Pollution of the Sediments of the Paz River basin

Scientific report within the framework of the international project "Development and realization of environment monitoring, and the program of estimation in border area between Finland, Norway and Russia" during 2003 - 2006

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Apatity, 2006

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1. Summary of the Sediment Investigations

1.1. Introduction

Lake Inari and the Paz River form one of the greatest water system in the Northern Fennoscandia. The drainage basin of this system includes the adjacent areas of Russia, Norway, and Finland. Within these areas, the anthropogenic load consists mainly of heavy metals released by the melting furnaces of the "Pechenganikel" Plant and domestic sewage from populated areas, which are located within the drainage basin of this system. The river is strongly regulated for hydroelectric power production. Therefore, the investigation of the ecological situation and improvement of environmental conditions in the Paz River basin are important for these three countries.

Last century in many countries of the world the increasing attention attracts high latitude regions having richest mineral resources. Development of mineral deposits, processing of mineral raw material, reception of a final product (including, chemical fertilizers and metals) have resulted in infringement of natural geochemical circulation of elements in Arctic and Subarctic ecosystems. The mining and metallurgical activity has significant negative influence on freshwaters of high latitude, which are extremely sensitive to anthropogeneous stress owing to low levels of masses and energy volumes (Moiseenko et al., 1996, 1997; Moiseenko, 1997).

The Paz River basin is one of industrial centres of ecological trouble in the Northern Fennoscandia with the advanced mining and metallurgical industry. The main pollution sources by heavy metals of the Kola Peninsula territory are the Pechenganickel and Severonickel Companies.

The significant part of heavy metals entering in a lake in composition of waste water and precipitated on watershed territory are connected and buried in sediments. Therefore their contents in sediments characterize total loading, allow to determine sources of pollution and to establish historical trends. In the majority of water systems, the element concentrations in the top several centimetres of sediments are much higher, than element concentrations in water column. The close connection of microelements (for example, heavy metals) with seston and sediments means, that distribution, transport and availability of these elements cannot be correctly appreciated extremely by means of only collection of water samples and analysis of a soluble phase (Horowitz, 1991).

Sediments accumulate many microelements and other polluting substances, therefore can be considered as an informative parameter of water quality and, simultaneously, source of secondary pollution for the following reasons:

- unbroken sediments contain "historical records" of the last chemical conditions and allow to establish background levels, to which the existing conditions can be compared;
- under influence of change of physical and chemical conditions (for example, pH, Eh, dissolved oxygen, bacterial activity) the compounds, connected with sediments, can be dissolved in water column, enter to foodweb and have secondary effects for hydrobionts;
- inorganic substances, some rather inert or harmless to environment, can be destroyed or react with others, forming soluble and potentially toxic forms (for example, transmission of elementary mercury into methyl-mercury (Linnik and Nabivanets, 1986; Moore and Ramamoorthy, 1987));
- sediments are one of main sources of pollution and should be investigated for definition of potential transmission of polluting substances.

Researches of the contents of elements in sediments in reservoirs of the Paz River basin were carried out within the framework of the international project "Development and realization of monitoring of an environment, and the program of an estimation in frontier area between Finland, Norway and Russia" during 2002 - 2005. These years the chemical composition of sediments has been investigated on 5 Paz River isolated water areas, in 19 Russian, 14 Norwegian and 11 Finnish lakes, and at all in 49 reservoirs of the Inari Lake – Paz River system.
The aim of the recent investigations is an evaluation of accumulation of heavy metals (Ni, Cu, Co, Zn, Pb, Cd, Hg) and As in the Paz River basin sediments. Four aspects are considered: 1) background concentrations of the elements; 2) vertical distribution of the elements in lake sediment cores; 3) distribution of the element concentrations in surface sediments; 4) contamination degree of Håkanson (1980).

1.2. Materials And Investigation Techniques

Sediment samples from the different lakes and stations of the Paz River watersheds on the Finnish, Russian and Norwegian sites were taken from the deepest area of lakes with the Skogheim (1979) gravity corer and divided into 1-cm thick horizontal layers to facilitate the analysis. These samples were analyzed for their water content (H_2O), loss on ignition (LOI) and concentrations of Ni, Cu, Co, Zn, Cd, Pb, Sr, Mn, Fe, Ca, Mg, Na, K, Al, As, Hg and P; the elements were extracted with nitric acid and determined with the atomic absorption spectrophotometer. Hg was determined utilizing cold vapour atomic absorption. The techniques of preparation and chemical analysis of samples are described in detail earlier (for example, Dauvalter, 1994). Results of these analyses are listed in the separate parts of the report (Finnish, Russian and Norwegian lakes) and in Appendix.

The data on chemical composition of sediments of some Finnish lakes have been kindly submitted by the Finnish Environment Institute and Lapland Regional Environment Centre.

1.3. Discussion

1.3.1. Background concentrations of the elements

Researches of the chemical composition of sediment column allow to restore a history of pollution of lake watersheds and to estimate a degree of their pollution. Lake sediments can be considered as a source of the available ecological information in a time scale.

The determination of undisturbed background concentrations of heavy metals forms a basis for all investigations of lake sediments. Sediment samples taken from deepest core layers (usually deeper than 20 cm) allow to determine background concentrations of elements in investigated lakes. These layers are several hundred years old, according to investigations of Norton et al. (1992, 1996), Rognerud et al. (1993), i.e., they predate the industrial development in the Northern Fennoscandia. These layers reflect the geochemical features of a drainage basin and permit to assess a degree of contamination of water objects, as well as to reveal anomalous concentrations of metals, which is useful in prospecting for mineral resources (Tenhola, Lummaa, 1979).

The long-term human impact on drainage basins of lakes resulted in changes in the environmental conditions that control the chemical composition of bottom sediments. Therefore, background concentrations of heavy metals are important for determination of the effect of industrial activity on aquatic ecosystems.

Maximal average background values of Ni, Zn, Co, Pb are found in sediments of the Paz River, Cu and Hg – in the Norwegian lakes, Cd – in the Finnish lakes, As – in the Russian lakes. Average background concentration of researched polluting elements in investigated Norwegian, Finnish and Russian lakes differed not many, maximum in 2 times.

The maximal background values of heavy metals and As are marked in sediments of the Paz River (Ruskebukta, Skrukkenbukta, Vaggatem), LN-2, Porojärvi, Kuetsjärvi, Langvatn, Kobbholmsvatn, Nammijärvi, Nitsijärvi and other lakes located close to deposits of copper-nickel ores (territory of "Pechenhanickel" Company). These increased concentration, probably, are connected with geochemical and morphometrical features as lake watersheds, and lakes themselves as well. Background concentration of heavy metals and As in these lakes at 2 - 10 times more, than in lakes of the southwest part of researched territory of Russia and the adjoining southeast part of researched territory of Finland. Basically average background concentration of investigated elements in lake sediments of the Paz River basin are similar to earlier determined average background concentrations for lakes of Northern Fennoscandia (Myllymaa, Murtoniemi, 1986; Rognerud, Fjeld, 1990; Dauvalter, 1994, 1999; Dauvalter, Rognerud, 2001). Long-term anthropogenic loading on lake watersheds has resulted in change of environment and sediment formation. Therefore, background concentrations of heavy metals and As are very important for definition of anthropogenic influence on fresh-water ecosystems.

1.3.2. Vertical distribution of elements in lake sediment cores

Investigations of vertical distribution of elements in sediments cores allow to reconstruct the succession of geochemical events within the drainage basin of lakes, as well as to assess background concentrations of elements and variations in their influx. These investigations are of special importance for regions in which the anomalous distribution of heavy metals is due to the combination of specific geochemical features and environmental pollution owing to a highly developed mining and smelting industry. The knowledge of the vertical distributions of heavy metals in lake sediments is the basis for investigating the effect of various anthropogenic factors on the evolution of contamination by heavy metals through time. The period of intense accumulation of heavy metals started concurrently with industrial activity in the northern part of Fennoscandia.

Significant changes in vertical distribution of concentrations of Ni, Cu, Co and Zn in sediment of headwaters of the Paz River (Hestefoss, Ruskebukta), and also in lakes of the southwest part of researched territory of Russia and the adjoining southeast part of researched territory of Finland, and also practically in all Norwegian lakes, have not been noticed. In these lakes the increase in concentrations of Pb, Cd, Hg and As in superficial layers of sediments was revealed. Input of Pb in many lakes is connected, first of all, with the deposition of atmospheric Pb from automobile exhaust. The increase in accumulation rate of Pb, Cd, Hg and As, most probably, is connected to global pollution by these elements of an atmosphere of Northern hemisphere (Norton et al., 1990). In the Russian lakes removed from "Pechenganickel" Company (for example in the lake Kochejävr which is taking place on distance more 100 km), the increase in concentrations of Pb, Cd, Hg and As in superficial layers of sediments is also observed.

In lakes close to the main source of pollution in this region – "Pechenganickel" Company – concentrations of Ni, Cu, Co and Zn in the top 4 - 7 cm of sediments are much higher than background values. Taking into account the fact, that "Pechenganickel" Company is the main source of pollution of surface waters of this region and that this pollution takes place during 60 years, it is possible to calculate (certainly, approximately) the sedimentation rate which is equal ~ 1 mm/year. Contents of Ni, Cu, Co and Zn decrease in younger sediments on the direction of the north and south from these lakes.

In vertical distribution of heavy metals in sediments of the lake Kuetsjärvi, accepting sewage waters of "Pechenganickel" Company, the maximal values of contents of Ni, Cu, Co and Zn are marked in an interval 2 - 4 cm. Reduction of concentration in the top 2 cm, probably, can be explained by changes of physical and chemical conditions in lake and in territory of watersheds, as well as reduction of atmospheric emissions of the smelters. Sedimentation rate in lake Kuetsjärvi, according to indirect determinations, is equal on the average on all researched water areas 1.5 mm/year. Sedimentation rate in the Shuonijärvi lake, determined by results of models of dating on ^{210}Pb, is equal 0.68 mm/year for last 20 years and 0.45 mm/year for last 60 years (Norton et al., 1996). The difference in sedimentation rate is connected, most likely, that lake Shuonijarvi becomes soiled by only air way, and in lake Kuetsjarvi a plenty of the suspended particles that increases input of mineral particles in lake acts also, and respectively increases the sedimentation rate. The average sedimentation rates of the Norwegian lakes Hundvatn, Durvatn and Dalvatn are equal 0.4, 0.6 and 0.54 mm/year, respectively (Norton et al., 1992, 1996), Finnish lakes Lampi 222, Nitsijärvi, Sierramjärvi and Pahtajärvi – 0.4, 1.0, 0.5 and 1.25 mm/year (data of Dr. Jaakko Mannio, Finnish Environment Institute). Therefore, it is possible to accept, that the average sedimentation rate in lakes of the Paz River basin is equal 1 mm/year.

The knowledge of the vertical distributions of heavy metals in lake sediments is the basis for investigating the effect of various anthropogenic factors on the evolution of contamination by heavy metals through time. The period of intense accumulation of heavy metals started concurrently with industrial activity in the northern part of Fennoscandia. Global transfer of air masses to Northern hemisphere is reflected in increase in accumulation of Pb Cd, Hg and As in surface sediment layers of the lakes removed from the main source of pollution.

1.3.3. Distribution of elements in the surface sediments

Emissions of heavy metals and wastewater from melting furnaces, slime pits, tailing dumps, and mines of the “Pechenganickel” Company are the main sources of increased concentrations of Ni, Cu, Co, Cd, Zn and Hg in the top layers of sediments of the Kuetsjärvi Lake. Significant accumulation of Ni, Cu, Co, Zn, Cd, connected mainly with input of sewage waters of the "Pechenganickel" Company through the Kuetsjärvi Lake, is marked on the middle current of the Paz River (Björnevatn). The analysis of accumulation of Ni, Cu, Co, Zn in sediments of the upper and lower current of the Paz River has not shown any influence of atmospheric emissions of smelters. The water of the Paz water system features neutral pH values and considerable neutralizing capacity with respect to acid compounds, which abundantly arrive from the Pechenganickel Company. This greatly favours the capture and accumulation of mobile heavy metals (e.g., Ni, Cu, and Cd) in lake sediments. The prevailing south-western winds mainly spread the emission plume in the north-eastern and southern direction (bottom sediments in lakes located 50 km and farther south of Nikel’ are contaminated only slightly). In northern areas of Norway and Finland, deposition of these elements with precipitation is low. In these places, emissions of the plant only slightly affect the heavy metal content of top layers of lake sediments.

The maximum Ni and Cu concentrations, which exceed their background values by a factor of 10 to 130, were recorded within 10 km of the “Pechenganickel” Company. Within 10 to 30 km of the source of contamination, these concentrations are only 3–7 times as high as their background values. Concentrations of Co were 4–10 times greater than their background values within 15 km of the contamination source and up to 3 times greater in other lakes on the distance more than 15 km, which is indicative of the effect of emissions from melting furnaces. Lakes Kuetsjärvi, LN-2, LN-3, LN-4 receive the basic part of emissions of the “Pechenganickel” Company and have maximal concentration of Ni, Cu, Co, Zn, Cd, Hg and As in superficial layers of sediments. High concentrations of Cd, Pb, Hg and As are marked as well in some lakes removed from the “Pechenganickel” Company that is connected to global pollution by these elements last decades.

In regional distribution of Pb the different patter from all heavy metals is noticed – the increase in concentrations in superficial layers of sediment of headwaters of the Paz River and the lakes removed from the main source of pollution, suggesting that that the basic sources of Pb are in Northern Finland and Northeast Norway. Main source Pb, most likely, is use of gasoline with tetra-ethyl lead in quality of antiknock component.

1.3.4. Contamination degree of Håkanson

The factor and degree of the heavy metal pollution of lake sediments with special indices were described by Håkanson (1980) (factor (C_f) and degree (C_d) of contamination). To evaluate the contamination by heavy metals in the investigated lakes, we have defined a contamination factor (C_f) values according to Håkanson, (1980) as a ratio of concentrations in a surficial sediment to a background value for a given lake. Contamination degree (C_d) values were defined as the sum of all contamination factors for a given lake. To determine the ecological state of the investigated lakes, the values of the contamination factor of eight elements (Cu, Ni, Zn, Co, Cd, Pb, Hg, As – the prevailed polluted elements in this region) were calculated. These values are shown in Table and Appendix.

The following terminology is suggested for describing the contamination factor (C_f):
$C_f <1$ – low contamination factor;
$1\leq C_f <3$ – moderate contamination factor;
$3\leq C_f <6$ – considerable contamination factor;
$C_f \geq 6$ – very high contamination factor.

The following terminology is adopted to describe the degree of contamination (C_d-values) for eight substances:
$C_d <8$ – low degree of contamination;
$8\leq C_d <16$ – moderate degree of contamination;
$16\leq C_d <32$ – considerable degree of contamination;
$C_d \geq 32$ – very high degree of contamination indicating serious anthropogenic pollution.

Maximal values of contamination factor (C_f) of almost all heavy metals are marked in sediments of the Kuetsjärvi and lakes (LN-2, LN-3, LN-4, Peschanoe, Palojärvi, Zapoljarny, Kirikovanjarvi) on distance up to 20 km from the “Pechenganickel” Company. The lake Björnevatn has very high values of C_f for Ni and Hg, considerable – Cu, Cd, As, moderate – for others TM. Values of C_f for many heavy metals for water areas of upper and lower watercourse of the Paz River are on the borderline between low and moderate, with exception Hg and Cd. Practically all researched Norwegian and Finnish lakes have low and moderate values of C_f for Ni, Cu, Zn, Co. Very high values of C_f are marked for Pb and As in lakes Isalombola, Sametivatn, Gjekvatn (Norway), Lampi 222, Mellalompolo, Kantojärvi (Finland) and of some other lakes.

Lakes on the distance up to 20 km from the “Pechenganickel” Company and lakes Kuetsjärvi and Björnevatn have maximal values of C_d (very high according to the classification of Håkanson). Very high values of C_d are fixed as well in more removed lakes – Alla-Akkajärvi (45 km, due to very high values of C_f for Ni, Cu, Pb), Isalombola (59 km, very high value of C_f for Pb), Virtuovoshjäur (90 km, very high value of C_f for Hg) (Fig. 1). For the most part of the Finnish lakes the values of C_d are on borderline between considerable and moderate owing to high values of C_f for Pb, Cd and As, moderate values of C_d – for the most part of the Norwegian lakes are typical.

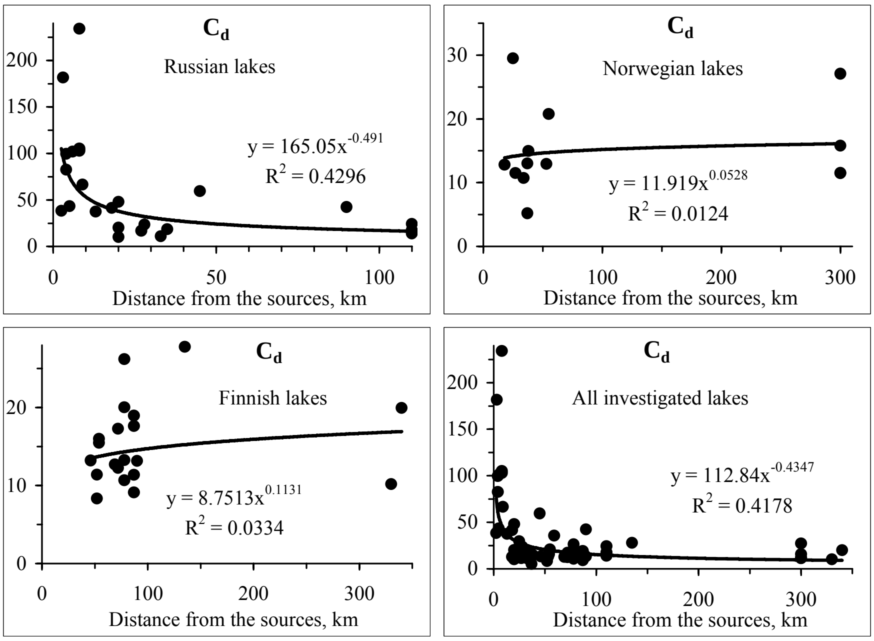

Fig. 1. Distribution of C_d (contamination degree) values in Russian, Norwegian and Finnish lakes depending on the distance from the smelters of the "Pechenganickel" Company.

Thus, the analysis of territorial distribution of heavy metals in sediments of researched lakes has shown that areas of high values of concentration closely correlated elements Ni, Cu, Co and Hg coincide and are limited to 50-km local zone around of the metallurgical enterprises. The in crease in contents of Pb is traced from the east to the west that reflects the general flux of polluting substances from the center of Europe on northeast to Arctic regions. Alongside with Pb, Cd, As and Hg are also the global pollutants. The maximum Ni and Cu concentrations, which exceed their background values by a factor of 10 to 130, were recorded within 10 km of the "Pechenganickel" Company. Within 10 to 30 km of the source of contamination, these concentrations are only 3–7 times as high as their background values. Concentrations of Co were 4–10 times greater than their background values within 15 km of the contamination source and up to 3 times greater in other lakes on the distance more than 15 km, which is indicative of the effect of emissions from melting furnaces. Lakes Kuetsjärvi, LN-2, LN-3, LN-4 receive the basic part of emissions of the "Pechenganickel" Company and have maximal concentration of Ni, Cu, Co, Zn, Cd, Hg and As in superficial layers of sediments. High concentrations of Cd, Pb, Hg and As are marked as well in some lakes removed from the "Pechenganickel" Company that is connected to global pollution by these elements last decades.

The significant part of heavy metals entering in a lake in composition of waste water and precipitated on watershed territory are connected and buried in sediments. Therefore their contents in sediments characterize total loading, allow to determine sources of pollution and to establish historical trends. In the majority of water systems, the element concentrations in the top several centimetres of sediments are much higher, than element concentrations in water column. The close connection of microelements (for example, heavy metals) with seston and sediments means, that distribution, transport and availability of these elements cannot be correctly appreciated extremely by means of only collection of water samples and analysis of a soluble phase. Therefore, the investigations of chemical composition of lake sediments have shown the efficiency for estimation of influence of the "Pechenganickel" Company on water ecosystems, and these researches are necessary for continuing.

1.4. Recommendations to the monitoring program

1.4.1. Obligatory monitoring – minimum quantity of researches carried out on seasons annually

1.4.1.1. Concrete lakes

Björnevatn, Skrukkebukta, Vaggatem (Paz River), Kuetsjärvi, Kochejäur, Virtuovoshjäur, Alla-Akkajärvi, Kirikovanjärvi (Russian Lakes), Isalombola, Sametivatn, Gardsjoen (Norwegian Lakes), Inari Vasikanselkä, Lampi 222, Kantojärvi (Finnish Lakes) – 14 lakes at all.

1.4.1.2. Controllable parameters, the suggested approach and method

a) Controllable parameters – water content, loss on ignition, elements – Ni, Cu, Co, Zn, Cd, Pb, Sr, Mn, Fe, Ca, Mg, Na, K, Al, As, Hg and P.
b) The suggested approach and method – sediment samples are collected by the Skogheim's sediment corer from the first 5 cm in layers through 1 cm and from the deepest part (usually 20 - 25 cm) of the sediment core.

