

Positive Uranium Anomalies in the Peatlands of Humid Zone: A Review

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Abstract—In recent years, geologists have found peatlands extremely rich in uranium. They can be considered an example of the efficient operation of natural organic geochemical barriers in the humid zone. They also open up the possibility of determining the age of these peatlands by the isotopic $^{230}\text{Th}/^{234}\text{U}$ method. The deposition of uranium in peat is due to the U(VI) bioreduction controlled by several geochemical factors: the composition of organic matter and soil solution, the redox potential, and the capacity of uranyl ions to make complexes with organic ligands. By the nature of uranium enrichment, peatlands can be subdivided into two groups: (a) peatlands enriched in uranium carried by soil and groundwater from peripheral sources and (b) peatlands enriched in uranium from underlying uraniferous rocks. The data on geography, genesis, and physicochemical conditions of positive uranium anomalies in peatlands of the humid zone are collected and analyzed in this review.

Keywords: biogeochemistry of uranium, positive uranium anomalies, reduction of uranium, U and Th isotopes, the age of peat

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INTRODUCTION

The mineral phase of peats depends strongly on the chemical and mineralogical composition of underlying deposits. Depletion or enrichment of bedrock in chemical elements are considered as negative (in case their content in peat ash is below the lithosphere clark) or positive (in the other case) peat anomalies. Deposits enriched in particular chemical elements in unstable minerals provide the material for forming positive anomalies in the nearby peat massifs.

In practical and theoretical respects, strong positive anomalies of uranium in peatlands of the humid zone are of particular importance. They were discovered as long ago as in the 1950s. In the early 1980s, the development of U peatland started in the northeastern part of Washington state, USA, as a source of uranium ore [35]. Field geologists often find peatlands with the balance uranium ore content [12, 34, 43].

Discoveries made by geologists may be very useful for soil scientists and geochemists as vivid examples of efficient work of natural geochemical barriers in peatlands in the humid zone. Their detailed investigation permits revealing the specificity of functioning geochemical barriers in U peatlands. These are sorption barriers, when uranium is deposited due to sorption by organic complexes; reductive barriers, when uranium is deposited in mineral phases U(IV); or mixed barriers, when uranium is deposited in different forms.

The aim of this study is to collect and to analyze data on geography, genesis and physico-chemical conditions of the formation of strong positive anomalies of uranium in peatlands of humid zone, as well as information on their age.

GENESIS OF URANIUM-CONTAINING PEATS

Geologists estimate the size of uranium positive anomalies in peatlands according to the uranium reserves expressed in tons U per a deposit.

In the Russian Federation and other countries of the northern hemisphere, hypotaxic uranium deposits are located only in the areas with humid climate. Uranium reserves in the deposits of humid regions in the USA, Sweden, and Great Britain vary from 100 kg in a thin organic-rich layer of soils in the vicinity of a uranium-bearing spring to 500 tons in mineralized valley sediments (calculated for an outlined deposit). Fig. 1 shows locations of some strong positive uranium anomalies in peats of the Earth humid areas.

Geochemists are used to assess positive anomalies of uranium and other elements in the form of element concentration in mg/kg and concentration clark (CC), i.e., the ratio of the element content in ash to its clark in the lithosphere (relative abundance) [13]. Uranium clark is equal to 2.3 mg/kg in the lithosphere [4]; it is equal to 3.0 mg/kg in the world soils;

