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Geochemical Features of Peat Deposits at Oligotrophic Bogs in the Southern Taiga Subzone of West Siberia

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Abstract—The paper presents original authors' data on the geochemical aspects and peat deposits and conditions of their accumulation at the three oligotrophic bogs in the south taiga subzone of West Siberia. These data were acquired with regard to a complex of factors impacting the development of peat deposits: the geomorphological setting in the landscape, the lithochemical composition of the underlying rocks, the physicochemical properties of the peat, and the contents of chemical elements and their distribution in the peat profiles. The impact of the geomorphological factor is reflected in the different ratios of peat layer thicknesses in the peat deposits of different type. The composition of the underlying rocks affected the concentration of elements and their distribution within the peat profile. The main element associations in the peat deposits of the bogs are identified using the method of principal components. The distribution of the elements in the peat deposits is shown to be differentially influenced by a number of factors: endogenous supply of elements from the underlying rocks and groundwater (Ca, Fe, Ti, Ni, Cu, Co, Cr, Ba, Cd, and Sr), the activity of redox processes (Mn, Pb, and Fe), redox-independent processes of the dissolution and mobilization of elements by plant roots (Ca, Cu, and Fe), the rate of peat decomposition (Mn, Pb, and the C/N ratio), the water level in the peatlands (C/N ratio), and atmospheric supply of anthropogenic compounds as a result of human activities (Pb).

Keywords: peat deposit, oligotrophic bog, chemical elements, underlying rocks, water–mineral nutrition, ash content, organic matter decomposition (C/N ratio), West Siberia

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INTRODUCTION

West Siberia is a unique territory, which is world-leading in terms of bogging, a process that continues until nowadays. According to (Neishtadt, 1972; Pologova and Lapshina, 2002; Kuryina and Veretennikova, 2015), the rate of peat thickness increase varies from 0.39 to 2.62 mm/yr, and the surface area of bogs increases at a rate of 100 km^2/yr. Considering the extent of bogging and its annual increment, bog ecosystems are viewed as one of the most important environment-controlling factors, which predetermines the trends and nature of many regional natural processes.

Nowadays the number of studies of the geochemistry of bog ecosystems in West Siberia is rocketing, and these studies are aimed at a vide circle of objects and employ a broad diversity of approaches. Currently numerous studies are focused on the monitoring of atmospheric pollution and on local ecological histories, and commonly place an accent on the importance of atmospheric fallouts of mineral particles and admixture elements in various peat bogs that are mostly impacted by an anthropogenic load (Mezhibor et al., 2009, 2013). Much attention is thereby attracted to bog ecosystems in their natural state. A number of publications report average concentrations of elements in peats sampled at various peat deposits in the Tomsk area and discuss the concentrations and distribution of chemical elements in the peats of different botanical composition (Arkhipov et al., 1988; Inisheva and Tsybukova, 1999; Arbuzov et al., 2009; Veretennikova, 2013). Some authors focus on studying certain elements in the profiles of the peat deposits, for example, Ca, Fe, and Mn (Arkhipov and Bernatonis, 2013, 2015) or Pb (Veretennikova, 2015). Data are currently available on concentrations of chemical elements in the profiles of peat deposits studied at the most widely spread bog types in various climatic zones of West Siberia (from the forest steppe to tundra zones), with these data acquired with the application of a spatio-temporal approach (Moskovchenko, 2006; Stepanova et al., 2015). Nowadays more and more attention is paid to the mineralogical composition of peat deposits

(Preis, 2010; Rudmin et al., 2018; Arbuzov et al., 2018; Savichev et al., 2020).

The geochemistry of bog landscape is determined by a complicated interplay of several processes (Chagué-Goff et al., 1996) and factors, such as climatic variations and vegetation in the Holocene and the nature and composition of the underlying rocks and waters, which control the supply of water and mineral compounds to the bogs (e.g., Lukashev et al., 1971; Kovalev, 1985; Matukhina and Popova, 2001; Larina et al., 2013, 2014; Steinmann and Shotyk, 1997; Mäkilä et al., 2015). Along with the aforementioned supergene factors, the evolution of bogs is associated with the development of certain geochemical conditions due to the integral effect of physicochemical and biological processes, which affect the distribution of chemical elements in the peat beds. Upon occurring in a peat bed (when brought there with atmospheric precipitation and with ground and surface waters), mineral compounds undergo systematic diagenetic transformations, which redistribute chemical elements within the peat bed. A leading role in this redistribution is played by the organic matter of the peat (its destruction and accumulation rates), redox processes, microbiological processes, pH of the environment, water amount in the bog, and chemical properties of the elements themselves, which can vary depending on the parameters of the bog environment and predetermine the biogenic accumulation of these elements or their migration (Kovalev, 1985; Savichev et al., 2019, 2020; Bergkvist, 1987; Steinmann and Shotyk, 1997; Derome and Nieminen, 1998; Biester et al., 2012).

Most bogs in West Siberia are oligotrophic, i.e., they have underwent a long-lasting evolution to a stage when they are fed by atmospheric precipitation and when the underlying rocks are buried inside and thus cease to be able to influence the current state and evolution of the bogs. The most widely spread vegetation on the surface of oligotrophic bogs in the taiga zone is of the pine–suffruticose–sphagnous type (riam) (Liss et al., 2001). Although these bogs now look like amazingly similar to one another, they are hosted in different landforms (watershed areas, ancient river valleys, and depressions) and were formed on underlying rocks of different composition, and it is thus reasonable to think that geochemical processes in these bogs may be different, because the bog-forming process induces fundamental transformations of the geochemical system even at relatively insignificant changes in environment parameters (Kovalev, 1985).

This paper reports complex geochemical estimates of peat deposits at three distinct bog ecosystems. The characteristics of these bogs are typical of the taiga zone in West Siberia. Two of the bogs selected for this study are situated on the left-hand riverside of the Ob, and the third bog is located on the right-hand bank of this river. The geochemical estimates are based on characteristics of the concentrations and distributions of some chemical elements (Ca, Fe, Ti, Sr, Ba, Mn, Cu, Ni, Co, Cr, Pb, and Cd) and on the identification of the dominant factors that controlled the differentiation of chemical elements in the peat profiles. Because the composition of underlying rocks and the mineralization of natural waters that provide nutriment to bogs on the left- and right-hand banks of the Ob River are principally different (Savichev, 2010; Evseeva et al., 2012), another aspect of our study was a geochemical estimation with regard to natural features that may have affected the evolution of the bog ecosystems.

MATERIALS AND METHODS

The study area occurs in the southern taiga subzone in West Siberia. We have studied three peat deposits in various bog massifs (Fig. 1). One of them is situated in the Bakchar bog, which is constrained within the watershed area between the Iksa and Bakchar rivers in the Bakchar district, near the village of Polynyanka at 82°36′ N, 56°58′ E. This bog is the southeastern part of the Vasyugan bog. The second peat deposit was studied at the Knyazevskoe bog on the second terrace above the floodplain of the Chaya River in the Chaya district, not far from the village of Ust-Bakchar, 82°18′ N, 57°38′ E. The third peat deposit is constrained to the Tsentralnoe bog in the Verkhneketskii district, in the vicinities of the village of Nibeginskii, 84°55′ N, 58°18′ E. The Tsentralnoe bog is hosted in the ancient watercourse in the left-hand side of the Suiga River, which is a left-hand tributary of the Ket River. The vegetation at each of the three bogs is similar: a pine–suffruticose–sphagnous phytocenosis. Phytocenoses of this type are dominant at bogs in southern taiga (Liss et al., 2001).

Peats of each of the bogs were sampled in the course of fieldwork by researchers from the Institute of Monitoring of Climatic and Ecological Systems, Siberian Branch, Russian Academy of Sciences. The samples were taken from each peat layer. The sampling sites were vertically spaced 10 cm apart, and samples were also taken from the rock underlying the peat. All samples were collected with a TGB-1 geological peat corer and were then analyzed at laboratories.

The botanical composition of the peat samples was identified by Dr. E.M. Volkova at the Tula State University in Tula, following the standardized conventional techniques (Kats et al., 1977). The ash contents of the peats were determined in compliance with the state standard GOST-11306-83. The degrees of peat decomposition were determined from the C/N ratios, which were calculated from the analyzed bulk carbon and nitrogen concentrations determined according to (Ponomareva and Plotnikova, 1975). The C/N ratio was calculated for each layer of the peat deposits based on the analyses.

