

**SPATIAL DISTRIBUTION OF IRON AND ALUMINUM IN  
PORE WATER AND BOTTOM SLUDGE OF THE  
MEROMICTIC ACID LAKE NO 54,  
ŁUK MUŻAKOWSKI, POLAND**

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The spatial distribution of iron and aluminum in bottom sludge and pore water of the meromictic acid pit lake no 54 situated in Łuk Mużakowski, Poland were examined. Samples were taken three times from two places located within the meromictic zone and one out of it. Chemical composition of pore water and sludge in vertical profiles were analysed. Two patterns of the distribution of elements between solid and liquid parts depending on the sampling location were found. Samples taken outside meromictic zone had comparable high concentration of iron in the sludge associated with its low amounts in pore water - and on the contrary: low concentration of alum in sludge associated with its high amount in pore water. Samples from the meromictic zone characterized reversed relations.

Keywords: bottom sludge, pore water, meromixis, acid pit lake

## **1. INTRODUCTION**

Meromictic lakes – that are lakes which do not mix completely. This phenomenon is not common in natural lakes, but it often occurs in mine lakes [9]. The following mechanism creates meromixis in pit lakes development: a) formation of a less mineralized mixolimnion by the inflow of less mineralized water to the lake surface, b) enrichment of iron and sulphate due to the transport of secondary minerals from mixolimnion to monimolimnion, c) influence of sea water d) accumulation of substances in the monimolimnion due to biological decay, e) evaporation f) influence of groundwater of high TDS [2]. The deepest part of the meromictic lake water body – monimolimnion – has often a very specific chemical composition: strong anoxia, rich in hydrogen sulphide and

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products of microbial decay. The pH value in monimolimnion has a great influence on the lake chemistry and results in iron and sulphate accumulation in monimolimnion. Higher pH of monimolimnion favors the precipitation of alum compounds and turns back the stratification of aluminium. The precipitation of iron compounds takes place in mixolimnion. In monimolimnion the minerals dissolve and accumulate in water body in the reduced form [1, 4, 8, 9]

Chemical composition of the sludge in the reservoir no 54 was examined by [5, 7] but only in one, the deepest place of the reservoir.

The aim of the research presented below was:

1. to compare the chemical composition of sludge sampled in the meromictic zone and out of it,
2. to describe the differences in chemical composition of sludge in vertical profile (up to 40 cm of depth),
3. to determine the composition of pore water.

It was expected, that the sludge composition would reflect the above described processes in water body. Higher pH and accumulation of aluminium in sludge in the meromictic zone and iron accumulation and lower pH outside was predicted.

## 2. THE STUDY AREA

Samples from the reservoir no 54, located about 2 km east of Łęknica, 2.3 km west of Przewoźniki and 2 km south of Nowe Czaple 51°32'23.97" and 14°46'27.89" (Fig. 1). The reservoir was generated due to lignite mining in the seventies of the 20-th century. Exploitation was done by means of open cast. The reservoir has never been remediated. The surrounding area is covered with forest. The morphometry of the reservoir is presented in Table 1.

The reservoir has no surface inflows such as streams or other lakes. It results in the fact that the chemical composition of its waters depends mainly on the composition of groundwater and precipitation, and reactions within the water body (biogenic meromixis).

Table 1. Morphometry of the res. no 54

No res.	Water level n.m.p	Surface area	Max length	Extending factor	Max width.	Max depth	Volume	Shore line length	Shoreline development
	m	ha	m	-	m	m	tys.m <sup>2</sup>	m	-
54	132,0	20,2	896	1,91	225	21,5	1950	2625	1,65