1.4.1.3. Frequency and periodicity of sampling – once a year, in September.

1.4.2. The comprehensive monitoring, spent ones in 3 - 4 years

1.4.2.1. Concrete lakes – all lakes investigated during this monitoring program.

1.4.2.2. Controllable parameters, the suggested approach and method

a) Controllable parameters – water content, loss on ignition, elements – Ni, Cu, Co, Zn, Cd, Pb, Sr, Mn, Fe, Ca, Mg, Na, K, Al, As, Hg and P.
b) The suggested approach and method – in accordance to earlier carried out investigations on the methods above described in this report. The sediment samples are collected by the Skogheim's sediment corer. The sediment cores are divided into 1-cm thick horizontal layers on the whole core.

1.4.2.3. Frequency and periodicity of sampling – once in 3 - 4 years, in September

2. Heavy Metals in the Sediments of the Paz System

The sediment cores from the different parts of the Paz River System (Björnevatn, Vaggatem, Ruskebukta, Skrukkenbukta, Hestefoss) have been taken during the field work in September 2002 to study chemical composition of sediments and assess the pollution of water ecosystems.

2.1. Background Concentrations of Heavy Metals

The maximum background concentrations of heavy metals that were recorded in Vaggatem (Zn, Co, As), Ruskebukta (Ni, Cu, Hg), Skrukkenbukta (Pb), Björnevatn (Cd), result from the geochemical and morphometric features of the lake and its drainage basin (Table 1). The background concentrations of Ni, Cu, Co, Zn, Cd, Pb and As in the abovementioned lakes were established to be higher than those in other lakes under study by a factor of 1.2–2. The highest variation of the background concentrations was noticed for Hg (more than 10 times). The average background concentrations of heavy metals in the Paz System Lakes and Lake Imandra (the largest lake of the Kola Peninsula) are approximately equal (Moiseenko et al., 2002), excluding Hg, Pb, Cd (in 1.5, 1.8 and 20 times less than in Lake Imandra) and Co (in 1.7 times higher than in Lake Imandra).

Table 1. Background concentrations of heavy metals and As (μg/g, dry weight) in sediment cores of the investigated Paz River parts

Lake	Cu	Ni	Zn	Co	Cd	Pb	As	Hg
Bjornevatn	42	58	100	27	0.11	11.2	3.36	0.003
Vaggatem	55	58	126	30	0.08	9.2	6.01	0.015
Ruskebukta	62	63	112	26	0.09	12.4	4.37	0.038
Skrukkenbukta	58	64	123	25	0.09	14.0	3.95	0.021
Hestefoss	36	46	100	21	0.05	6.8	3.95	0.021
Average	51	58	112	26	0.08	10.7	4.32	0.020
Minimum	36	46	100	21	0.05	6.8	3.36	0.003
Maximum	62	64	126	30	0.11	14.0	6.01	0.038
Standard deviation	11	7	12	3	0.02	2.8	1.01	0.013

2.2. Vertical Distribution of Heavy Metals in Bottom Sediments

The vertical distribution of concentrations of Ni, Cu, Co and Zn in the sediments of parts Ruskebukta and Hestefoss varies only slightly (Fig. 2). However, in these aquatories , the concentration of Cd, Pb, As and Hg in the top layers of the sediments is substantially higher than that of the background. It is unlikely for this elevated concentration to be due to the Pechenganikel' Plant operation, since this part of the drainage basin of the Paz River is only slightly affected by emissions of heavy metals from the plant.

In Lake Björnevatn, the maximum concentrations of heavy metals (except for Pb) were recorded in the upper 1-cm-thick layer of bottom sediments. The Pb content of bottom sediments decreases from bottom to top. Heavy metal concentrations elevated relative to the background values occur at a depth of 7 - 8 cm and lower. Taking into account that the "Pechenganickel" Plant has been the main source of pollution in this region for as long as 60 years, one can assess the rate of deposition (~1 mm/year). Almost the same situation is in the sediment core of the Lake Skrukkenbukta, situated downstream of the Paz River and polluted in lower degree , but the sedimentation rate is much smaller – ~0.3 mm/year (see distribution of Cu and Ni in Fig. 2).

Concentrations of the almost all investigated polluted elements (excepting Zn and Co) in the sediment core of the Vaggatem, situated upstream of the Paz River from the entrance of sewage waters of the Pechenganickel Company through the Salmijarvi, increase towards to the sediment surface (Fig. 2) in 1.3 - 2.9 times in comparison with the background values.

2.3. Distribution of Heavy Metals in the Top Layers of Lake Sediments

Emissions of heavy metals and wastewater from melting furnaces, slime pits, tailing dumps, and mines of the Pechenganikel' Plant are the main sources of increased concentrations of Ni, Cu, Co and Zn in the top layers of sediments in Lakes Björnevatn and Skrukkenbukta (Fig. 3). The water of the Paz water system features neutral pH values and considerable neutralizing capacity with respect to acid compounds, which abundantly arrive from the plant. This greatly favours

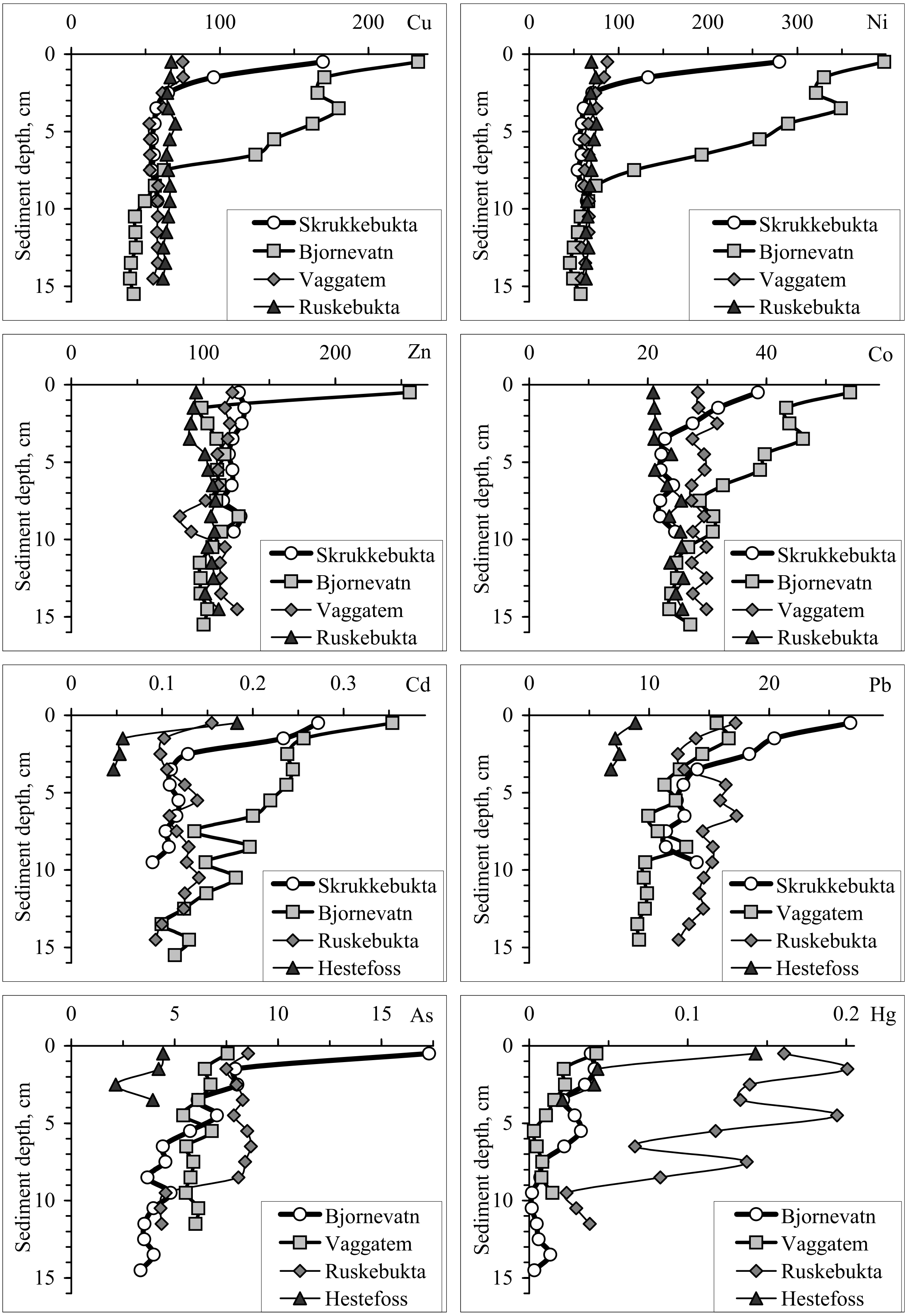

Fig. 2. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the investigated Paz River parts.

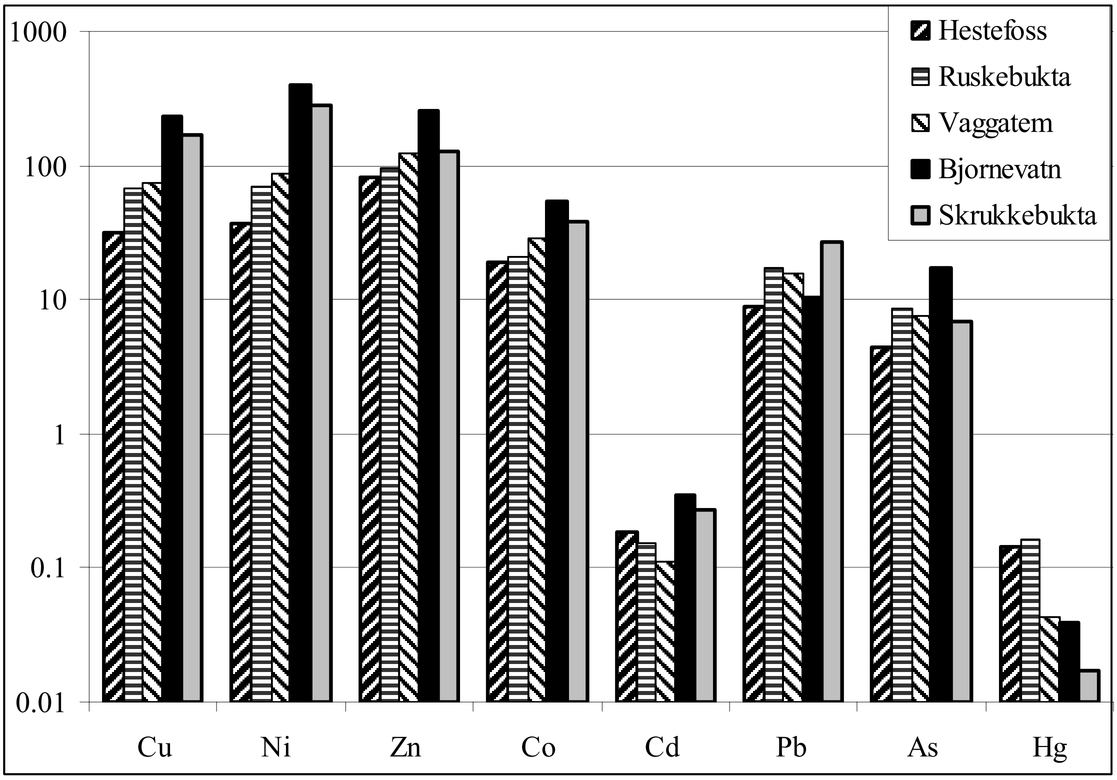

Fig 3. Distribution of the element concentrations in the upper layer (0 - 1 cm) of the sediment cores downstream the investigated Paz River parts.

the capture and accumulation of mobile heavy metals (e.g., Ni, Cu, and Cd) in lake sediments. The prevailing south-western winds mainly spread the emission plume in the north-eastern and southern direction (bottom sediments in lakes located 40 km and farther south of Nikel' are contaminated only slightly). In northern areas of Norway and Finland, deposition of these elements with precipitation is low. In these places, emissions of the plant only slightly affect the heavy metal content of top layers of lake sediments.

The Lake Björnevatn received the contaminated water from Lake Kuetsjärvi accumulates the maximum concentrations in the surface sediment layer of the almost all contaminated elements (Table 2, Fig. 3). The exception are Pb and Hg, which have the highest concentrations in the top sediment layer in Skrukkebukta and Ruskebukta respectively. Concentrations of the Ni, Cu, Zn and Co in the top sediment layers of the Lake Björnevatn increased during the last ten years in 1.1 - 2.1 times, Cd decreased, and Pb is the same (Dauvalter, 1998).

In distribution of concentration Hg in the top layers of sediment cores decreasing contents downstream of the Paz River has been marked (Fig. 3).

In top layers of the sediments in the upper reaches, the concentrations of Ni, Cu, Co, and Zn do not much exceed their background values.

2.4. The Factor and Degree of Contamination of Lake Sediments

Maximum values of contamination factor (C_f) for the investigated elements were noticed for sediments of Björnevatn, polluted by sewage waters of the Pechenganickel smelters (Table 3). This lake has very high C_f values for Ni and Hg, considerable C_f values of Cu, Cd and As, and moderate values of Zn and Co of according to the Håkanson (1980) classification. In the lakes, situated on the greater distance from the Pechenganickel smelters, the main polluting elements are Cd, Pb, Hg and As which on of classification Håkanson have contamination factors from very high up to moderate.

Table 2. Concentrations of heavy metals and As (µg/g, dry weight) in surface sediment layer (0 - 1 cm) of the investigated Paz River parts

Lake	Cu	Ni	Zn	Co	Cd	Pb	As	Hg
Bjornevatn	234	397	256	54	0.35	10.3	17.3	0.039
Vaggatem	75	87	122	28	0.11	15.6	7.56	0.042
Ruskebukta	67	70	95	21	0.15	17.2	8.55	0.161
Skrukkenbukta	169	280	127	39	0.27	26.8	6.89	0.017
Hestefoss	32	37	81	19	0.18	8.8	4.45	0.143
Average	115	174	136	32	0.21	15.8	8.95	0.080
Minimum	32	37	81	19	0.11	8.8	4.45	0.017
Maximum	234	397	256	54	0.35	26.8	17.3	0.161
Standard deviation	83	157	70	14	0.10	7.1	4.91	0.066

Table 3. Concentrations of heavy metals and As (µg/g, dry weight) in sediment cores, values of contamination factor (C_f) and degree of contamination (C_d) of the investigated Paz parts

Lake, Date Depth, m	Layers, cm	Cu µg/g	Ni µg/g	Zn µg/g	Co µg/g	Cd µg/g	Pb µg/g	As µg/g	Hg µg/g	C_d
Skrukkebukta 16.09.02	0 - 1 9 - 10	169 58	280 64	127 123	39 25	0.27 0.09	26.8 14.0	6.9 9.0	0.017 0.032	
37 m	C_f	2.9	4.3	1.0	1.6	3.0	1.9	0.8	0.5	16.1
Bjornevatn 16.06.02	0 - 1 15 - 16	234 42	397 58	256 100	54 27	0.35 0.11	10.3 11.2	17.3 3.4	0.039 0.003	
23 m	C_f	5.6	6.9	2.6	2.0	3.1	0.9	5.2	12.2	38.3
Vaggatem 11.09.02	0 - 1 14 - 15	75 55	87 58	122 126	28 30	0.11 0.08	15.6 9.2	7.6 6.0	0.042 0.015	
19 m	C_f	1.4	1.5	1.0	1.0	1.5	1.7	1.3	2.9	12.1
Ruskebukta 11.09.02	0 - 1 14 - 15	67 62	70 63	95 112	21 26	0.15 0.09	17.2 12.4	8.5 4.4	0.161 0.038	
15 m	C_f	1.1	1.1	0.8	0.8	1.7	1.4	2.0	4.2	13.1
Hestefoss 13.09.02	0 - 1 3 - 4	32 36	37 46	81 100	19 21	0.18 0.05	8.8 6.8	4.4 3.9	0.143 0.021	
10.5 m	C_f	0.9	0.8	0.8	0.9	3.9	1.3	1.1	6.8	16.5

Björnevatn has maximum value of degree of contamination (C_d), which according to Håkanson (1980) classification is estimated as very high C_d (Table 3). Considerable and moderate values of C_d are characterized for other distinct lakes. Skrukkebukta and Hestefoss situated down-stream and upstream from the Björnevatn respectively have the considerable C_d values, the first lake due to pollution by Ni, Cu and Cd, and the latter – Hg and Cd.

3. Pollution of the Sediments of the Russian Lakes of the Paz River System

During three field expeditions (August 2002, August 2003, August 2004) nineteen Russian Lakes of the Paz River basin (Kochejäur, Virtuovoshjäur, Alla-Akkajärvi, Kuetsjärvi, Kaskamajärvi, Porojärvi, Shuonijäur, Keudsherjäur, LN-2, LN-3, LN-4, Palojärvi, Zapoljarny, Trifonojärvi, Kjantejärvi, Kirikovanjärvi, Njasjukkjajärvi, Pikku-Heynjajärvi, Peschanoe) have been investigated to study chemical composition of sediment cores and assess the pollution of water ecosystems.

3.1. Background Concentrations of Heavy Metals

The maximum background concentrations of heavy metals that were recorded in LN-2 (Ni, Cd, Hg), Porojärvi (Cu, As), Kuetsjärvi (Zn, Pb), Trifonojärvi (Co) Lakes result from the geochemical and morphometric features of the lake and its drainage basin. The background concentrations of the polluted heavy metals and As in the abovementioned lakes were established to be higher than those in other lakes under study by a factor of 1.5 - 10. Minimum concentrations in the deepest parts of the sediment cores of the Russian investigated lakes were noticed in the south-west part of the studied territory (Kochejävr, Virtuovoschävr, Alla-Akkajärvi), as well as quite close to the industrial centre (Shuonijaur, Keudsherjaur, LN-3). The average background concentrations of heavy metals and As in sediments of the investigated Russian lakes of the Paz River System are approximately equal to earlier calculated average background concentrations in lake sediment of the Kola Peninsula and the Paz River Basin in 1991 - 1992 (Dauvalter, 1994a, 1994b), excepting Cd (see Table 4). The average background concentration of Cd was more than 10 year ago in 5 times higher than in our recent investigations. Probably, it has taken place due to more perfect analytical equipment for definition of Cd contents in present time.

3.2. Vertical Distribution of Heavy Metals in Bottom Sediments

Markedly elevated concentrations of Cd, Pb and As were revealed on the sediment surface in the Kochejävr Lake (Fig. 1); at a depth of 10 cm and lower, their concentrations in the sediments core are equal to background values. In a large number of lakes, the influx of Pb results from its deposition from the atmosphere and from autopollution (vehicles). The accelerated accumulation of Pb is, apparently, due to the air pollution by Pb, which is ubiquitous in the northern hemisphere. In the sediment cores of the Kochejävr Lake there is no the pollution by priority contamination heavy metals for the Kola Peninsula industrial regions – Ni, Cu, Co, Zn (Fig. 4).

Lake Kuetsjärvi features maximum concentrations of Ni, Co and Zn in the sediment cores at a depth of 2 to 4 cm (Fig. 5), particularly in the northern part of the lake. The maximum of Cd and Pb concentrations were noticed in the top layers of sediment cores. The similar vertical distribution (but with the lower concentrations of Ni and Cu) was recorded in the sediments of Lake Alla-Akkajärvi, which is ~45 km south of melting furnaces of "Pechenganickel" Plant. Reduced concentrations of these elements within the top 2-cm-thick layer of bottom sediments in Lake Kuetsjärvi may be explained by a change in the physicochemical conditions both in the lake and in its drainage basin, as well as by reduced emissions of heavy metals by Pechenganikel' Plant in the last decade.

Unfortunately sediment dating was not carried out in the Kuetsjärvi, but it is possible to estimate the sediment accumulation time of the appropriate layers. The appreciable increase of the contents of the main polluted heavy metals (Cu, Ni) starts at 11, 12 and 8 cm depth (in Gulf Stream, Salmijärvi and White Stone aquatories of the Kuetsjärvi, respectively), which should coincide with the beginning of the anthropogenic loading of the lake, i.e. 1932.