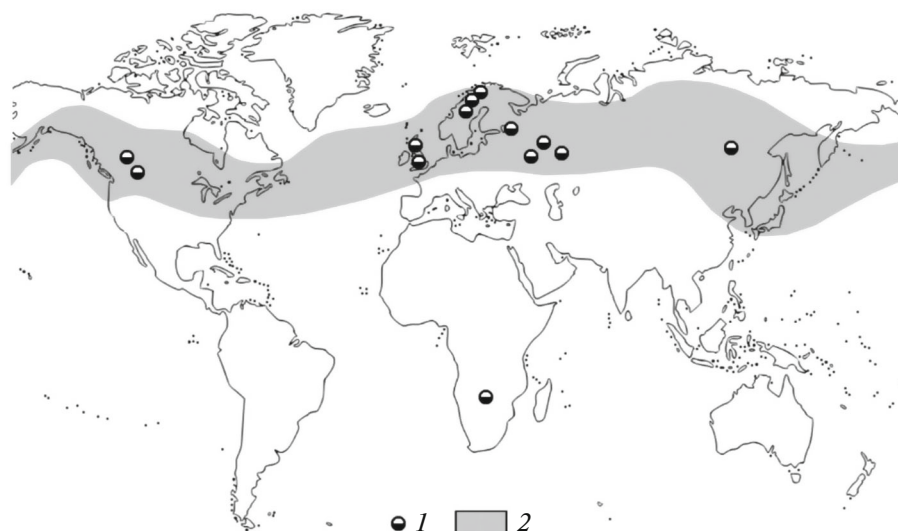


Fig. 1. The scheme of world distribution of surface deposits, according to [12]. Designations: (1) peatlands and lacustrine-alluvial deposits enriched in organic residues; (2) humid climatic zone of the Earth.

and the average uranium content in European soils constitutes 2.4 mg/kg [27]. Uranium supposedly continues to accumulate at present, this process being reversible, as uranium may be oxidized and mobilized in a drying bog in a dry summer.

Peats may be subdivided in two groups by the genesis of their enrichment with uranium. The first group includes peat enriched in uranium that is brought by soil and groundwater flows. The second group encompasses peat enriched in uranium from the underlying rocks. These two types may coexist within one large bog [12]. Peatlands of the first type are often formed on sedimentary rocks, and they are typical of plains. Peatlands of the second type are usually formed on magmatic rocks in mountainous areas, e.g., granitoids rich in uranium.

Two types of uranium-rich peatlands differ noticeably in the modes of U occurrence. Ion-sorption forms of U in association with organic matter and newly formed reduced uranium compounds predominate in uranium-bearing peatlands acting as a reductive barrier on the way of soil- and groundwater flow. In peatlands formed directly on uranium-bearing deposits, in addition to these forms, particles of uranium-containing accessory minerals inherited from parent rocks are preserved.

THE ROLE OF PLANTS IN THE URANIUM ACCUMULATION IN PEATS

Data on the uranium content in plants are very controversial. According to Perel'man [13], uranium CC is equal to 0.2 in plants. There are data about a more intense consumption of uranium by plants, ranging from 0.5 to 4.4 mg U/kg ash [7], i.e., CC ~ 1. According to Hawkes and Webb's review [15], the

average uranium content in soil and in plant ash averages 1 and 0.6 mg/kg, respectively, with CC being equal to 0.6.

Our data on the uranium content in peat composed mainly of mosses testify to the moderate biological accumulation of this element. In the Khibiny-Lovozero province, uranium CC constitutes 0.6–0.8 [2], which is typical for elements of moderate biological accumulation [13]. An increase in the total uranium content usually raises its concentration in mosses [2].

Uranium differs of another actinide, i.e., thorium, in its biophilic properties. Puzanov et al. [14] studied the content of U and Th in mountainous-meadow and mountainous-forest soils of the northern Altai region. The Th : U ratio differs noticeably in soddy and underlying horizons. In soddy horizons, it constitutes 3.1 on average, and it is equal to 4.1, in the underlying horizons. An elevated content of uranium in the soddy horizon may be related to its higher biological consumption as compared to thorium.

Nevertheless, the biological mechanism of uranium accumulation at the peat surface is less important than its accumulation in the bottom part of peatbogs.

BIOGEOCHEMISTRY OF URANIUM

Uranium is of the varying valence, with its main oxidation degrees being +4 and +6. Uranium forms (oxidation degree and the type of ligands in water) influence the physico-chemical processes and uranium mobility in the supergenesis zone. These parameters also control the element sensitivity to the redox conditions of the environment. In oxidative medium, uranium mainly occurs in the form of U(VI) ion, i.e., uranyl (UO_2^{2+}), which is labile in a wide range of geo-

chemical conditions [1, 13, 16]. U(VI) is reduced (either abiotically or microbiologically) to the low-soluble U^{4+} ion, which precipitates from the solution in the form of uraninite (UO_2) [36] or other non-uranite U(IV) compounds [17]. They control uranium mineralogy in peats.