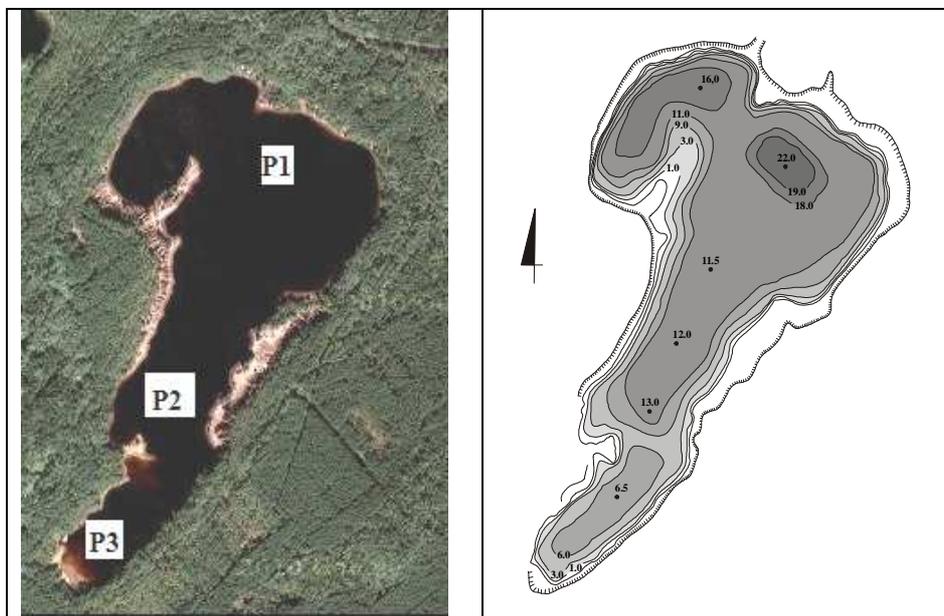


Fig. 1. Bathymetric map of the reservoir no 54 and sampling location

The lake is extremely acidic with a high concentration of iron and sulphur. Chemical composition of reservoir modified significantly during the years of observation. The pH of bottom layer has been increasing systematically and reached in 2008 values of about 4.8-4.9. Iron concentration in the mixolimnion layer was almost steady, but in monimolimnion increased from about 100 to more than 800 mg/dm<sup>3</sup> in the years 1981-88 and, since 1993, to more than 1500 mg/dm<sup>3</sup>. Sulphate concentration did not change as rapidly as iron ones. In the years 1981-88 sulphate concentration was almost steady in the upper part of water body (from the surface to 11 m in depth). Deeper, its content increased with depth. The research done later, showed low concentration of sulphate in the layer 0-7 m, and rapid concentration increase between 7 and 11 m to about 3000 mg/dm<sup>3</sup>, and then gentle increase to the maximum concentration about 4300 mg/dm<sup>3</sup>.

Aluminium concentration had two different profile patterns. In 1981 aluminium concentration increased with depth. Later the concentration of aluminium decreased significantly with depth from the amount of about 35 to less than 10 mg/dm<sup>3</sup>.

### 3. METHODS

Samples were taken three times in September and December 2009 y. and April 2010 y. from three points labeled P1, P2 and P3 (Fig. 1) by the sampler of

Limnos type. The depth of water body was as follows P1 – 21 m, P2 – 10 m, P3 – 4 m. Thermocline layer was situated between 8 and 9 m of depth. Each core was split into three pieces of the following thickness:

- 2 cm – upper layer,
- 5 cm – intermediate layer,
- 9 cm. – the deepest layer.

Two sampling points, P1 and P2 were influenced by meromixis. Point P3 was located out of meromictic zone. To extract pore water samples were centrifuged by 30 min (2000 r/min). Pore water was trickled by 0,45 $\mu$ m drains, and then pH value was measured and acidified. The sludge after dewatering was dried and wet mineralized. Metals were analysed by means of AAS Specr AA 10 Varian.

## 4. RESULTS

### 4.1. pH value in pore water

The pH value varied from 2.28 to 4.76. P1 and P2 samples had pH in the range from 3.33 to 4.76. Samples from P3 profile were more acid and had pH from 2.28 to 4.05, but the upper layers had pH from 2.37 to 3.38. No essential variations of pH value in vertical profile were stated. Only in April, in P2 profile pH decreased significantly with depth (Fig. 2).

