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THE EFFECT OF SEDIMENT GRAIN SIZE ON HEAVY METAL CONTENT

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Abstract
In the natural surroundings tectonical, climatological, dynamic and physico-chemical conditions of sedimentation are the crucial factors in the process of sediment composition formation. Grain size is one of the most investigated reasons of space and temporary variability in heavy metal concentration. In general, the data on grain size measurement afford to appreciate sorption capacity of sediments and arrange them. The dependence heavy metal content on grain size of sediments has been examined in the enormous amount of research works. The main conclusion is that if grain size decreases, metal content increases.We have carried out sediment grain size measurement of two lakes (Chebachje Lake, Piketnoye Lake) located in the South of Western Siberia, Russia. To define grain size of these sediments the sorting of samples collected layer-by-layer has been conducted by nest of sieves (from 43 to 1000 µm). Accomplished examinations allow to state that layer-by-layer grain size measurement of sediments has significant importance in reconstruction of paleoecologic peculiarities and also influences organic and inorganic matter concentrating in the sediments in dynamics.

Keywords: Grain size, Sediments, Lakes, Heavy metals, Layer-by-layer analysis

1 INTRODUCTION

Size is a fundamental property of sediment particles. It affects their entrainment, transport and deposition, and therefore provides important clues to the sediment provenance, transport history and depositional conditions (Kenneth Pye, 2004). Heavy metal pollution, owing to its permanent existence and biological enrichment, has long been an important subject in the field of international environmental science. As a result of complex physical, chemical and biological processes, a major fraction of trace metals is found to be associated with water body sediments. Sediments are multi-phase solids containing silicates, carbonates, hydroxides/oxides, sulfates and organic substances as major components (Zhu, 2006). The essential factors influencing the heavy metal contents in sediments include the physical and chemical properties (grain size, surface to volume ratio, heavy metal contents of the main geochemistry phase), in which grain size is a main control parameters. There is a theory that finer sediments contain more heavy metals than coarser ones. The main reason is that smaller grain-size particles have a larger surface-to-volume ratio (Salomons, 1984; Martincic, 1990). However, some studies have indicated that coarser particles show a similar or even higher heavy metal concentrations than finer ones and the presence of coarser particles are possibly responsible for higher metal content in the coarser size fractions (Tessier, 1982; Singh,1999).

2 MATERIALS AND METHODS
2.1 Study area

Ghebachje Lake is located in Tyumen region (fig. 1a). The lake has a diameter about 900 meters, its maximum deep is 2,5-2,8 m; this lake is plant-filled along its perimeter. Piketnoye Lake is situated in river-valley (fig. 1b), its maximum deep 2,5 m. Both lakes are located in an ancient hollow of flowing within Western part of Ishim-Irtysh interstream area. Sediments were collected from central part of the lakes by Edelman's borer. The columns of the sediments (60 cm) were separated step by step – 3 cm (Chebaje Lake), 5 cm (Piketnoye Lake).

Figure 1. Location of investigated lakes (1 – Chebachje Lake, 2 – Piketnoye Lake)

2.2 Sample collection and size fractionation

Sediment samples were collected from Chebachje Lake (Tyumen region) and Piketnoye Lake (Omsk region) in the different depths. The collected sediment samples were packed and sealed in pre-washed polyethylene bags and transferred to the laboratory within a week, where they were dried at room temperature. For determining the relationship between grain size and metal contents, the sediment samples were fractionated into nine sizes by nest of sieves (from 43 to 1000 µm).