Bulk concentrations of chemical elements (Ca, Fe, Ti, Sr, Ba, Mn, Ni, Co, Cr, Pb, and Cd) in samples of

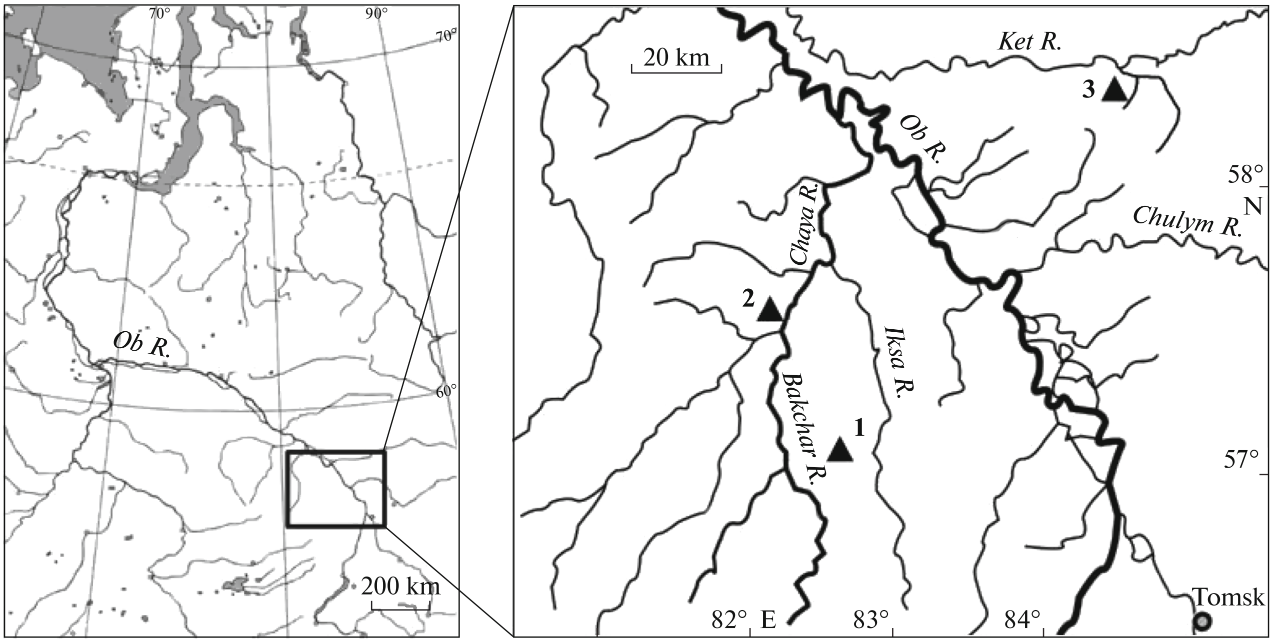

Fig. 1. Schematic map of the study area and the studied bogs: (*1*) Bakchar bog, (*2*) Kinzyarovskoe bog, and (*3*) Tsentralnoe bog.

peats and underlying rocks were analyzed by quantitative atomic-emission method on a STE-1 quartz spectrograph with a three-lens system for slit illumination and a working range of 200–600 nm, according to the certified method (*Methods for Quantitative...,* 1993) at the Laboratory of Mineral and Geochemistry of the Tomsk State University in Tomsk, analyst Dr. E.D. Agapova. Preparatorily to their analysis, peat samples were ashed and then placed into the crater of the carbon electrode (4 mm in diameter and 4 mm deep) and analyzed in an alternating-current electric arc. The excitation source of the spectra was an IVS-29 generator.

Peat samples from discrete peak layers were dated by ^{14}C at the Sobolev Institute of Geology and Mineralogy, Siberian Branch, Russian Academy of Sciences, in Novosibirsk (analyst L.A. Orlova) and at the Institute of Monitoring of Climatic and Ecological Systems, Siberian Branch, Russian Academy of Sciences, in Tomsk (analyst G.V. Simonova) on a QUANTULUS 1220 (Wallac, Finland) ultra-low background liquid scintillation spectrometer. Fourteen dates were obtained. The raw data were calibrated on a IntCal13 calibration curve (Reimer et al., 2013) and were then utilized in a depth–age model, which was simulated with the CLAM program package (Blaauw, 2010).

The statistical processing of the data involved the estimation of the desired parameters with descriptive statistics and correlation and factor analysis. Factor analysis was conducted using a correlation matrix and the principal-component method. The results of factor analysis were then interpreted with regard for the loads, which are, in fact, correlation coefficients between the identified components and variables. Variables more strongly correlated with a given factor than with others correlate its core, and the components themselves are ranged according to their influence, which is estimated from their contribution to the general dispersion. Statistical processing of the results was carried out with the STATISTICA 10 (StatSoft) and SigmaStat 6 (Systat Software Inc.) applications. The total number of peat samples studied in the selections by bog was as follows: 19 for the Bakchar bog, 27 for the Kinzyarovskoe bog, and 23 for the Tsentralnoe one.

RESULTS

Principal Parameters of the Peat Deposits

The modern vegetation of all of the peat deposits is a pine–suffruticose sphagnum phytocenosis. The moss cover is dominated by fiscum; the suffruticose layer consists of leatherleaf, ledum, and Andromeda; and the tree layer consists of dwarf pine. Depth–age models were calculated based on radiocarbon dating data (Table 1) and the thickness of the peat deposits.

The ***Bakchar bog*** rests on carbonate loams and clays. At the drilling site, the peat deposit is 180 cm thick, and the age of the bottom layer is 2800 calib BP. According to the age model, the peat accumulation rate varied: this rate was low (0.42 mm/yr) during the eutrophic evolutionary stage of the bog and then drastically increased (to 1.16 mm/yr), and the bog entered the mesotrophic stage. The time span from 1270 BP to the present time corresponded to the oligotrophic stage of bog evolution, when the peat accumulation rate varied from 0.36 to 1.74 mm/yr.

The peat deposit of the ***Kinzyarovskoe bog*** has a thickness of 270 m (at the drilling site) and an age of

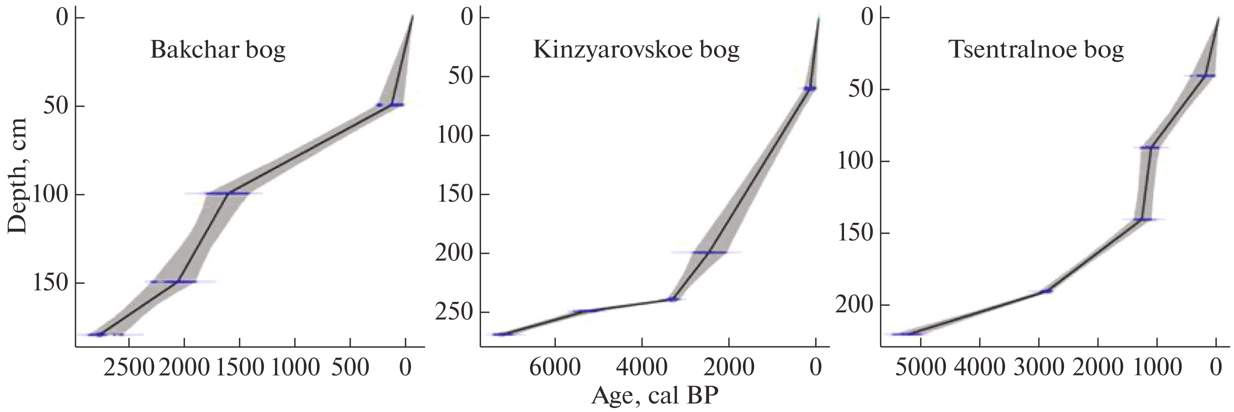

Fig. 2. Depth–age models for the peat deposits based on calibrated radiocarbon dates (Table 1).

7200 calib BP and, similar to the peat deposit at the Bakchar bog, is underlain by carbonate loams. The peat deposit at this bog is noted for the occurrence of a thick (approximately 170 cm) bottom layer of eutrophic (fen) peat, which was accumulated during a long time interval (about 6000 years). The peat accumulation rate then varied from 0.11 to 0.71 mm/yr and gradually increase when the peat deposit thickened. The thin (close to 20 cm in thickness) layer of mesotrophic (transitional-type) peat indicates that the bog passed to a mesotrophic stage, which lasted for about 200 years, and the peat accumulation rate was then 0.71 mm/yr. The bog then evolved to an oligotrophic stage (about 800 calib BP), when the peat accumulation rate increased and is now 1.90 mm/yr.

The peat deposit at the ***Tsentralnoe bog*** is 220 cm thick, the peat started to accumulate at approximately 5200 calib BP, and the peat deposit almost entirely consists of oligotrophic peats. The peat accumulation rate was evaluated at 0.04 mm/yr. Under these conditions, as little as 10 cm of eutrophic peat was accumulated for 1000 years. Then, the peat accumulation rate gradually increased starting at 3600 BP but remain relatively low (0.18 mm/yr). The bog-forming processes then proceeded according to the mesotrophic type and resulted in a thin bed of mesotrophic peat. Starting at 2850 BP, the bog passes into the oligotrophic stage, which still continues. The peat accumulation rate during this time span systematically increased, reached higher value by 1000 BP, and was 2.44 mm/ye over the past 200 years.

Ash Contents of the Peat and Their Degrees of Decomposition in the Profiles of the Peat Deposits

To make comparison between the peat deposits more accurate, we compared the average ash contents of each of the peat types composing the profiles.