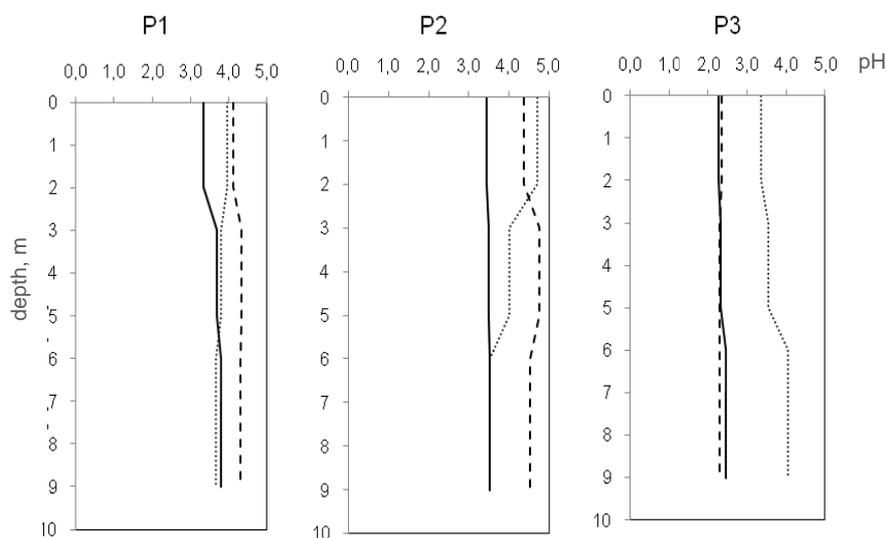


Fig. 2. pH value of pore water in vertical profiles, (dashed line represents results from September, continuous from December and dotted line – April – the same labeling is repeated in the following figures).

## 4.2. Iron

The concentration of iron in upper layers of the sludge in P1 and P2 profiles ranged from 18 to 43 mg/g dry mass (Fig.3). Much higher iron concentrations, from 80 to 224 mg/g dry mass, were stated in the upper and medium layers of P3 samples. Iron concentration decreased with the depth in P1 and P3 profiles and was almost constant in P2 profile. The abnormal high amount of iron were stated in September P2 sample. It seems, that the “base” concentrations in the ground, before lake water impact was the range from 30 to 50 mg/g dry mass. In the profile P3 iron precipitations were cumulated at the bottom surface.

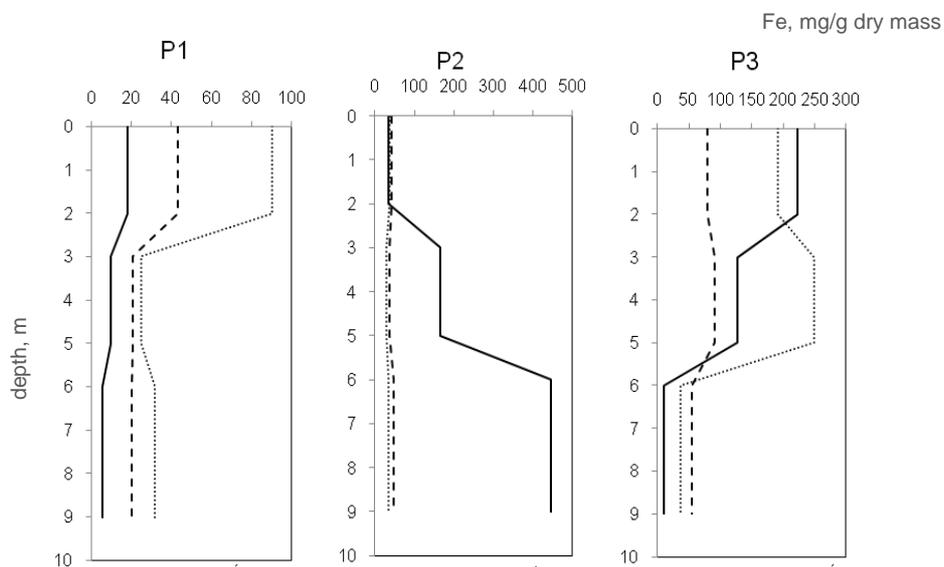


Fig. 3. Vertical variability of iron content in sludge core, mg/g dry mass

The concentration of iron in pore water taken from meromictic zone (P1 and P2) and outside (P3) differed considerably. Pore water in P1 and P3 profiles contained respectively from 995 to 1782 mg/dm<sup>3</sup> and from 465 to 1029 mg/dm<sup>3</sup> and showed no remarkable changes with the depth (Fig.4). In the profile P3 maximal concentration of iron equaled 72 mg/dm<sup>3</sup> and occurred in the upper layers in each period of sampling. The iron content decreased with the depth and reached the minimal value, about 18 mg/dm<sup>3</sup>, in the deepest layer. The amount of iron in the profile P3 was ten times lowered, than the concentration detected in other profiles. The comparison of iron amounts in the sludge and pore water points that high iron amounts in bottom sludge are accompanied by low concentration of this element in pore water and inversely.

