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COMPARATIVE ^{230}Th/U AND ^{14}C DATING OF A BURIED STUMP LAYER (WESTERN SIBERIA)

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Abstract: Dating of late Pleistocene sediments remains a challenge in Quaternary chronology, due to the inherent limitations of the ^{14}C and OSL methods. The ^{230}Th/U radioisotope method is theoretically applicable to wood remnants contained within Pleistocene sediments, but few results have been published to date and in some cases, the age data are ambiguous. This paper tests the use of ^{230}Th/U dating of fossil wood remnants dated earlier by radiocarbon method. We analyzed a buried larch trunk from a well-known stump layer in the Lipovka outcrop, located on the Tobol River bank in Western Siberia. The stump layer is preserved *in situ*. We determined the specific activities of U and Th isotopes in samples of both modern pine and fossil larch and proposed a model for the incorporation and distribution of U and Th in the buried wood during aging. Complications related with the recognition of geochemical closed systems with respect to U did not allow obtaining completely reliable ^{230}Th/U age. Despite this the ^{230}Th/U age obtained for the uppermost heartwood sample and ^{14}C ages of the same larch trunk and other wood and vegetation remnants gave consistent results. These age data in combination with previously obtained pollen data testify the stump layer formation during the late cooling stage of the Karganian time (MIS-3, Middle Valdai).

Keywords: ^{230}Th/U dating, ^{14}C dating, buried larch trunk, isotopes geochemical behavior, Karganian time, MIS-3.

1. INTRODUCTION

The reliable application of geochronometric methods to environmental samples of various origins is key to addressing problems in Quaternary chronology. The ^{14}C method is widely used but is applicable only to geological samples younger ~50 ka. Quantitative age determination of continental sediments beyond the ^{14}C-age limit, moreover, is still controversial (Astakhov and Mangerud, 2005, 2007). Optically Stimulated Luminescence (OSL) dates are commonly obtained from glacial and alluvial sediments (up to ~150 ka), for example, as well as aeolian deposits (up to ~300 ka), but in some cases the method yields conflicting age data (Astakhov and Mangerud, 2007).

In recent decades, the ^{230}Th/U radioisotope method has been applied to organic-rich, terrestrial, Interstadial (Interglacial) deposits with ages up to approximately 300–350 ka (Vogel and Kronfeld, 1980; Van der Wijk *et al.*, 1988; Heijnis, 1992; Ivanovich and Harmon, 1992; Geyh, 2001; Geyh and Müller, 2005; Kuznetsov, 2008; Kuznetsov and Maksimov, 2012). In Russia, we utilized ^{230}Th/U analyses of interstadial peats and gyttja to develop its theoretical and practical aspects (Kuznetsov *et al.*,

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2002, 2003; Kuznetsov and Maksimov, 2003; Maksimov *et al.*, 2006; Maksimov and Kuznetsov, 2010). On the basis of the isochron approach described by Maksimov and Kuznetsov (2010) we have obtained a number of ^{230}Th/U ages for the middle and upper Pleistocene organic-rich deposits from Siberia and Europe (Arslanov *et al.*, 2004; Maksimov *et al.*, 2006, 2010a, 2010b; Gaigalas *et al.*, 2007; Laukhin *et al.*, 2008a, 2008b).

These Pleistocene sediments commonly contain wood remnants, but few results of their dating by the ^{230}Th/U method have been published up to now (de Vernal *et al.*, 1986; Oschadleus *et al.*, 1996; Allard *et al.*, 2012). Wood remnants are found in so-called stump layers, but occur as trunk and branch fragments as well. Stump layers are always preserved *in situ* and have the same age as enclosing sediments.

The main goal of this study is to analyze the same buried wood remnants applying both the ^{14}C and ^{230}Th/U methods to compare ages.

For this purpose, we retrieved a buried larch trunk from a well-known stump layer in the Lipovka outcrop, located on the Tobol River bank in Western Siberia (**Fig. 1**). The profile has been studied many times since the 1960's (Kind, 1974; Kaplyanskaya and Tarnogradsky, 1974; Firsov *et al.*, 1985; Krivonogov, 1988; Arslanov *et al.*, 2009). A number of finite ^{14}C ages for the stump samples and enclosing soils were reported earlier (Arslanov *et al.*, 2009) and confine the layer's formation to the final stage of the Karganian time (MIS 3, middle Valdai, 57–24 ka).

