasyfikowane do Fluvic Umbric Gleysol, Fluvic Mollic Gleysol, and Eutric Fluvic Histic Gleysol (IUSS Working Group WRB 2015). Celem badań było określenie składu masy mineralnej, a zwłaszcza składu frakcji ilastej, w tym określenie typów minerałów ilastych i ich stadiów przejściowych metodą dyfraktometrii rentgenowskiej (XRD). Gleby występujące na równinie zalewowej są zasobne w materię organiczną i zawierają znaczne ilości (48,5–89,2%) aluwialnej frakcji mineralnej. Zawartość frakcji ilastej (ø < 2,0 µm) jest mała i stanowi od 0,02% do 5,61% ogólnej masy mineralnej. Większa zawartość frakcji ilastej dotyczy gleb o większej zawartość materii organicznej, co może świadczyć o łącznej akumulacji obu tych komponentów. W głębszych obniżeniach występujących w dolinach rzecznych (starorzeczach) akumulował się specyficzny utwór określany jako pyłowy muł telmatyczny (16–24% TOC, 50–75% frakcji pyłu, 3,1–5,6% frakcji iłu). Natomiast w płytszych zagłębieniach akumulował się utwór mułowaty (5,7–7,7% TOC, piaszczyste uziarnienie). Główne zidentyfikowane minerały ilaste to: smektyt, wermikulit, illit i kaolinit. Skład frakcji ilastej badanych gleb wykazuje podobieństwo do typowych gleb mineralnych występujących w dolinach rzecznych (mady, Fluvisols). Mineralny komponent badanych gleb jest głównie pochodzenia allochtonicznego.

Słowa kluczowe: doliny rzeczne, pyłowy muł telmatyczny, gleby mułowe, minerały ilaste, proces murszotwórczy