2.3 Chemical analysis

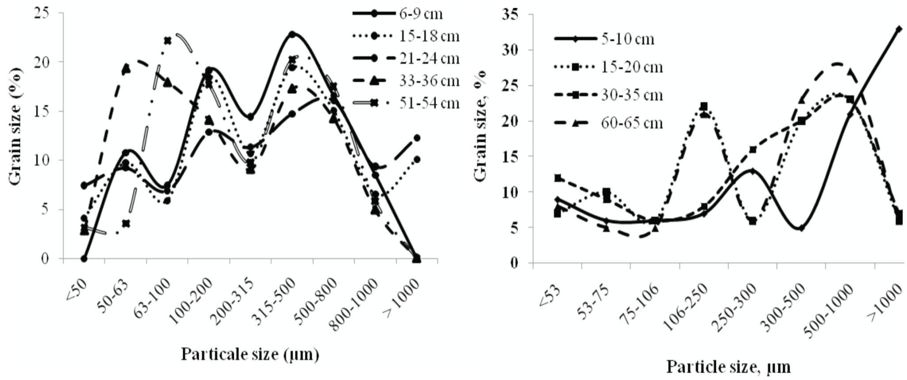
The different grain-size fractions were analysed for some heavy metal contents. For determination of metal total concentrations in different grain-size fractions, sediments were digested in glass-carbon open cups with a mixture of aqua regia and HF. The determination of metals was carried out by AAS (ContrAA 700 Analytic Jena).

3 RESULTS AND DISSCUTION

3.1 Grain size

Grain size of sediments can indicate spatial inhomogenuity. Thus, a wide range of heavy metal concentrations can be detected. Some investigations have shown (Jernstrom, 2010) that if grain size varies greatly, the comparison of metal concentrations in different sampling location can be inadequate without accounting grain size. Grain size of sediments collected layer-by-layer is given in Figure 2.

Grain size of the sediments from Chebachje Lake (fig. 2a) has a twin-peaked and trimodal character and differs in the various depths. The depth from 6 to 18 cm is characterized by domination of 100-200 µm fraction (about 20 %) and 315-500 µm fraction (above 20 %). According to Lane’s classification (Lane, 1947) the sediments are fine sand and medium sand at the depths 6-9 cm, 15-18 cm. The depth 21-24 cm is marked by domination of 315-800 µm (above 30 %) - medium sand and coarse sand. In general the sediments at this depth distinguish more uniform presence of all fractions both most coarse (>1000 µm) and most fine (<50 µm). Prevalence of 50-63 µm can be observed at the depth 33-36 cm (about 20 %) – silt; 63-100 µm is 18 % (very fine sand), 315-500 µm is 17 % (medium sand). The depth 51-54 cm is characterized by domination of 63-100 μm (22 %) and 315-500 μm (20 %).



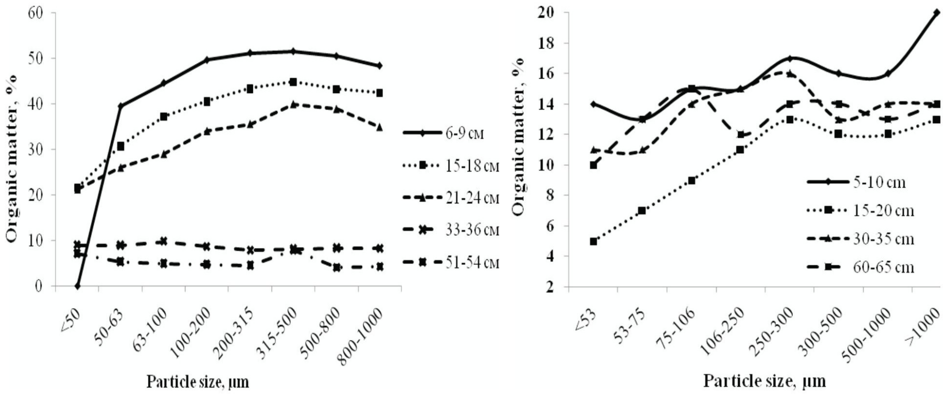
(a) (b)

Figure 2. The size distribution of sediments at different depths (a – Ghebachje Lake; b – Piketnoye Lake)