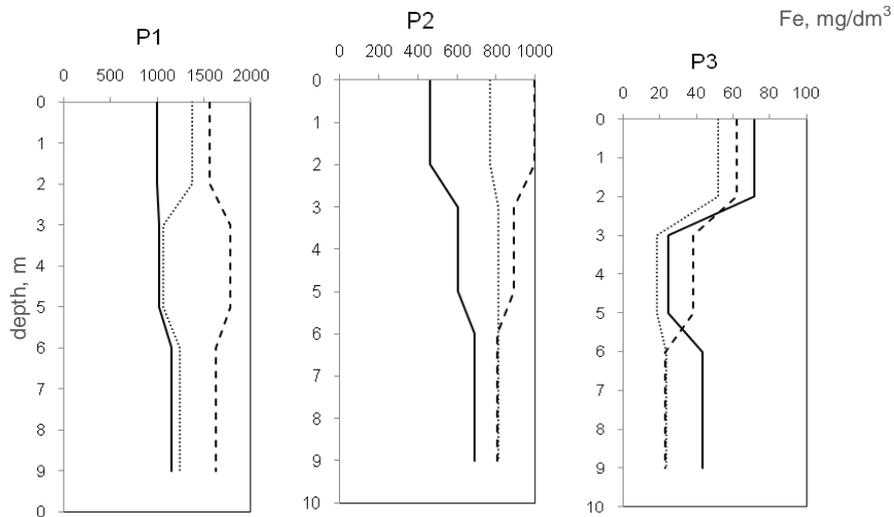


Fig. 4. Vertical variability of iron content in pore water, mg/dm<sup>3</sup>

### 4.3. Aluminium

Aluminium concentration in bottom sludge of the profiles P1 and P2 was on the similar level, from 9 to 18 mg/g dry mass in the upper layer and decreased with depth to at least 2 mg/g dry mass. The sludge in the profile P3 contained aluminium in the range from 0.4 to 4.5 mg/g dry mass depending on sampling period. Its concentration was almost constant in two upper layers and changed deeper (Fig. 5).

