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LITHOLOGY OF THE PROFUNDAL SEDIMENTS IN SŁUPIAŃSKA BAY (WIGRY LAKE, NE POLAND) – INTRODUCTION TO INTERDISCIPLINARY STUDY

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Abstract: In this paper, a lithological study taking into account trace metals of the profundal sediments from Słupiańska Bay in Wigry Lake is presented. A profile 5.26 m long has sandy muds at the bottom and moving upwards layers of calcareous gyttja, lacustrine chalk, and again calcareous gyttja are present. The profile is continuous, typical for the sediments of NE Poland formed from Allerøde to recent time. The results of the lithological analysis were correlated with results of high-resolution seismic survey. The results together with radiocarbon dating are part of interdisciplinary complex research comprising paleobiological study of pollen, Cladocera, diatom successions and human activity, which will be published in successive papers.

Keywords: Lake deposits, Wigry Lake, Holocene, trace metals

1. INTRODUCTION

The aim of this research is a complex analysis of changes of natural environment since Allerøde through the whole Holocene until recent times. As the object of research Wigry lake in NE Poland was chosen (**Fig. 1**).

This lake is the largest one in Suwałki Lakeland. Its physiographic and natural conditions are generally well known (Zdanowski, 1992) together with its lithology, sedimentation of its deposits (Rutkowski *et al.*, 2002; Rutkowski, 2004) and the problem of trace metals (Prosowicz and Helios-Rybicka, 2002; Migaszewski *et al.*, 2003; Prosowicz, 2006). Geological conditions of the lake sediments and their later deformations were determined by means of high-resolution seismic (seismoacoustic) survey (Rutkowski *et al.*, 2002a and 2005). Wigry Lake is one of the few lakes in Poland with contemporaneous carbonate sedimentation. Because of its natural values Wigry Lake was "adopted" in 1998 by the International Association of Theoretical and Applied Limnology (SIL "Lake Adoption" Project; Kamiński, 1999).

The research comprises physiographic features of Wigry Lake, lithological analysis and some geochemical data from a 5.26 m long profile of lacustrine deposits from the drilling WZS-03. Other analyses of lacustrine sediments of Wigry Lake are presented in following papers: Kupryjanowicz (2007), Piotrowska *et al.* (2007) and Zawisza and Szeroczyński (2007).

2. SITE DESCRIPTION

Wigry Lake is located in the Suwałki Lakeland (NE Poland) and it is the fifth largest lake (21.2 km^2) in NE Poland. The degree of coastline development is very high (4.35), and the lake bathymetry is fairly complicated. Distinct shallows and narrowings divide the lake into five basins, differing in physiographic characteristic. Wigierki Bay and Szyja Basin are of furrow type (**Fig. 1**), with the depth up to 73 m at the width below 1 km. Bryzgiel and Zakątowski Basins are of morainic type. They are broad (more than 2 km), and have numerous near-shore and central shallows and the depths up to 50 m. Wigry Basin (Northern) are partly of morainic and partly, in SW part, of furrow type.

Wigry Lake lies in the moderate climate zone with some continental influences. The average summer temperature is 17°C, and average winter temperature is -4,2°C. Average annual precipitation is 581 mm with fluctuation from 334 mm to 829 mm. Main wind direc-

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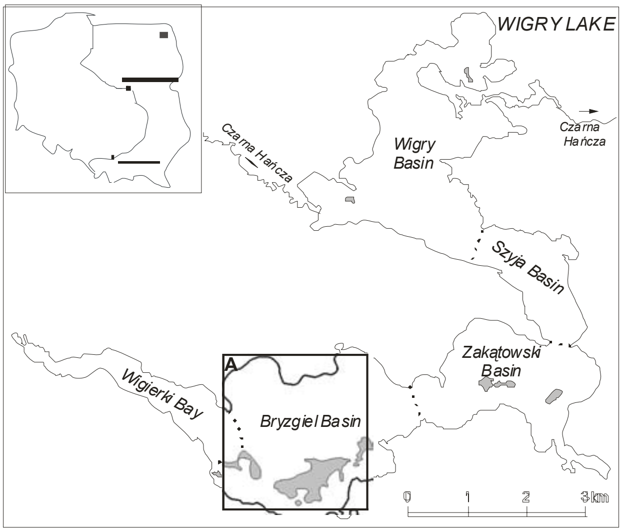

Fig. 1. *Map of the Wigry Lake. Shadowed area – islands. Area in rectangle A is enlarged on* ***Fig. 3****.*

tions are SW, W, NW and SE. Ice cover on the lake surface appears usually in the end of December and melts in March, but during last years there was no ice cover at all.