The sediments of Chebachje Lake are marked by prevalence of the particles in range of 50-1000 μm not taking into consideration a depth. The presence of the particles in range of 315-800 μm (medium and coarse sand) is discernible with small variation (34,8±4,2 %). The particles (50-100 μm) are presented at the deep layers (33-54 cm). The particles (less 50 μm) are from 3 to 7 % excepting the highest layer where owing to sediment detachment the transition of this fraction in suspension is possible. The sediments of Piketnoye Lake mainly consist of the following fractions: 106-250 μm and 300-1000 μm; according to Lane's classification they are fine, medium and coarse sand (fig. 2b). Thus, the fractions of fine sand and medium sand are prevailing in both lakes. Remaining fractions are little at the majority of the layers.

3.2. Organic matter

To explore relation of particle size to organic matter, organic matter content was defined in each fraction at the different depths. Organic matter content in the sediments from Chebachje Lake 33-36 cm and 51-54 cm is not high (7 ± 0,7 %) and does not almost depend on particle size (fig. 3a).



a b

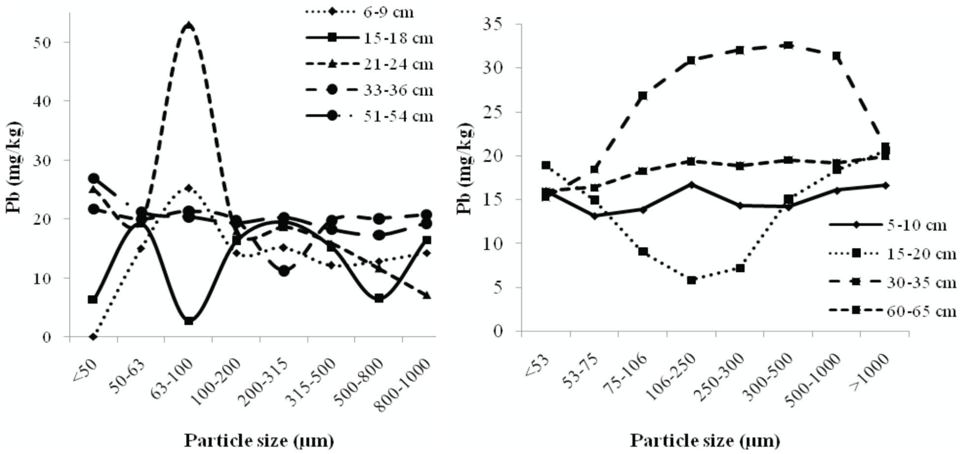
Figure 3. Organic matter distribution at different depths (a – Ghebachje Lake; b – Piketnoye Lake)

Beginning with the depth 21-24 cm organic matter content significantly increases (33 ± 3,3 %) and keeps growing to the surface reaching 50 %. There is a tendency of increasing organic matter content with increasing particle size. In the case of the sediments from Piketnoye Lake the highest organic matter content corresponds the coarse fractions > 1000 µm (fig. 3b).

Thus, distribution of organic matter in the sediments does not clearly depend on particle size but it predominantly depends on the conditions of the layer formation.

3.3. Heavy metals

The heavy metal contents were determined in each size fraction. The distribution character of metals in the examined profile of the sediments from Chebachje Lake in the different size particles is ambiguous. Lead concentration increases with decreasing particle size only at the lower part of the profile (fig. 4a). At the depth of 51-54 cm Pb content tends to increase, but concentration varies slightly except for <53 µm fraction. At the depth of 33-36 cm a slight grow of lead concentration also takes place with decreasing particle size. The particles 200-315 µm in which the metal content is much lower are exception. The depth 21-24 cm is characterized by the increase of metal concentration with increasing particle size, but there is an anomalous high lead content in 63-100 µm fraction at this depth. The horizon of 15-18 cm is characterized by the absence of a pronounced dependence Pb concentration on particle size. The minimum amount of lead contains in 63-100 µm fraction. Pb content is comparable the remaining fractions.