Table 4. Background concentrations of heavy metals and As (µg/g, dry weight) in sediment cores of the Russian investigated lakes

Lake	Layers, cm	Cu µg/g	Ni µg/g	Zn µg/g	Co µg/g	Cd µg/g	Pb µg/g	As µg/g	Hg µg/g
Kochejäur-North	18 - 19	18	22	74	13.5	0.21	1.8	1.26	0.012
Kochejäur-Middle	16 - 17	16	19	85	7.7	0.21	5.1	1.13	0.017
Kochejäur-South	19 - 20	16	20	69	8.8	0.16	3.4	-	-
Virtuovoshjäur	16 - 17	18	19	83	11.6	0.12	5.5	1.21	0.003
Alla-Akkajärvi	26 - 27	12	12	103	9.0	0.09	3.3	1.86	0.028
Kuetsjärvi-Golfstream	15 - 16	47	39	106	20.8	0.16	8.4	7.95	0.035
Kuetsjärvi-Salmijarvi	20 - 21	52	66	127	30.7	0.18	9.2	11.92	0.007
Kuetsjärvi-Whit Stone	22 - 23	40	32	173	15.9	0.10	6.6	2.62	0.049
Kaskamajärvi	19 - 20	57	33	115	23.1	0.09	2.1	4.83	0.057
Porojärvi	22 - 23	68	42	161	11.8	0.20	2.9	13.7	0.058
Shuonijäur	14 - 15	14	13	47	4.3	0.06	0.8	0.74	0.019
Keudsherjäur	15 - 16	9	15	93	8.0	0.06	1.4	1.16	0.032
LN-2	17 - 18	53	214	121	26.2	0.40	1.0	4.29	0.111
LN-3	30 - 31	27	13	54	7.0	0.11	0.7	1.16	0.045
LN-4	14 - 15	21	27	66	10.7	0.14	1.0	1.62	0.026
Zapoljarny	17 - 18	28	72	119	39.0	0.31	1.3	12.40	0.039
Trifonojärvi	9 - 10	54	58	140	40.3	0.26	3.9	7.17	0.025
Kirikovanjärvi	20 - 21	32	26	88	8.8	0.14	1.6	0.85	0.040
Pikku-Heynjajärvi	14 - 15	29	20	137	17.4	0.25	1.6	5.06	0.061
Peschanoe	13 - 14	53	61	61	11.4	0.12	1.5	5.99	0.045
Average		33.2	41.2	101.1	16.3	0.17	3.2	4.57	0.037
Min		9	12	47	4.3	0.06	0.7	0.74	0.003
Max		68	214	173	40	0.40	9.2	13.7	0.111
Standard deviation		18	45	35	10.5	0.09	2.5	4.25	0.025
Average*		36.2	34.9	112.9	19.8	<0.50	3.4	-	0.042
Average**		37	36	95	13.4	0.94	3.7	-	0.042

* – average background values of heavy metals in sediment cores of the lakes of the Kola Peninsula in 1991 - 1992 (Dauvalter, 1994a)

** – average background values of heavy metals in sediment cores of the Russian lakes of the Paz River Basin in 1991 - 1992 (Dauvalter, 1994b)

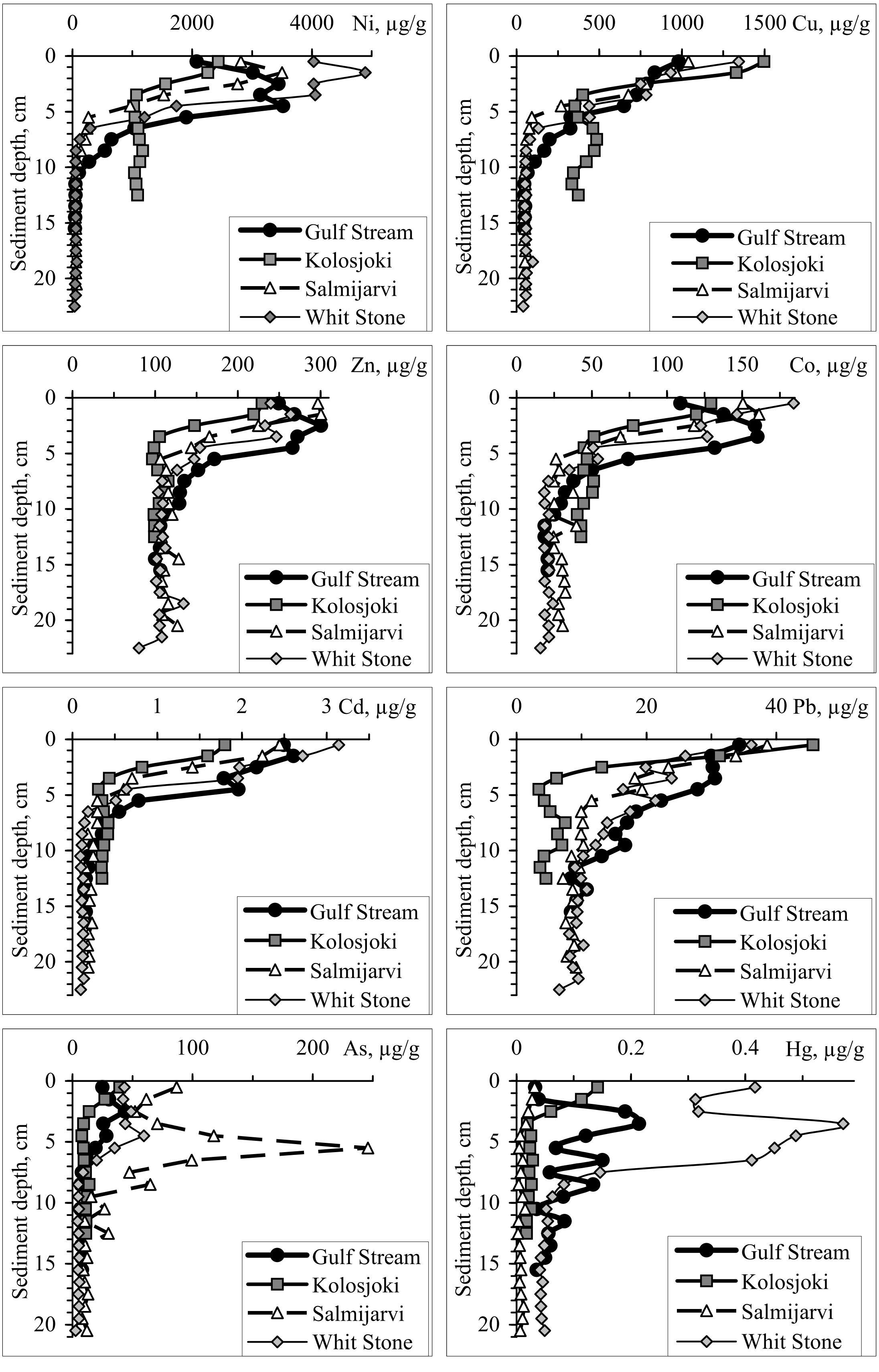

Fig.4. Vertical distribution of elements (µg/g) in the sediment cores of the Kochejävr Lake.

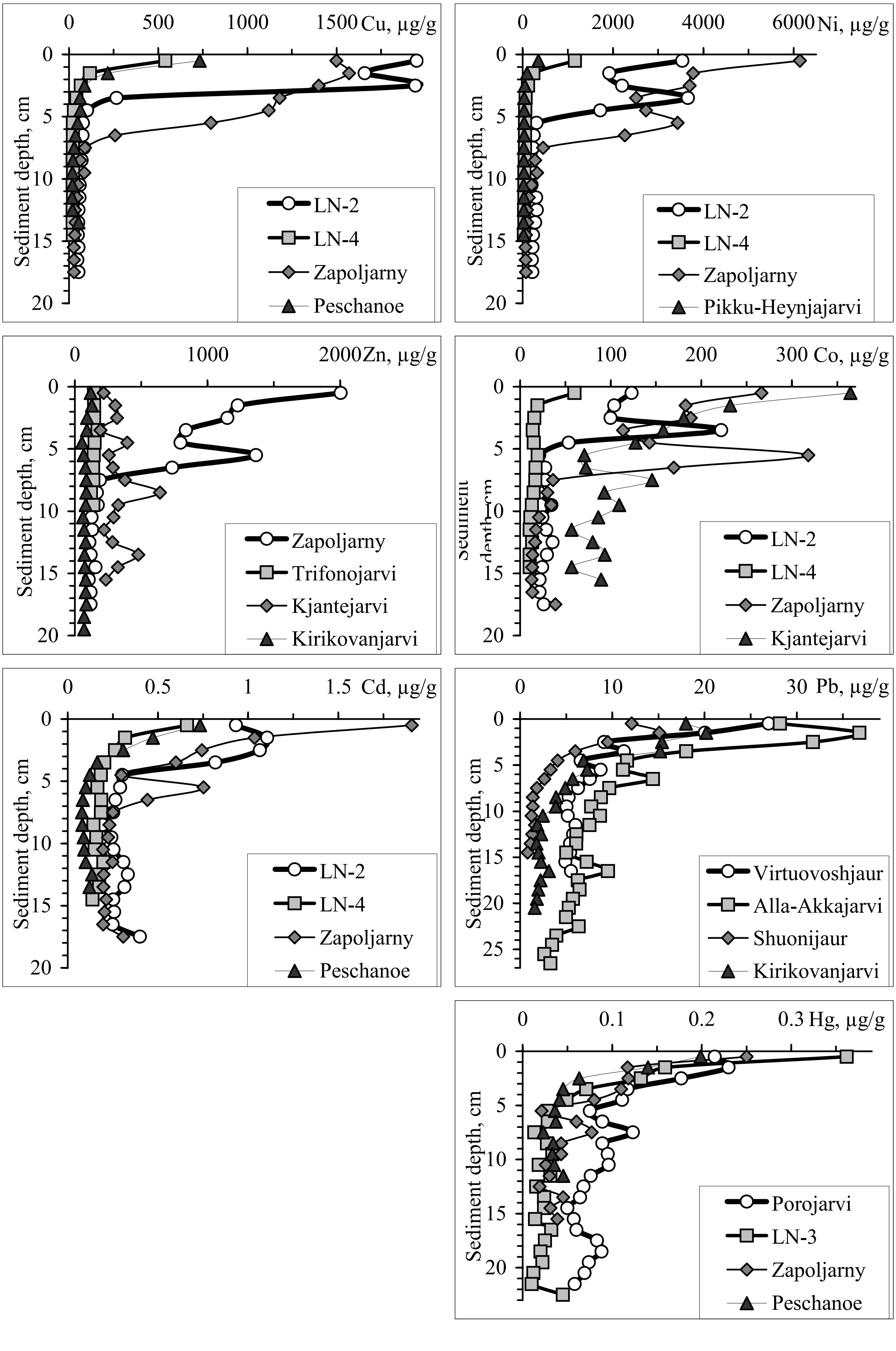

Fig. 5. Vertical distribution of elements (µg/g) in the sediment cores of the Kuetsjärvi Lake.

Over the subsequent years, the gradual increase of heavy metals concentrations is marked, and the sharp increase at 5, 5 and 4 cm depth (respectively) can be connected to the beginning of the processing of Norilsk ores in 1971, when production volume and thus anthropogenic loading to the lake increased significantly. Taking into account that the sediment cores of sampled stations were collected in 2003 - 2004, it is possible to estimate that for the past 70 year period represented in the core, the average sedimentation rate approaches 1.57, 1.71 and 1.14 mm/year for Gulf Stream, Salmijärvi and White Stone aquatories of the Kuetsjärvi, respectively, and for the last 30 years it is 1.67, 1.67 and 1.33 mm/year, respectively. This is consistent with compaction at higher depth. Besides increase in concentration of the basic polluting heavy metals (Ni, Cu, Co, Zn), in sediments cores of lake Kuetsjärvi the increase in concentration towards the sediment surface other researched heavy metals and As is observed (Fig. 5). This fact suggests that sewage waters of the "Pechenganikel" Company also are polluted by Cd, Pb, As and Hg.

Sedimentation rate estimates for Lake Shuonijärvi (23 km to the south-west of Nikel), from which the Shuonijöki river flows, based on ^{210}Pb using CRS and CIC dating models (Appleby, Oldfield, 1978) for the past 20 years was 0.68 mm/year and 0.45 mm/year over the past 60 years (Norton et al., 1993). The smaller sedimentation rate in Lake Shuonijärvi is likely related to lower runoff of mineral particles into the lake, which is consistent with a higher content of organic material (15 - 20 %) than observed for Lake Kuetsjärvi. In the other lake on the border between Russia and Norway, Hundvatn (24 km to northeast of Nikel), the sedimentation rate is a little bit higher namely 0.88 and 0.57 mm/year for the last 20 and 60 years, respectively (Norton et al., 1996). In Lake Hundvatn sediments, the content of organic material is also within the range 15 - 20 %.

Substantial increasing of concentration Ni, Cu, Co, Zn is marked also in superficial layers of sediments of lakes close to Pechenganikel Company (Fig. 6). The greatest increase is noticed in lakes Zapoljarny, LN-2, LN-4, located in several kilometers from the smelters. In lakes more removed from the point sources the basic polluting heavy metals are Cd, Pb and Hg (Fig. 6).

3.3. Distribution of Heavy Metals in the Top Layers of Lake Sediments

Emissions of heavy metals and wastewater from melting furnaces, slime pits, tailing dumps, and mines of the Pechenganikel' Plant are the main sources of increased concentrations of Ni, Cu, Co and Zn in the top layers of sediments pf lakes close to the sources (Lakes Kuetsjärvi, LN-2, LN-4, Palojärvi, Zapoljarny, Alla-Akkajärvi and Peschanoe). The prevailing southwestern winds mainly spread the emission plume in the north-eastern and southern direction (bottom sediments in lakes located 40 km and farther south of Nikel' are contaminated only slightly). In northern areas of Norway and Finland, deposition of these elements with precipitation is low. In these places, emissions of the plant only slightly affect the heavy metal content of top layers of lake sediments.

The maximum Ni and Cu concentrations, which exceed their background values by a factor of 10 to 130, were recorded within 10 km of the "Pechenganickel" Plant. Within 10 to 40 km of the source of contamination, these concentrations are only 3 - 7 times as high as their background values. Concentrations of Co were 4–10 times greater than their background values within 15 km of the contamination source and up to 3 times greater in other lakes, which is indicative of the effect of emissions from melting furnaces. The bulk of the industrial wastewater from the "Pechenganickel" Plant enters Lake Kuetsjärvi, where the maximum concentrations of Ni, Cu, Co, Zn, and Cd were recorded within top layers of bottom sediments (Fig. 5).

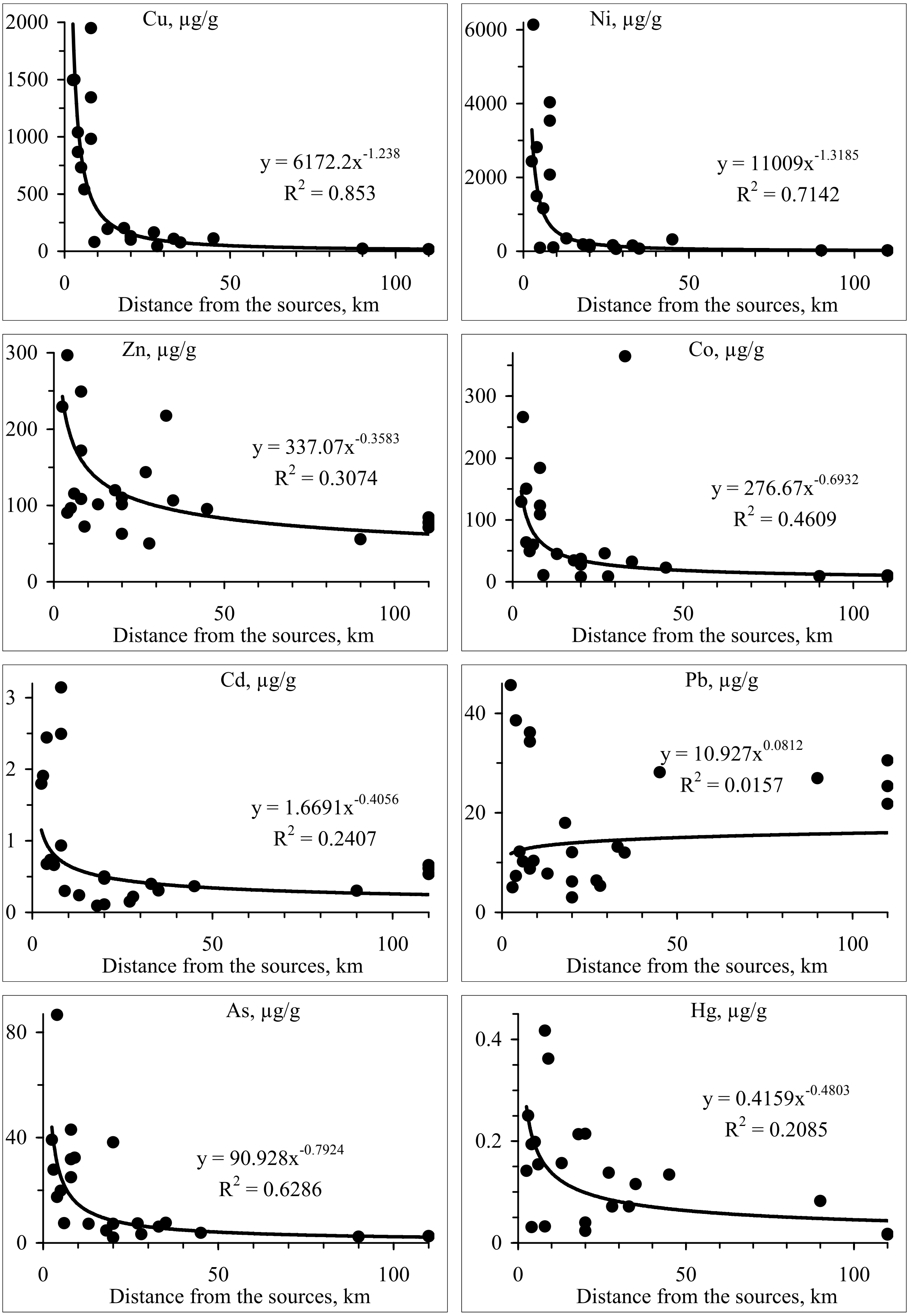

Fig. 6. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the investigated Russian lakes of the Paz River basin.

Increased concentrations of Cd, Pb and As were recorded in the upper layers of the sediments in almost all investigated lakes. This indicates that these elements now are the status of global pollutants. The lead content of the environment is controlled by tetraethyl lead, an antiknock component of gasoline. Another, rather small (several t/year) source of Pb (as well as Cd and As) pollution is the emissions of melting furnaces. Since the melting point of Pb, Cd and As is lower than that of other heavy metals (including Ni and Cu), these elements virtually completely goes into aerosol, which, on emission by melting furnaces, spreads (similar to SO_2) over greater distances than any other heavy metal. Therefore, near the plant, elevated concentrations of Pb, Cd and As can be absent.

In Figure 7 the distribution of heavy metals concentrations in superficial layers (0 - 1 cm) of lake sediments when moving away from the metallurgical plants is shown. Concentration of Ni and Cu are sharply reduced when moving away from pollution sources and on distance more than 40 km they do not exceed 100 µg/g (Fig. 7). The lakes which are taking place to northeast from the smelters are considerably more polluted by Ni and Cu while other lakes have much smaller concentration Ni and Cu.

The similar pattern of distribution of concentrations of Ni and Cu in superficial lake sediments is marked also around of the world's largest copper-nickel smelters – Norilsk in Siberia and Sudbury in Canada. Concentration of Ni in superficial lake sediments around of Norilsk plants are sharply reduced from 2142 up to 37 µg/g (Blais et al., 1998), excess over background contents make from 0.71 up to 22.6, and last value is marked in lake in 17 km from smelters. The same decrease is observed and around of Sudbury where influence of emissions of copper-nickel plants on concentration Ni and Cu in superficial lake sediments is limited 30 - 40 km (Bradley, Morris, 1986; Palmer et al., 1989; Semkin, Kramer, 1976; Nriagu et al., 1982), while impact zone around of Norilsk smelters is distributed up to 60 km (Blais et al., 1998). Spatial distribution of Ni and Cu has northeast-southwest elliptic character with the center in Sudbury (Controy et al., 1975; Semkin, Kramer, 1976). The similar trend for Ni and Cu is marked for atmospheric precipitation and for hydrochemistry of lakes, including water pH (Controy et al., 1975). Therefore, distribution of Ni and Cu in superficial lake sediments of Kola Peninsula and Sudbury completely coincides, as well as distribution of these elements in an atmospheric precipitation (Kruchkov, Makarova, 1989) and water of lakes (Moissenko et al., 1996).

In Figure 7 also it is visible, that Pechenganickel Company, besides Ni and Cu, is also a source of emissions of other heavy metals – Zn, Co, Cd, Hg, and also As, concentrations of which in the top layers of sediments of the Russian lakes of the watershed of the river Paz are reduced when moving away from pollution sources. Except for heavy metals and As, the smelters are as well a source of emission in atmosphere in increased concentrations of Cr, Fe, Na, Mg, Al (Fig. 7), since Ni-Cu ores and gob rocks in the increased concentrations contain all abovementioned elements.

3.4. The Factor and Degree of Contamination of Lake Sediments

Maximum values of contamination factor (C_f) for heavy metals (Ni, Cu, Zn, Co, Cd, Pb and Hg) and As were noticed for sediments of Kuetsjärvi and lakes (LN-2, LN-3, LN-4, Palojärvi, Zapoljarny, Kirikovanjärvi, Pikku-Heynjärvi, Peschanoe, Shuonijäur) at distances up to 20 km from the “Pechenganickel” smelters (Table5). These lakes have very high C_f values for Ni, Cu, Cd, Pb, Hg and As according to the Håkanson (1980) classification. In the lakes (Kochejäur, Virtuovoshjäur, Alla-Akkajärvi), situated on the greater distance from the “Pechenganickel” smelters, the main polluting elements are Cd, Pb, Hg and As which on of classification Håkanson have contamination factors from very high up to moderate (Table 6).
Kuetsjärvi and lakes at distances up to 20 km (including Alla-Akkajärvi and Virtuovoschjäur lakes – 45 and 90 km, respectively) from the “Pechenganickel” smelters have maximum values

of degree of contamination (C_d), which according to Håkanson (1980) classification is estimated as very high C_d (Table 6). Considerable and moderate values of C_d are characterized for other distinct lakes.