Table 1. Radiocarbon dating data on the peat deposits of the bogs

Depth, cm	Laboratory number	Age, ^{14}C BP	Calibrated age, cal BP
Peat deposit at the Bakchar bog			
40–50	IMKES-14C219	105 ± 20	130
90–100	SOAN-7867	1695 ± 85	1602
140–150	SOAN-7868	2075 ± 70	2056
180–190	SOAN-7869	2637 ± 55	2762
Peat deposit at the Kinzyarovskoe bog			
50–60	IMKES-14C1088	106 ± 40	142
190–200	IMKES-14C1103	2410 ± 172	2470
230–240	IMKES-14C718	3102 ± 64	3302
240–250	IMKES-14C1090	4609 ± 94	5297
260–270	IMKES-14C761	6310 ± 109	7215
Peat deposit at the Tsentralnoe bog			
40–50	IMKES-14C881	160 ± 85	167
90–100	IMKES-14C894	1175 ± 86	1082
140–150	IMKES-14C891	1307 ± 90	1239
190–200	IMKES-14C882	2743 ± 54	2849
210–220	IMKES-14C887	4552 ± 78	5196

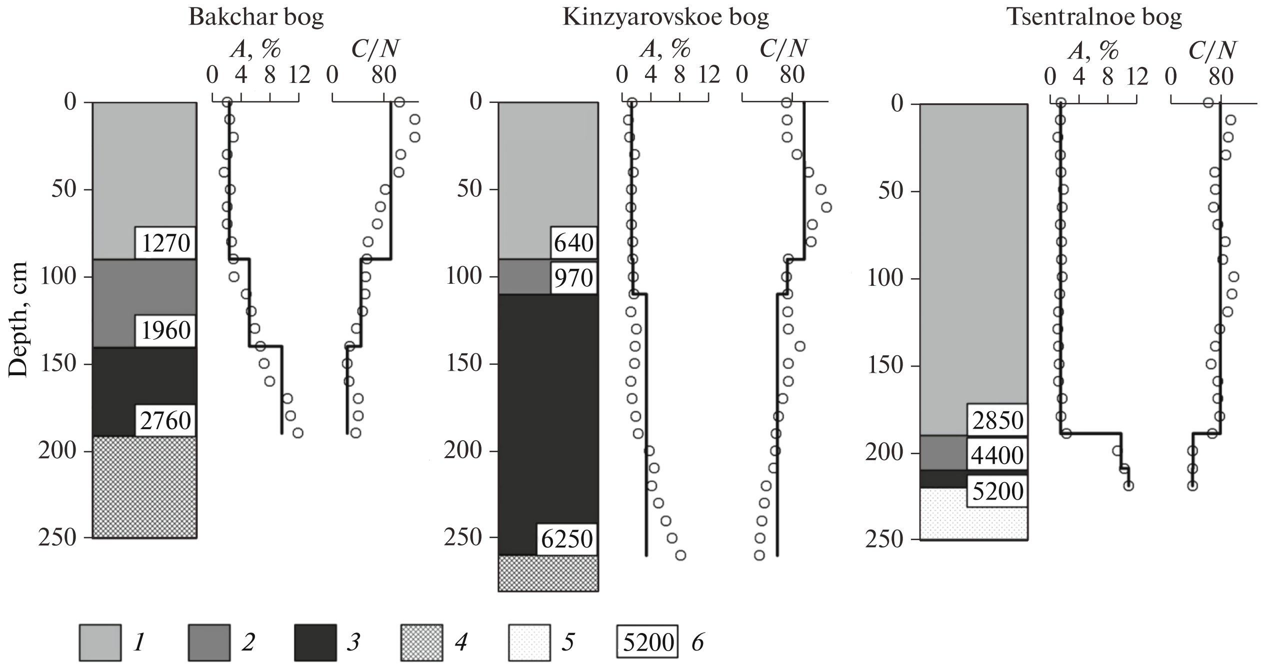

Fig. 3. Schematic vertical sections through and characteristics of peat deposits of the bogs in the southern taiga subzone in West Siberia: (*1*) oligotrophic peat, (*2*) mesotrophic peat, (*3*) eutrophic peat, (*4*) underlying rocks (loams and clays), (*5*) underlying rocks (sands and sandy loams), (*6*) calibrated age of the peat layer; *A*, % is the ash contents of peat layers.

The ash content of the peat of the Bakchar bog varies from 1.71 to 11.88%, and this parameter is clearly differentiated in the profile of the peat deposit (Fig. 3): the ash contents of the eutrophic peats varies from 7.28 to 11.88% (at an average of 9.70 ± 1.97), the maximum values are detected in the near-bottom layers, the ash content of the mesotrophic peat is 3.13–6.76% (at an average 5.21 ± 1.37), and this parameter of the oligotroiphic peat is 1.71–3.05% (average 2.43 ± 0.42). The ash content of the peat deposit at the Kinzyarovskoe bog is lower than at the Bakchar one: 1.37–8.23%. The highest values are typical of the eutrophic peats, which occur in immediate contact with the underlying rocks (8.20–6.20%) than those of the eutrophic peats of the Bakchar bog. The ash content of eutrophic peat at depths of 230–110 cm at the Kinzyarovskoe bog varies from 5.20 to 1.39% (at an average of 2.63 ± 1.33), which corresponds to the ash content of mesotrophic peats at the Bakchar bog. The ash content of mesotrophic peats is 1.64% on average, and that of the oligotrophic peats is much lower: 1.42 ± 0.23%. The whole peat deposit at the Tsentralnoe bog consists of low-ash peats (ash contents 1.00–1.80%, average 1.40 ± 0.22). The ash contents in the bottom peat layers at contact with the underlying rocks are higher: 9.30–10.80%.

As a measure of the extent of organic matter decomposition, we used a biomarker: the carbon/nitrogen ratio (C/N). Low values of this ratio indicate that the decomposition rates of the organic matter (i.e., the rates of carbon loss) were higher during dry seasons, when the bog-water levels were low. Conversely, high C/N ratios corresponded to higher water levels at the bogs, when the decomposition rates of the organic matter were lower. Because of this, the C/N ratio is very often employed as an indicator of changes in hydrological conditions at bogs (Kuhry and Vitt, 1996; Malmer and Wallen, 2004; Biester et al., 2012). This parameter is very important for interpreting how chemical elements are distributed in peat profiles, because the process of decomposition can significantly affect the post-sedimentation transformations of the distributions of chemical elements (Bergkvist, 1987; Derome and Nieminen, 1998; Biester et al., 2012). It is necessary to take into account that the variability of this biomarker can depend not only the rates of carbon losses but also on an increase in the nitrogen concentrations in anaerobic layers of the peat deposits and strongly depend on the peat-forming plants (Muller et al., 2008; Biester et al., 2012). The values of the C/N ratio indicate that decomposition processes are more active in the peat deposit of the Bakchar bog than that of the Kinzyarovskoe bog (Fig. 3). The highest C/N ratios at the Tsentralnoe bog indicate that the rates of the decomposition processes was low.

Concentrations and Distributions of Chemical Elements in the Peat Deposits

Our data on concentrations of chemical elements in the peat deposits are summarized in Table 2. Because these peat deposits include peat layers of the oligotrophic, mesotrophic, and eutrophic types of different thickness, we calculated the average concentrations of chemical elements and other statistic characteristics separately for each of the peat types to make the comparison more accurate. For the peat deposit at the Tsentralnoe bog, practically all data on concentrations of chemical elements are presented for oligotrophic peats. The mesotrophic and eutrophic peat types were represented by relatively low numbers of samples (one and two samples, respectively), which hampered the statistical processing of the data. However, judging from the data themselves, the eutrophic peat obviously contains much higher concentrations of chemical elements than those in the oligotrophic and mesotrophic peats.

The distribution functions of most of the analyzed chemical elements in the peat deposits are asymmetric, which indicates that the maximum number of the concentrations does not correspond to the arithmetic average, and hence, the distributions of the elements are not normal. In view of this, we calculated not only the traditionally used average concentrations of the elements but also their median values (Table 2).

Results of statistical processing (with the application of the Mann–Whitney test) indicate that the eutrophic and mesotrophic peats of the Bakchar and Kinzyarovskoe bogs typically contain low Ti, Ba, Cu, Ni, Cr, Pb, and Cd concentrations and statistically significantly ($p < 0.05$) differ in Ca, Fe, Sr, Mn, and Co concentrations, which are higher in the peat deposit at the Bakchar bog. The oligotrophic peats of the three bogs bear similar concentrations of most chemical elements: Fe, Ca, Ti, Co, Pb, Cd, Cr, and Ni. Higher Mn and Ni concentrations ($p < 0.05$) were found in the oligotrophic peats of the Bakchar bog compared to the peat deposits of the Kinzyarovskoe and Tsentralnoe bogs. The oligitrophic peats of the Kinzyarovskoe bog contain the lowest Ba concentrations ($p < 0.05$), and Mn concentrations are the lowest in the Tsentralnoe bog.

A number of distribution types of chemical elements in the peat profiles were distinguished (Fig. 4). Thereby some elements (Ca, Fe, and Cu) are differently distributed in various peat deposits, whereas others (Ti, Ba, Sr, Cu, Ni, Co, Cr, Cd, Mn, and Pb) always show similar distribution patterns. The peat deposits of the Bakchar and Kinzyarovskoe bogs are characterized by strongly differentiated types of element distributions, with their concentrations significantly increasing in the lower layer of eutrophic peats (beneath a depth of 150 cm at the Bakchar bog and below 190 cm at the Kinzyarovskoe bog). In this part of the profile, the average concentrations of elements are higher (twice and more) than in the overlying peat layers (Figs. 4a, 4b). The Mn and Pb distributions in both peat deposits are characterized by a drastic increase in the uppermost layer of 0–50 cm. In the peat deposit of the Bakchar bog, a maximum of Pb concentration was found in the layer 10–20 cm, and the maximum of Mn occurred in the upper layer of 0–10 cm. In the peat deposit of the Kinzyarovskoe bog, a general increase in the Mn concentration in the upper 1-m layer is associated with significant variations in this parameter, with alternating local minima and maxima. A peak of the maximum Mn concentration was found at a depth of 30–40 cm, after which the Mn concentration systematically decreased toward the bottom layers.

The peat deposit of the Tsentralnoe bog shows a number of distribution types (Fig. 4c). Strongly differentiated distribution types are characteristic of Mn and Pb, whose concentrations are at a maximum in the surface layers and at depths of 40–50 cm and then drastically decrease downward and remain almost unchanging throughout the whole vertical section. Strongly differentiated distributions are also typical of Ti, Sr, Co, and Cd, but their concentrations are obviously higher in the bottom layers. Weakly differentiated distributions in vertical sections are typical of Ca, Fe, and Cu, whose concentrations vary insignificantly.