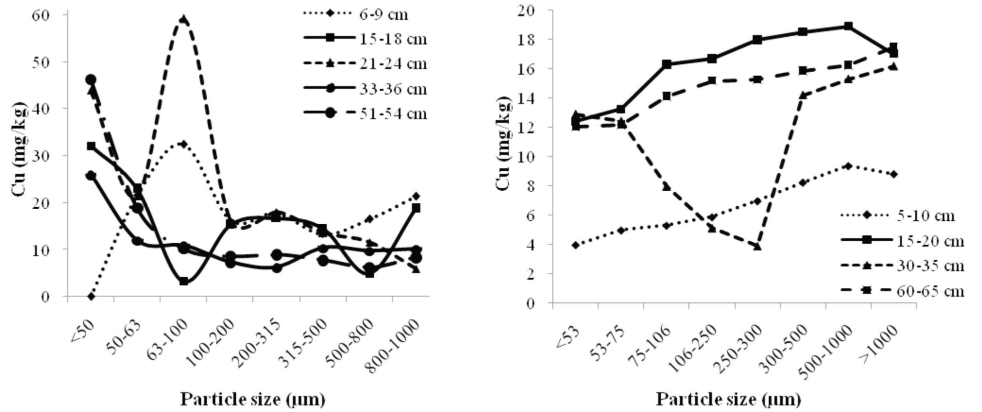
(a) (b)

Figure 4. Variation of Pb concentrations against particle size at different depths (a – Ghebachje Lake; b – Piketnoye Lake)

Lead content in the sediments of Piketnoye Lake does not almost depend on particle size in the highest and the lowest layers (fig. 4b). At the depth 15-20 cm the minimal content of lead is in from 75 to 300 µm fractions and while decreasing and increasing of particle size lead content increases.

In the case of copper (fig. 5a) there is a tendency of increasing metal content as far as decreasing particle size at the low part of profile (33-36 cm, 51-54 cm). It should be noted that the increase of concentration is essential in the fine fraction. The depth 21-24 cm is characterized by two maximums of Cu concentration in <50 µm and 63-100 µm fraction, though these fractions are not prevail. Copper distribution in surface layer is similar to lead distribution at this depth. In the sediments from Piketnoye Lake (fig. 5b) Cu concentration grows monotonically with increasing particle size except for the layer 30-35 cm where there is a sudden decrease of Cu content for 75-300 µm fraction.

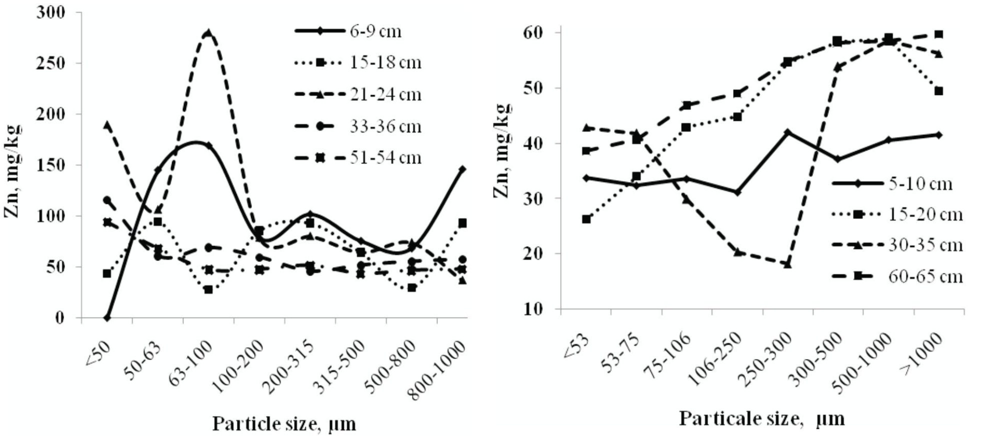
Distribution of zinc depending on particle size of the sediments from Chebachje Lake has a similar character with distribution of previously mentioned metals at depths 33-36 cm and 51-54 cm (fig. 6a). Depth 21-24 cm is also characterized by concentration maximum in 63-100 µm fraction. At the depth of 6-9 cm zinc content dominates in the fine fraction.