Lake Wigry is principally a mezotrophic lake fed by the Czarna Hańcza and the Wiatrołuża rivers (Bajkiewicz-Grabowska, 1992) that fall into Northern Basin. Underground flow and precipitation also markedly contribute, mainly in the other basins. Wigry is a dimictic lake with summer and winter stagnation and spring and autumn mixion. Thermal stratification observed in the middle of Bryzgiel Basin during the maximum of summer stagnation is illustrated in **Fig. 2**. Water temperatures in epilimnion (water depth down to 4 – 5 m, maximum 8 m) reach 24°C. Beneath, in the metalimnion (8 – 14 m) the temperatures rapidly decrease. In hypolimnion, at the depth below a dozen or so meters, water temperatures are permanently low and just above the bottom in the profundal part of the lake reach 4-6°C. The oxygen conditions of bottom water in this part of the lake during summer stagnation are rather bad, and even anoxic. The value of pH in hypolimnion water is ca. 7.3 and electric conductivity ca. 0.346 S/cm. In the surface water, pH is much higher (up to 8.7) and conductivity lower (0.283 S/cm). Main chemical components (in mg/dm^3) of hypolimnion water (at temperature ca. 6°C) are shown in **Table 1**.

Total mineralization	354.1
Ca^{2+}	57.92
Mg^{2+}	16.45
Na^{+}	7.57
K^{+}	1.97
HCO_3^{2-}	218.58
SO_3^{2-}	24.56
Cl^{-}	13.1

Table 1. *Main chemical components (in mg/dm^3) of near bottom water.*

The surface water contains lower amounts of Ca^{2+} and HCO_3^{2-}, due to its higher temperature. The most important component of Wigry water is Ca^{2+}, which comes from the dilution of Pleistocene deposits rich in carbonates.

The drilling WZS-03 was done on 13.07.2003 at the point of geographic coordinates N54°01.053' and E23°03.085', determined by GPS. It was situated in the southern part of the lake, in Bryzgiel Basin, and precisely in the Słupiańska Bay in the western part of this basin. This bay is large with a broad connection with Bryzgiel Basin. It is fed by water coming from Wigierki Bay (ca. 15 x 10^6 m^3 annually). Areas surrounding the bay are forested and a Phragmites community covers 1/3 of the coastline. Direct surrounding of the Słupiańska Bay is built by glacial and fluvioglacial deposits from the last glaciation. They form an uneven upland, which rises steeply a dozen or so meters above the lake level. At its feet are lake sands and gravels, stretching as a narrow path along the shore. In the NW part of the bay surrounding there is a peat-bog present. The main components of