Table 5. Concentrations of heavy metals and As (µg/g, dry weight) in surface sediment layer (0 - 1 cm) of the investigated Russian lakes and distance from the pollution sources (smelters of the Pechenganickel Company)

Lake	Cu µg/g	Ni µg/g	Zn µg/g	Co µg/g	Cd µg/g	Pb µg/g	As µg/g	Hg µg/g	Distance km
Kochejäur-North	16	21	78	9.9	0.66	25.4	2.54	0.016	110.0
Kochejäur-Middle	16	19	71	7.8	0.54	21.8	2.60	0.018	110.0
Kochejäur-South	16	25	84	10.3	0.62	30.5			110.0
Virtuovoshjäur	23	25	56	9.0	0.30	26.9	2.33	0.083	90.0
Alla-Akkajärvi	112	321	95	23.0	0.36	28.2	3.83	0.134	45.0
Kuetsjärvi-Golfstream	981	2075	249	108.9	2.49	34.3	24.98	0.033	8.0
Kuetsjärvi-Kolosjoki	1496	2435	229	129.3	1.80	45.7	39.18	0.142	2.5
Kuetsjärvi-Salmijarvi	1039	2814	297	150.4	2.44	38.6	86.66	0.031	4.0
Kuetsjärvi-Whit Stone	1343	4032	172	184.1	3.14	36.1	43.05	0.417	8.0
Kaskamajärvi	77	70	107	32.4	0.30	12.0	7.63	0.116	35.0
Porojärvi	131	173	110	27.8	0.50	6.2	38.20	0.215	20.0
Shuonijäur	100	117	63	7.8	0.47	12.1	2.03	0.040	20.0
Keudsherjäur	45	65	50	8.7	0.22	5.3	3.36	0.072	28.0
LN-2	1949	3535	108	123.1	0.93	8.8	31.80	2.890	8.0
LN-3	81	103	72	10.6	0.30	10.4	32.40	0.362	9.0
LN-4	540	1157	116	60.0	0.66	10.2	7.50	0.154	6.0
Palojärvi	867	1494	91	63.5	0.68	7.3	17.50	0.194	4.0
Zapoljärny	1500	6139	2004	266.3	1.91	5.0	27.80	0.250	3.0
Trifonojärvi	164	164	144	45.8	0.15	6.4	7.41	0.138	27.0
Kjantejärvi	108	159	218	364.5	0.40	13.2	6.18	0.072	33.0
Kirikovanjärvi	202	183	120	34.6	0.09	18.0	4.71	0.214	18.0
Njasjukkjajärvi	131	141	101	37.0	0.11	3.0	7.26	0.023	20.0
Pikku-Heynjajärvi	194	350	101	45.1	0.24	7.8	7.26	0.157	13.0
Peschanoe	733	93	96	49.3	0.73	12.2	19.80	0.199	5.0
Average	494	1071	201	75	0.84	17.7	18.52	0.259	30.7
Min	16	19	50	8	0.09	3.0	2.03	0.016	2.5
Max	1949	6139	2004	365	3.14	45.7	86.66	2.890	110.0
Standard deviation	591	1629	389	90	0.85	12.5	20.23	0.583	35.9

Table. 6. Concentrations of heavy metals and As (µg/g, dry weight) in sediment cores, values of contamination factor (C_f) and degree of contamination (C_d) of the Russian investigated lakes

Lake, Date, Depth, m	Layers	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	$\mathbf{C_d}$
Kochejäur-North	0 - 1	16	21	78	9.9	0.66	25.4	2.54	0.016	
20.08.02	18 - 19	18	22	74	13.5	0.21	1.8	1.26	0.012	
4 m	C_f	0.9	1.0	1.1	0.7	3.1	14.1	2.0	1.4	24.2
Kochejäur-Middle	0 - 1	16	19	71	7.8	0.54	21.8	2.60	0.018	
20.08.02	16 - 17	16	19	85	7.7	0.21	5.1	1.13	0.017	
8 m	C_f	1.0	1.0	0.8	1.0	2.5	4.3	2.3	1.1	14.0
Kochejäur-South	0 - 1	16	25	84	10.3	0.62	30.5			
20.08.02	19 - 20	16	20	69	8.8	0.16	3.4			
4 m	C_f	1.0	1.2	1.2	1.2	3.9	9.0			17.5
Virtuovoshjäur	0 - 1	23	25	56	9.0	0.30	26.9	2.33	0.083	
21.08.02	16 - 17	18	19	83	11.6	0.12	5.5	1.21	0.003	
11 m	C_f	1.3	1.4	0.7	0.8	2.5	4.9	1.9	29.1	42.5
Alla-Akkajärvi	0 - 1	112	321	95	23.0	0.36	28.2	3.83	0.134	
28.08.02	26 - 27	12	12	103	9.0	0.09	3.3	1.86	0.028	
28 m	C_f	9.4	27.0	0.9	2.5	4.2	8.6	2.1	4.8	59.5
Kuetsjärvi-Golfstream	0 - 1	981	2075	249	108.9	2.49	34.3	24.98	0.033	
14.08.03	15 - 16	47	39	106	20.8	0.16	8.4	7.95	0.035	
23 m	C_f	20.8	52.9	2.3	5.2	15.8	4.1	3.1	0.9	105.3
Kuetsjärvi-Kolosjoki	0 - 1	1496	2435	229	129.3	1.80	45.7	39.18	0.142	
14.08.03	12 - 13	373	1087	99	42.8	0.35	4.5	11.06	0.017	
12 m	C_f	4.0	2.2	2.3	3.0	5.2	10.1	3.5	8.1	38.5
Kuetsjärvi-Salmijarvi	0 - 1	1039	2814	297	150.4	2.44	38.6	86.66	0.031	
14.08.03	20 - 21	52	66	127	30.7	0.18	9.2	11.92	0.007	
10 m	C_f	20.0	42.8	2.3	4.9	13.2	4.2	7.3	4.7	99.5
Kuetsjärvi-Whit Stone	0 - 1	1343	4032	172	184.1	3.14	36.1	43.05	0.417	
08.08.04	22 - 23	40	32	173	15.9	0.10	6.6	2.62	0.049	
32 m	C_f	33.5	125.7	1.0	11.6	32.1	5.5	16.4	8.5	234.2
Kaskamajärvi	0 - 1	77	70	107	32.4	0.30	12.0	7.63	0.116	
04.09.04	19 - 20	57	33	115	23.1	0.09	2.1	4.83	0.057	
13 m	C_f	1.3	2.1	0.9	1.4	3.6	5.6	1.6	2.0	18.6
Porojärvi	0 - 1	131	173	110	27.8	0.50	6.2	38.20	0.215	
24.08.04	22 - 23	68	42	161	11.8	0.20	2.9	13.69	0.058	
11 m	C_f	1.9	4.1	0.7	2.4	2.6	2.1	2.8	3.7	20.2
Shuonijäur	0 - 1	100	117	63	7.8	0.47	12.1	2.03	0.040	
25.08.04	14 - 15	14	13	47	4.3	0.06	0.8	0.74	0.019	
5 m	C_f	7.3	9.3	1.3	1.8	8.5	14.9	2.7	2.1	48.0

Keudsherjäur	0 - 1	45	65	50	8.7	0.22	5.3	3.36	0.072	
25.08.04	15 - 16	9	15	93	8.0	0.06	1.4	1.16	0.032	
2 m	C_f	5.0	4.3	0.5	1.1	3.6	3.9	2.9	2.2	23.6
Lake, Date, Depth, m	Layers	Cu	Ni	Zn	Co	Cd	Pb	As	Hg	**C_d**
LN-2	0 - 1	1949	3535	108	123.1	0.93	8.8	31.80	2.890	
26.08.04	17 - 18	53	214	121	26.2	0.40	1.0	4.29	0.111	
6 m	C_f	36.7	16.5	0.9	4.7	2.3	8.4	7.4	26.0	103.0
LN-3	0 - 1	81	103	72	10.6	0.30	10.4	32.40	0.362	
26.08.04	30 - 31	27	13	54	7.0	0.11	0.7	1.16	0.045	
7 m	C_f	3.0	7.8	1.3	1.5	2.8	14.3	27.9	8.1	66.7
LN-4	0 - 1	540	1157	116	60.0	0.66	10.2	7.50	0.154	
29.08.04	14 - 15	21	27	66	10.7	0.14	1.0	1.62	0.026	
2 m	C_f	25.5	43.2	1.8	5.6	4.8	10.7	4.6	5.9	102.0
Palojärvi	0 - 1	867	1494	91	63.5	0.68	7.3	17.50	0.194	
26.08.04	C_n*	33	41	101	16.3	0.17	3.2	4.57	0.037	
5 m	C_f	26.1	36.3	0.9	3.9	4.0	2.3	3.8	5.2	82.6
Zapoljarny	0 - 1	1500	6139	2004	266.3	1.91	5.0	27.80	0.250	
26.08.04	17 - 18	28	72	119	39.0	0.31	1.3	12.40	0.039	
2 m	C_f	54.1	85.1	16.9	6.8	6.2	3.9	2.2	6.5	181.7
Trifonojärvi	0 - 1	164	164	144	45.8	0.15	6.4	7.41	0.138	
27.08.04	9 - 10	54	58	140	40.3	0.26	3.9	7.17	0.025	
11 m	C_f	3.1	2.8	1.0	1.1	0.6	1.6	1.0	5.5	16.8
Kjantejärvi	0 - 1	108	159	218	364.5	0.40	13.2	6.18	0.072	
27.08.04	15 - 16	112	72	233	89.5	1.40	24.7	4.53	0.112	
15.5 m	C_f	1.0	2.2	0.9	4.1	0.3	0.5	1.4	0.6	11.0
Kirikovanjärvi	0 - 1	202	183	120	34.6	0.09	18.0	4.71	0.214	
27.08.04	20 - 21	32	26	88	8.8	0.14	1.6	0.85	0.040	
8 m	C_f	6.4	6.9	1.4	3.9	0.7	11.4	5.5	5.3	41.4
Njasjukkjajärvi	0 - 1	131	141	101	37.0	0.11	3.0	7.26	0.023	
27.08.04	4 - 5	87	84	148	38.9	0.07	3.9	5.70	0.014	
7 m	C_f	1.5	1.7	0.7	1.0	1.7	0.8	1.3	1.7	10.2
Pikku-Heynjajärvi	0 - 1	194	350	101	45.1	0.24	7.8	7.26	0.157	
28.08.04	14 - 15	29	20	137	17.4	0.25	1.6	5.06	0.061	
11 m	C_f	6.6	17.8	0.7	2.6	0.9	4.8	1.4	2.6	37.5
Peschanoe	0 - 1	733	93	96	49.3	0.73	12.2	19.80	0.199	
29.08.04	13 - 14	53	61	61	11.4	0.12	1.5	5.99	0.045	
14 m	C_f	13.8	1.5	1.6	4.3	6.1	8.2	3.3	4.4	43.3

*C_n – average background concentrations of elements in sediment cores of the Russian investigated lakes of the Paz River Basin (see Table 1)

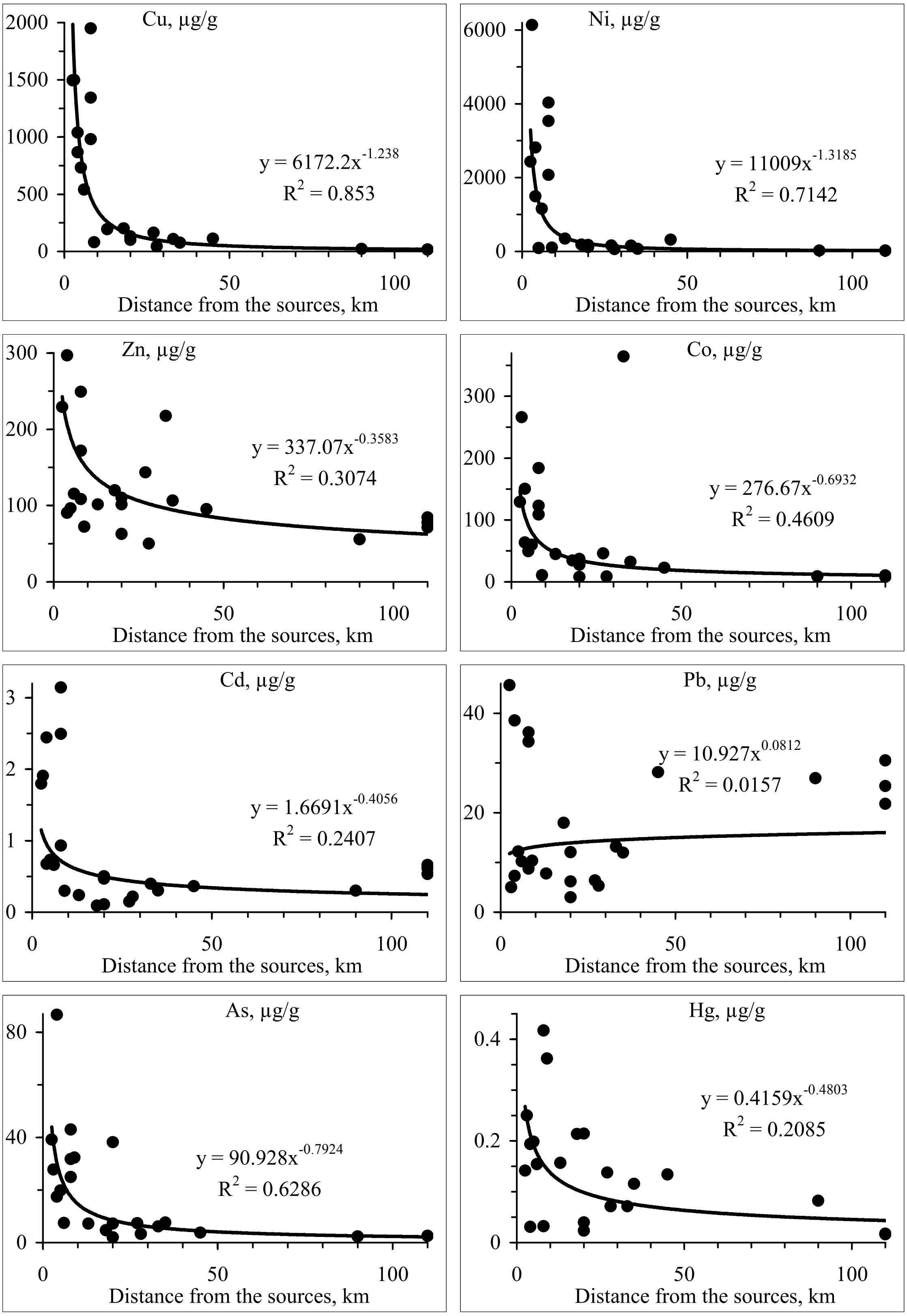

Fig. 7. Distribution of element concentrations (µg/g d.w.) in the top sediment layer (0 - 1 cm) of the investigated Russian lakes of the Paz River basin depending on the distance from the smelters of the Pechenganickel Company.

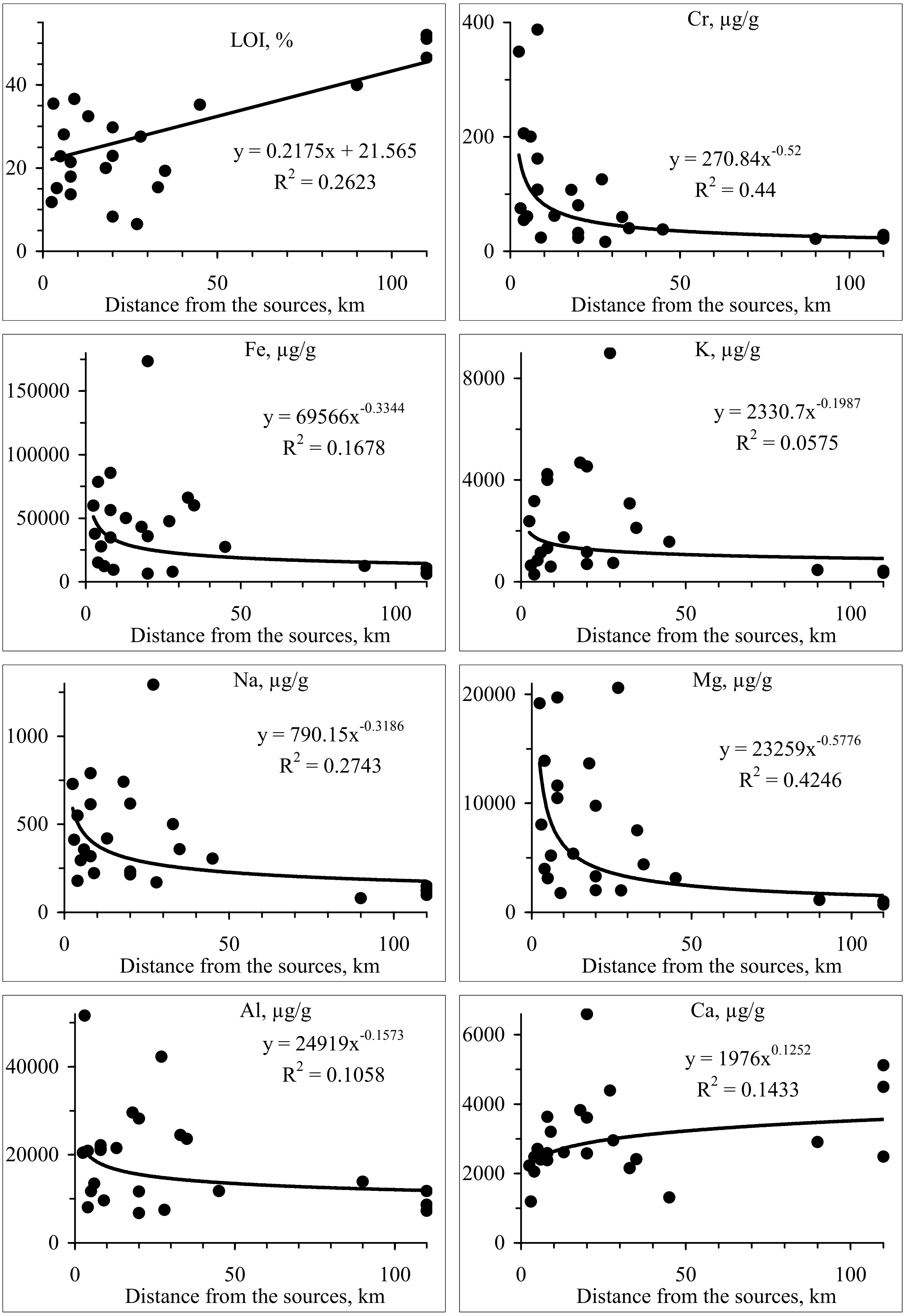

Fig. 7. Continue.

4. Pollution of the Sediments of the Norwegian Lakes of the Paz River basin

During two field expeditions (September, 2004 and June-July 2005) fourteen Norwegian Lakes of the Paz River basin (Isalombola, Gjekvatn, Sametivatn, Skrukkevatn, lake N-254, Langvatn, Kobbholmsvatn, Holmvatn, Gardsjoen, Ellentja, Suopatjavre, Stuorajavre-1, Stuorajavre-2, Biggejavre) have been investigated to study chemical composition of sediment cores and assess the pollution of water ecosystems.

4.1. Background Concentrations

The maximum background concentrations of heavy metals recorded in the Lakes Gjekvatn (Cu, Zn, Hg), Langvant (Cd), Kobholmsvatn (Ni, Co, Pb), Stuorajavre (As) of the Paz River basin result from the geochemical and morphometric features of the lake and its drainage basin (Table 7). The background concentrations of Cu, Ni, Zn, Co, Cd, Pb, As and Hg in the abovementioned lakes were established to be higher than those in other lakes (Isalombola, Skrukkevatn, Gardsjoen, etc.) by a factor of 1.5–5 in average. The average background concentrations of some heavy metals (Ni, Zn, Pb, Hg) in the Norwegian Lakes of the Paz System are approximately equal to those in the small lakes of the Northern Norway and Kola Peninsula (Rognerud, Fjeld, 1990; Dauvalter, 2000). The average background concentrations of Cu and Co in the Norwegian investigated Lakes in 2 times higher than those in the small lakes of the Kola Peninsula, Cd – in 4 times smaller.

Table 7. Background concentrations of heavy metals and As (µg/g, dry weight) in sediment cores of the investigated Norwegian lakes

Lake	Layers, cm	Cu µg/g	Ni µg/g	Zn µg/g	Co µg/g	Cd µg/g	Pb µg/g	As µg/g	Hg µg/g
Isalombola	22 - 23	80	13	93	6.7	0.09	1.1	1.02	0.090
Gjekvatn	21 - 22	151	36	236	25	0.33	8.0	0.07	0.168
Sametivatn	18 - 19	133	39	153	14	0.19	2.4	0.11	0.080
Skrukkevatn	14 - 15	88	44	138	21	0.16	6.7	1.97	0.035
lake N-254	6 - 7	28	36	45	7	0.33	1.63	0.93	0.025
Langvatn	13 - 14	137	31	109	24	0.50	20	3.53	0.056
Kobbholmsvatn	14 - 15	130	60	197	61	0.22	33.5	1.53	0.037
Holmvatn	12 - 13	67	20	59	13	0.08	21.9	3.94	0.035
Gardsjoen	16 - 17	41	28	81	25	0.23	3.1	0.94	0.056
Ellentja	22 - 23	51	32	123	9.5	0.14	3.5	2.80	0.051
Suopatjavre	17 - 18	17	22	61	19.3	0.11	4.8	1.77	0.018
Stuorajavre-1	24 - 25	73	43	51	34.8	0.14	4.4	3.14	0.055
Stuorajavre-2	22 - 23	68	43	79	25.5	0.08	11.5	6.46	0.064
Biggejavre	25 - 26	88	35	79	35.1	0.17	1.8	6.63	0.070
Average		82	34	107	23.0	0.20	8.9	2.49	0.060
Min		17	13	45	6.7	0.08	1.1	0.07	0.018
Max		151	60	236	61	0.50	33.5	6.63	0.168
Standard deviation		42	12	57	14.2	0.12	9.7	2.09	0.037

The long-term human impact on drainage basins of lakes resulted in changes in the environmental conditions that control the chemical composition of sediments. Therefore, background concentrations of heavy metals are important information for determination of the effect of anthropogenic activity on aquatic ecosystems.