Associations of Chemical Elements

To identify groups of chemical elements (geochemical associations), which are interrelated because of their similar behavior in peat profiles, and to elucidate some hypothetical (unobvious) factors that control correlations between the variables, we have conducted principal-component factor analysis (Table 3). Note that the distinguished associations sometimes overlap, which is rather an advantage of this method, because the distribution and concentrations of elements may be controlled by many factors and processes.

According to the results of factor analysis, the peat deposits of the Bakchar and Kinzyarovskoe bogs are characterized by identical composition of the identified associations and the numbers of factors that explain 95.10 and 95.60% of the total variance, respectively. Factor 1, which most significantly contributes to the total variance, pertains to the geochemical association (Ca–Fe–Ti–Ni–Cu–Co–Cr–Ba–Cd–Sr), which comprises most of the studied elements. All elements of this association correlate with one another and with the ash content ($r = 0.70–0.90$ at $p = 0.00$). Moreover, all elements of this association show similar distributions in the vertical sections (high concentrations in the lower parts of the peat deposits, which consist of mesotrophic and eutrophic peats, and lower concentrations in the upper parts, which consist of oligotrophic peat).

Factor 2 in both peat deposits is characterized by high negative load on three components (Table 3). For the peat deposit of the Bakchar bog, this factor is characterized by the maximum load on the C/N ratio and lower ones on Pb and Mn. The Mn and Pb distributions in the profile of the peat deposit varies practically exactly conformably with that of the C/N ratio in the

Table 2. Statistical characteristics of chemical elements in the peat deposits of oligotrophic bogs in the southern taiga subzone of West Siberia

Element	Bakchar bog			Kinzyarovskoe bog			Tsentralnoe bog		
	Oligotrophic peat (n = 10)			Oligotrophic peat (n = 9)			Oligotrophic peat (n = 20)		
	$X(n)$ ± StDev	*Me*	*V*, %	$X(n)$ ± StDev	*Me*	*V*, %	$X(n)$ ± StDev	*Me*	*V*, %
Ca	970 ± 610	1164	63	945 ± 245	1014	26	956 ± 212	992	20
Fe	956 ± 391	926	41	503 ± 177	580	35	540 ± 48.12	574	39
Ti	44.44 ± 10.14	44.22	23	46.39 ± 24.55	43.17	53	62.47 ± 29.25	51.58	47
Sr	10.24 ± 4.11	9.39	40	5.72 ± 1.80	5.40	31	5.77 ± 1.85	6.06	32
Ba	13.31 ± 4.29	15.80	32	8.03 ± 1.79	7.80	22	15.31 ± 6.41	15.81	42
Mn	48.87 ± 41.93	36.26	86	40.45 ± 27.68	28.16	68	23.30 ± 42.51	8.76	182
Cu	0.43 ± 0.29	0.40	69	1.60 ± 0.64	1.61	40	1.47 ± 0.53	1.39	36
Ni	0.31 ± 0.08	0.29	23	0.64 ± 0.29	0.65	45	0.70 ± 0.36	0.65	50
Co	0.73 ± 0.17	0.68	23	0.16 ± 0.03	0.17	19	0.16 ± 0.06	0.18	30
Cr	1.09 ± 0.65	1.03	60	1.51 ± 0.38	1.55	25	0.93 ± 0.40	0.85	43
Pb	1.13 ± 1.63	0.43	144	1.11 ± 1.81	0.54	163	0.96 ± 1.43	0.33	148
Cd	0.09 ± 0.02	0.10	23	0.13 ± 0.05	0.15	38	0.08 ± 0.03	0.08	30
	Mesotrophic peat (n = 5)			Mesotrophic peat (n = 4)			Mesotrophic peat (n = 2)		
Ca	2131 ± 1560	1386	73	976 ± 271	897	29	276 ± 86	276	31
Fe	2252 ± 1069	1655	47	614 ± 165	620	27	412 ± 299	412	102
Ti	74.16 ± 27.15	71.42	36	32.52 ± 11.29	35.80	34	197.64 ± 61.03	197.64	31
Sr	23.81 ± 3.43	22.76	14	4.97 ± 1.40	4.96	28	26.31 ± 8.19	26.31	31
Ba	24.49 ± 7.38	28.00	30	6.91 ± 2.83	7.10	41	62.50 ± 17.68	62.50	28
Mn	22.39 ± 5.94	21.38	26	13.43 ± 11.1	9.50	85	2.62 ± 1.52	2.62	58
Cu	0.33 ± 0.14	0.33	40	1.33 ± 0.55	1.11	41	0.92 ± 0.29	0.92	32
Ni	0.55 ± 0.11	0.60	20	0.70 ± 0.24	0.73	33	3.16 ± 0.98	3.16	31
Co	1.15 ± 0.53	1.01	46	0.09 ± 0.07	0.08	78	0.42 ± 0.11	0.42	24
Cr	0.22 ± 0.12	0.27	54	1.14 ± 0.45	1.05	39	2.86 ± 2.31	2.86	81
Pb	0.28 ± 0.09	0.32	29	0.48 ± 0.17	0.52	34	0.50 ± 0.02	0.50	4
Cd	0.13 ± 0.02	0.13	15	0.15 ± 0.03	0.15	20	0.87 ± 0.36	0.87	41
	Eutrophic peat (n = 5)			Eutrophic peat (n = 14)			Eutrophic peat (n = 1)		
Ca	10250 ± 5314	10602	52	2866 ± 1640	2370	57	1092	–	–
Fe	9877 ± 5712	10431	58	1757 ± 1451	1255	83	910	–	–
Ti	340.47 ± 213	413.82	63	306.15 ± 90.78	346.36	85	327.60	–	–
Sr	73.67 ± 21.37	67.51	28	24.62 ± 21.52	9.06	88	60.06	–	–
Ba	106.40 ± 52.48	84.00	49	35.49 ± 26.64	10.51	75	136.5	–	–
Mn	72.91 ± 52.88	97.73	73	24.88 ± 13.75	13.28	55	9.10	–	–
Cu	4.26 ± 2.49	5.56	58	5.12 ± 4.66	1.33	91	1.46	–	–
Ni	2.81 ± 1.58	2.74	56	3.18 ± 3.22	0.84	101	4.37	–	–
Co	5.14 ± 1.90	5.64	37	0.78 ± 0.77	0.23	98	2.37	–	–
Cr	3.22 ± 2.18	3.25	68	2.89 ± 1.70	1.55	59	5.10	–	–
Pb	1.79 ± 1.38	1.75	77	0.89 ± 0.61	1.09	69	1.27	–	–
Cd	0.36 ± 0.14	0.25	18	0.23 ± 0.14	0.12	41	1.27	–	–
	Underlying rocks (n = 4)			Underlying rocks (n = 4)			Underlying rocks (n = 3)		
Ca	35150 ± 2920	35660	9	29590 ± 5056	28529	17	11549 ± 3278	11549	28
Fe	45773 ± 7107	44470	16	26200 ± 3775	26200	14	1900 ± 558	1933	
Ti	2321 ± 337	2250	15	2271 ± 183	2271	8	2279 ± 484	2279	21
Sr	406 ± 59	406	15	278 ± 36	285	13	262 ± 38.5	262	15
Ba	355 ± 72	360	20	290 ± 21	299	7	871 ± 92	871	11
Mn	897 ± 104	913	12	584 ± 55	612	9	624 ± 14	623	2
Cu	16.5 ± 2.5	16.0	15	83 ± 10.3	80	12	7.9 ± 1.9	7.9	24
Ni	39.3 ± 8.0	36.9	20	47.4 ± 2.2	47.4	5	17.1 ± 9.1	12.0	53
Co	18.8 ± 4.2	19.1	23	9.8 ± 1.9	9.8	19	13.1 ± 2.3	13.2	17
Cr	30.5 ± 22.5	23.0	74	38.1 ± 20.6	35.1	54	22.5 ± 2.4	14.8	16
Pb	17.8 ± 1.9	18.4	11	18.1 ± 3.8	18.1	21	14.8 ± 2.4	14.8	16
Cd	3.3 ± 1.4	3.3	41	5.2 ± 0.4	5.2	8	6.5 ± 0.8	6.5	12

X is the average concentration (ppm) of an element, StDev. is the standard deviation, *Me* is the median value, *V* is the variation coefficient; dashes mean that no statistical calculations were made.