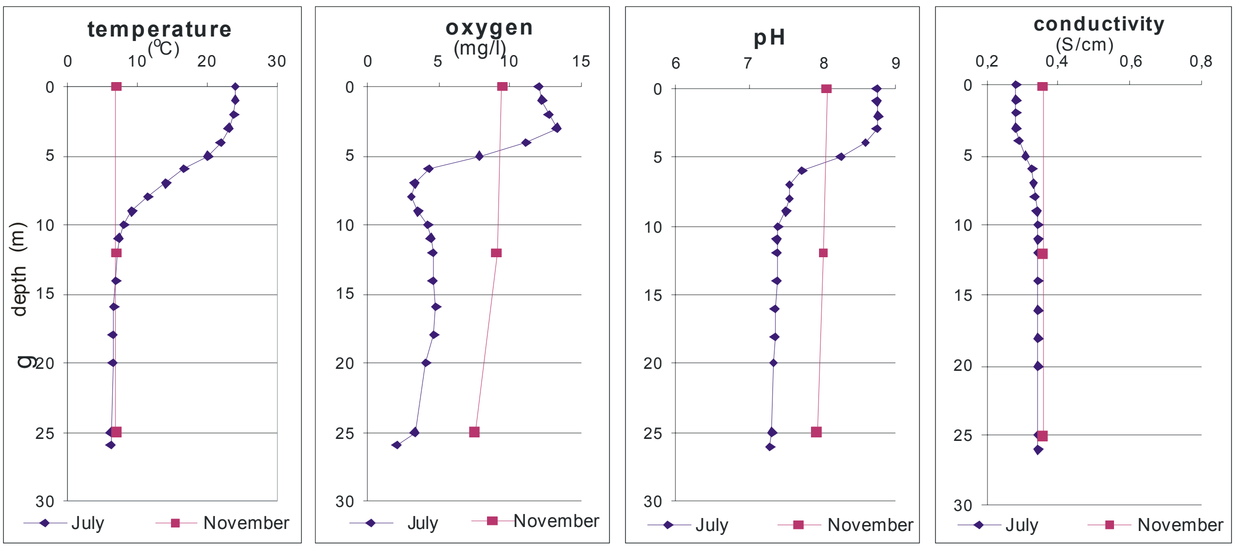

Fig. 2. *Main features of the lake water in the central part of Bryzgiel Basin during summer stagnation (July 26. 2006) and in autumn mixion (November 10, 2006y).*

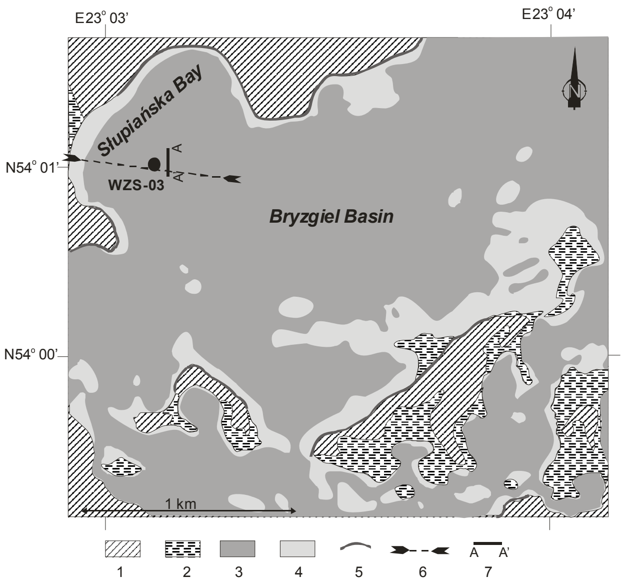

Fig. 3. *Location of the WZS-03 borehole with simplified geological sketch of surrounding of Słupiańska Bay. 1 – glacial sediments; 2 – peat; 3 – calcareous gyttja (profundal); 4 – lacustrine chalk (littoral); 5 – zone with clastic sedimentation (out of scale); 6 - bathymetric profile; 7; - seismic profile.*

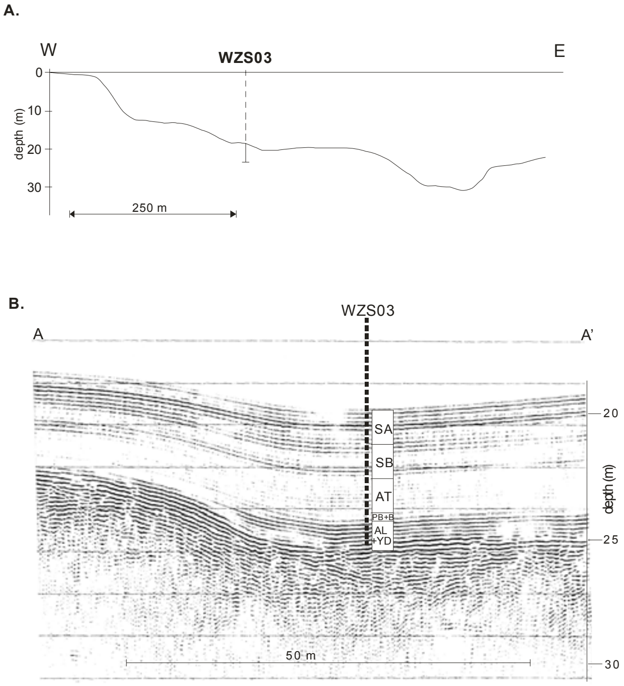

Fig. 5. *A - Bathymetric profile, B - Seismic profile witch chronozones.*

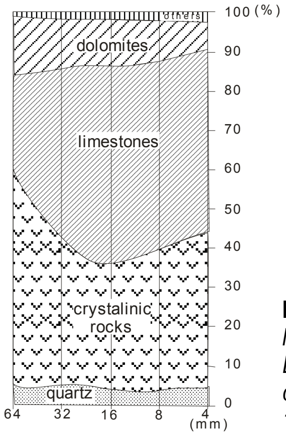

Fig. 4. *Petrographic composition of lacustrine gravels from Słupiańska Bay in percent of the number of clasts, taking each grain-size class as 100 percent.*