U(VI) bioreduction is controlled by various geochemical factors. They include the composition of organic matter and soil solution, variation of charge and redox potential, the capacity of uranyl ion to complexing with ligands, as well as the activity of metal-reducing microbes.

The Role of Organic Substance

Organic substance plays an important role in fixing uranium in peat soils. The role of humates is of particular importance. They represent a complicated mixture of organic compounds, which influence significantly physical, chemical and biological processes in soils [29]. Humates contain loci enriched and depleted in electrons; they are responsible for electron supply and their acceptance, which makes them very redox-active, capable of participating in electron-transfer reactions [24, 29]. Thus, humic substances facilitate the electron transfer from the microbial metabolism products to metals, U(VI), in particular, with the formation of low soluble oxides (UO_2).

Let us enumerate the aspects of organic substance influence on uranium accumulation in a peat massif.

(1) Humus acids can form complexes with U(VI) [25], promoting uranium leaching from the parent deposit.

(2) Organic substance fractions available to microorganisms, such as lactate, provide the source of energy necessary to reduce U(VI) to U(IV) [29].

(3) Humus acids serve as an electron shuttle upon bacterial reduction U(VI) [24, 29]. Humic substances accept electrons from microbial metabolites and transfer them to metals with the variable oxidation degree [21, 29]. Bacteria *Shewanella alga*, *Geobacter metallireducens* and *Geobacteraceae* accelerate the electron transfer to uranium (VI). The velocity of uranium reduction rises significantly in the presence of humic substances in the system.

Some cations suppress the biological reduction of U(VI). The role of humates was investigated in laboratory kinetic tests in the presence of Ca^{2+} and Ni^{2+} ions, which suppress the biological reduction of U(VI) [24]. Under highly anaerobic conditions, humic substances raise the U(VI) reduction velocity up to 10 times and mitigate the toxic effect of Ni^{2+} on microorganisms. Humic acids are more efficient than fulvic acids in U(VI) reduction. This effect is attributed to the capacity of humates in assisting the electron-transfer reaction and complexing with Ni^{2+} and Ca^{2+} ions. Field tests attested to a substantially higher velocity of U(VI)

reduction after introducing humic acids to groundwater. Complexing with the reduced U(VI) raises the uranium oxidation velocity [24].

The Role of Uranium Reducing Microorganisms

Uranium reduction is a biological process requiring organic substance as an energy source and biota forming enzymes that catalyze the reduction process. The effects of microorganisms from the gram-negative *Geobacter* and *Shewanella* spp. and gram-positive *Desulfitobacterium* spp. bacterial groups are well known. In the model test, five different *Desulfitobacterium* spp. isolates have reduced 100 μ MU(VI) to U(IV) in less than 10 days, whereas no U(IV) sediment has been formed in the abiotic control test with killed bacteria [22].

Kinetics of U(VI) microbial reduction depends strongly on the type of uranyl ligands. Labile uranyl complexes ("free" hydrated, hydroxide, or uranyl organic compounds) represent the biologically available fraction U(VI) [40]. Bioreduction velocity decreases in the presence of dissolved inorganic carbon and Ca^{2+} because of the formation of stable Ca-uranyl-carbonate complexes, which are more stable to reduction and unavailable to bacteria due to low affinity to the cell membrane [18, 42].

Uranium toxicity to *Shewanella putrefaciens* bacteria is explained by bioreduction inhibition when bioavailability U(VI) reaches its maximum. Vitality of *S. putrefaciens* bacteria depends more on uranyl forms than on the total concentration of dissolved uranium as a toxicant.

The results of bacterial vitality analyses prove that the uranium toxicity is the main reason for stopping bioreduction upon a high concentration of bioavailable uranyl-carbonate particles. Under certain geochemical conditions, uranium becomes toxic for bacteria, which adversely affects its reduction and the formation of stable sediments. Although some bacterial species are able to keep growing cells using U(VI) as the terminal acceptor of electrons in the course of anaerobic respiration [30, 38], uranium appears to be toxic for many microorganisms [28].