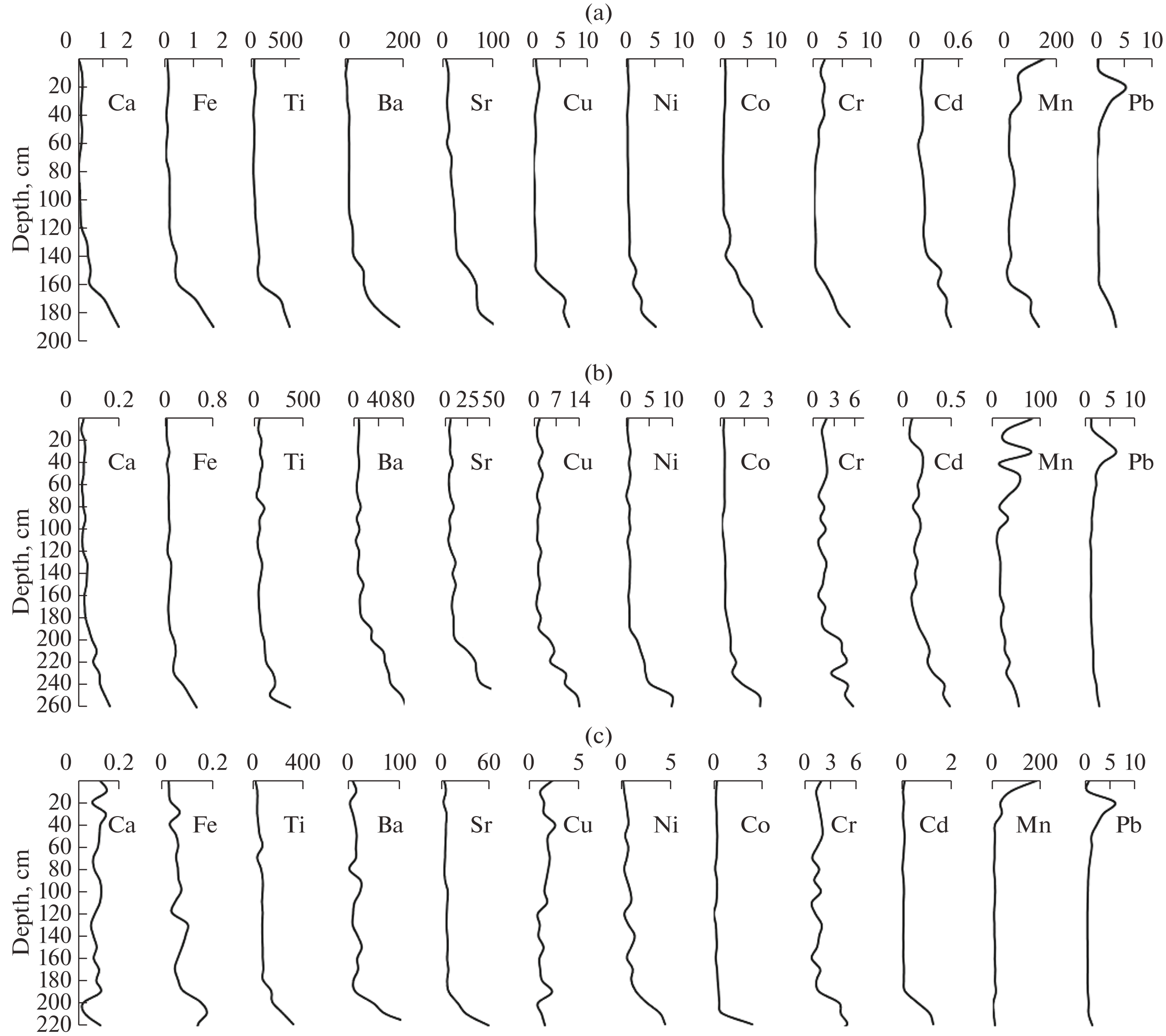

Fig. 4. Distribution of concentrations (ppm) of chemical elements with depth in the peat (per dry weight) of the peat profiles of (a) the Bakchar bog, (b) Kinzyarovskoe bog, and (c) Tsentralnoe bog. Calcium and Fe concentrations are given in %.

upper part of the profile, which is confirmed by correlations between these parameters ($r_{\text{Mn-C/N}} = 0.69$, at $p = 0.00$ and $r_{\text{Pb-C/N}} = 0.60$ at $p = 0.01$), with Mn and Pb also showing a strong correlation ($r_{\text{Mn-Pb}} = 0.55$ at $p = 0.01$). For the peat deposit of the Kinzyarovskoe bog, factor 2 reflects loads on the same components but with higher loads on Mn and Pb and lower onto C/N. No correlations were detected between the concentrations of the metals and the C/N ratio, as was mentioned above for the peat deposit of the Bakchar bog. Some similarities were found between the behaviors of Mn and Pb in the peat profile, and this is confirmed by a significant positive correlation ($r_{\text{Mn-Pb}} = 0.58$, at $p = 0.00$). Factor 3 shows a load only on Pb.

Factor analyses has yielded principally different results for the peat deposit of the Tsentralnoe bog (Table 3). For this deposit, three major factors were found, which collectively explain 89.0% of the total variation. Most of the studied parameters are significantly defined by factor 1 (whose contribution to the total variance is 58.25%). This factor pertains to the element association Ni–Ti–Cd–Sr–Ba–Cr. At the same time, a higher negative load on this factor was found for the C/N ratio. Factor 2 accounts for 13.5% of the total variance and reflects a high load on the association Ca–Fe–Cu. Factor 3 accounts for 10.6% of the total variance. A high load of this factor was determined for Mn. Factor 4 is associated with Pb, similar to the peat deposits of the Bakchar and Kinzyarovskoe bogs.

Table 3. Results of the factor analysis of the distribution of chemical elements with depth in the peat deposits

Variable	Dominant factors									
	1 (76.81%)	2 (14.52%)	3 (3.77%)	1 (77.50%)	2 (13.58%)	3 (4.51%)	1 (58.25%)	2 (13.47%)	3 (10.61%)	4 (6.67%)
	Bakchar bog			Kinzyarovskoe bog			Tsentralnoe bog			
Ca	**0.99**	–	–	**0.99**	–	–	0.33	**0.83**	–	–
Fe	**0.99**	–	–	**0.96**	–0.13	–0.20	–	**0.70**	**–0.66**	–
Ti	**0.99**	–	–	**0.96**	–	–	**0.97**	–	–0.13	–
Sr	**0.93**	0.31	–	**0.99**	–	–	**0.96**	0.12	–	–
Ba	**0.97**	–	–	**0.98**	–	–0.13	**0.95**	0.14	–	–
Mn	0.43	**–0.60**	–	–0.24	**–0.85**	0.29	–0.23	0.20	**0.77**	–
Cu	**0.98**	–	–	**0.94**	–	0.10	–0.10	**0.74**	0.30	–0.28
Ni	**0.98**	–	–	**0.96**	–	0.15	**0.98**	–	–	–
Co	**0.97**	–	–	**0.98**	–	–	**0.75**	0.38	0.13	–0.23
Cr	**0.96**	–0.20	–	**0.94**	–0.17	–0.24	**0.92**	0.20	–	0.11
Pb	0.41	**–0.65**	**0.53**	–0.39	**–0.73**	**0.54**	–0.13	–	0.30	**0.85**
Cd	**0.91**	–0.17	–	**0.96**	–0.17	–0.17	**0.97**	–	0.15	–
A	**0.97**	0.16	–	**0.97**	–0.10	–0.17	**0.97**	–	0.13	–
C/N	–0.41	**–0.87**	–	–0.47	**–0.63**	–0.23	**–0.81**	–	–0.25	0.11
% of explained dispersion	95.10			95.60			89.00			

Numerals printed in a semibold face are the principal components for each variable. dashes correspond to statistically insignificant loads.

DISCUSSION

The three studied bogs look similar, and their surfaces are currently covered by similar vegetation. However, our data indicate that the peat deposits are of different age, and the peat accumulation rates were different during the same time intervals. It should be emphasized that the geomorphological settings of the bogs in the landscapes are also different: the Bakchar bog is situated at a watershed area, the Kinzyarovskoe bog is constrained to a terrace above a floodplain, and the Tsentralnoe bog is hosted in an ancient watercourse. The bogs developed on underlying rocks of different lithochemical composition.

The peat deposits of the Bakchar and Kinzyarovskoe bogs developed according to the oligotrophic type of upland bogging (autochthonous type) (Karavaeva, 1982). The thick autotrophic peat layer was formed at the Kinzyarovskoe bog because the bog is constrained to a terrace above the floodplain. In a system of conjugated landscapes, such bog massifs are less geochemically autonomous than watershed bogs, and this predetermines stable mineral nutrition during a long period of time and is favorable for the accumulation of a thick peat deposit with a thicker layer of eutrophic peat. This feature was also identified at some other bogs of central setting in West Siberia (Archipov and Bernatonis, 2013). The structure of the peat deposit at the Tsentralnoe bog show features indicating an autochthonous bogging type (soil–ground bogging on light rocks) as a result of long-lasting surface flooding (Karavaeva, 1982). The lithology of the underlying sandy rocks ensured an intense drainage of atmospheric precipitation falling out on the surface and predetermined a very low rate of peat accumulation during the early evolution of this bog. Further flooding and the weakening of the drainage were associated with an increase in the peat accumulation rate. This gave rise to a peat deposit consisting mostly of oligotrophic peat with only very thin beds of auto- and mesotrophic peat in the bottom part of the peat deposit.

The peat deposits of the Bakchar and Kinzyarovskoe bogs were formed on rocks heavy in mechanical composition (carbonate loams and clays), and hence, the bogs developed with more abundant water and mineral nutrition, and thus clearly distinguishable beds of eutrophic, mesotrophic, and oligotrophic peat were formed. Conversely, the peat deposit at the Tsentralnoe bog was produced on sandy rocks poor in many chemical elements, and this was favorable for the development of oliotrophic bog vegetation, which does not necessarily require rich mineral nutrition, and hence, a peat deposit dominated by oligotrophic peat (86%) was formed.