(a) (b)

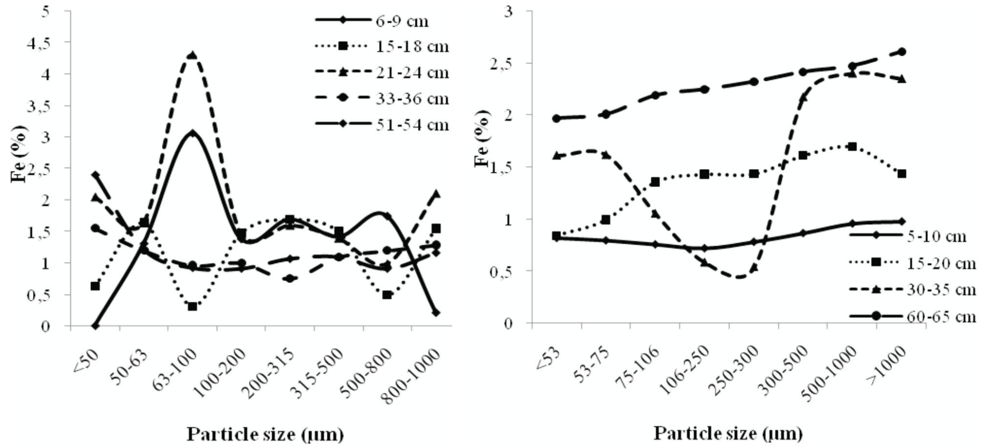
Figure 5. Variation of Cu concentrations against particle size at different depths (a – Ghebachje Lake; b – Piketnoye Lake)

There is high content of zinc in the coarse farctions of the sediments from Piketnoye Lake (fig. 6b). Three dependences from four have a monotonous character; depth 30-35 cm is characterized by concentration minimum in 106-300 µm fraction. Iron distribution (fig. 7a) in the sediments of Chebachje Lake in different fractions is similar to lead and copper distribution at all depths excepting the highest layer. Also at this depth the minimal concentration of iron is in <50 µm 800-1000 µm fractions. For the sediments of Piketnoye Lake (fig. 7b) the decrease of Fe content accompanies the decrease of particle size at three examined layers.



(a) (b)

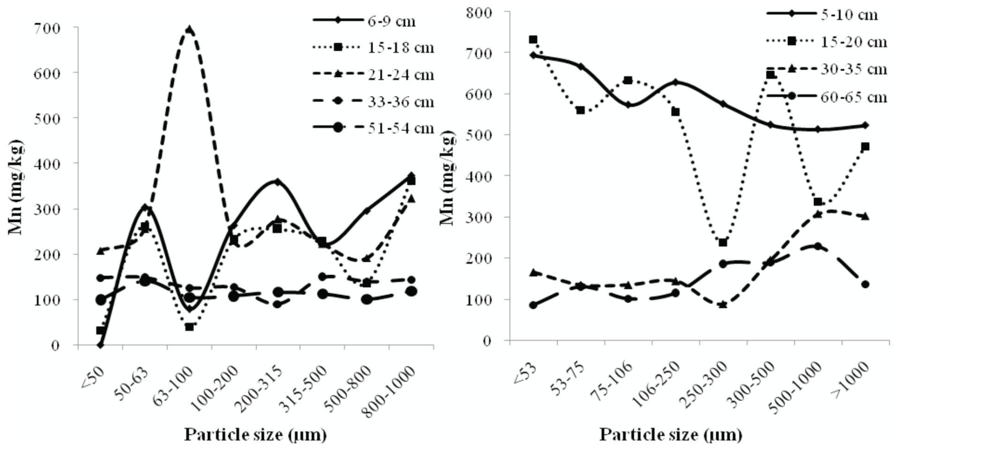
Figure 6. Variation of Zn concentrations against particle size at different depths (a – Ghebachje Lake; b – Piketnoye Lake)