Uranyl UO_2^{2+} is the most reducible uranium fraction in soil solutions. However, too high concentration of bioavailable uranyl in the solution is toxic for a number of metal-reducing bacteria [16]. Thus, even in a simple system (with the absence of other terminal acceptors of electrons except for U(VI)), the velocity of biological reduction depends on the environment geochemistry controlling the biological availability and toxicity of U(VI).

Since the metal toxicity depends on the form of the dissolved metal rather than on its total concentration, uranium toxicity for aquatic organisms is related to the concentration of UO_2^{2+} ions in water and not that of UO_2OH^+ [32, 33].

Such ligands as carbonates [19, 32, 41], phosphates [23], sulfates [32] and the dissolved organic carbon [39] mitigate the uranium toxicity by decreasing the concentration of UO_2^{2+} and UO_2OH^+ . Ca^{2+} , Mg^{2+} and H^+ cations lower the uranium toxicity because of the competition for organic ligands with uranyl complexes [16].

PEATLANDS ENRICHED IN URANIUM BROUGHT WITH SOIL AND GROUNDWATER

The content of uranium in uranium-bearing peats in Sweden reaches 30000 mg/kg (in ash), being controlled by metal concentration in ground- and surface water as well as by the organic substance amount in the sediments [12]. CC value reaches 10 000 in the local peat anomalies [35].

Uranium is accumulated not in any bogs. This is clearly seen from the comparison Th : U ratios in peats of upland and low moors in Tomsk oblast [8]. With the low content of actinides in the upland moor peats (less than 0.4 mg/kg of dry matter), the average ratio Th : U = 4.3, which is close to the clark ratio. However, in low moor peat (with the actinide content more than 0.4 mg/kg of dry matter), the ratio Th : U decreases sharply to 0.44 due to the enrichment with uranium. As a rule, uranium is accumulated on the lowland peat due to its ingress with the groundwater.

Peat deposits in the Washington and Idaho US states may serve as an example of U-rich peat. The most of the lowland area there is covered by weakly drained glacial, glacial-alluvial and glacial-lacustrine sediments. U-peat soils develop in places, where groundwater flowing to the river valleys comes across a geochemical barrier, with uranium precipitating [12].

In bogs of the western Sierra Nevada, the uranium content in the soil- and groundwater decreased by a factor of ten after the water flow passed a swamped meadow [40]. Uranium content in peat depends on the "cross-section" dimensions of the U water flow, the content of uranium in it and the efficiency of uranium retention by peat.

Uranium is accumulated in the bottom part of peat as well as in the underlying parent rock always with gley features. With the full water saturation, a reductive barrier is formed there due to oxygen deficit, presence of organic matter available to microorganisms and activity of metal-reducing bacteria. As a result, U(VI) is reduced to U(IV) in minerals, where uranium is safely deposited; however U(IV) minerals are preserved in peat only till its drying.

The detailed studies on the distribution of heavy metals in the peat massif of 7.5 m thick in the Ob and Tom rivers interfluvium elucidated the leading role of redox zonality in the uranium accumulation. Only the bottom layer of peat at a depth of 7.0–7.5 m and the underlying gleyed loam layer at a depth of 7.5–8.0 m are enriched in uranium (up to 9–10 mg/kg); whereas its concentration was only 0.07–0.56 in the overlying

peat layer [6]. The authors truly relate the uranium accumulation to the reducing conditions in the bottom peat layer. Note that in swamps of British Columbia province, Canada, the main uranium deposits are found not at the surface but deeper than 1.5 m [20].

Redox conditions in peat soils show a strong variability in time, which complicates distinguishing the oxidation and reduction zones in the soil profile. Nevertheless, the following regularity is traced: the medium is more reducing in the lower part of the massif (where uranium is fixed) than in the upper part of peat [9]. The reductive barrier for uranium operates at $\text{Eh} < 200$ mV and $\text{pH} > 6$ according to the pH~Eh diagram of the principle aquatic uranium complexes. U(IV) minerals, which are revealed in some U-peats of humid zones are deposited at this barrier [1].