The aforementioned circumstances under which the peat deposits were formed (geomorphological settings, the lithochemistries of the underlying rocks, and water and mineral nutrition) predetermined the individual stratigraphic features of each of the bogs and are fully reflected in the composition of their peat profiles. For example, our data on the ash contents of the peats fairly well correlate with the structure and characteristics of the water–mineral supply of the peat deposits, which systematically decrease from eutrophic to oligotrophic peats. At the same time, each of the peat deposits is characterized by their own ranges of these parameters. For example, the ash content of the eutrophic peats at the Kinzyarovskoe bog is lower than that of the eutrophic peat at the Bakchar bog. We believe that the main reason for this was the greater thickness of eutrophic peat layer at the Kinzyarovskoe bog, and this weakened the effect of the underlying rocks on the nutrition of the developing peat deposit, and this is correspondingly reflected in the ash contents of the peats. The ash contents of the bottom peats at contact with underlying rocks in the peat deposit of the Tsentralnoe bog are relatively high and comparable to the ash contents of eutrophic peat at the Bakchar bog. However, the ash contents of the oligotrophic peats, which are strongly dominant in the peat deposit of the Tsentralnoe bog, are relatively low. This confirms that the bog was fed mostly by atmospheric precipitation and very little supplied from the underlying rocks and nearby slopes.

In contrast to most geological bodies, which are dominated by mineral components, peats are dominated by organic material. The C/N ratios in the peat deposits of the Bakchar and Kinzyarovskoe bogs are characterized by similar trends: high C/N ratios occur in upper layers and correspond to ombotrophic conditions and low contents of inorganic matter in the peats. In the peat deposit of the Bakchar bog, the highest C/N ratios are constrained to the uppermost layer 0–40 cm, and those in the Kinzyarovskoe bog occur in the layer 40–80 cm. The C/N ratio decreases down the vertical section of the peat deposits, which provides evidence that the degree of peat decomposition correspondingly increases. Such variations are fairly typical of most oligotrophic bogs and are explained by the fast biocycling of nitrogen and slow carbon losses during peat decomposition under anoxic conditions (Biester et al., 2012). The peat deposit of the Tsentralnoe bog has higher C/N values, and these values vary not as significantly over the vertical section: they show no clearly pronounced peaks, indicating that the peat decomposition processes were drastically intensified and then deintensified, except only the bottom peat layers, in which the C/N ratio decreases. The nitrogen content weakly varies over the vertical section and increases only in the bottom layer, whereas the carbon concentration notably varies and tends to increase with depth.

All of the three peat deposits are currently fed mostly by atmospheric precipitation. This is evident from the similar concentrations of most chemical elements in the top parts of these peat deposits (Table 2). More significant differences in the concentrations of chemical elements are seen deeper in the vertical sections, with the transitions to the mesotrophic and then to eutrophic peats (Table 2). The elements whose variations are the most conspicuous are Ca, Mn, Fe, Sr, and Co, with their concentrations in the mesotrophic peats being two to four times higher at the Bakchar bog than in the analogous peats at the Kinzyarovskoe bog and six to nine times higher than at the Tsentralnoe bog. The differences between the peat deposits are even more contrasting for the eutrophic peats, in which the concentrations of the aforementioned elements are even greater (from three to eleven times) (Table 2).

The detected differences in concentrations of the chemical elements in the peat deposits are consistent with compositional features of the underlying rocks and with the mineralization (TDS) of the waters that provide nutrition to the peat deposits typical of the left- and right-hand banks of the Ob River (Savichev, 2010; Evseeva et al., 2012). For example, the supply of water and mineral compounds to the Bakchar bog is controlled by rocks of heavy mechanical composition: loams and clays with elevated carbonate concentrations (containing up to 13% calcium; Neishtadt, 1972). Compositional features of the underlying rocks on the left-hand bank of the Ob River predetermines the geochemistry of the bog and groundwaters, caused their higher total concentrations of dissolved salts, and consequently, the elevated mineralization (TDS) (Savichev and Kameneva, 2010). These natural conditions are responsible for a certain geochemical background favorable for the enrichment of the bog ecosystems in chemical elements (Arkhipov et al., 1988, 2000), which also pertains to the Bakchar and Kinzyarovskoe bogs. Our data indicate that Ca concentrations in the grounds underlying the Bakchar bog vary from 3.0 to 3.9%, those in the grounds beneath the Kinzyarovskoe bog are 2.0 to 3.6%, and those in the grounds beneath the Tsentralnoe bog are 0.8 to 1.6% (Table 2).

The peat deposit of the Bakchar bog is noted for a high Fe concentration in the peats, with these concentrations most likely controlled by the ubiquitous presence of this element in groundwaters and bog waters. The reasons for this are still not filly understood. On the one hand, high Fe concentrations in the bog ecosystems may be explained by the effect of Russia's largest Bakchar Fe deposit (Arkhipov et al., 1988), whose ores contain 30 to 46% iron. The bog is situated in the vicinities of the deposit. Other researchers are prone to think that iron passed into the bog waters from aluminosilicate rocks. When dissolved, iron and other chemical elements occur in the near-neutral gley environment with elevated concentrations of organic compounds, which are favorable for the enrichment of the elements (Ivanova et al., 2014). Still other scientists (Savichev et al., 2020) argue that the accumulation of iron and other chemical elements in the peat profile of a bog in the area is controlled by two adsorption reactive barriers: an upper sulfide redox barrier and a more complicated lower mechanical alkaline one. Thereby it is more probable to find high concentrations of various chemical elements at the lower barrier, which spans the lower part of the peat profile and the top part of the underlying ground.

The Tsentralnoe bog is located on the right-hand bank of the Ob River, and the Paiduginskaya Formation underlying this bog is dominated in the area by alluvial terrace rocks (sands and gravel–sands) of poorer chemical composition than that of loams and clays. For example, the composition of peat at the Tsentralnoe bog was affected by the lithological composition of the loose host rocks, dominantly sands, which is reflected in the water–mineral nutrition of the peat deposit, its structure, and concentrations and distributions of chemical elements in the peat profile.

To identify trends in the distribution of elements in the peat profile and elucidate the genesis of the peat deposits, we analyzed geochemical data with the application of factor analysis.

Factor analysis of data on the peat deposits of the Bakchar and Kinzyarovskoe bogs has shown that the distributions of most of the analyzed elements (Ca, Fe, Ti, Ni, Cu, Co, Cr, Ba, Cd, and Sr) depend on factor 1 (Table 3). Factor 1 is defined by strong correlation between the elements. This factor solution may be explained by some characteristics of the underlying rocks and, hence, the composition of the waters, which were the main supplier of elements for the accumulated peat deposits. In other words, this factor may reflect characteristics of the water–mineral nutrition of the peat deposits. Both peat deposits were formed at rich mineral nutrition. In the course of their upward developed, their links with the underlying rocks gradually weakened, and the concentrations of chemical elements in the newly accumulated peat layers decreased. This explains the detected trend in the distribution of these elements over the profiles of the peat deposits (Fig. 3). On the other hand, this distribution of chemical elements in the profile of the peat deposit may have also been caused by the effect of the bog microflora, which is an important factor affecting the distribution of chemical elements in various bog ecosystems in the eastern part of the Vasyugan bog (Savichev et al., 2018). The ability of some low-solubility compounds of Ca, Fe, and some REE to enrich peats is reportedly explained by the activation of the development of bog microflora under anaerobic conditions, ensuing shift in the carbonate equilibrium, and the precipitation of low-solubility Ca compounds. However, it is worth mentioning that this reasoning is applicable solely to the peat deposit of the Bakchar bog.

Factor 2 in both peat deposits is characterized by a strong negative load onto the C/N ratio and onto Pb and Mn. For the peat deposit of the Bakchar bog, the maximum load of this factor falls onto the C/N ratio, and this can be interpreted as an effect of diagenesis because of the decomposition of organic matter under anaerobic conditions, as has also been demonstrated by other researchers (Bergkvist, 1987; Derome and Nieminen, 1998; Biester et al., 2012). This process controlled by behavior of Mn and Pb. The distributions of these elements vary almost exactly conformably with the C/N ratio in the upper part of the profile, which is confirmed by correlations between these parameters ($r_{\text{Mn-C/N}} = 0.69$ at $p < 0.001$ and $r_{\text{Pb-C/N}} = 0.60$ at $p = 0.01$). This indicates that the Mn and Pb distributions in the peat profile of the Bakchar bog are controlled by the destruction of organic matter, and the redistribution of the elements in the peat profile may depend on the origin of organometallic complexes with organic ligands, as has been detected at other bogs worldwide (Biester et al., 2012; Vasilevich, 2018).

For the peat deposit of the Kinzyarovskoe bog, factor 2 reflects the load onto the same components as in the peat deposit of the Bakchar bog, but the load on Mn and Pb is greater and that onto the C/N ratio is smaller. On the one hand, the distribution of the three components reflects a general decreasing trend of the values with depth. On the other hand, the peaks of the Mn and Pb concentration and that of the C/N ratio occur at different depths and do not coincide with one another, which indicates that the behavior of the metals is controlled by processes not related to the decomposition of organic matter. No correlations have been detected between the metals and the C/N ratio, contrary to what was determined for the Bakchar bog. This factor most likely points to a role of redox processes, which control the behavior of the elements in the peat profile, with these elements accumulated in the upper parts of the peat profile, where conditions are dominantly oxidizing. Because of this, Mn (an element most susceptible to redox conditions) is characterized by the maximum load onto this factor. Manganese oxides can act as natural sorbents of some heavy metals (including Pb) (Kabata-Pendias and Pendias, 1989) in acidic environments, which is likely reflected by our data. Similarities between the behaviors of these elements in the peat profile are confirmed by the positive correlations ($r_{\text{Mn-Pb}} = 0.58$ at $p < 0.001$).