Fig. 1. *Location of the Lipovka outcrop containing the stump layer with buried larch trunks.*

The Karganian time in Western Siberia is divided into three warm stages (according to uncalibrated, conventional ^{14}C dates): early (~50–45 ka), middle (~43–33 ka) and late (~30–23 ka). The warm stages are separated by two intervals of cool stages: early (~45 ka) and late (~33–30 ka). The most severe climate during the Karganian was typical for the late cool period (Kind, 1974), during which the stump layer was formed.

2. LIPOVKA SECTION DESCRIPTION AND ENVIRONMENTAL CONDITIONS OF STUMP LAYER FORMATION

The reference Lipovka section is located on the Tobol River bank (SW Western Siberia, 57°55' N, 67°30' E) (**Fig. 1**). There, a coastal terrace exposes 25 meters of the Lipovka outcrop (**Fig. 2**), whose stratigraphy, palynology, and chronology have been studied by several researchers. A buried soil occurs in the middle part of the sequence where the stump layer was found. Numerous larch stumps occur *in situ*; therefore, we assumed no redeposition of wood remnants. Detailed descriptions of the profile are available from (Kaplyanskaya and Tarnogradsky, 1974) and (Krivonogov, 1988). We studied the Lipovka outcrop in 2008 and 2012 (Arslanov *et al.*,

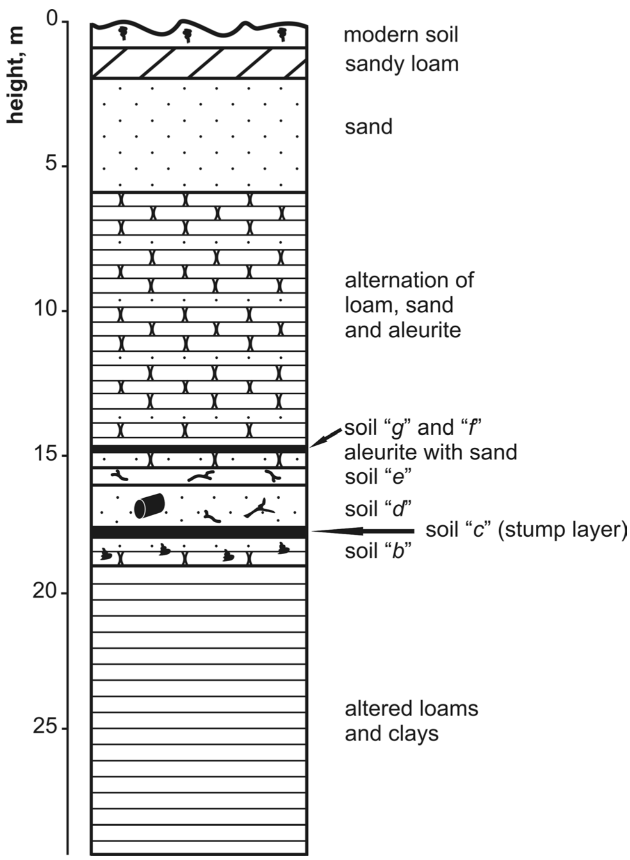

Fig. 2. *Stratigraphic scheme representing the main units documented in sedimentary sequences in the Lipovka profile.*

2009). The edge of outcrop has decreased from a height of ~24 m above river level in 1961–1962 down to a height of ~18–19 m above present river level. This is explained by the influence of river water at the shore slope, which causes the outcrop wall to retreat into the bank every year. The stratigraphy of the profile investigated is summarized in **Fig. 2**.

Detailed description of the sequence (from top to bottom).

Description of the profile below the water level is derived from (Krivonogov, 1988).