(a) (b)

Figure 7. Variation of Fe concentrations against particle size at different depths (a – Ghebachje Lake; b – Piketnoye Lake)

Mn concentration in two low layers of the sediments from Chebachje Lake does not depend on particle size (fig. 8a). There is no clear tendency at the depth 21-24 cm. It can separate 63-100 µm fraction (it is characteristic for all metals) in which Mn content is high. Mn concentration in the sediments from Piketnoye Lake (fig. 8b) decreases in the case of increasing particle size at the depths 5-10 cm and 15-20 cm, but increase at the depths 30-35 cm and 60-65 cm. The layer 15-20 cm is characterized by concentration minimum for 250-300 µm as well as by maximum – 300-500 µm.



(a) (b)

Figure 8. Variation of Mn concentrations against particle size at different depths (a – Ghebachje Lake; b – Piketnoye Lake)

4 CONCLUSION

Thus, the investigation devoted to metal and organic matter distribution did not show a strongly marked dependence of its content on particle size while the distribution character of some metals has a clear similarity. To confirm observed peculiarities related to metal distribution depending on particle size correlation analysis and factorial analysis were used. Layer-by-layer correlation analysis has shown the existence of high correlation between heavy metals.

Factorial analysis was carried out two matrix of data for each lake: in the first case - the data on organic matter and metal content in each fraction at different depths (Table 1, Table 2); in the second case – the content of each fraction (%), total content of metals and organic matter in each examined layer (Table 3).

Table 1. Factorial analysis (Chebachje Lake)

Variable	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
	Depth 6-9 cm		Depth 15-18 cm		Depth 21-24 cm		Depth 33-36 cm		Depth 51-54 cm	
Grain size	0,49	**0,74**	-0,40	**-0,67**	**0,82**	0,40	0,32	**0,89**	**0,69**	**0,65**
Organic matter	**0,89**	0,44	-0,43	**-0,86**	**0,66**	**0,74**	-0,50	**0,55**	**-0,53**	0,41
Cu	**0,92**	-0,35	-0,24	0,91	**-0,96**	-0,06	**-0,90**	-0,29	**-0,99**	0,10
Pb	**0,95**	-0,29	**-0,98**	0,12	**-0,94**	0,23	**-0,80**	0,49	**-0,96**	0,03
Zn	**0,85**	-0,31	**-0,95**	0,26	**-0,96**	0,00	**-0,88**	-0,26	**-0,98**	-0,06
Fe	**0,75**	-0,33	**-0,98**	0,12	**-0,93**	0,27	**-0,93**	-0,16	**-0,98**	0,13
Mn	**0,53**	**0,68**	**-0,94**	-0,08	**-0,83**	0,49	**-0,77**	0,36	0,03	**-0,89**
Expl.Var	4,34	1,63	4,12	2,11	5,39	1,08	4,05	1,65	4,58	1,43
Prp.Totl	0,62	0,23	0,59	0,30	0,77	0,15	0,58	0,23	0,65	0,20

In the first case we have obtained that factor 1 is determinative, its part is about 60 % (for Chebachje Lake) and 70 % (for Piketnoye Lake) of observed correlations. However the relation of metal content to particle size is not obvious. At depths 21-24 cm and 51-54 cm in the sediments from Chebachje Lake (tabl. 1) there is a decrease of metal concentration with increasing of particle size while organic matter grows (21-24 cm). At other depths particle size plays a support role and is related to organic matter content (more particle size, more organic matter) and sometimes Mn content. In the sediment from Piketnoye Lake particle size influences metal and organic matter content only at two layers – 5-10 cm and 30-35 cm (tabl. 2). It worth noting that this dependence is opposite to literary data: if grain size decreases, metal content increases. At remaining layers metal content is governed by organic matter.