4.2. Vertical Distribution of Heavy Metals in Bottom Sediments

The vertical distribution of concentrations of Ni, Cu and Zn in the sediment cores of the Norwegian lakes of the Paz River basin varies only slightly (Fig.8). The maximal increase of the Ni concentration was fixed in the upper part of the sediment core of the Sametivatn. This lake is one of the closer situated lakes from the smelters of the Pechenganickel Company. Vertical distribution of Co in sediment core of the investigated lakes has very interesting pattern – maximal contents of this heavy metal were noticed on the depth 2 - 5 cm (Fig. 8). The decreasing concentrations of Co in the sediment cores may be connected with the reduction of the Co emissions of the Pechenganickel Company. In the investigated Norwegian lakes of the Paz River basin, the concentrations of Cd and Pb in the top layers of the sediments is substantially higher than the background contents. It is unlikely for this elevated concentration to be due to the Pechenganikel Company operation, since this part of the drainage basin of the Paz River is only slightly affected by emissions of heavy metals from the plant, particularly, south-west from the Pechenganikel Company (Lakes Isalombola and Gjekvatn). Obvious increasing of the Pb concentrations in the upper part on the sediment cores were noticed in the Sametivatn and Gardsjoen Lakes (Fig. 8). These abovementioned lakes (Lakes Isalombola, Gjekvatn, Sametivatn and Gardsjoen) showed also the increasing concentrations of As and Hg in the upper layers of the sediment cores. It should also be stated that Cd, Pb, As and Hg become the main polluting elements on the Norwegian site of the Paz River watershed, in contrast of Russian site, where Ni, Cu, Zn and Co are the main polluting heavy metals.

4.3. Distribution of heavy metals in the top layers of lake sediments

Increased concentrations of Cd, Pb, As and Hg were recorded in the upper layers of the sediments in almost all investigated Norwegian lakes of the Paz River watershed (Table 8). This indicates that these elements now received the status of global pollutants. The Pb contents of the environment are controlled by tetraethyl lead, an antiknock component of gasoline. Another, rather small (several t/year) source of Pb (as well as Cd and As) pollution is the emissions of melting furnaces. Since the melting point of Pb, Cd and As is lower than that of other heavy metals (including Ni and Cu), these elements virtually completely go into aerosol, which, on emission by melting furnaces, spreads (similar to SO_2) over greater distances than any other heavy metal. Therefore, close to the Pechenganickel Company, elevated concentrations of Pb, Cd, As and Hg in the top sediment layers of the investigated Norwegian lakes can be absent (Fig. 9). Metals, emitted to the atmosphere by smelters of the Pechenganickel Compony in elevated concentrations (Cu, Ni, Co, Zn), show the highest contents in the top layers of lake sediments close to the smelters that is confirmed by relatively high values of the correlation coefficient in regression equation (Fig. 9). Other elements either have no reliable values of the correlation coefficient (Cd, Pb), or show the reverse dependence – the elevated concentrations (As, Hg) with distance increasing from the smelters (Fig. 9). This fact suggests about insignificant influence of the smelter emission on concentrations of these latter fore elements in sediment of the investigated Norwegian lake of the Paz system.

4.4. The Factor and Degree of Contamination of Lake Sediments

The Norwegian lakes of the Paz River watershed, situated more distant from the Pechenganickel smelters, have maximum values of contamination factor (C_f) for heavy metals (mainly Cd, Pb, As) in sediments – Isalombola, Gjekvatn and Sametivatn lakes (Table 9). The highest values (very high) of C_f have been noticed for Pb and As, as well as for Co in Sametivatn, the considerable value – for Cd (Isalombola). The highest values (very high) of degree of contamination (C_d) have been noticed for the Isalombola lake. Gjekvatn, Sametivatn and Biggejavre lakes have the considerable values of C_d. Other lakes have moderate and low values of C_f and C_d.

Table 8. Concentrations of heavy metals and As (µg/g, dry weight) in surface sediment layer (0 - 1 cm) of the investigated Norwegian lakes

Lake	Cu µg/g	Ni µg/g	Zn µg/g	Co µg/g	Cd µg/g	Pb µg/g	As µg/g	Hg µg/g
Isalombola	71	28	109	8.3	0.35	21.6	4.56	0.188
Gjekvatn	73	56	111	36.1	0.67	34.3	0.60	0.309
Sametivatn	72	87	134	104.9	0.37	21.1	0.77	0.082
Skrukkevatn	95	77	157	35.2	0.17	20.2	3.50	0.053
lake N-254	34	53	169	9.1	0.44	2.6	1.67	0.022
Langvatn	121	52	166	61.7	0.19	26.5	4.14	0.096
Kobbholmsvatn	74	67	163	27.5	0.13	16.0	1.35	0.022
Holmvatn	62	37	160	47.9	0.16	25.6	1.60	0.048
Gardsjoen	66	72	154	12.1	0.18	17.7	1.52	0.082
Ellentja	41	36	82	9.4	0.17	13.2	2.72	0.174
Suopatjavre	13	17	77	18.0	0.23	12.9	6.73	0.065
Stuorajavre-1	48	45	55	38.1	0.21	10.9	4.41	0.126
Stuorajavre-2	58	33	75	20.7	0.19	20.1	11.93	0.146
Biggejavre	53	25	62	12.5	0.24	33.8	15.08	0.163
Average	63	49	120	32	0.26	19.7	4.33	0.113
Min	13	17	55	8	0.13	2.6	0.60	0.022
Max	121	87	169	105	0.67	34.3	15.08	0.309
Standard deviation	26	21	43	27	0.15	8.7	4.30	0.079

Table 9. Concentrations of heavy metals and As (µg/g, dry weight) in sediment cores, values of contamination factor (C_f) and degree of contamination (C_d) of the investigated Norwegian lakes of the Paz River basin.

Lake Date Depth, m	Layers, cm	Cu DW µg/g	Ni DW µg/g	Zn DW µg/g	Co DW µg/g	Cd DW µg/g	Pb DW µg/g	As DW µg/g	Hg DW µg/g	C_d
Isalombola	0 - 1	71	28	109	8.3	0.35	21.6	4.56	0.188	
12.09.04	22 - 23	80	13	93	6.7	0.09	1.1	1.02	0.090	
11 m	C_f	0.9	2.1	1.2	1.2	3.8	19.9	4.5	2.1	35.7
Gjekvatn	0 - 1	73	56	134	36	0.67	34.3	0.600	0.309	
12.09.04	21 - 22	151	36	236	25	0.33	8.0	0.070	0.168	
12 m	C_f	0.5	1.5	0.6	1.5	2.0	4.3	8.6	1.8	20.8
Sametivatn	0 - 1	72	87	82	105	0.37	21.1	0.77	0.082	
14.09.04	18 - 19	133	39	153	14	0.19	2.4	0.11	0.080	
10 m	C_f	0.5	2.2	0.5	7.4	2.0	8.9	7.0	1.0	29.5
Skrukkevatn	0 - 1	95	77	135	35	0.17	20.2	3.50	0.053	
15.09.04	14 - 15	88	44	138	21	0.16	6.7	1.97	0.035	
15 m	C_f	1.1	1.7	1.0	1.7	1.1	3.0	1.8	1.5	12.8
lake N-254	0 - 1	34	53	89	9	0.44	2.58	1.67	0.022	
16.09.04	6 - 7	28	36	45	7	0.33	1.63	0.93	0.025	
2.5 m	C_f	1.2	1.5	2.0	1.3	1.3	1.6	1.8	0.9	11.5
Langvatn	0 - 1	121	52	110	62	0.19	26	4.14	0.096	
16.09.04	13 - 14	137	31	109	24	0.50	20	3.53	0.056	
21 m	C_f	0.9	1.7	1.0	2.6	0.4	1.3	1.2	1.7	10.7
Kobbholmsvatn	0 - 1	74	67	107	27	0.13	16.0	1.35	0.022	
16.09.04	14 - 15	130	60	197	61	0.22	33.5	1.53	0.037	
43 m	C_f	0.6	1.1	0.5	0.5	0.6	0.5	0.9	0.6	5.2
Holmvatn	0 - 1	62	37	98	48	0.16	25.6	1.60	0.048	
15.09.04	12 - 13	67	20	59	13	0.08	21.9	3.94	0.035	
15 m	C_f	0.9	1.9	1.6	3.6	2.1	1.2	0.4	1.4	13.0
Gardsjoen	0 - 1	66	72	58	12	0.18	17.7	1.52	0.082	
15.09.04	16 - 17	41	28	81	25	0.23	3.1	0.94	0.056	
10 m	C_f	1.6	2.6	0.7	0.5	0.8	5.7	1.6	1.5	15.0
Ellentja	0 - 1	41	36	82	9.4	0.17	13.2	2.72	0.174	
11.09.04	22 - 23	51	32	123	9.5	0.14	3.5	2.80	0.051	
5.5 m	C_f	0.8	1.1	0.7	1.0	1.2	3.8	1.0	3.4	13.0
Suopatjavre	0 - 1	13	17	77	18.0	0.23	12.9	6.73	0.065	
29.06.05	17 - 18	17	22	61	19.3	0.11	4.8	1.77	0.018	
12 m	C_f	0.8	0.8	1.3	0.9	2.1	2.7	3.8	3.5	15.8
Stuorajavre-1	0 - 1	48	45	55	38.1	0.21	10.9	4.41	0.126	
30.06.05	24 - 25	73	43	51	34.8	0.14	4.4	3.14	0.055	
12 m	C_f	0.7	1.0	1.1	1.1	1.5	2.4	1.4	2.3	11.5
Stuorajavre-2	0 - 1	58	33	75	20.7	0.19	20.1	11.93	0.146	
30.06.05	22 - 23	68	43	79	25.5	0.08	11.5	6.46	0.064	
21 m	C_f	0.9	0.8	1.0	0.8	2.3	1.8	1.8	2.3	11.5
Biggejavre	0 - 1	53	25	62	12.5	0.24	33.8	15.08	0.163	
01.07.05	25 - 26	88	35	79	35.1	0.17	1.8	6.63	0.070	
16 m	C_f	0.6	0.7	0.8	0.4	1.4	18.7	2.3	2.3	27.1

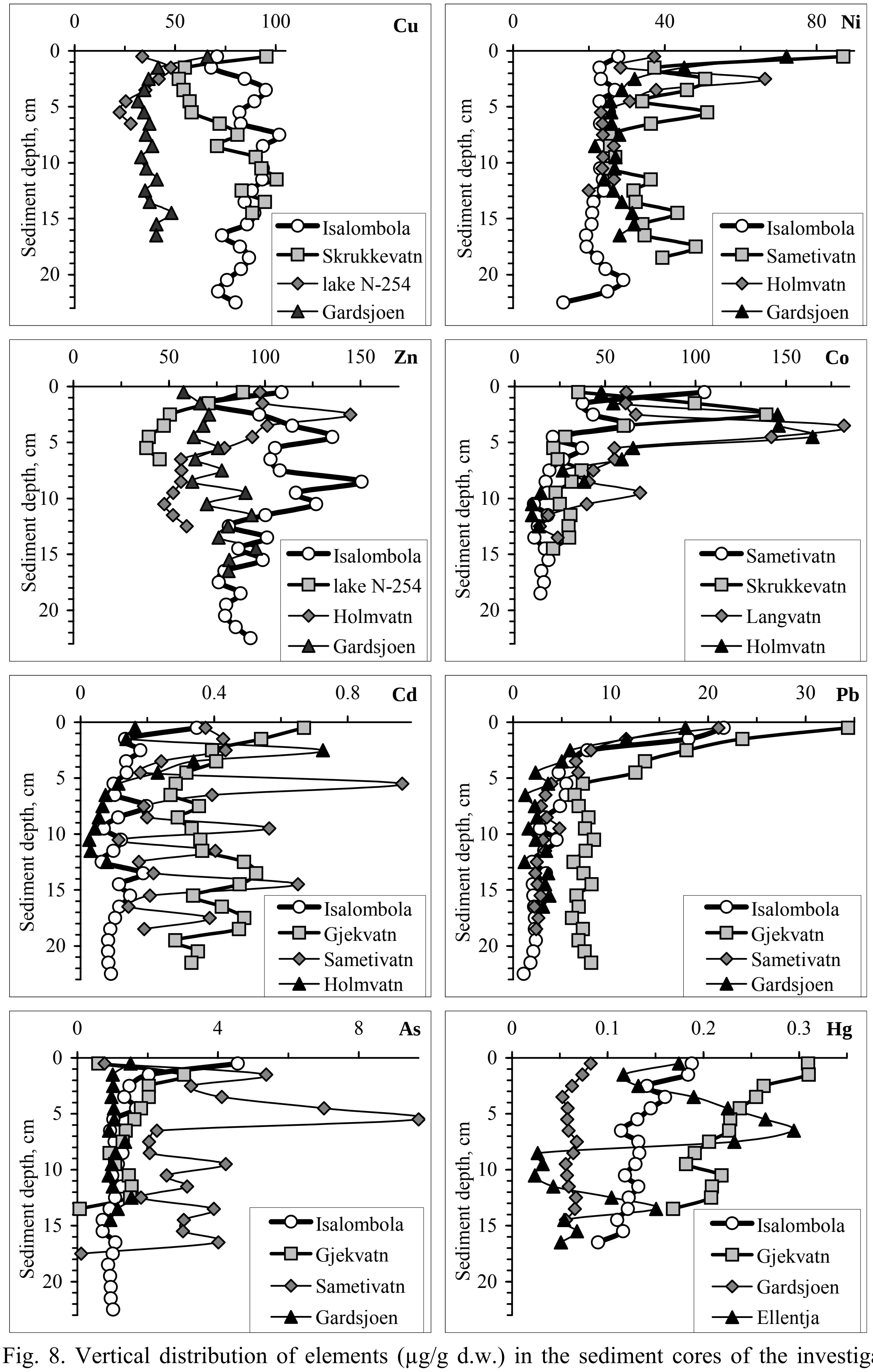

Fig. 8. Vertical distribution of elements (μg/g d.w.) in the sediment cores of the investigated Norwegian lakes of the Paz River basin.

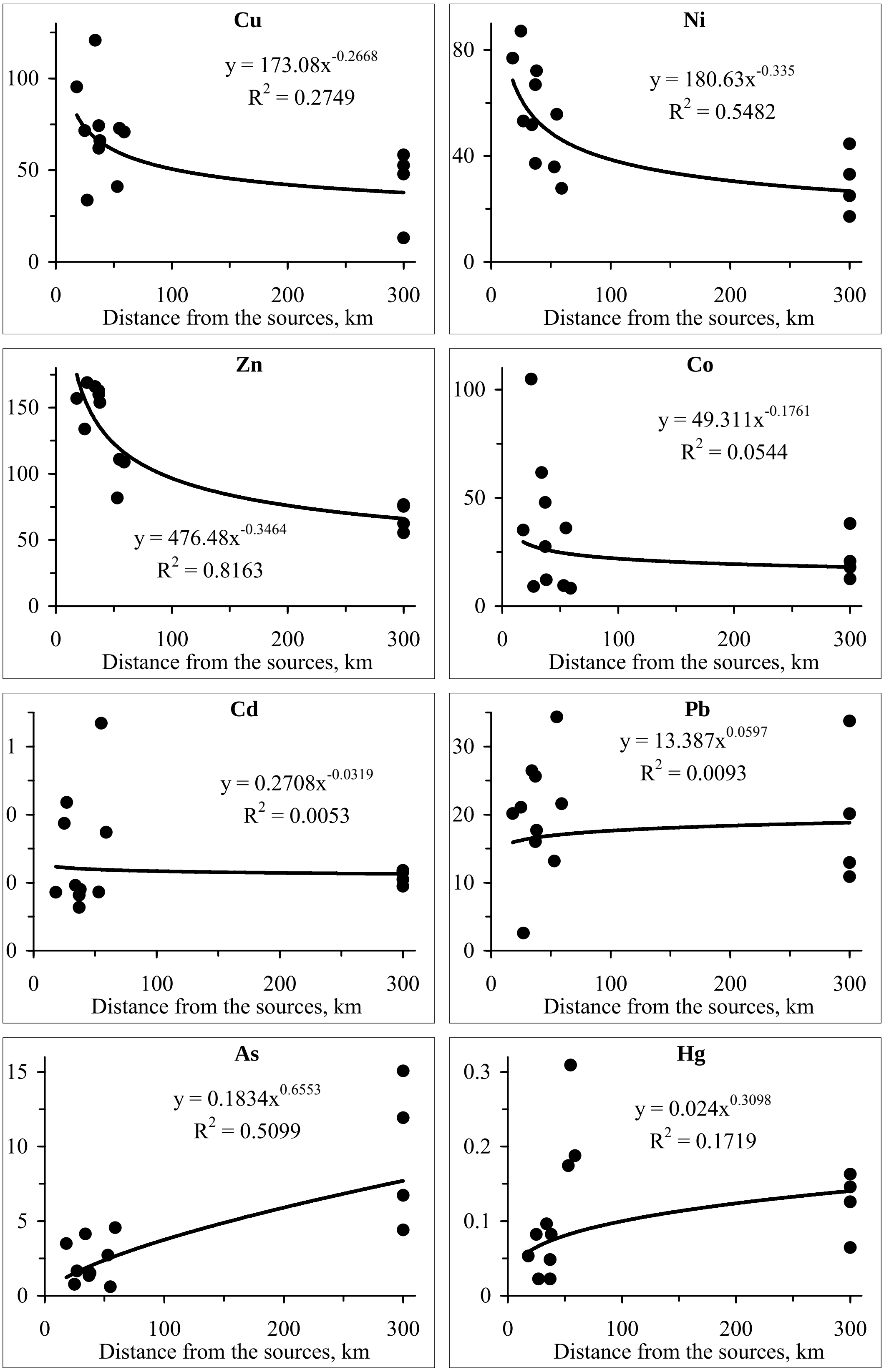

Fig. 9. Distribution of element concentrations (µg/g d.w.) in the top sediment layer (0 - 1 cm) of the investigated Norwegian lakes of the Paz River basin depending on the distance from the smelters of the Pechenganickel Company.

5. Pollution of the Sediments of the Finnish Lakes of the Inari Lake – Paz River basin

During expeditions of 2005 (April, September and October) seven Finnish Lakes of the Inari Lake – Paz River basin (Aitojärvi 2, Mellalompolo, Nammijärvi, Inari Vasikanselkä, Kantojärvi, Suovaselkajärvi, Kivijärvi) have been investigated to study chemical composition of sediment cores and assess the pollution of water ecosystems. Data of lake sediments collected earlier and kindly presented by Dr. Jaakko Mannio (Lampi 222, Nitsijärvi, Sieramjärvi and Pahtajärvi) have been also used in the investigations.

5.1. Background Concentrations

The minimum background concentrations of investigated heavy metals in sediments of Finnish lakes of the Lake Inari – River Paz system were found in Suovaselkajärvi for almost all elements, and only Cu was noticed in the lowest concentration in the Sieramjärvi (Table 10). The maximum background concentrations of heavy metals recorded in the Nammijarvi (Cu, Ni), Nitsijärvi (Zn, Cd), Inari Vasikkaselka (Pb, As), Kivijävri (As) of the Lake Inari – Paz River basin result from the geochemical and morphometric features of the lake and its drainage basin (Table 10). The background concentrations of heavy metals and As in the abovementioned lakes were established to be higher than those in other lakes by a factor of 10 in average. The average background concentrations of some heavy metals (Ni, Zn, Cd) in the investigated Finnish lakes of the Lake Inari – River Paz system are approximately equal to those in the small lakes of background concentrations of heavy metals in sediments of 42 small lakes in Kuusamo, North-Eastern Finland (Myllymma, Murtoniemi, 1986). The average background concentrations of Cu in the investigated Lakes in more than 2 times higher than those in the small lakes in Kuusamo, Co and Pb – in 2 times lower.