1) 0.0–2.0 m — loess-like sandy loam; 0.0–0.6 m — modern soil;
2) 2.0–5.6 m — brownish sand, yellow at the bottom, fine grained;
3) 5.6–15.0 m — alternation of loam, sands and aleurite; 6.2–10.7 m — three levels of pseudomorphs along the icy veins up to 0.3–0.5 m length; 14.0–15.0 m — buried soils "*g*" and "*f*" according to (Kaplyanskaya and Tarnogradsky, 1974);
4) 15.0–15.5 m — greenish-grey aleurite with sand interlayers;
5) 15.5–16.2 m — dark-brown fossil soil "*e*" with sporadic tree stumps, and remnants of tree roots; gray aleurite with thin sand interlayers at the bottom;
6) 16.2–17.7 m — dark-gray fossil soil "*d*" dissected by pseudomorphs along the ice wedges, silty loam; fine-grained sand with aleurite interlayers, wood fragments and tree trunks up to 30 cm diameter;
7) 17.7–18.0 m — dark-gray and black fossil soil "*c*" inclosing the stump layer (horizon), gray loam at the bottom, forest litter in the top. The soil «*c*» is slightly destroyed by permafrost and is well traced along the outcrop;
8) 18.0–19.0 m — dark-brown fossil soil "*b*" with cryogenic disturbances, along the course it is replaced by the black gyttja lens with a large number of plant residues and freshwater mollusk shells; bluish-gray aleurite with fine-grained sand interlayers at the bottom;
9) 19.0–29.3 m — alternation of loams and clays; from the layer roof there are pseudomorphs along the icy veins of more than 3 m length which go under the water level in the Tobol River. Starting from 22 meters depth down to the water level "there are three fossil soils similar those from the previous layer" (Krivonogov, 1988);
10) 29.3–29.5 m – Paleogene brown heavy clays, identified by drilling (Krivonogov, 1988).

The section has a three-layered structure and contains pseudomorphs along the icy veins (Kaplyanskaya and Tarnogradsky, 1974) (**Fig. 2**). The lower 9–9.5 meters contains laminated aleurite of oxbow facies located below the water level. Loamy sand with pebble of channel facies is present below, according to the drilling data (Krivonogov, 1988). The middle package of 5–6 m thickness is "transitional" (Kaplyanskaya and Tarnogradsky, 1974) and consists of 6–7 buried soils separated by laminated aleurite and loam of floodplain facies. The upper package of 10–15 m thickness is comprised of laminated sands, aleurite and loam. Until recently (Volkova *et al.*, 2003), the upper package was assumed to be comprised of sediments derived from an icedam lake, which was formed by the Sartanian (MIS-2, Upper Valdai, 24–11 ka) ice sheet. More recently, however, it was demonstrated that the Sartanian ice sheet did not block Western Siberia between the Ural and Taimyr Peninsula regions, and moraines previously considered as Sartanian were dated much older. At present, the upper package is considered to be aeolian-thermokarst in origin (Astakhov, 2009).

Our focus lies with the middle or "transitional" package, which was formed in the Karganian time. The buried soils of middle package are separated and identified from the bottom to the top as *a, b, c, d, e, f, g* (Kaplyanskaya and Tarnogradsky, 1974) (**Fig. 2**). The soil "*c*" is developed most fully. Its upper part is represented by the forest litter of mosses, pine needles, branches, cones of spruce. This soil itself contains larch stumps *in situ* and is the so-called stump layer.

The buried soil "*c*" is comprised of tundra, gley, and podzolized soil types. These soil types occur primarily in the south of the modern tundra as well as in the forest-tundra. The larch roots in the stump layer lie in a horizontal position, close to the surface of the soil "*c*". This may indicate a high depth of permafrost close to its current position in the modern forest-tundra. Data on depression of trees from the stump layer, as well as the composition of the macroflora, confirm that soil "*c*" developed in the zone of northern edge of the northern taiga or in the forest-tundra (Kaplyanskaya and Tarnogradsky, 1974; Krivonogov, 1988).

Spore-pollen analysis of sediments from the Lipovka outcrop has been studied many times since the 1960's (Volkova, 1966; Kaplyanskaya and Tarnogradsky, 1974; Arslanov *et al.*, 2009). According to new data obtained by L. Savelyeva (Arslanov *et al.*, 2009), the underlying layers, soil "*c*", and overlying sediments were formed under environmental conditions of forest-tundra, northern taiga, and the northern edge of the northern taiga, respectively. These conclusions corroborate previously published data (Volkova, 1966; Kaplyanskaya and Tarnogradsky, 1974) and have been confirmed recently by Volkova (2011). At the present time, the Lipovka outcrop is located in the south of the southern taiga, where lime grove grows on the terrace surface. The border of northern taiga and forest-tundra is situated almost on 800 km to the north, meaning that vegetation zones have shifted this distance southward since the formation of soil "*c*" and the stump layer. Therefore, environmental conditions during soil development were significantly colder relative to the modern climate.