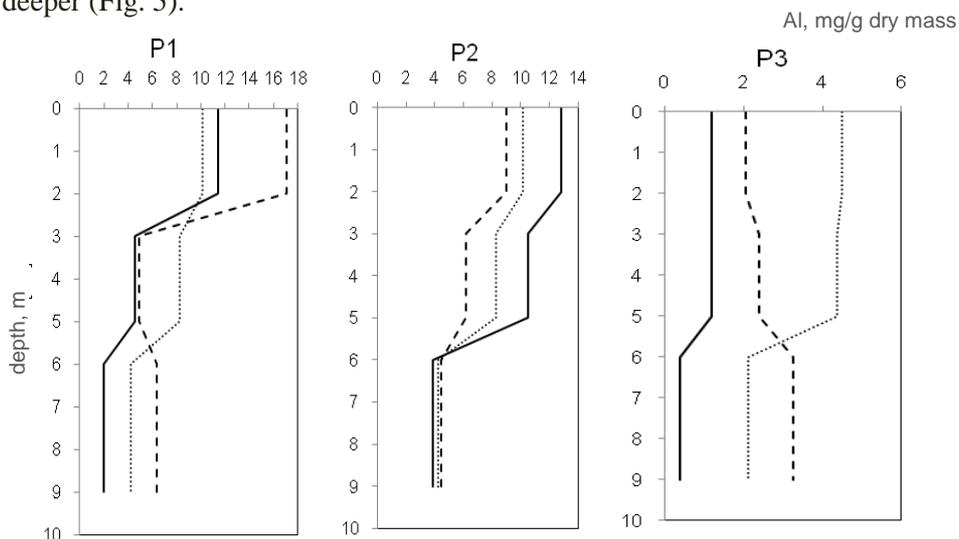


Fig. 5. Vertical variability of aluminum content in sludge core, mg/g dry mass

Aluminium concentration in pore water in P3 profile was higher than in the other profiles. The concentration of the element in pore water in profiles P1 and P2 ranged from 0.32 mg/dm<sup>3</sup> to 24.62 mg/dm<sup>3</sup>, whereas in profile P3 ranged from 25.86 mg/dm<sup>3</sup> to 36.09 mg/dm<sup>3</sup>. The concentration of aluminum in the profiles P1 and P2 changed according to the sampling period and the depth. The concentration of aluminum in the profiles P3 was almost constant each time and slightly increased with the depth.

## 5. DISCUSSION OF THE RESULTS

The differences between chemical composition of sludge and pore water coming from meromictic zone (P1 and P2) and outside (P3) were very significant, especially in the upper layer. The chemistry of deeper layers was similar, what suggests that only 5 cm thin, top layer is influenced by the processes in the lake body.

The distribution of the analysed elements between sludge and pore water had two patterns (Table 2):

1. for iron and aluminum the comparable high concentration of element in sludge is associated with its low amounts in pore water
2. on the contrary, low concentration of element in sludge is associated with its high amounts in pore water.

It proved, that these elements take part in geochemical processes in the lake. In meromictic zone pore water is undersaturated with iron and potassium, which cumulate, and are present at low amounts in sludge. On the contrary aluminum precipitate, so its concentration in pore water should be low, but in sludge high. Outside the meromictic zone, there are conditions for iron compound precipitation, so the element is cumulated in the sludge and precipitates from water. Iron is supposed to precipitate as potassium or natrium jarosite, schwertmannite or different hydrous oxides. The accumulation of potassium and natrium can be observed in the pore water in meromictic zone and the sludge outside.

Table 2. The comparison of the composition of bottom sludge and pore water in upper layer of the cores

Parameter		P1	P2	P3
iron	sludge	medium	medium	high
	pore water	high	medium	low
aluminium	sludge	high	high	low
	pore water	low	low/high	high
pH	pore water	3.5-4.5	3.5-4.5	2.5-3.5

The redox reaction with iron and sulphate participation depend mainly on the organic matter availability. The profiles P1 and P2 cut through coal stratum [3], so higher concentration of organic matter in the sludge samples can be connected with brown coal presence. TOC concentration in pore water in P1 and P2 profiles is higher than in the P3 profile (with exclusion the samples taken in September). In P3 profile the concentration of TOC in pore water and sludge decreased with depth. It suggests that some redox processes can take part in deeper parts of sludge where oxygen resources had been exhausted.

## 6. SUMMARY

The studies have confirmed the influence of meromixis phenomena of the iron and aluminium content in bottom sludge and pore water. The greatest differences were observed in the upper layer of sample cores. Samples coming from the meromictic zone consisted comparable low amounts of iron and aluminium in the solid part and their high concentrations in pore water. Sample P3 characterised reversed relationship.

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ZAWARTOŚĆ ŻELAZA I GLINU W WODZIE POROWEJ I OSADACH DENNYCH  
ACIDOTROFICZNEGO ZBIORNIKA MEROMIKTYCZNEGO NR 54 W ŁUKU  
MUŻAKOWSKIM, POLSKA

Streszczenie

W publikacji przedstawiono zmiany zawartości żelaza i glinu w wodzie porowej i osadach dennych acidotroficznego zbiornika meromiktycznego nr 54 w Łuku Mużakowskim. Próbkę pobierano trzykrotnie z dwóch miejsc w strefie meromiksji i jednego poza nią. Analizowano skład chemiczny osadów i wody porowej w profilu pionowym obranych prób. Stwierdzono dwa wzory rozkładu stężeń badanych pierwiastków między wodą porową i osadami. W próbkach pochodzących spoza strefy meromiksji stosunkowo wysokim stężeniem żelaza w osadach towarzyszyła jego niska zawartość w wodzie porowej, natomiast odwrotną zależność stwierdzono dla glinu, tj. wysokim stężeniem glinu w wodzie porowej towarzyszyła jego niska zawartość w osadach. W próbkach pochodzących ze strefy meromiksji zależności te przebiegały odwrotnie.