lacustrine gravels from the surrounding of Słupiańska Bay are carbonate rocks (**Fig. 4**). There are mainly lower Paleozoic limestones (33.3 – 49.8%) and Devonian dolomites (7 – 13.4%), but crystalline rocks as well as sandstone and quartzite are also observed. Such petrographic composition of gravels is typical for Late Quaternary sediments in NE Poland. Carbonate materials from these gravels and diamicton are the main source of calcium carbonate in the lake water and finally in lacustrine sediments of Wigry lake.

Maximum water depth in Słupiańska Bay is 29 m. As shown on the bathymetric (**Fig. 5**) and seismic profiles, the bottom is rather flat and the sediment cover is 3.5 – 5.6 m thick. The nearshore shallows are 10-100 meters wide; lacustrine chalk occurs there. It is a rock of white, white-grayish or beige color, with varied size of grains, mainly of silt, sand or clay fractions. It contains more than 80 % of $CaCO_3$ and a few percent of organic substance. Top part of the chalk, several centimeters thick, is often more coarse-grained and without silt-clay fraction. The lithology of the calcareous gyttja will be described further, together with the description of the WZS-03 core. The drilling was located in profundal zone at the point of depth of 18.2 m; The distance from the lake shore was about 270 m, and from the slope of the nearshore bank – 180 m (**Figs 3** and **5**).

3. METHODS

Physical properties of water and content of oxygen (**Fig. 2**) were determined by a multiparameter water quality analyzer (YSI model 6920). The analysis of sediments from WZS-03 drilling comprised the determination of water contents (obtained by drying at 110°C) and volume density (**Fig. 6**). In dry residue, the content of $CaCO_3$ was determinated by Scheibler's volumetric method and organic matter as loss of ignition at 550°C after 4 h. The analysis of trace metals TM involved decomposition of solid samples with concentrated nitric acid (65%) at a pressure of 30 atm and a temperature of 200°C with the use of a microwave mineralizer Perkin Elmer. The diluted solutions were analyzed with the use of mass spectrometry with inductively coupled plasma (ICP-MS Perkin Elmer ELAN 6100). For determining trace metals in the top part of the profile, an additional core was taken with a gravitational sampler at the depth 0 – 0.4 m.

4. RESULTS

The 5.26 m long profile of lacustrine sediments was received from the drilling WZS-03. The profile is continuous, without any traces of sedimentation break. In its lowermost part (5.0 – 5.26 m), dark lacustrine sandy mud with a low amount of $CaCO_3$ (9.1 – 19%) and 4-5% of organic matter occur (Fig. 6). It contains also a small amount of plant detritus. Prevailing components of this