The soil "*c*" contains larch stumps 10–15 cm in diameter with growth ages of 45–60 years. The roots spread radially in the thin near-surface layer of soil. Stumps are located far from each other due to the sparsity of the ancient forest. The width of annual tree rings is less than 1 mm, and the diameter of trunks and location of the roots indicate that forest site factors were close to modern tundra. The forest likely grew on continuous permafrost, whose level was near the soil surface. The terrace on which trees grew was protected from frequent floods by its elevated position within the floodplain, allowing soil and forest to develop. Several extreme floods could have resulted in the death of trees, but the trunks continued to stand in the water. Ice drifts amid subsequent flooding cut the trunks approximately 30–50 cm above the floodplain surface and all the stumps found in the soil "*c*" have the same height. The stumps were then buried under nearly one meter of floodplain alluvium (fluvial sediments) prior to the formation of soil «*d*». Finally, the stump layer was gradually buried as the floodplain alluvium of the middle package continued to accumulate.

3. MATERIALS AND METHODS

A well-preserved piece of buried larch trunk found *in situ* was collected from the stump layer of the Lipovka section for cross dating by the ^{14}C and the ^{230}Th/U methods. The diameter of the trunk was 10–12 cm and around 45 cm length.

Samples of modern trees were collected from two pine trunks with diameters of 10 and 18 cm from the Leningrad Region for radiochemical analysis. The first sample (LUU-546) was taken from a living tree, whereas the second and third samples (LUU-547, LUU-548) were taken from trees lying on the forest floor for at least several years. We were not able to take samples of a live larch near the Lipovka outcrop, because it no longer grows there.

^{14}C dating

The ^{14}C ages of stumps, trunks, soil, and vegetative detritus from the stump layer have been reported in several studies (Kind, 1974; Firsov *et al.*, 1985; Krivonogov, 1988). The most recent ^{14}C age of the larch trunk was reported by Arslanov *et al.* (2009). We dated a sample (LU-6026) taken from the lower part of the lurch trunk close to its stump (**Table 1**). Radiocarbon dating of this trunk sample was performed using benzene liquid scintillation counting (Arslanov *et al.*, 1993).

^{230}Th/U dating

The accumulation of uranium at the time of sample formation forms the theoretical basis of the ^{230}Th/U dating method for quantitative age determination of various environmental materials, such as oceanic and terrestrial carbonates, peat, gyttja, hydrothermal sulfides *etc*. Fossil wood is no exception, as it can extract U from groundwater like peat (Heijnis, 1992; Geyh, 2001). It has also been proposed that this process is irreversible (Manskaya and Kodina, 1975). For dated materials, including wood remnants, the two ideal, theoretical prerequisites underlie the ^{230}Th/U method (Ivanovich and Harmon, 1992; Kuznetsov and Maksimov, 2003; Maksimov and Kuznetsov, 2010): the material to be dated (1) includes sufficient uranium and negligible ^{230}Th (and ^{232}Th) at the time of its formation and (2) has behaved under geochemically closed conditions with regard to U and Th since that time.

The theoretical application of this radioisotope method to wood remnants dated by conventional methods allows us to assess the reliability of ^{230}Th/U ages. It is necessary first, however, to constrain the geochemical behavior of these elements within living and fossil trees.

Therefore, we determined the specific activities of U and Th isotopes in samples of both modern pine and fossil lurch. Larch and pine relate to heartwood trees, which contains two main parts: the heartwood (kernel) and the sapwood (**Fig. 3**).