5.2. Vertical Distribution of Heavy Metals in Bottom Sediments

The vertical distribution of Cu, Zn and Co in the sediment cores of the investigated Finnish lakes of the Inari Lake – Paz River system shows usually decreasing concentrations towards sediment surface (Fig. 10). This pattern is characterized for lakes Lampi 222, Aitojärvi 2, Nitsijärvi, Nammijärvi, Suovaselkajärvi, Kivijärvi (see Figures 10 - 20). In some of the investigated Finnish lakes the subsurface maximum of the Cu concentrations was fixed – lakes Aitojärvi 2 (on the depth 5 cm), Nitsijärvi (11 cm), Inari Vasikanselkä (3 cm), Kantojärvi (3 cm), Suovaselkajärvi (5 cm), Kivijärvi (3 cm). This fact may be explained by two reasons – 1) decreasing atmospheric emissions of the main Cu pollution sources of this Region – smelters of the Pechenganickel Company, and 2) influences of acidification processes on the behaviour of such mobile heavy metal as Cu, Zn, Co. Almost all investigated lakes have water pH values lower than neutral, closer to subacid up to 6.0. Profiles of heavy metals versus depth in sediment cores of acidified lakes typically exhibit subsurface maxima. This phenomenon could be explained by: 1) remobilization of metals from the sediments, 2) lower metal sedimentation rates due to decreased metal sorption to suspended particles in the water column and decreased availability of adsorbing surface (Nelson, Campbell, 1991). Concentrations of Cu, Ni, Cd, Zn, Al in the top sediments of the 15 lakes of the Finnish Lapland decreased with reduction of water pH (Dauvalter, 1997). Increasing Cu concentrations in the top layers of the investigated Finnish lakes were found in lakes, situated quite close to the smelters of the Pechenganickel Company (Mellalompolo – 54 km, Sieramjärvi – 135 km).

Overwhelming majority of the investigated Finnish lakes show increasing concentrations of Ni towards sediment surface and maximum contents have in the top (0 - 1 cm) or subsurface layers, particularly, lakes located close to the smelters of the Pechenganickel Company – Lampi 222, Aitojärvi 2, Mellalompolo, Nitsijärvi, Inari Vasikanselkä, Kantojärvi, Suovaselkajärvi, Sieramjärvi, Pahtajärvi, Kivijärvi. Decreasing contents of Ni in the upper sediment layers relatively to background values were noticed in Nammijärvi (Fig. 14).

The vertical distribution of concentrations of Cd and Pb in the sediment cores of the Finnish lakes of the Inari Lake Paz River basin show usually subsurface maximum on the depth 3 - 12 cm (Fig. 10 - 20). Two reasons are again responsible for this fact – decreasing atmospheric emissions of anthropogenic sources (the decreased use of Pb in gasoline) and influences of acidification processes on the behaviour of these mobile heavy metals.

Chalcophile non-metal As shows usually surface and subsurface (2 - 10 cm) maximum concentrations in sediment cores of the investigated Finnish lakes (Fig. 10 - 20). Arsenic (as well as other chalcophile elements) is highly toxic element and is very dangerous for the environment and people. As (and Hg, Cd, Pb) can migrate in air and aquatic media over large distances owing to their geochemical properties, e.g., relatively low melting temperature, high ability to form organometallic compounds, etc. During the latest decades, these elements have become the main global contaminating agents (Dauvalter, 2006).

Decreased concentrations of Al from lower to higher layers of sediment cores of the investigated Finnish lakes may indicate the demonstration of acidification processes (Dauvalter, 1997). All investigated Finnish lakes (with exception of Inari Vasikanselkä) show this decreasing of Al concentrations towards sediment surface (Fig. 10 - 20), that may suggest beginning or development of acidification processes in these lakes.

5.3. Distribution of Heavy Metals in the Top Layers of Lake Sediments

Metals, emitted to the atmosphere by smelters of the Pechenganickel Compony in elevated concentrations (Cu, Ni, Co, Zn), show the highest contents in the top layers of lake sediments close to the smelters that is confirmed by relatively high values of the correlation coefficient in regression equation (Fig. 21). Particularly this fact was noticed for Ni and Cu, distribution of them has a view of power function with very high values of correlation coefficient. Maximal concentrations of Ni, Cu and Zn were fixed in the top layers of the sediment Mellalompolo, situated in 54 km from the smelters of the Pechenganickel Company (Table 12), Co – in sediments of Kantojärvi – 78 km. The highest concentrations of Cd and Pb were found in the top layer of sediment core of the largest lake of the Finland Lapland – Inari; As – in the Sieramjärvi. Other elements Cd, Pb, As) have no reliable values of the correlation coefficient (with distance increasing from the smelters (Fig. 21). This fact suggests about insignificant influence of the smelter emission on concentrations of these latter fore elements in sediment of the investigated Finnish lake of the Inari Lake – Paz River system. Increased concentrations of Cd, Pb and As were recorded in the surface or subsurface layers of the sediments in almost all investigated Finnish lakes of the Inari Lake – Paz River watershed (Table 11). This indicates that these elements now received the status of global pollutants. The Pb contents of the environment are controlled by tetraethyl lead, an antiknock component of gasoline. Another, rather small (several t/year) source of Pb (as well as Cd and As) pollution is the emissions of melting furnaces, and also by transboundary transport from as Scandinavian countries, as well as from Central Europe.

5.4. The Factor and Degree of Contamination of Lake Sediments

Almost all investigated Finnish lakes of the Inari Lake – Paz River watershed have very high values of contamination factor (C_f) for more polluted heavy metals – Pb, considerable and moderate values for Cd and As (Table 12). Considerable contamination by Ni was found only in upper layer of sediments of lakes, located close to the smelters of the Pechenganickel. Other heavy metals (Cu, Zn, Co) have low and moderate values of the contamination factor (C_f). The highest values (very high) of degree of contamination (C_d) have been noticed for the Kantojärvi and Si-erramjärvi due to very high contamination of sediments by Pb, Cd and As. The considerable values of C_d have been found in the bulk of the investigated lakes, and only Aittojärvi, Nammi-järvi, Kantojärvi, Pahtajärvi have moderate values of C_d.

Table 10. Morphometrical and limnological data of the investigated Finnish lakes of the Lake Inari – River Paz System

No	Name	Russian analysis	Finnish analysis	Coordinates N ° ' E ° '	Surface area, ha	Length of coastal line, km	Depth, m	Altitude above sea level, m	Distance from pollution sources, km
1	Lampi 222		Jaakko Mannio	69 26.775 29 06.478	25.593	4.209	22	222	46
2	Aitojärvi 2	Fin.corer	Fin.corer	69 25.575 28 57.482	57.252	8.018	5.0	164.0	52
3	Mellalompolo	Fin.corer	Fin.corer	69 19.794 28 54.703	227.149	14.935	12.5	149.5	54
4	Nitsijärvi		Jaakko Mannio	69 15.262 28 01.711	4117.18	199.85	34	119	90
5	Nammijärvi		Fin.corer	69 08.770 28 41.537	1499.94	75.737	6	158.5	69
6	Inari Vasikanselkä	Rus.corer	Fin.corer	69 08.816 28 19.922	104028	3277.802	max93 ca 14	119	72
7	Kantojärvi	Fin.corer Rus.corer	Fin.corer Rus.corer	68 59.745 28 39.937	36.285	4.099	5.0	168.0	78
8	Suovaselkajärvi	Fin.corer Rus.corer	Fin.corer Rus.corer	68 57.176 28 27.514	43.512	5.098	2.7	168.0	87
9	Sieramjärvi		Jaakko Mannio	69 11.039 26 54.136	107.928	5.509	18	254	135
10	Pahtajärvi (Pallas)		Jaakko Mannio	68 12.912 23 53.980	4.858	1.700	11	410	330
11	Kivijärvi (Pallas)		Fin.corer	67 58.638 24 19.438	186.924	7.219	9.0	267.7	340

Table 11. Background concentrations of heavy metals and As (µg/g, dry weight) in sediment cores of the investigated Finnish lakes

Lake	Analysis*	Layers, cm	Cu	Ni	Zn	Co	Cd	Pb	As
Lampi 222	J.Mannio	29 - 30	147	13	100	-	0.36	6.4	1.43
Aittojärvi	RF	28 - 30	69	23	64	4.8	0.11	6.1	-
Aittojärvi	FF	28 - 30	74	22	58	4.0	0.25	7	0.96
Mellalompolo	RF	28 - 30	43	17	69	6.9	0.10	4.6	-
Mellalompolo	FF	28 - 30	72	21	86	5	0.37	8.9	1.3
Nitsijärvi	J.Mannio	30 - 32	69.2	30	120	-	0.39	8.7	1.49
Nammijärvi	FF	38 - 40	350	53	83	9	0.37	3.9	1.8
Inari Vasikanselkä	RR	21 - 22	51	32	90	13	0.21	7.0	-
Inari Vasikanselkä	FF	38 - 40	52	33	78	9	0.26	9.1	2.3
Kantojärvi	RR	13 - 14	38	19	78	13.6	0.15	3.6	-
Kantojärvi	RF	18 - 20	30	15	46	9.8	0.08	1.1	-
Kantojärvi	FR	9 - 10	41	15	67	8	0.26	6.4	1.4
Kantojärvi	FF	18 - 20	44	16	69	11	0.25	1.8	1.0
Suovaselkajärvi	RR	23 - 24	40	13	32	6.0	0.09	1.1	-
Suovaselkajärvi	RF	18 - 20	24	7	22	3.0	0.08	3.1	-
Suovaselkajärvi	FR	18 - 20	34	12	29	3.0	0.2	5.1	0.75
Suovaselkajärvi	FF	23 - 24	45	15	38	5.0	0.2	1.4	0.68
Sierramjärvi	J.Mannio	28 - 30	16	14	78	-	0.37	6.3	0.8
Pahtajärvi	J.Mannio	28 - 30	22.5	7.36	25.9	-	0.36	4.73	1.46
Kivijärvi	FF	38 - 40	27	12	84	16	0.28	1.9	0.93
Average			64	19	66	8	0.24	4.9	1.2
Min			16	7	22	3	0.08	1.1	0.7
Max			350	53	120	16	0.39	9.1	2.3
Standard deviation			73	11	27	4	0.11	2.6	0.5
Average**			25	17	75	17	0.23	8.0	-
Min**			5	3	18	3	0.10	2	-
Max**			74	53	168	234	0.9	26	-
Standard deviation**			27	10	38	13	0.18	4.6	-

* J.Mannio – data of Dr. Jaakko Mannio; RR – Russian analysis, Russian corer; RF – Russian analysis, Finnish corer; FR – Finnish analysis, Russian corer; FF – Finnish analysis, Finnish corer;
** – background concentrations of heavy metals in sediments of 42 small lakes in Kuusamo, North-Eastern Finland (Myllymma, Murtoniemi, 1986)

Table 12. Concentrations of heavy metals and As (µg/g, dry weight) in surface sediment layer (0 - 1 cm) of the investigated Finnish lakes

Lake	Analysis	Cu	Ni	Zn	Co	Cd	Pb	As
Lampi 222	J.Mannio	94	44	51	-	0.30	40	2.3
Aittojärvi	RF	62	44	38	2.8	0.55	14	-
Aittojärvi	FF	65	44	92	2.0	0.31	15	1.4
Mellalompolo	RF	90	60	57	7.8	0.15	32	-
Mellalompolo	FF	97	55	140	7	0.41	37	4.2
Nitsijärvi	J.Mannio	55	35.9	113	-	0.58	35	7.1
Nammijärvi	FF	63	35	54	4	0.54	27	4.3
Inari Vasikanselkä	RR	58	45	83	11	1.10	54	-
Inari Vasikanselkä	FF	54	39	63	11	0.4	33	6.5
Kantojärvi	RR	42	33	84	16.8	0.37	20	-
Kantojärvi	RF	43	31	78	13.0	0.30	17	-
Kantojärvi	FR	38	26	61	8	0.35	18	2.7
Kantojärvi	FF	41	29	53	8	0.41	20	2.9
Suovaselkajärvi	RR	29	25	33	2.5	0.25	12	-
Suovaselkajärvi	RF	24	22	28	1.4	0.21	9	-
Suovaselkajärvi	FR	25	21	32	1.0	0.26	11	1.3
Suovaselkajärvi	FF	38	24	40	2.0	0.37	15	1.7
Sierramjärvi	J.Mannio	22	23	86	-	0.40	49	11.3
Pahtajärvi	J.Mannio	20	8	30	-	0.39	22	1.7
Kivijärvi	FF	17	12	87	14	0.46	16	5.9
Average		49	33	65	7	0.41	24.9	4.1
Min		17	8	28	1	0.15	9.5	1.3
Max		97	60	140	17	1.10	54.0	11.3
Standard deviation		25	13	30	5	0.20	12.9	2.9

Table 13. Concentrations of heavy metals and As (μg/g, dry weight) in sediment cores, values of contamination factor (C_f) and degree of contamination (C_d) of the investigated Finnish lakes

Lake, Date, Depth,m	Analysis	Layers, cm	Cu	Ni	Zn	Co	Cd	Pb	As	C_d
Lampi 222	Jaakko Mannio	0 - 1	94	44	51	-	0.30	39.9	2.29	
		29 - 30	147	13	100	-	0.36	6.4	1.43	
22 m		C_f	0.6	3.4	0.5	-	0.8	6.2	1.6	13.2
Aittojärvi	Russian	0 - 1	62	44	38	2.8	0.55	14.4	-	
12.04.05	Finnish	28 - 30	69	23	64	4.8	0.11	6.1	-	
7 m		C_f	0.9	1.9	0.6	0.6	5.1	2.3	-	11.4
Aittojärvi	Finnish	0 - 1	65	44	92	2.0	0.31	15	1.4	
12.04.05	Finnish	28 - 30	74	22	58	4.0	0.25	7	0.96	
7 m		C_f	0.9	2.0	1.6	0.5	1.2	2.1	1.5	8.3
Mellalompolo	Russian	0 - 1	90	60	57	7.8	0.15	32.0	-	
13.04.05	Finnish	28 - 30	43	17	69	6.9	0.10	4.6	-	
12 m		C_f	2.1	3.5	0.8	1.1	1.5	6.9	-	16.0
Mellalompolo	Finnish	0 - 1	97	55	140	7	0.41	37	4.2	
13.04.05	Finnish	28 - 30	72	21	86	5	0.37	8.9	1.3	
12 m		C_f	1.3	2.6	1.6	1.4	1.1	4.2	3.2	15.5
Nitsijärvi	Jaakko Mannio	0 - 1	55	35.9	113	-	0.58	34.5	7.11	
		30 - 32	69.2	30	120	-	0.39	8.7	1.49	
34 m		C_f	0.8	1.2	0.9	-	1.5	4.0	4.8	13.2
Nammijärvi	Finnish	0 - 1	63	35	54	4	0.54	27	4.3	
16.09.04	Finnish	38 - 40	350	53	83	9	0.37	3.9	1.8	
6 m		C_f	0.2	0.7	0.7	0.4	1.5	6.9	2.4	12.7
Inari Vasikanselkä	Russian	0 - 1	58	45	83	11	1.10	54.0	-	
24.06.92	Russian	21 - 22	51	32	90	13	0.21	7.0	-	
95 m		C_f	1.1	1.4	0.9	0.8	5.2	7.7	-	17.3
Inari Vasikanselkä	Finnish	0 - 1	54	39	63	11	0.4	33	6.5	
05.09.05	Finnish	38 - 40	52	33	78	9	0.26	9.1	2.3	
93 m		C_f	1.0	1.2	0.8	1.2	1.5	3.6	2.8	12.2
Kantojärvi	Russian	0 - 1	42	33	84	16.8	0.37	20.2	-	
15.04.05	Russian	13 - 14	38	19	78	13.6	0.15	3.6	-	
5 m		C_f	1.1	1.8	1.1	1.2	2.5	5.6	-	13.3
Kantojärvi	Russian	0 - 1	43	31	78	13.0	0.30	16.8	-	
15.04.05	Finnish	18 - 20	30	15	46	9.8	0.08	1.1	-	
5 m		C_f	1.4	2.0	1.7	1.3	3.8	16.0	-	26.2
Kantojärvi	Finnish	0 - 1	38	26	61	8	0.35	18	2.7	
15.04.05	Russian	9 - 10	41	15	67	8	0.26	6.4	1.4	
5 m		C_f	0.9	1.7	0.9	1.0	1.3	2.8	1.9	10.7
Kantojärvi	Finnish	0 - 1	41	29	53	8	0.41	20	2.9	
15.04.05	Finnish	18 - 20	44	16	69	11	0.25	1.8	1.0	
5 m		C_f	0.9	1.8	0.8	0.7	1.6	11.1	3.1	20.0

Table 13. Continue

Lake, Date, Depth,m	Analysis	Layers, cm	Cu	Ni	Zn	Co	Cd	Pb	As	C_d
Suovaselkajärvi 15.04.05	Russian Russian	0 - 1 23 - 24	29 40	25 13	33 32	2.5 6.0	0.25 0.09	12.2 1.1	- -	
2.7 m		C_f	0.7	1.9	1.0	0.4	2.7	10.8	-	17.6
Suovaselkajärvi 15.04.05	Russian Finnish	0 - 1 18 - 20	24 24	22 7	28 22	1.4 3.0	0.21 0.08	9.5 3.1	- -	
2.7 m		C_f	1.0	2.9	1.2	0.5	2.7	3.0	-	11.4
Suovaselkajärvi 15.04.05	Finnish Russian	0 - 1 18 - 20	25 34	21 12	32 29	1.0 3.0	0.26 0.2	11 5.1	1.3 0.75	
2.7 m		C_f	0.7	1.8	1.1	0.3	1.3	2.2	1.7	9.1
Suovaselkajärvi 15.04.05	Finnish Finnish	0 - 1 23 - 24	38 45	24 15	40 38	2.0 5.0	0.37 0.2	15 1.4	1.7 0.68	
2.7 m		C_f	0.8	1.6	1.1	0.4	1.9	10.7	2.5	19.0
Sierramjärvi	Jaakko Mannio	0 - 1 28 - 30	22 16	23 14	86 78	- -	0.40 0.37	49.3 6.3	11.3 0.8	
18 m		C_f	1.4	1.6	1.1	-	1.1	7.8	14.8	27.8
Pahtajärvi	Jaakko Mannio	0 - 1 28 - 30	20.1 22.5	8.46 7.36	29.8 25.9	- -	0.39 0.36	22.4 4.73	1.72 1.46	
11 m		C_f	0.9	1.1	1.2	-	1.1	4.7	1.2	10.2
Kivijärvi 18.10.05	Finnish Finnish	0 - 1 38 - 40	17 27	12 12	87 84	14 16	0.46 0.28	16 1.9	5.9 0.93	
9 m		C_f	0.6	1.0	1.0	0.9	1.6	8.4	6.3	19.9

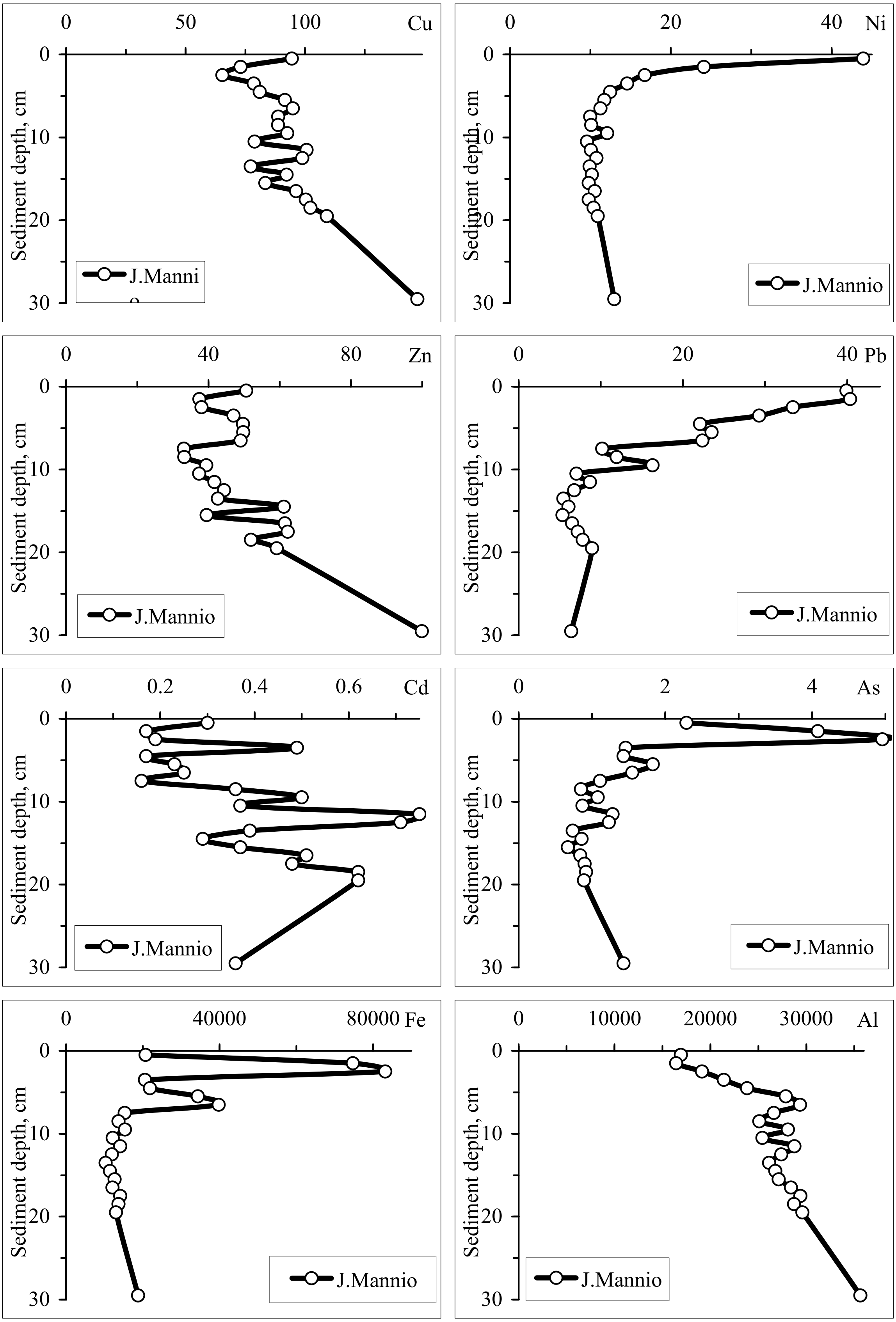

Fig.10. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Lampi 222.