Table 2. Factorial analysis (Piketnoye Lake)

Variable	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2	Factor 1	Factor 2
	Depth 5-10 cm		Depth 15-20 cm		Depth 30-35 cm		Depth 60-65 cm	
Grain size	**-0,88**	0,33	-0,17	**-0,81**	**-0,66**	**-0,71**	-0,49	
Organic matter	**-0,90**	0,07	**0,52**	**-0,65**	**-0,59**	**0,69**	**-0,98**	
Cu	**-0,91**	-0,24	**-0,99**	0,07	**-0,97**	0,12	**-0,98**	
Pb	**-0,45**	**0,83**	**-0,95**	0,22	**-0,89**	0,07	**-0,97**	
Zn	**-0,88**	-0,22	**-0,99**	-0,06	**-0,98**	0,05	**-0,97**	
Fe	**-0,85**	0,03	**-0,99**	-0,0	**-0,95**	0,14	**-0,96**	
Mn	**0,83**	0,42	**-0,85**	-0,40	**-0,87**	-0,36	0,60	
Expl.Var	4,82	1,09	4,85	1,31	5,21	1,17	5,32	
Prp.Totl	0,69	0,15	0,69	0,18	0,74	0,16	0,76	

Determination of dependence metal content on grain size by factorial analysis of the second type (tabl. 3) has shown that Factor 1 is determinative for both lakes, though in this case Factor 2 is also substantial. For the sediments from Chebachje Lake at the approach to the surface content of fine fractions (63-100 µm) decreases, but the amount of particles which have size 200-315 µm and 800-1000 µm increases, while there is a rise of organic matter, Cu, Zn, Pb and Mn content. For the sediments from Piketnoye Lake there is a growth of fine fraction content by means of coarse fraction content.

Table 3. Factorial analysis (Chebachje Lake, Piketnoye Lake)

Variable	Factor 1	Factor 2	Factor 1	Factor 2
	Chebachje Lake		Piketnoye Lake	
Depth	**0,93**	0,17	-0,87	**-0,30**
<50 µm	**-0,11**	-0,80	**0,39**	**0,04**
50-63	**-0,11**	-0,41	**0,17**	0,98
63-100	**-0,93**	**0,36**	**0,82**	0,56
100-200	**0,39**	0,87	**-0,83**	0,23
200-315	**0,85**	0,29	**0,73**	-0,01
315-500	**0,31**	0,93	**-0,86**	0,40
500-800	0,05	0,58	-0,95	-0,23
800-1000	0,73	-0,26	0,79	-0,54
organic matter	0,99	-0,11	0,96	0,10
Cu	0,93	-0,23	-0,45	-0,88

Pb	0,17	0,14	0,21	-0,96
Zn	0,97	-0,13	-0,71	0,51
Mn	0,97	0,14	0,91	-0,08
Expl.Var	8,04	3,23	7,65	3,95
Prp.Totl	0,53	0,22	0,55	0,28

As a result of heavy metal content determination in different fractions of the sediment collected layer-by-layer from two lakes located in the south of Western Siberia we have discovered the following regularities. In the sediments from Chebachje Lake heavy metals accumulate equally on the particles from 100 to 1000 μm or there is a tendency associated with increasing metal content as far as decreasing particle size. The significant accumulation of heavy metals takes place at coarse fractions in surface layers. Coarse fractions of the sediments from Piketnoye Lake sorb most content of heavy metals.

Thus, the investigations allow stating that content and distribution of heavy metals and organic matter are defined not only particle size of sediments but also the conditions of its accumulation, particularly, the ecological state of a reservoir and climatic parameters.

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