In the initial growth stage, these trees consist of sapwood only. Groundwater containing dissolved mineral matter, and possibly the finest fraction of mineral detritus, penetrate the vessels located along the fibers of sapwood from the roots to the leaves of the growing tree. With time, sapwood consisting of previous annual layers is converted to the kernel. This process occurs as living cells die off and vessels become clogged. Heartwood (the trunk interior) has low absorption and permeability, therefore, relative to the sapwood, and vessels transporting groundwater shift gradually from the inner part of the trunk to the periphery closer to the bark.

Table 1. *The ^{14}C ages of different wood remnants and soil within the stump layer from the soil "c" of the Lipovka outcrop.*

Lab. No.	Type of sample	Radiocarbon age BP (kyr)		Calibrated (calendar) ^{14}C age (kyr)
GIN-126	larch (stump)	30.7 ± 0.3	(Kind, 1974)	34.50–35.28
LG-37	larch (stump)	30.56 ± 0.24	(Kind, 1974)	34.42–35.05
SOAN-40	larch (stump)	30.2 ± 1.42	(Firsov *et al.*, 1985)	33.20–36.13
SOAN-2274	humus from soil "*c*"	31.26 ± 0.28	(Krivonogov, 1988)	34.84–35.63
*LU-6026	larch (part of trunk close to stump)	32.64 ± 0.38	(Arslanov *et al.*, 2009)	36.40–37.93
LU-6027	vegetative detritus	32.77 ± 0.24	(Arslanov *et al.*, 2009)	36.61–37.95
LU-6028	larch (part of trunk close to stump)	31.76 ± 0.23	(Arslanov *et al.*, 2009)	35.26–36.14
LU-6029	larch (stump)	32.52 ± 0.23	(Arslanov *et al.*, 2009)	36.35–37.79

During growth, aqueous solutions also move horizontally along so-called heart-shaped rays (**Fig. 3**). Since it can be assumed that migration of soluble forms of U (and possibly Th in suspended mineral detritus) can occur in the wood both vertically and horizontally, we sought to analyze both the vertical and horizontal distribution of U and Th isotopes in the wood stratum of the trunks. This test determines whether the prerequisites of ^{230}Th/U method are met for buried tree samples.

The buried larch trunk was divided into three parts by means of cross sections. Each of the three pieces was then divided into layers in the radial direction from the surface to the center of the trunk (**Fig. 4**). Modern pine trunks were prepared in the same manner.

The external layer (bark) of the wood samples was mechanically removed to reduce the possible contamination of the sample by ^{230}Th-bearing mineral detritus. Wood samples were dried to constant weight and burned.

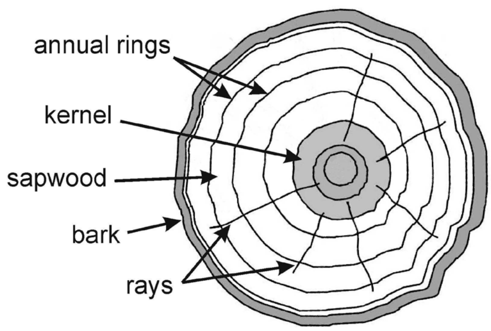

Fig. 3. *Cut of a heartwood tree trunk.*

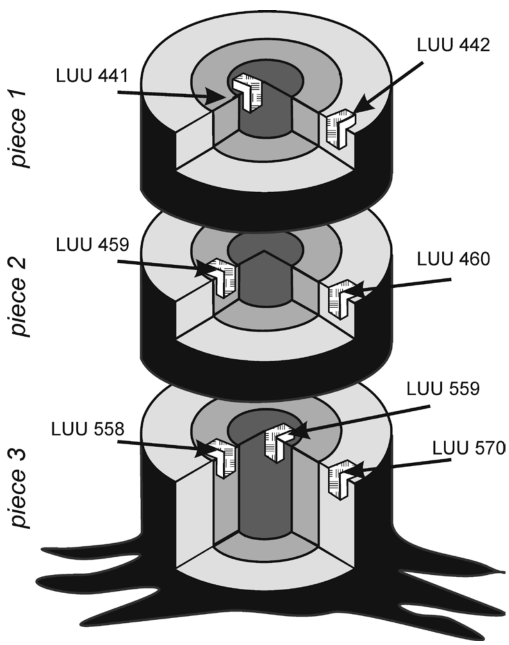

Fig. 4. *Wood fragments collected from the fossil larch trunk for ^{230}Th/U dating.*