Factor 3 in the peat deposits of the Bakchar and Kinzyarovskoe bogs reflects only the load onto Pb, which is a chalcophile element, is one of the anthropogenic pollutants, is accumulated in the upper parts of peat profiles, and can be controlled by the atmospheric transport of this element, as has been demonstrated for various bogs worldwide (Shotyk et al., 1997, 1998; Weiss et al., 2002; Ukonmaanaho et al., 2004; Ferrat et al., 2012; and others). It can be hypothesized that this separated position from the other studied elements may only indicate that the current Pb supply to the peat deposits is controlled by principally other processes and sources, which may be not natural.

Results of the factor analysis of the peat deposit of the Tsentralnoe bog uncover a somewhat different distributions of chemical elements in the peat. Factor 1 exhibits high positive loads onto the element association Ni–Ti–Cd–Sr–Ba–Cr and a high negative load onto the C/N ratio. Note that elements of this association do not correlate with one another, i.e., their sources were different. Although the geochemical behaviors of the elements are different, their concentrations vary similarly to the variations in the C/N ratio. According to (Biester et al., 2012) covariations between concentrations of elements and the C/N ratio in a peat profile may indicate that the elements fell out with atmospheric dust, and these fallouts varied with time. For example, dry seasons, when the peat decomposition rate and mass losses were high, were characterized by smaller (but not greater) atmospheric dust fallouts. Considering the facto that the peat deposit of the Tsentralnoe bog was formed at dominant atmospheric nutrition, this interpretation is able to reasonably convincingly explain our data on correlations between the concentrations of the studied elements and the C/N ratio.

Factor 2 reflects a high load onto the Ca–Cu–Fe association. This association may reflect redox-independent processes of Ca and Cu dissolution and mobilization, including the uptake of these elements by plants (Lukashev et al., 1971; Muller et al., 2008; Biester et al., 2012). It is interesting that there are no correlations between the ash contents of the peats and their Ca and Fe concentrations, although these chemical elements are usually thought to be the dominant ash-forming elements. We believe that these elements were brought to the peat deposit biogenically, with peat-forming plants.

The effect of factor 3 most likely points to the opposite redox behaviors of Fe and Mn, because their loads onto this factor are opposite in sign. The high load of this factor onto Mn largely accounts for the elevated concentrations of this element in the upper parts of the peat deposit, which was accumulated under oxidizing conditions. The underlying rocks are generally depleted in Mn, and this element actively migrates under reducing conditions, depletes the peat deposit, and is accumulated in near-surface layers (Steinmann and Shotyk, 1997; Gallego et al., 2013), which is not the case with Fe. Similar to Fe, Mn is one of the most important elements of the geochemical processes because its oxides and hydroxides are active adsorbents of many trace elements.

Factor 4 shows a high load on Pb alone, similar to the two aforementioned peat deposits.

Analysis of the factor solution with regard to the detected features of the origin of the peat deposits led us to the following principal considerations. The peat deposit of the Bakchar bog contains higher concentrations of elements, particularly ash-forming ones (Ca and Fe), as well as Sr, Ba, Co, Cr, and Mn, than the peat deposits of the Kinzyarovskoe and Tsentralnoe bogs. However, these differences between the bogs are predetermined by the aforementioned regional features of the territories.

Although the peat deposits of the Bakchar and Kinzyarovskoe bogs differ in the concentration levels of chemical elements, their geochemical portraits reveal more similarities than differences. Both peat deposits consist of three stratigraphic units, and the only difference between them is a thicker eutrophic peat layer at the Kinzyarovskoe bog, which is predetermined by the setting of this bog in the landscape. Moreover, factor analysis has revealed an identical character of the geochemical associations and the number of factors explaining the similar contributions to the total variances. In fact, the elements studied in these peat deposits can be classified into two groups. The distribution of Ca, Fe, Ti, Ni, Cu, Co, Cr, Ba, Cd, and Sr in both peat profiles reflects, in our opinion, the general tendencies of the bog-forming process on heavy underlying rocks (clays and loams), which is controlled by the water–mineral nutrition and is associated with gradual oligotrophisation of bogs in the course of their evolution. Conversely, the Mn and Pb distribution is different from that of the aforementioned elements and is controlled, on the one hand, by reducing processes and, on the other, by the diagenetic transformation at the destruction of the organic matter.

Peat was accumulated at the Tsentralnoe bog in a principally different geochemical environment. The scarce mineral nutrition of the peat deposit predetermined the low ash content of the peats and their low concentrations of the chemical elements. Consequently, correlations between elements in the peats are different, as also are the associations of elements. The accumulation of such elements as Ni, Ti, Cd, Sr, Ba, and Cr proceeded simultaneously and was controlled by a single process, which was not related to the accumulation of Ca, Fe, and Cu; the latter elements formed another association. This was typical of the Tsentralnoe bog, in which the absence of an additional introduction of mineral components was associated with an active role of the biogenic factor in the accumulation of elements of this association.

A common feature of all three peat deposits, regardless of their genesis, the structure of the peat profiles, and geochemical circumstances, is similar trends in the behavior of Pb. This element behaved differently from the other elements and, hence, was recognized as an individual association. This may indicate that Pb supply to the peat deposits is now controlled by principally different processes and sources, which are likely not natural.

It is also worth mentioning the heterogeneous behavior of Fe in the peat profiles. Iron sometimes behaves as the main ash-forming element and is actively involved in the mineral nutrition, as at the Bakchar and Kinzyarovskoe bogs. In other situations, Fe manifests its redox characteristics and, hence, its concentrations in the peat deposit of the Tsentralnoe bog vary and are controlled by the biogenic factor. Differences between the geochemical behaviors of Fe in various environments have also been emphasized for others peat bogs (Lukashev et al., 1971; Steinmann and Shotyk, 1997; Weiss et al., 2002; Gallego et al., 2013).

CONCLUSIONS

The geochemical portraits of peat deposits are predetermined by the geochemical specifics of the areas. In spite of similarities in their vegetation, the studied bogs differ from one another in stratigraphic profiles and age, were formed on different landscape elements, and are underlain by rocks of different composition. The effects of these factors predetermined the different structures of the peat deposits (proportions of the thicknesses of their eutrophic, mesotrophic, and oligotrophic peat layers), differences in concentrations of chemical elements in the peats (peats on clayey and loamy underlying rocks bear higher concentrations of chemical elements than peats on sandy underlying rocks), and differently affected the geochemical associations of elements in each of the peat deposits.

Using factor analysis, we have identified a number of factors that explain, in our opinion, inherent relations and trends in the distribution of chemical elements in the profiles of the peat deposits. These factors are as follows: the endogenic supply of chemical elements from the underlying rocks and groundwaters (for Ca, Fe, Ti, Ni, Cu, Co, Cr, Ba, Cd, and Sr), the activity of the redox processes (for Mn, Pb, and Fe), redox-independent processes of the dissolution and mobilization of elements by plant roots (Ca, Cu, and Fe), the intensity of peat decomposition (for Mn, Pb, and the C/N ratio), waterlogging of the bogs (C/N ratio), and the supergenic introduction of Pb from the atmosphere, into which this element is brought owing the anthropogenic activities.

Our results demonstrate that it is necessary to take into account the aforementioned factors to geochemically accurately estimate the state of bog ecosystems and in the ecological monitoring of the state of the territory as a whole. Otherwise, the wide scatter of the concentrations of chemical elements may result in that the beginning of anthropogenic pollution is overlooked or, conversely, that the natural regional background is mistook for anthropogenic pollution.

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REFERENCES

S. I. Arbuzov, V. S. Arkhipov, V. K. Bernatonis, V. A. Bobrov, S. G. Maslov, A. M. Mezhibor, Yu. I. Preis, L. P. Rikhvanov, A. F. Sudyko, and A. I. Syso, "Average content of some trace elements in peats of southeastern West Siberian Plate," Izv. Tomsk. Politekhn. Univ. **315** (1), 44–48 (2009).

V. S. Arkhipov, and V. K. Bernatonis, Calcium and iron distribution in the vertical profile of peat deposits of the West Siberian taiga zone," Izv. Tomsk. Politekhn. Univ. Girdogeol. **323** (1), 173–178 (2013).

V. S. Arkhipov, and V. K. Bernatonis, "Manganese distribution in peat deposits of Tomsk region," Izv. Tomsk. Politekhn. Univ. Inzh. Geores. **326** (7), 27–35 (2015).

V. S. Arkhipov, V. I. Rezchikov, S. I. Sml'yaninov, and T. S. Myshov, "Trace elements in peat deposits of the Ob–Irtysh interfluve," Khimiya Tv. Topliva, **9**, 25–27 (1988).

V. S. Arkhipov, V. K. Bernatonis, and V. I. Rezchikov, "Distribution of iron, cobalt, and chromium in peatlands of the central part of Western Siberia," Euras. Soil Sci. **33** (12), 1265–1272 (2000).

B. Bergkvist, "Soil solution chemistry and metal budgets of spruce forest ecosystems in S. Sweden," Water Air Soil Pollut. **33**, 131–154 (1987).

H. Biester, Y.-M. Hermanns, and A. Martinez Cortizas, "The influence of organic matter decay on the distribution of major and trace elements in ombrotrophic mires—a case study from the Harz Mountains," Geochim. Cosmochim. Acta **84**, 126–136 (2012). https://doi.org/10.1016/j.gca.2012.01.00

M. Blaauw, "Methods and code for 'classical' age-modelling of radiocarbon sequences," Quant. Geochronol. **5**, 512–518 (2010).