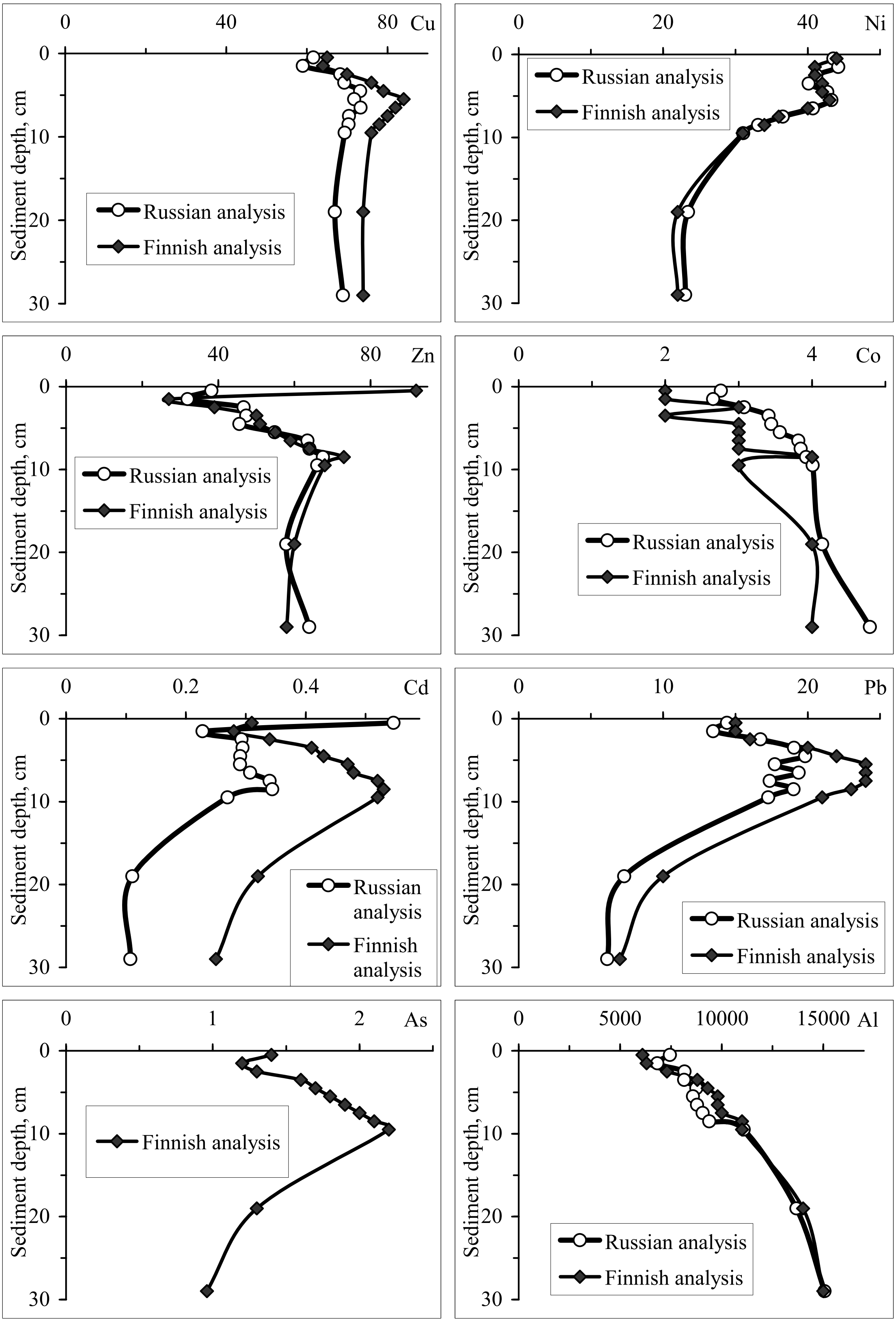

Fig. 11. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Aitojärvi 2.

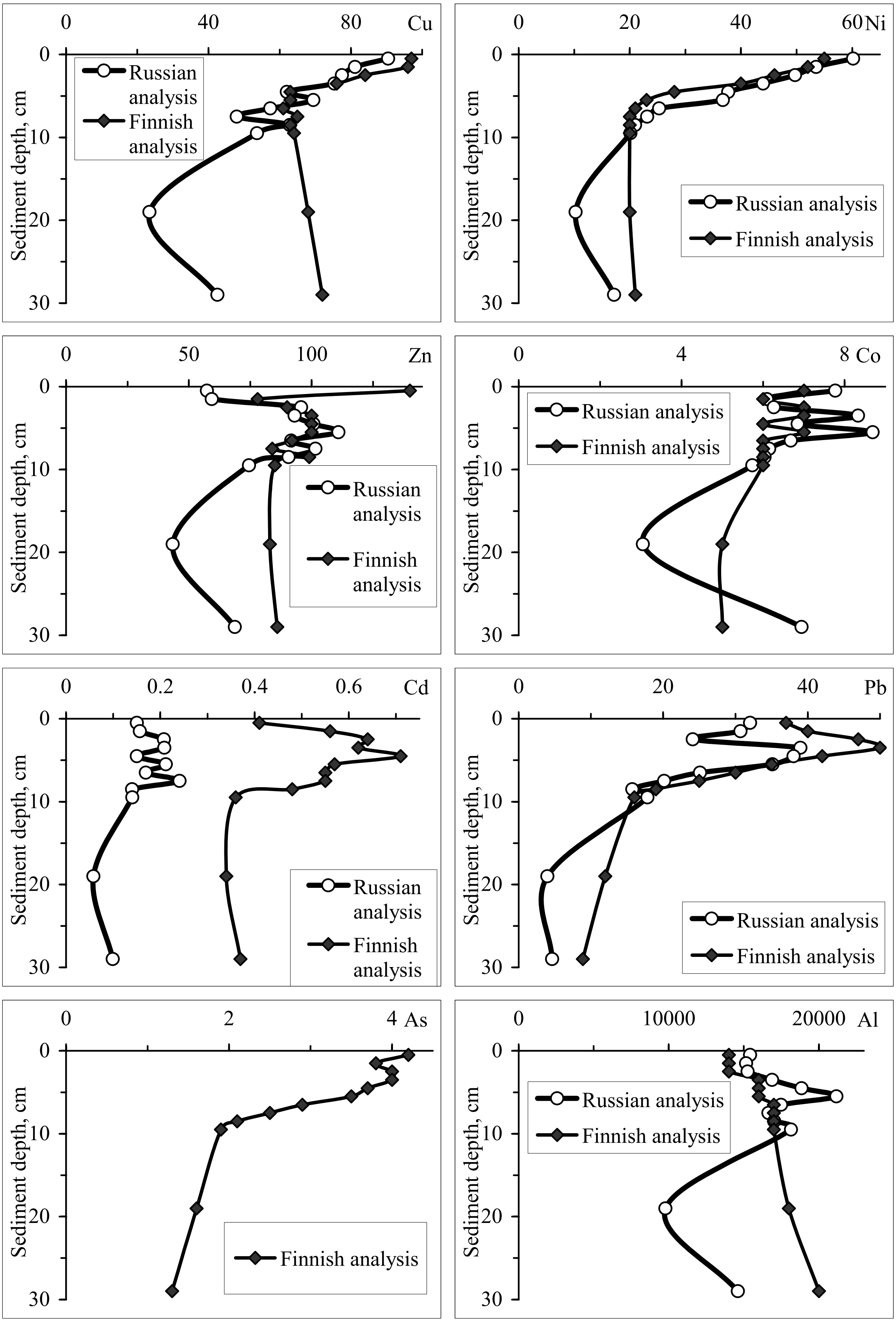

Fig. 12. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Mellalompolo.

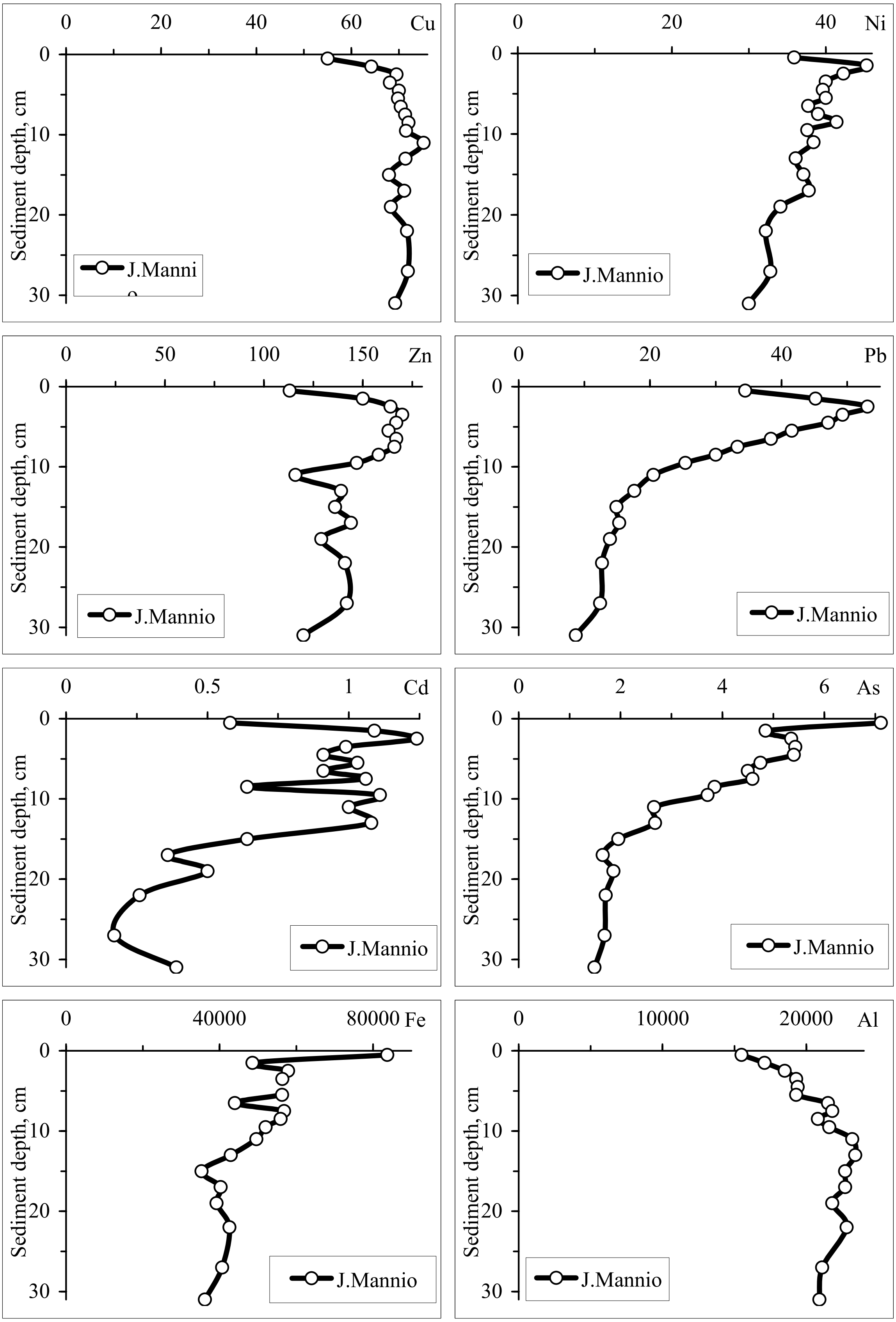

Fig. 13. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Nitsijärvi.

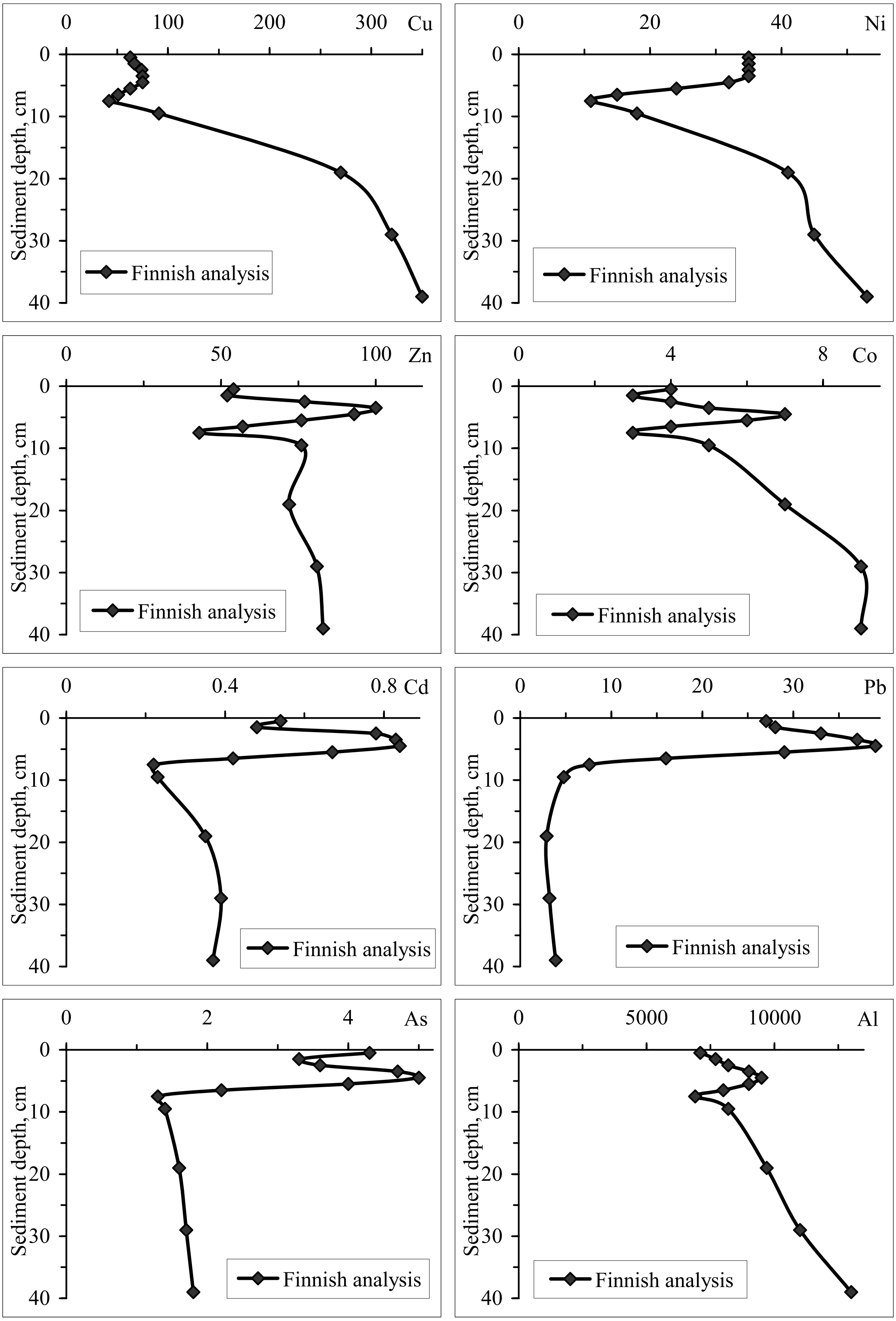

Fig. 14. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Nammijärvi.

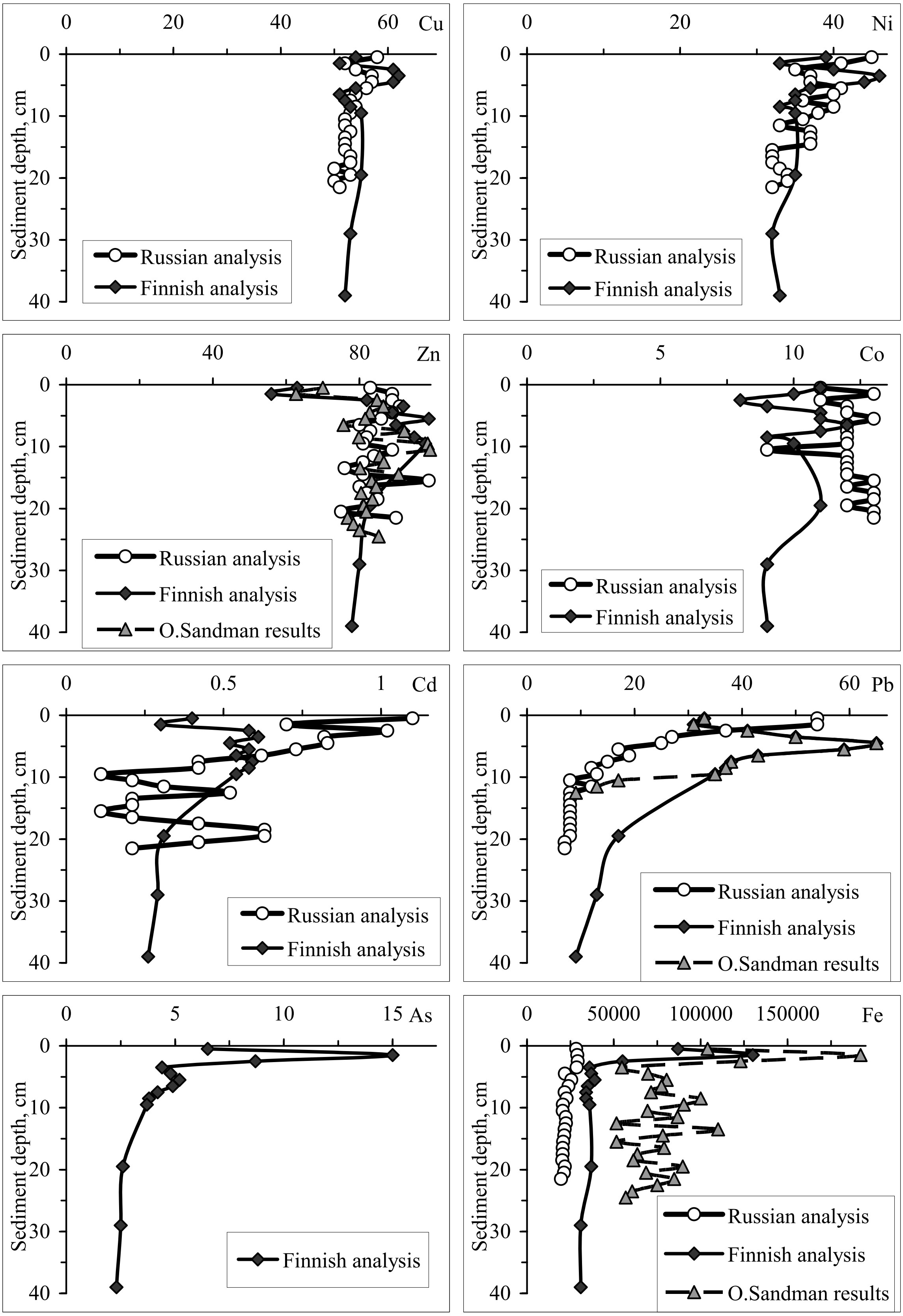

Fig. 15. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Inari Vasikanselkä.