Thus, under reducing conditions, uranium accumulation is provided by the activity of anaerobic bacteria, in particular, sulfate- and metal-reducing bacteria with the participation of organic substance as an energy source for reduction processes [3, 5].

PEATLANDS ENRICHED WITH URANIUM FROM UNDERLYING U-ROCKS

Magmatic rocks (granites, above all) and uranium-containing sedimentary rocks [12, 26, 37] are the principal lithogenic uranium sources in peats of humid regions [12, 26, 37]. Most of uranium anomalies are confined to peat formed immediately on the deposits enriched in uranium (5 mg/kg). High fracturing of rock and unstable forms of uranium contained in it favor the formation of strong U anomalies in peats.

For example, let us consider the uranium distribution in Sirovinka and Orogochi peatlands, Vitim-Karenga region, Transbaikalia. These U-peats have been formed immediately at the surface of uranium-containing rocks. The principal ore-like formations developed in the active soil-peat layer of the permafrost, which thaws in summer season. Light- and dark-brown peat with clay and sand admixture is found in the upper part of the ground massif.

Mineralogical and geochemical studies included X-ray phase quantitative analysis using X, PertPRO MPD (PANalytical) diffractometer. To characterize the microstructure of fine mineral systems, to identify microphases and to determine the actual composition and structure of minerals, as well as to reveal their location specifics in rocks, which influence the degree of uranium extraction, the transmitting and scanning electron microscopy was applied. The scanning electron microscope Tesla BS-301 (Slovenia) was used equipped with the X-ray dispersion spectrometer, which is capable to register chemical elements starting with Na and to determine U concentration $>0.8\%$. Micro-X-ray-spectral (microsound) analyzer JXA-8100 by JEOL (Japan) with energy dispersion device Inca

Table 1. The bulk chemical composition of uranium-containing inclusions in peatlands Sirotinka and Orogochi, %

Spectrum	O	Al	Si	P	S	K	Ca	Ti	Mn	Fe	Zn	Sn	Ce	Nd	Pb	Th	U
002	44.05	9.84	22.39	—*	2.13	0.81	5.58	0.65	—	6.57	—	—	—	—	—	—	7.59
006	47.09	16.77	22.82	—	1.77	0.98	2.16	0.52	—	3.99	—	—	—	—	—	—	3.91
006-a	44.68	13.71	21.50	—	1.38	1.05	4.30	—	—	8.04	—	—	—	—	—	—	5.36
009	40.44	3.95	14.28	2.02	2.37	1.00	8.15	—	—	25.05	—	—	—	—	—	—	2.74
012	35.18	4.01	7.72	—	—	—	—	—	—	53.10	—	—	—	—	—	—	—
017	39.82	8.09	14.61	1.53	2.11	0.42	9.08	0.60	1.16	9.44	4.11	—	—	—	—	—	8.05
020	45.09	14.72	20.72	—	1.48	0.37	6.32	—	—	6.95	—	—	—	—	—	—	4.35
024	25.88	—	4.28	10.23	—	—	1.64	—	—	0.06	—	—	23.51	9.46	—	9.39	15.56
026	42.60	5.68	21.24	—	4.21	1.55	4.48	—	—	9.04	—	—	—	—	—	—	9.84

* Dash designates the undetectable values.

Energy 400 (Oxford Instruments, Great Britain) was also used.

The mineralized ore part contains surface almost nonradioactive ore with the uranium content ranging from the first hundredths parts of percent to 1–2%. Geochemical specifics of the ore-containing soils are formed by a number of heavy metals with the concentrations above their clarkes. The maximal concentrations of heavy elements, mass %, (in respect to their concentration clarkes in clay deposits, in parentheses) are: U ~ 0.3 (774), Mo ~ 0.004 (13.6), Pb ~ 0.004 (2), Th ~ 0.005 (4.3), Ce ~ 0.03 (4.6), Nd ~ 0.006 (2.4); the ratio Th : U is low: 0.02.