The ashes were dissolved with a mixture of strong hydrochloric and nitric acids (aqua regia) and a known amount of spike (^{232}U and ^{234}Th) was added to determine U and Th isotopes by isotope dilution technique. The solution was separated from any insoluble residue (e.g. silicates) by centrifugation. The U and Th isotopes were purified and separated using chromatographic columns and then deposited from alcohol solutions to the Pt-disks according to the previously described analytical techniques (Kuznetsov and Maksimov, 2012; Kuznetsov *et al.*, 2002; Maksimov and Kuznetsov, 2010). Alpha-spectrometric measurements were made for several days applying the alpha-spectrometer "Alpha Duo" (ORTEC). The ^{230}Th/U age of each buried wood sample was calculated according to Kaufman and Broecker (Kaufman and Broecker, 1965).

4. RESULTS

Radiocarbon dating results

All previously obtained ^{14}C dates for the stump layer from the Lipovka outcrop are summarized in **Table 1**. The ^{14}C dates obtained recently (Arslanov *et al.*, 2009) fall into the interval 35.3–38.0 cal ka BP (samples No. LU-6026 – LU-6029), while the ages reported prior are slightly younger and range from 33.2–36.1 cal ka BP (samples No. GIN-126, LG-37, SOAN-40, SOAN-2274). Modern analytical methods almost completely preclude any contamination of the analyzed material by the modern carbon, resulting in apparently older sample ages (Arslanov, 1987). We conclude, therefore, that the most probable age of stump layer formation was approximately 35–38 cal kyr BP.

^{230}Th/U dating results

Radiochemical analyses determined the specific activities of ^{230}Th, ^{232}Th, ^{234}U and ^{238}U in the samples of the modern pine trunks (**Table 2**).

The application of U-series dating to fossil wood is difficult because of the lack or very negligible content of uranium in the structure of living trees (Allard *et al.*, 2012). Our data testify that despite the low specific activity of uranium isotopes, they are present in measurable concentrations and show that modern wood is able to incorporate uranium from the groundwater while excluding thorium. The specific activity of both Th isotopes was below the detection limit, whereas activities of both U isotopes were in the range of 0.050–0.013 dpm/10 g in the samples of the modern pine trunks. These data confirm the first prerequisite that both living and recently dead trees include detectable U and negligible ^{230}Th and ^{232}Th.

Results of the radiochemical analyses of the samples from the buried larch trunk are given in the **Table 3**. The specific activity of uranium in samples of fossil larch is 1–2 orders of magnitude higher than in the samples of the living pines. This difference between the U content (specific activity) in the modern and fossil wood samples can be attributed to one of two independent reasons (or a combination of both). Firstly, the concentration of dissolved U in groundwater in the area of Lipovka outcrop might have been significantly higher than in the modern groundwater within the Leningrad Region. Secondly, the accumulation of water-soluble forms of U might have continued *post mortem* during subsequent sedimentation. It was previously shown, for example, that U concentration in destroyed wood residues can be 2–3 orders of magnitude higher than in the living plants (Manskaya and Kodina, 1975).

5. DISCUSSION

The U content (specific activity) in the butt-end samples is 2–30 times higher than in the two other pieces from the upper trunk. This difference may reflect additional U uptake during very high floods, when the living trees stood in the water and U penetrated into the trunks through the vessels located along the fibers of sapwood and moved up the trunk. All larch trunk samples contain non-authigenic ^{230}Th, as indicated by a variable amount of ^{232}Th (**Table 3**). The butt-end samples also have significantly higher ^{232}Th specific activities than the upper trunk pieces (**Table 3**). The ^{232}Th content of pieces 1 and 2 was below detection limit (sample LUU-459) or was very negligible (samples LUU-441, 442, 460). We suspect that thorium contamination originated with the penetration of ^{230}Th- and ^{232}Th-bearing mineral detrital particles into the wood. Preferential U and Th enrichment of butt-end samples is likely due to significantly more prolonged contact with water relative to the upper trunk parts, regardless of individual flood levels. Therefore, the highest content of U and Th accumulated at the trunk bottom.