J. Derome and T. M. Nieminen, "Metal and macronutrient fluxes in heavy-metal polluted Scots pine ecosystems in SW Finland," Environ. Pollut. **103**, 219–228 (1998).

Y. Eckstein, O. G. Savichev, and E. Yu. Pasechnik, "Two decades of trends in ground water chemical composition in The Great Vasyugan Mire, Western Siberia, Russia," Environ. Earth Sci. **73**, 7329–7341 (2015).

M. Ferrat, D. J. Weiss, S. Dong, D. J. Large, B. Spiro, Y. Sun, and K. Gallagher "Lead atmospheric deposition rates and isotopic trends in Asian dust during the last 9.5 kyr recorded in an ombrotrophic peat bog on the eastern Qinghai–Tibetan Plateau," Geochim. Cosmochim. Acta. **82**, 4–22 (2012).

J. L. Gallego, R. J. E. Ortiz, C. Sierra, T. Torres, and J. F. Llamas, "Multivariate study of trace element distribution in the geological record of Roñanzas Peat Bog (Asturias, N. Spain). Paleoenvironmental evolution and human activities over the last 8000 cal yr BP," Sci. Total Environ. **454–455**, 16–29 (2013). https://doi.org/10.1016/j.scitotenv.2013.02.083

GOST11306–83. Peat. Methods of Ash Determination (Izd. Standartov, Moscow, 1984) [in Russian].

L. I. Inisheva, and T. N. Tsybukova, "Ecological–geochemical assesment of peat of the southeastern West Siberian plain," Geograf. Prir. Resursy **1**, 45–51 (1999).

A. Kabata-Pendias, and H. Pendias, *Trace Elements in Soils and Plants* (CRC Press, 2010).

N. A. Karavaeva, *Swamping and Soil Evolution* (Nauka, Moscow 1982) [in Russian].

N. Ya. Kats, S. V. Kats, and N. I. Skobeeva, *Atlas of Plant Remains in Peats* (Nedra, Moscow, 1977) [in Russian].

V. A. Kovalev, *Swamp Mineralogical–Geochemical Systems* (Nauka i Tekhnika, Minsk, 1985) [in Russian].

P. Kuhry and D. H. Vitt, "Fossil carbon/nitrogen ratios as a measure of peat decomposition," Ecology **77**, 271–275 (1996).

I. V. Kur'ina and E. E. Veretennikova, "Influence of climatic changes on the evolution of the hummock–ridge swamp complex in the Holocene," Izv. Ross. Akad. Nauk, Ser. Geograf. **2**, 74–87 (2015).

O. L. Liss, L. I. Abramova, N. A. Avetov, N. A. Berezina, L. I. Inisheva, T. V. Kurnishkova, Z. A. Sluka, T. Yu. Tolpysheva, and N. K. Shvedchikova, *Swamp Systems of West Siberia and their Natural Significance,* Ed. by V. B. Kuvaev (Grif and K, Tula, 2001) [in Russian].

K. I. Lukashev, V. A. Kovalev, and A. L. Zhukhovitskaya, *Geochemistry of Lacustrine–Swamp Lithogenesis* (Nauka i Tekhnika, Minsk, 1971) [in Russian].

M. Mäkilä, T. M. Nieminen, H. Säävuori, K. Loukola-Ruskeeniemi, and L. Ukonmaanaho, "Does underlying bedrock affect the geochemistry of drained peatlands?," Geoderma **239–240**, 280–292 (2015). https://doi.org/10.1016/j.geoderma.2014.11.002

N. Malmer and B. Wallen, "Input rates, decay losses and accumulation rates of carbon in bogs during the last millennium: internal processes and environmental changes," *Holocene.* **14**, 111–117 (2004).

A. M. Mezhibor, S. I. Arbuzov, and L. P. Rikhvanov, "Accumulation and average contents of trace elements in the high–moor peat of Tomsk region (Western Siberia, Russia)," Energy Explor. Exploit. **27**(6), 401–410 (2009).

A. Mezhibor, S. I. Arbuzov, and V. Arkhipov, "Trace elements in peat bogs of Tomsk region (South Siberia, Russia)," Energy Explor. Exploit. **31**(4), 629–644 (2013).

D. V. Moskovchenko, "Biogeochemical features of the highland peats of West Siberia," Geograf. Prir. Resurs., **1**, 63–70 (2006).

J. Muller, M. Kylander, A. Martinez-Cortizas, R. A. J. Wust, D. Weiss, K. Blake, B. Coles, and R. Garcia-Sanchez, "The use of principle component analyses in characterizing trace and major elemental distribution in a 55 kyr peat deposit in tropical Australia: Implications to paleoclimate," Geochim. Cosmochim. Acta **72**, 449–463 (2008). https://doi.org/10.1016/j.gca.2007.09.028

M. I. Neishtadt, "Swamps of the Ob–Irtysh interfluve," *Natural Conditions of Development of the Ob–Irtysh Interfluve,* Ed. by G. D. Rikhter (IGAN, Moscow, 1972), pp. 322–346 [in Russian].

N. N. Pologova and E. D. Lapshina, "Carbon accumulation in peat deposits of the Bol'shoe Vasyuganskoe swamp," *Bol'shoe Vasyuganskoe Swamp. Modern State and Processes of Evolution,* Ed. by M. V. Kabanov (Inst. Optiki Atmosfery SO RAN, Tomsk, 2002), pp. 174–179 [in Russian].

V. V. Ponomareva and T. A. Plotnikova, *Methodical Recommendations on the Determination of Contents and Composition of Humus in Soils (Mineral and Peat)* (TsMP im. Dokuchaeva VASKhNIL, Leningrad, 1975) [in Russian].

R Core Team, R: A Language and Environment for Statistical Computing, *R Foundation for Statistical Computing* (Vienna, 2012). URL: https://www.r–project.org/ (accessed: 01.02.2019)

P. J. Reimer, E. Bard, A. Bayliss, J. W. Beck, P. G. Blackwell, C. Bronk Ramsey, C. E. Buck, R. L. Edwards, M. Friedrich, P. M. Grootes, T. P. Guilderson, I. Hajdas, C. Hatté, T. J. Heaton, H. Haflidason, A. G. Hogg, K. A. Hughen, K. F. Kaiser, B. Kromer, S. W. Manning, M. Niu, R. W. Reimer, D. A. Richards, E. M. Scott, J. R. Southon, C. S. M. Turney, and J. van der Plicht, "Intcal13 and Marine13 Radiocarbon age calibration curves 0–50.000 years calBP," Radiocarbon **55** (3), 1869–1887 (2013).

O. G. Savichev, "Geochemical indicators of swamp waters in the taiga zone of West Siberia," Izv. Ross. Akad. Nauk. Ser. Geograf. **4**, 47–57 (2015).

O. G. Savichev, and O. A. Kameneva, Spatiotemporal changes in the mineralization of waters in the Middle Ob Basin," Razvedka Okhr. Nedr, **11**, 67–70 (2010).

W. Shotyk, A. K. Cheburkin, P. G. Appleby, A. Fankhauser, and J. D. Kramers, "Lead in three peat bog profiles, Jura mountains, Switzerland: enrichment factors, isotopic composition, and chronology of atmospheric deposition," Water Air Soil Pollut. **100**, 297–310 (1997).

W. Shotyk, D. Weiss, P. G. Appleby, A. K. Cheburkin, R. Frei, M. Gloor, J. D. Kramers, S. Reese, and W. O. Van der Knaap, "History of atmospheric lead deposition since 12,370 ^{14}C yr BP from a peat bog, Jura Mountains, Switzerland," Science **281**, 1635–1640 (1998).

P. Steinmann and W. Shotyk, "Geochemistry, mineralogy, and geochemical mass balance on major elements in two peat bog profiles (Jura Mountains, Switzerland)," Chem. Geol. **138**, 25–53 (1997).

V. A. Stepanova, O. S. Pokrovsky, J. Viers, N. P. Mironycheva-Tokareva, N. P. Kosykh, and E. K. Vishnyakova, "Elemental composition of peat profiles in western Siberia: Effect of the micro-landscape, latitude position and permafrost coverage," Ap. Geochem. **53**, 53–70 (2015). https://doi.org/10.1016/j.apgeochem.2014.12.004

L. Ukonmaanaho, T. M. Nieminen, N. Rausch, and W. Shotyk, "Heavy metal and arsenic profiles in ombrogenous peat cores from four differently loaded areas in Finland." Water Air Soil Pollut. **158**, 277–294 (2004).

R. S. Vasilevich, "Major and trace element compositions of hummocky frozen peatlands in the forest–tundras of northeastern European Russia," Geochem. Int. **56** (12), 1158–1172 (2018).

E. E. Veretennikova,"Content and distribution of chemical elements in the peats of the southern taiga subzone of West Siberia," Geograf. Prir. Resursy **2**, 89–95 (2013).

E. E. Veretennikova, "Lead in the natural peat cores of ridge–hollow complex in the taiga zone of West Siberia," Ecol. Eng. **80**, 100–107 (2015). https://doi.org/10.1016/j.ecoleng.2015.02.001

D. Weiss, W. Shotyk, E. A. Boyle, J. D. Kramers, P. G. Appleby, and A. K. Cheburkin, "Comparative study of the temporal evolution of atmospheric lead deposition in Scotland and eastern Canada using blanket peat bogs," Sci. Tot. Environ. **292**(1–2), 7–18 (2002).

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