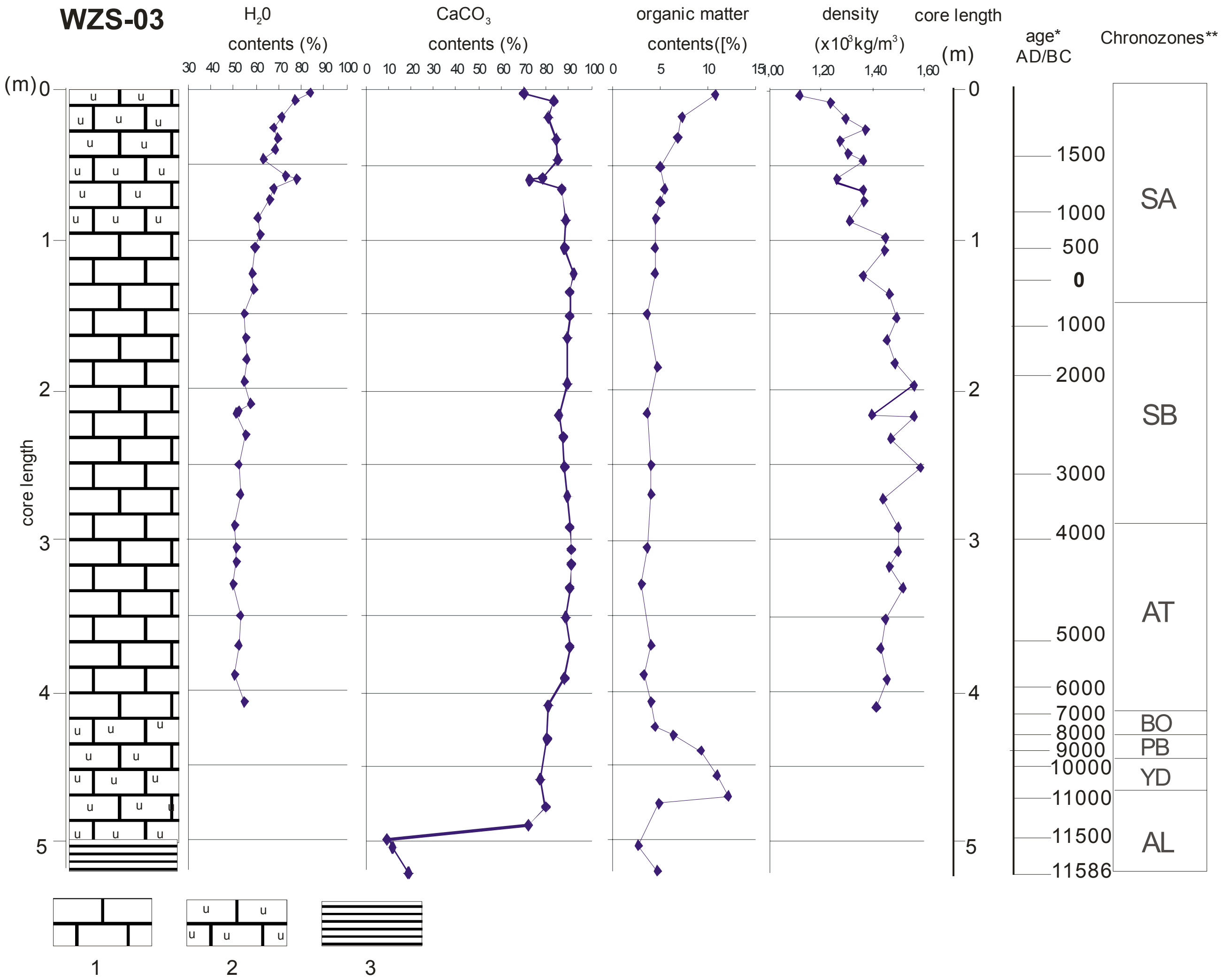

Fig. 6. *Main lithological features of WZS-03 core. 1 – lacustrine chalk, 2 – calcareous gyttja; 3 – sandy muds. Age AD/BC after Piotrowska et al. (2007), Chronozones according Mangerud et al. (1974) in interpretation of Kupryjanowicz (2007).*

mud are quartz grains in fraction lower than 0.06 mm (55-80%). Admixtures of grains in fraction 0.06 – 0.5 mm (9- 33%), 0.5 – 2 mm (0.2 –7.9%), and in coarser than 2 mm (0.1-6%) are also observed. The coarsest fractions consist of quartz, granitoids as well as limestone grains, which are indicative of fluvioglacial or glacial sediments in the underground of lake basin (Rutkowski *et al.*, 2002a).

Upwards the profile (4.2-5.0 m) the amount of calcium carbonate radically increases (from 71.8 in the base, to 80.3% in the top of this interval). The content of organic matter oscillates from 4 to 13% and the sediments are represented by dark-grey calcareous gyttja.

The main part of the profile (0.86-4.2m) consists of rather monotonous, very fine-grained and plastic, white-beige lacustrine chalk. Lamination of sediment does not occur, only some darker, grey, few millimeters thick streaks with unsharp borders can be observed in the interval 1.05-2.15 m. The content of water in this sediment is 50-60%, the amount of $CaCO_3$ reaches 85 – 92% of the dry residuum. The content of organic matter is 4-5%, and volume density of the lacustrine chalk fluctuates from 1.34 to 1.52 x 10^3 kg/m^3.

Moving upwards along the profile, in the interval 0.83-0.10 m, a progressive decrease of $CaCO_3$ content (up to 80%) and increase of water content (up to 75%) is observed. The content of organic matter also slightly increases up to 7%. The lacustrine chalk becomes darker in color and jellylike in consistency. Volume density of this sediment oscillates from 1.22 to 1.37 x 10^3 kg/m^3. In the interval 0.60-0.63 m, an insert of semi-fluid, dark-grey calcareous gyttja with 78% of water and 72% of calcium carbonate occurs.