The mineral composition of the ore part of these peat soils reflects the composition of parent granitoids, as the source of U. The soil-forming minerals are mainly represented by quartz and K–Na feldspars, their total content reaching ~50% of the mass of soil-forming mineral phases. Clay minerals are represented by montmorillonite (>30%), illite (1–5%), and chlorite (1–3%). Goethite is found in U-peats of Sirotinka and Orogochi peatland along with the inclusions of sulfides, which attests to the non-equilibrium redox environment.

The chemical composition of some inclusions enriched in U was determined (Table 1). Spectrum 002: plant residues in soils, enriched in U. Spectrum 006: a spherical neoformation composed of coal substance and phyllosilicates; the soil ore-containing horizon. Spectrum 006-a: a fragment of spherical neoformation composed of coal matter. Spectrum 009: the contact between porous coal matter and fine-grained fine-platy uranium-containing aggregate of hydrous aluminum phyllosilicates saturated with organic substance. Spectrum 012: bacterial residues saturated with Fe hydroxides. Spectrum 017: organic substance enriched in U and associated with hydrous aluminum phyllosilicates and possibly with sulfides. Spectrum 020: gel-like drop-shaped high soluble formations enriched in U localized on the surface of hydrous aluminum phyllosilicates enriched in organic matter.

Spectrum 024: a tabular-shaped rounded particle of an accessory monazite rich in Ce, Nd, Th, and U. Spectrum 026: a shell-like neoformation composed of organic substance (possibly, flora and fauna remnants) and layered aluminosilicates with a high content of U and S.

As is seen from Table 1, various accessory minerals containing uranium and thorium are preserved in peat soils, which proves their inheritance from the parent granitoids. Accessory minerals are represented by titanite, zircon, monazite, rutile, anatase, fluorite apatite, ilmenite, etc. Monazite particles are enriched in Ce up to 21.5% and in Th up to ~8%, with the content of U in zircon crystals reaching 0.5%.

Proceeding from the results of electron-microscopy analysis, uranium for the most part is concentrated in the X-ray amorphous phase bound to multi-element vitreous gel particles (Fig. 2). Uranium is also concentrated in plant residues, the organic substance of which usually showing a cellular dendritic structure; here, U content reaches 2%. Uranium is also accumulated in spherical formations, i.e., soil concretions of 200–500 µm in size, as well as in fine aggregates of hydrous aluminum phyllosilicates associated with films of organic substances sometimes with the inclusions of sulfides. In the mineralized part of peat, high-dispersed minerals of uranium proper are also present, i.e., uranium oxides, ningyoite, more rarely coffinite, localized mainly in organic-silicate amorphous substance and between scales of phyllosilicates.

THE AGE OF U-PEATS

Soil scientists usually determine the age of soils (peats, in particular) by radiocarbon method according to the content of carbon isotopes [10]. For peats enriched in uranium, it appears possible to determine the age independently by the $^{230}\text{Th}/^{234}\text{U}$ method [11, 46].

Dating by uranium is widely used for age reconstructions in Quaternary marine and continental deposits over the last 500 thousand years [27]. This is