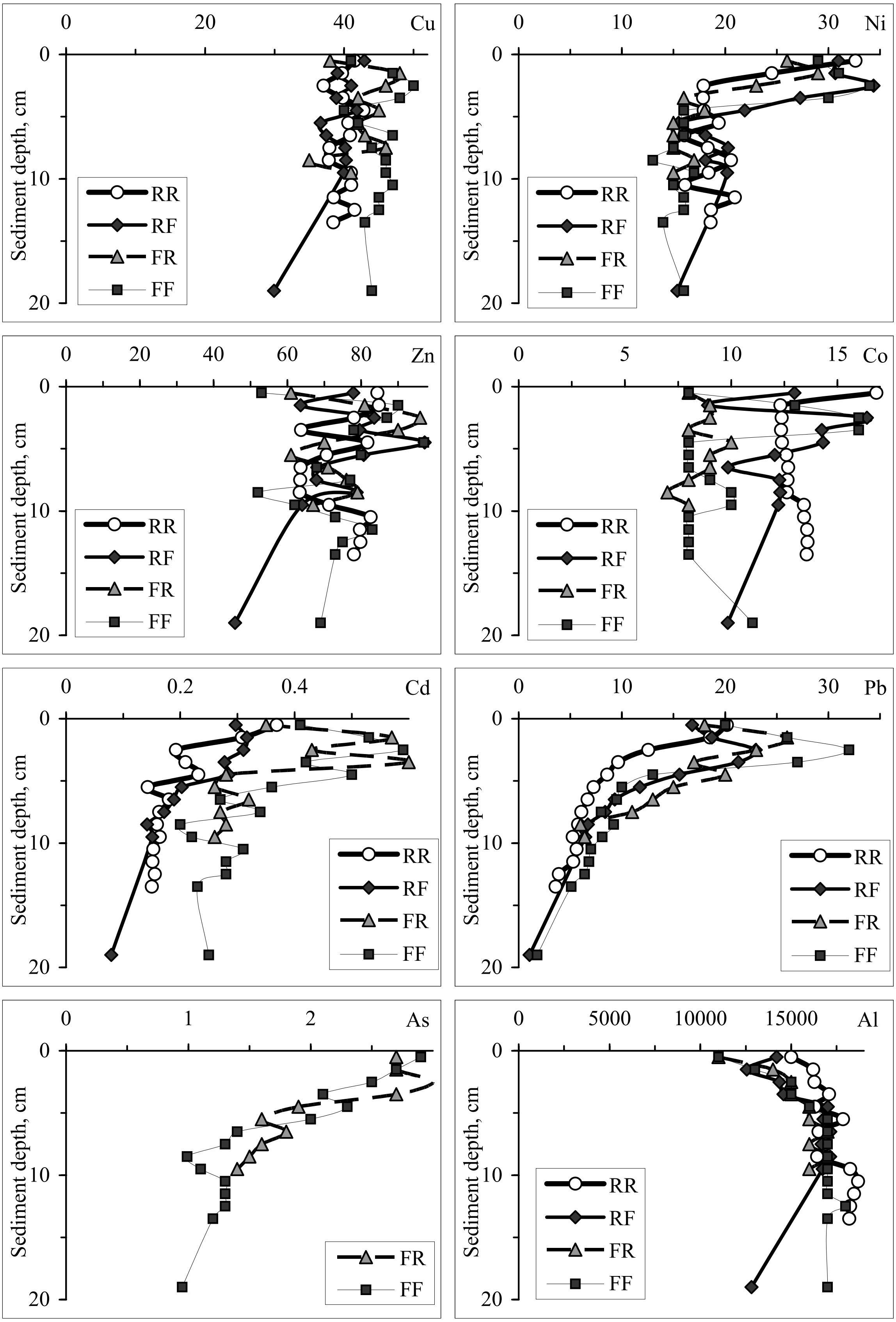

Fig. 16. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Kantojärvi.

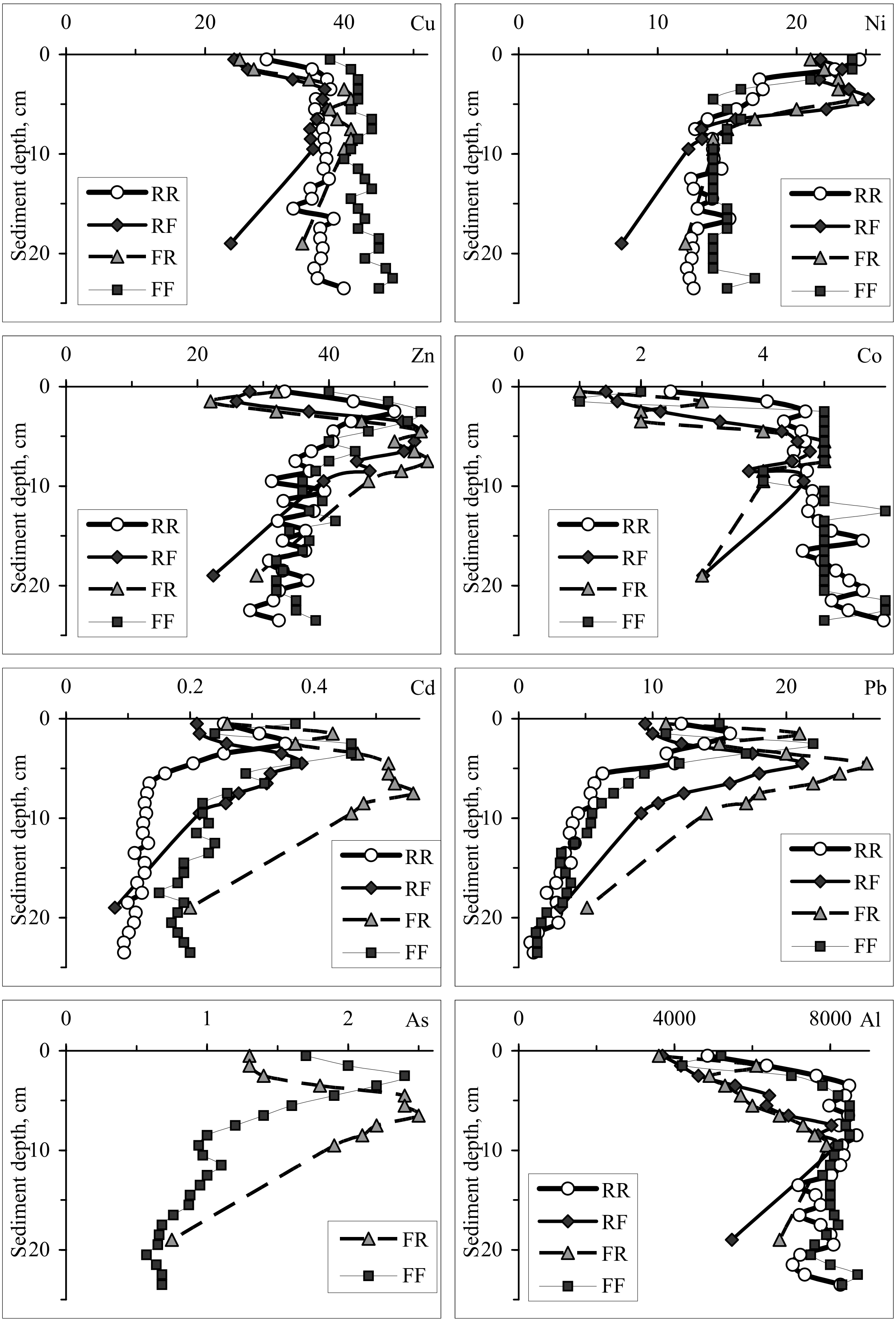

Fig. 17. Vertical distribution of elements (µg/g) in the sediment cores of the Suovaselkajärvi.

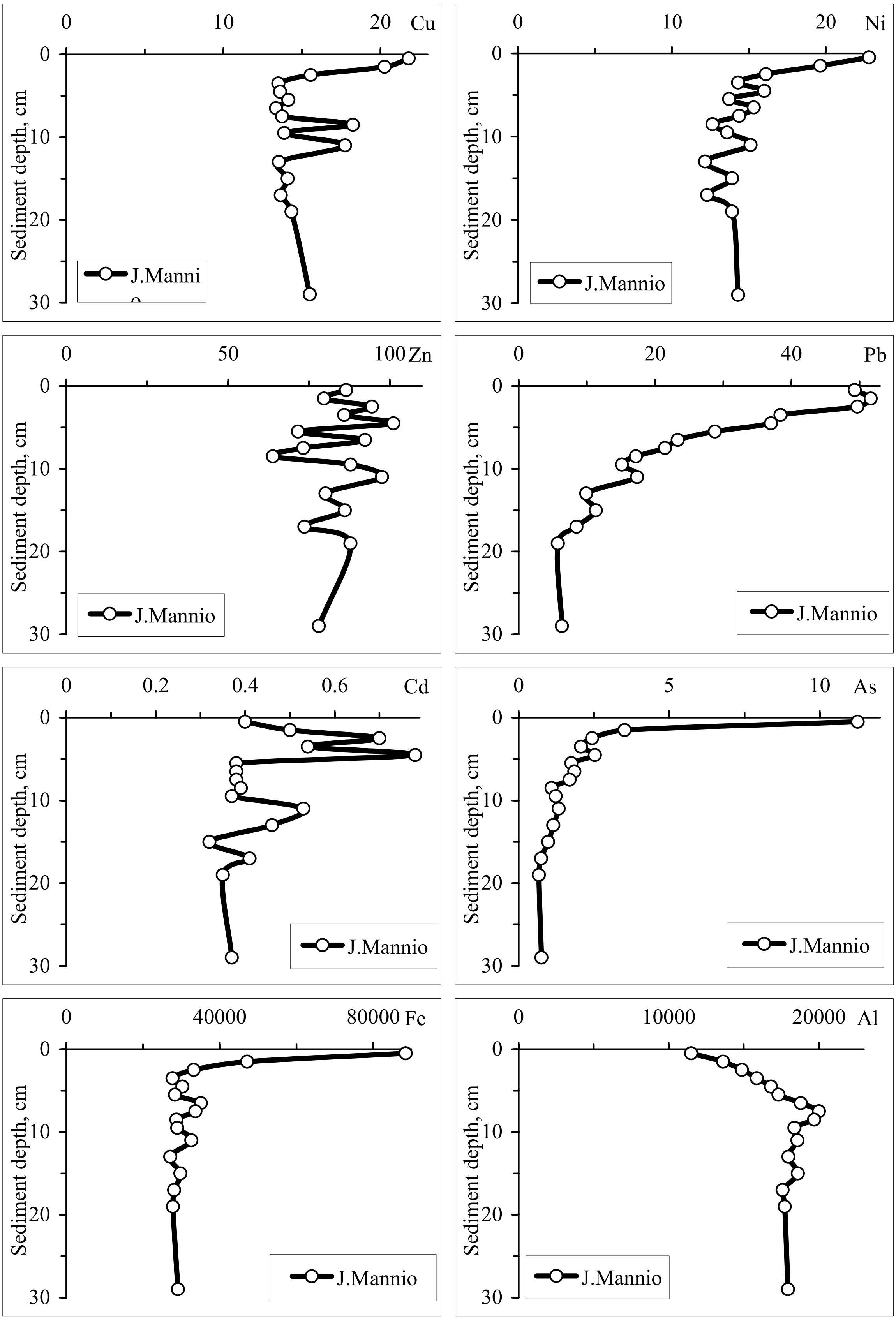

Fig. 18. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Sieramjärvi.

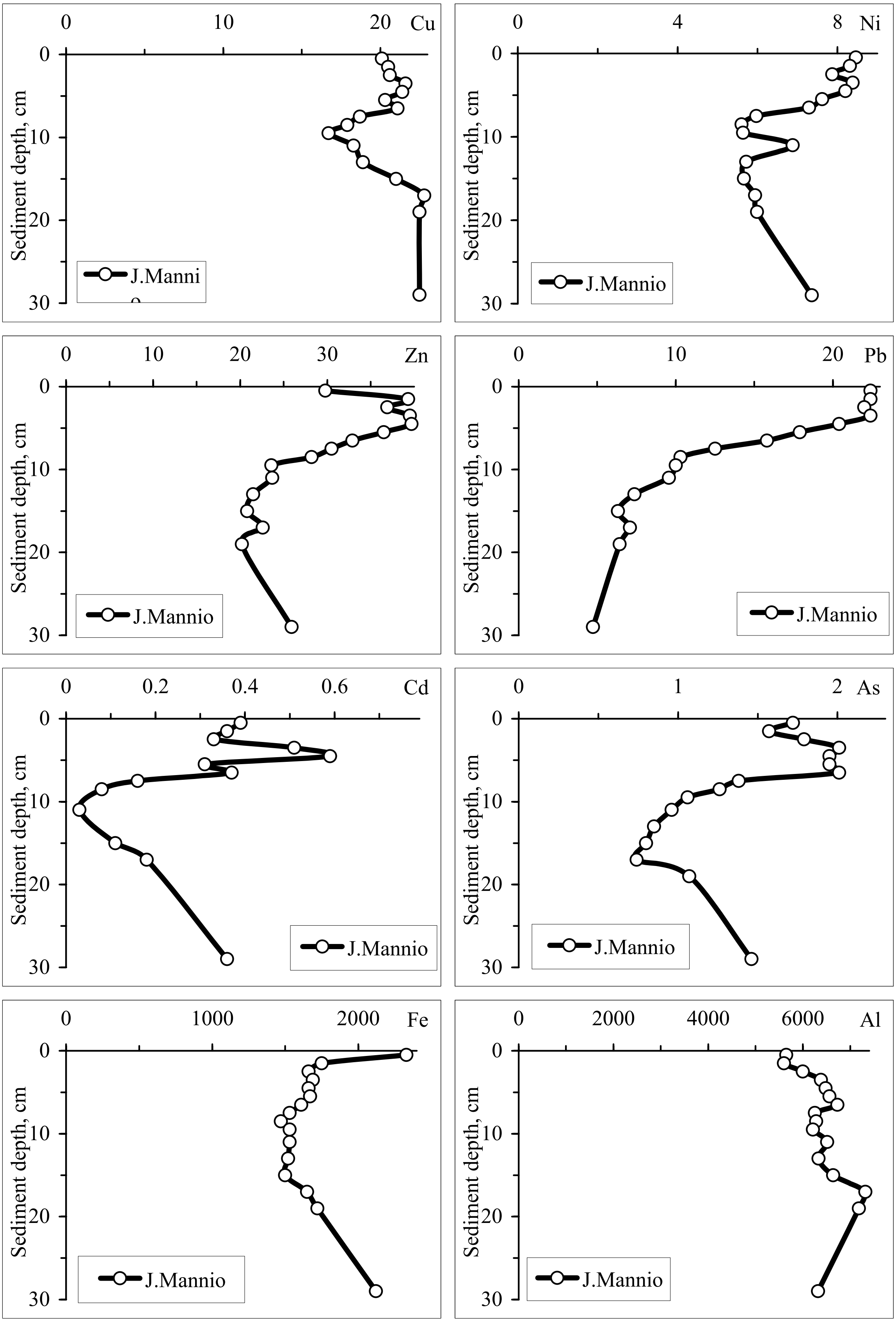

Fig. 19. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Pahtajärvi.

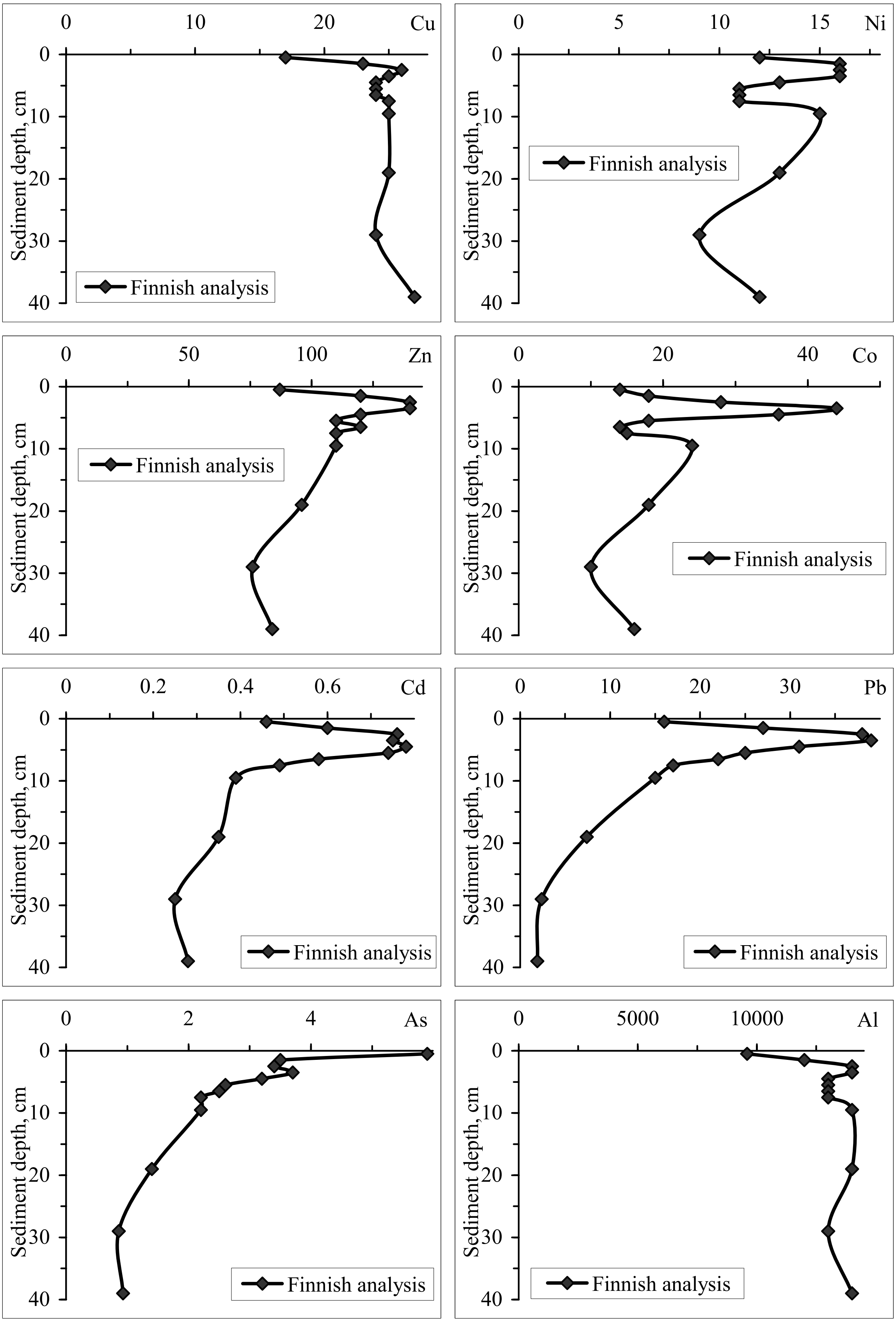

Fig. 20. Vertical distribution of elements (µg/g d.w.) in the sediment cores of the Kivijärvi.

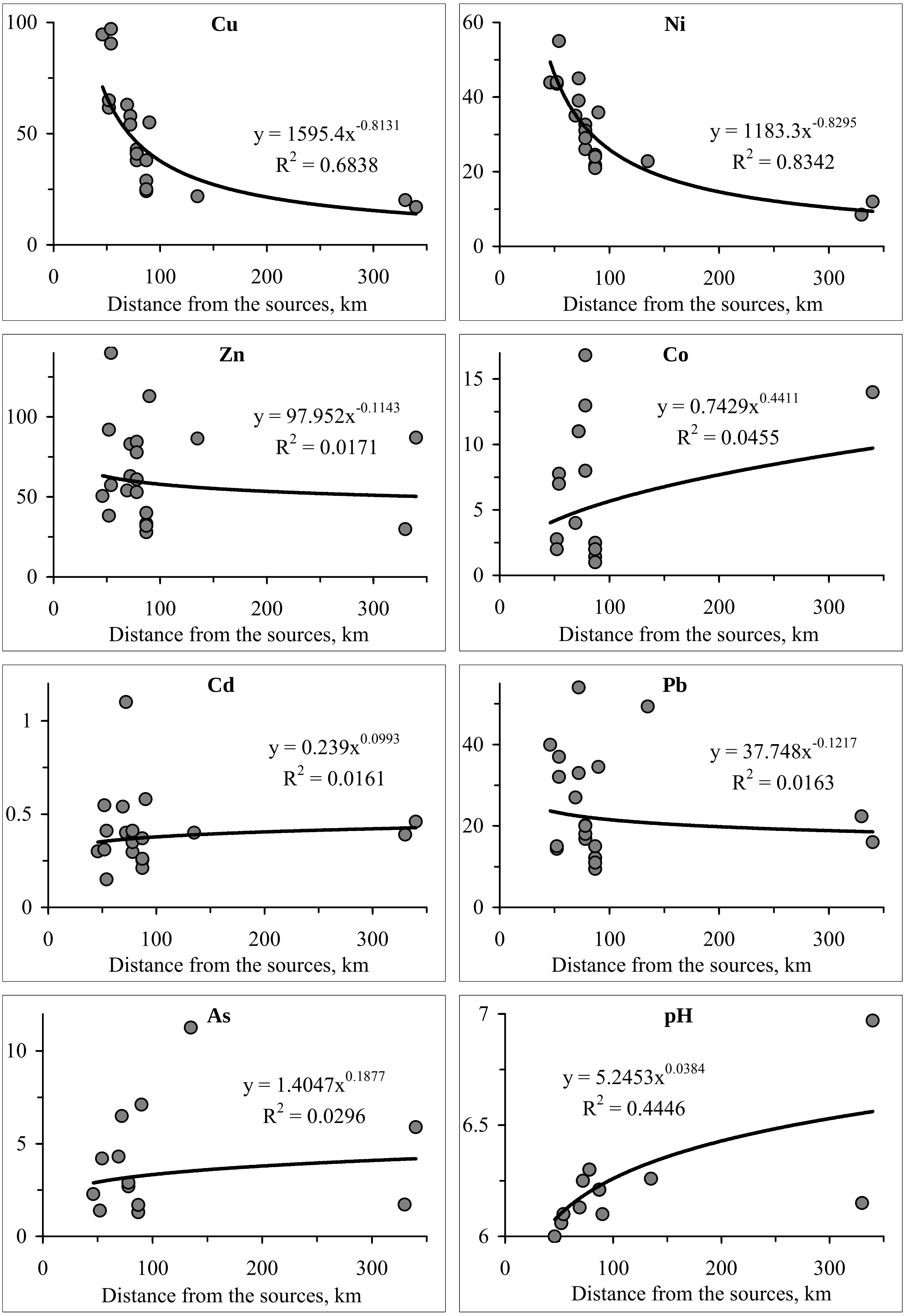

Fig. 21. Distribution of element concentrations (µg/g d.w.) in the top sediment layer (0 - 1 cm) and water pH values of the investigated Finnish lakes of the Paz River basin depending on the distance from the smelters of the Pechenganickel Company.

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