In the topmost part of the profile (0-0.10 m), lacustrine chalk is replaced by green to dark-grey, liquid, calcareous gyttja (**Fig. 6**) with high water content (84%) and volume density of ca. 1.1 x 10^3 kg/m^3. The content of calcium carbonate decreases to 70%, and the amount of organic matter increases to 10.9%.

The lacustrine deposits from the drilling WZS-03 represent succession which is typical for postglacial lakes on the Polish Lowland. Sandy muds with plant detritus and admixture of sand and gravel observed in the base of the profile are characteristic for the lake forming stage (Stasiak, 1971; Więckowski, 1988). Fine-grained carbonate deposits, mainly lacustrine chalk, typical for Słupiańska Bay (Rutkowski *et al.*, 2002), are connected with the

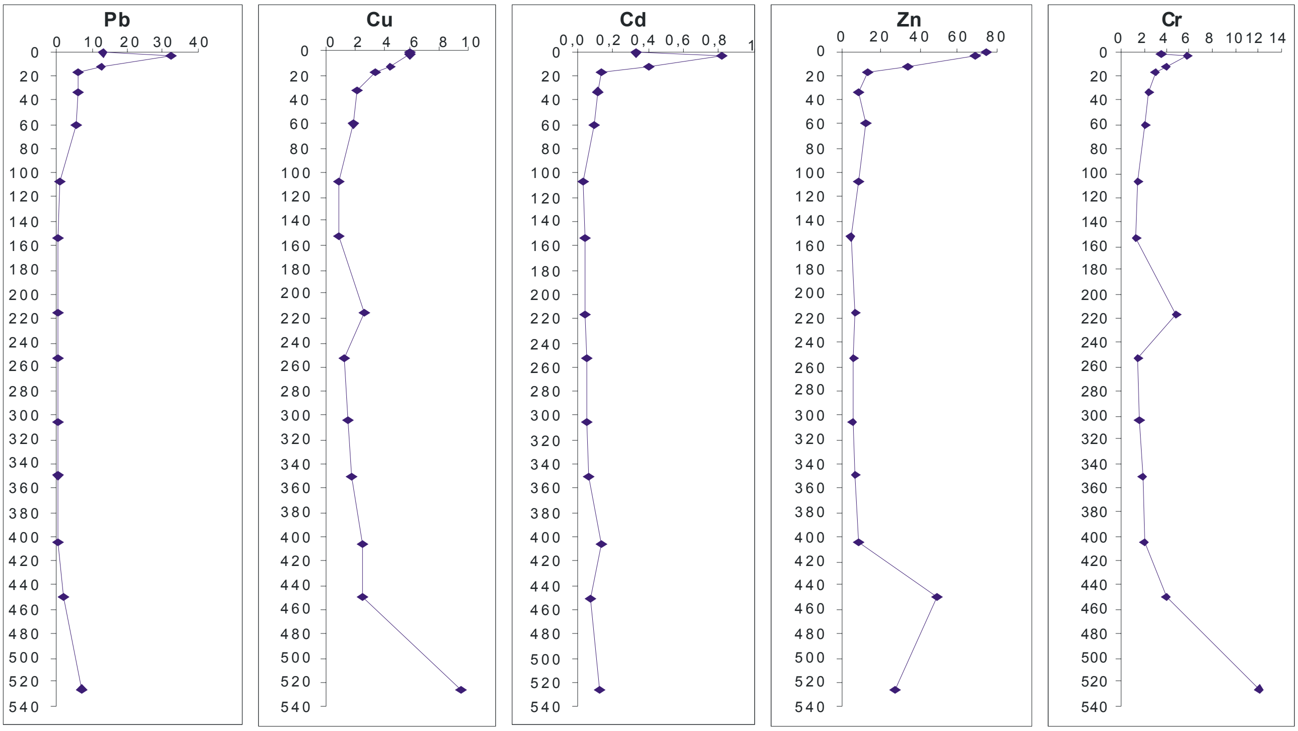

Fig. 7. *Trace metals in sediments of WZS-03 core. All values in ppm.*

period of calm sedimentation in profundal zone mainly in oligotrophic lakes. The decrease of calcium carbonate content and darkening of the color of sediments in the uppermost part of the profile is connected with deteriorating oxygenation conditions and increasing trophy of the lake, which indicate aging of the lake.