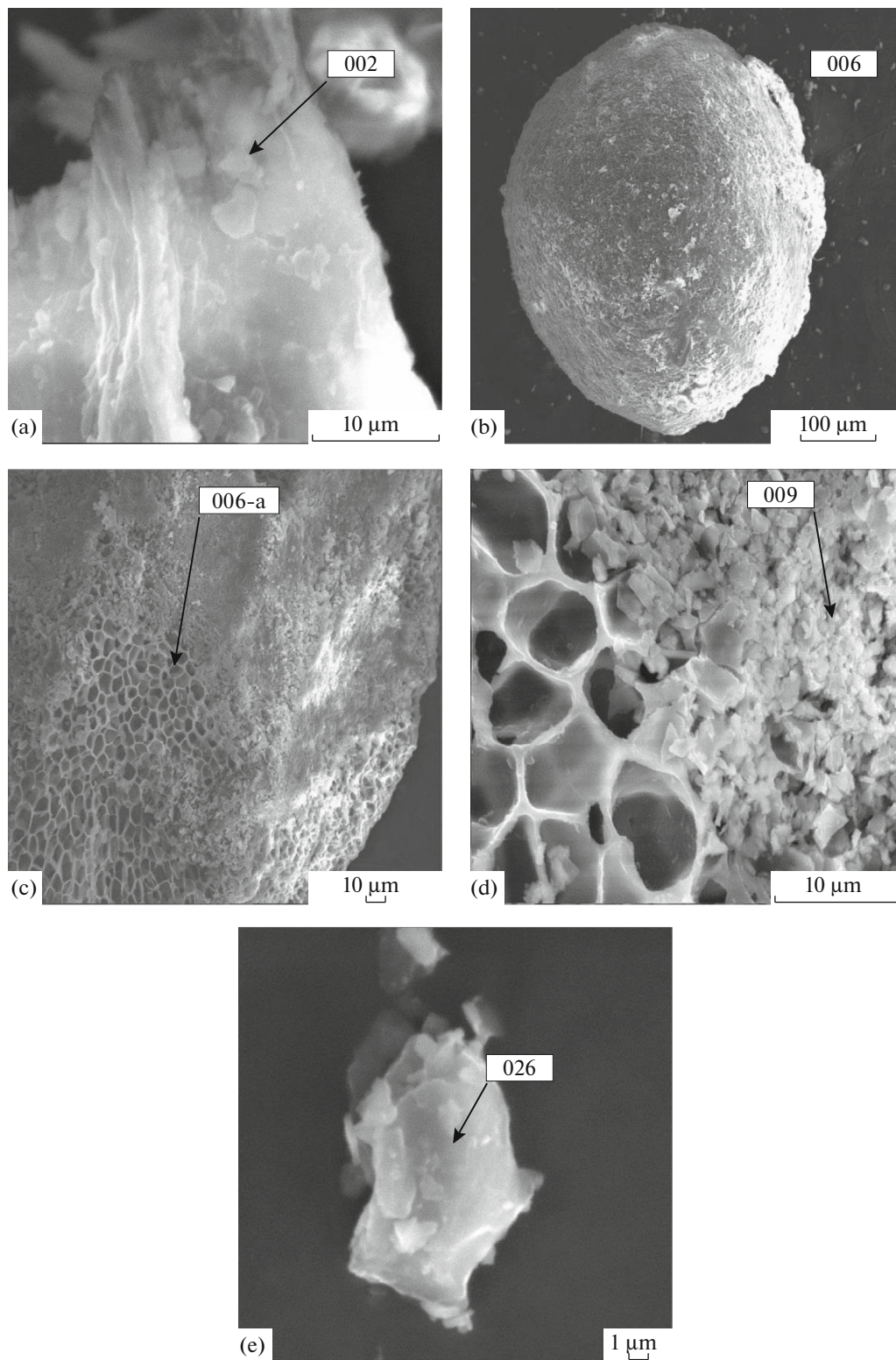


Fig. 2. Microphotographs of uranium-containing inclusions in peats Sirotinka and Orogochi: (a) plant residue in soils enriched in U (spectrum 002); (b) spherical body composed of coaly matter and hydrous aluminum phyllosilicates; the soil ore-containing horizon (spectrum 006); (c) fragment of a spherical pedofeature composed of coaly matter (spectrum 006-a); (d) contact between porous coaly matter and fine-grained thin platy uranium-containing aggregate of hydrous aluminum phyllosilicates saturated with organic substance (possible, flora and fauna remnants) and layered aluminosilicates with a high content of U and S (spectrum 026).

also possible for peats, which accumulate uranium in the course of their formation and then being preserved in a closed system.

The method of $^{230}\text{Th}/^{234}\text{U}$ dating is based on the ^{234}U radioactive decay sequence. ^{238}U isotope is decomposed via various daughter radioactive products to a stable ^{206}Pb [46]. Geochemical processes affect uranium and thorium in different ways due to their chemical differences. Unlike thorium, which is insoluble under exogenous environment, uranium is easily dissolved to enter the soil- and groundwater. Geochemical separation of uranium and thorium occurs.

^{238}U decomposition chain is disturbed, and geological clock registers a starting point. Starting from this point, ^{230}Th with half-life period 75380 years is accumulated due to the decay of ^{234}U (half-life period 245500 years) [23, 46].