In the studied core, the amount of 20 trace metals (TM) was determined, and for five of them, the results are given in **Fig. 7**. Changes of these metal content over the length of the profile led to the distinction of its five parts. The lowest part is represented by sandy muds with higher content of TM (e.g. Co 4.4 ppm, Cr 12.2 ppm and Zr 13.1 ppm). The middle part of the profile (4.0 – 1.0) contains small amounts of TM, the lowest and the least varied in the whole profile. For example, the content of Cd is most often 0.03-0.06 ppm, Co 0.3-0.8 ppm and Ni 1.4-2.8 ppm and Pb 0.3-0.4 ppm. Slightly higher amount of Cu and Zn in the sample taken from the depth of 2.2 m (**Fig. 7**) can be connected with the defect of the apparatus.

Above that, at the depth 0.6-0.2, the amount of TM is clearly, although slightly higher, and it is approximately twice as big as in the middle part of the core. The highest amount of TM is found in the upper part of the core (above 0.15 m, but most often in the interval 0.05 – 0.1 m). The amounts of Zn and Pb are respectively ca 190 and 80 times higher than those in the middle part of the profile. It applies also to Cd (20 times) and Cr and Cu (4 times).

Particularly interesting is the decrease of the content of some TM in the uppermost part of the core (interval 0-0.5 m). It is most prominent for Pb and Cd which are present in amounts 2.5 times smaller than in the lower part of the core. The amount of other elements: Zr, As, Ni, Cr and Co is also smaller, whereas the content of Cu and Zn does not change.

High content of TM in sandy muds is connected with the admixture of crystalline rocks and an intensive surface washout. The middle part of the profile was formed in the period when the terrain was fully covered by forest. Slow increase of TM content in the interval 0.6 – 0.2 m was caused by deforestation and increase of agricultural activity. The same factors, and first of all the increase of the industrial activity caused the sudden increase of TM content. The same is found by Migaszewski *et al.* (2003) and Prosowicz (2006)**.** The historical data indicate that it happened around 1960 – 1990. Decrease of the amount of TM in the last 5 cm of profile is connected with the decrease of the industrial and agricultural activity after the year 1990.

5. CONCLUSIONS

At the end of last cold period (glaciations) basin of Wigry Lake was filled with blocks of dead ice. On their surface, clastic sediments were deposited, on some places covered by land peat (Więckowski, 1988; Stasiak, 1971). Dead ice melting started in Allerøde. In this period, in the place of Słupiańska Bay there was a shallow, oligotrophic reservoir, in which sandy muds with carbonate and organic matter admixture were deposited. These deposits to a great extent resemble clays, underlying lacustrine sediments described by Stasiak (1971).

Wigry Lake as a deep water reservoir was formed between Younger Dryas and Holocene, when dead ice blocks in the substrate were completely melted. In the same time the clastic sedimentation was replaced by carbonate one, which lasts till now. The very fine-grain sediments indicate that the sedimentation proceeds in profundal conditions (Rutkowski *et al.*, 2002) with only minor influence of littoral zone.

The distinct rise of lake trophy, expressed in an increase of organic matter admixture and decrease of $CaCO_3$ amount in the sediments took place ca. 1200 years cal BP ago, i.e. around 800 AD (at the depth 1 m). An acceleration of this process takes place at the depth 0.1 m.

In seismic profiles from profundal deposits of Wigry lake, a characteristic pattern of weak and strong reflections could be observed, which could be correlated in almost the whole lake. It seems that these reflections may be important seismostratigraphic horizons, or even chronohorizons. Pollen analysis (Kupryjanowicz, 2007) and radiocarbon dating (Piotrowska *et al.*, 2007) allows to correlate the seismic profiles with Pleistocene and Holocene stratigraphy.

Lithological analysis of deposits from drilling WZS-03 shows that there is a continuous, undisturbed profile which is suitable for interdisciplinary, comparison investigations, such as sedimentary rate and stable isotopes, pollen and Cladocera stratigraphy (Kupryjanowicz, 2007; Zawisza and Szeroczyńska, 2007) and diatoms succession (Witkowski *et al.*, in press), seismostratigraphy and human activity.

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