To use $^{230}\text{Th}/^{234}\text{U}$ method, the systems should keep closed for both elements during the whole lifetime. This method, as any other, has its own restrictions, as the elements are of different origin. Firstly, ^{234}U at the capture moment may occur not in equilibrium with its predecessor ^{238}U . Secondly, in the course of peat formation, ^{230}Th may enter it, and its amount should be taken into consideration using the ^{232}Th isotope genetically unrelated to ^{238}U . To consider the matter contamination with ^{230}Th , the fractions differing in chemical properties are analyzed and the isochronous diagram is built in coordinates $^{230}\text{Th}/^{232}\text{Th}$ – $^{230}\text{Th}/^{234}\text{U}$ ratios. Thirdly, peat during its life may undergoes drying periods, which increase the mobility of uranium and result in its leaching.

Using the α -spectrometric determination of $^{230}\text{Th}/^{234}\text{U}$ and $^{230}\text{Th}/^{232}\text{Th}$ ratios, it is possible to date samples aging from several to 350 thousand years, and using mass-spectrometry with thermal ionization, the samples dating back from 10 to 550 thousand years ago [46].

The age of uranium deposits is believed to comply with the beginning of the peat massif formation. Thus, it appears possible to date U-peat age, which is important for clearing up its genesis. Vogel and Kronfeld [45] were the first to publish the uranium dating results for a series of U-peats in Europe. Van der Wijk and coauthors investigated several sites in the north-western Europe and confirmed good agreement between the radiocarbon age and $^{230}\text{Th}/^{234}\text{U}$ dating. Heijnis and van der Plicht [31] obtained the $^{230}\text{Th}/^{234}\text{U}$ age for the Pleistocene peat deposits in northern Greece and Ireland, which turned to be equal to 122 and 118 thousand years, respectively. In addition, they proved that it was possible in principle to use $^{230}\text{Th}/^{234}\text{U}$ dating for open systems. Maksimov and coauthors [11] obtained the mid-Pleistocene age (about 200 thousand years ago) of peat deposits in the Western Siberia. Waas et al. [46] found the Middle

Pleistocene age (201–227 thousand years) using the $^{230}\text{Th}/^{234}\text{U}$ dating method for peat steams in the clay quarry in the north of Germany.

The age of swamps permits reconstructing the climatic changes in the Middle and Upper Pleistocene.

CONCLUSIONS

In last years, geologists have discovered peatlands extremely rich in uranium, which may be of interest as a source of uranium ore. Theoretically, soil scientists and geochemists consider the strong positive anomalies of uranium in peatlands as an example of efficient work of natural organic geochemical barriers in areas with humid climate.

Uranium sedimentation in peats goes due to the U(VI) bioreduction process, which is controlled by many geochemical factors, i.e., the composition of organic matter and soil solution, redox-potential of the environment, capacity of the uranyl ion to complexing with ligands. Organic matter is of particular importance, as humic acids can form complexes with U(VI) favoring leaching uranium from the parent deposit, and the organic fractions available to microorganisms serve as the source of energy necessary for reducing U(VI) to U(IV). Humic acids also serve as an electron shuttle upon the bacterial reduction of U(VI). Due to enzymes, biota operates as a catalyst of U(VI) reduction.

According to the type of their enrichment in uranium, peats may be divided in two groups. The first group includes peatlands enriched in uranium brought by soil- and groundwater. The second group includes peatlands enriched in uranium originated from the underlying deposits. The peatlands of the first type are typical for the plain areas with prevailing sedimentary deposits. In U-peatlands acting as a reduction barrier on the way of soil- and groundwater flow, U-organic complexes predominate, as well as neoformed reduced uranium compounds. The peatlands of the second type are usually formed on magmatic rocks, e.g., granitoids enriched in uranium, in mountainous areas. Besides the mentioned forms, the particles of uranium-containing minerals inherited from the parent deposits are preserved in peats.

The possibility also appears for dating the age of these peatlands using the $^{230}\text{Th}/^{234}\text{U}$ ratio method.

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