The outer layers of the trunk contain measurably higher U activities than internal samples, particularly piece 3 (**Table 3**). This distribution is consistent with the penetration of U and Th into the wood during flooding, as well as during burial. The outer rims may have acted as a peculiar geochemical barrier, absorbing U and preventing its penetration further into the trunk heartwood. As a result, the outer layers were enriched with U compared to the heartwood samples of the trunk. Those outer layers could be a geochemical barrier also for both ^{232}Th and non-authigenic ^{230}Th contained in detrital particles. In

Table 2. *Results of the radiochemical analyses (1σ uncertainties) of the modern pine samples (Leningrad Region). *R — diameter of the pine layers analyzed.*

Lab. No.	Sample thickness, (cm)	^{238}U	^{234}U	^{230}Th	^{232}Th	^{230}Th/^{234}U	^{234}U/^{238}U
		dpm/10 g of dry food					
piece of a living pine (R*=5 cm)							
LUU-546	0–5	0.0120 ± 0.0012	0.0130 ± 0.0014	-	-	-	1.08 ± 0.16
pieces of pine lying in the forest of at least several years (R*=9 cm)							
LUU-547	5–7	0.0097 ± 0.0021	0.0118 ± 0.0024	-	-	-	1.22 ± 0.36
LUU-548	2.5–5	0.0050 ± 0.0008	0.0080 ± 0.0011	-	-	-	1.60 ± 0.34

Table 3. *Results of the radiochemical analyses and ^{230}Th/U ages (1σ uncertainties) of the samples from the buried larch trunk (the Lipovka outcrop). * - Piece 1 is trunk portion furthest from the roots, piece 2 is the middle portion, piece 3 is trunk portion (butt-end) nearest to the roots (Fig. 3).*

Lab. No.	Sample thickness (cm)	^{238}U	^{230}Th	^{232}Th	^{234}U/^{238}U	^{230}Th/^{232}Th	^{230}Th/^{234}U	Age (kyr)
		dpm/10 g of dry food						
piece 1*								
LUU-442	3.75–5.63	0.2461 ± 0,0079	0.0564 ± 0.0032	0.0088 ± 0.0013	1.2483 ± 0.0540	~ 6.4	0.1836 ± 0.0117	21.9±1.6
LUU-441	0–1.88	0.0925 ± 0.0053	0.0380 ± 0.0042	≤0.0032	1.3395 ± 0.0984	≥ 11.9	0.3066 ± 0.0370	39.1±5.7
piece 2*								
LUU-460	3.75–5.63	0.1504 ± 0.0131	0.0335 ± 0.0021	≤0.0026	1.1185 ± 0.1276	≥ 12.9	0.1992 ± 0.0204	24.0±2.8
LUU-459	1.88–3.75	0.1247 ± 0.0077	0.0330 ± 0.0024	-	1.2069 ± 0.0957	-	0.2193 ± 0.0198	26.7±2.8
piece 3*								
LUU-570	3.75–5.63	3.0409 ± 0.0715	0.3942 ± 0.0149	0.0557 ± 0.0056	1.2334 ± 0.0225	~ 7.1	0.1051 ± 0.0046	12.0±0.6
LUU-558	1.88–3.75	0.5137 ± 0.0296	0.0823 ± 0.0057	0.0057 ± 0.0018	1.0945 ± 0.0768	~ 14.4	0.1464 ± 0.0132	17.1±1.8
LUU-559	0–1.88	0.7585 ± 0.0473	0.2656 ± 0.0128	0.0243 ± 0.0040	1.1209 ± 0.0961	~ 10.9	0.3124 ± 0.0238	40.3±3.9

fact, the outer layers of the trunk contain higher content of ^{232}Th compared to the internal ones (**Table 3**). However, the relatively high $^{230}Th/^{232}Th$ activity ratios (AR) of approx. 6.4–14.4 indicate that all samples have low Th contamination.

Based on these data, we propose the following model for U and Th geochemical behavior in the water-soil-wood system. During larch growth, and possibly for a short period after its death (though insignificant compared with the time since burial), dissolved U in groundwater and floodwater penetrated through the roots upward into the trunk. The largest fraction of U content was absorbed by larch butt-end, while the remaining insignificant amount of U was distributed along the trunk. Increase of $^{234}U/^{238}U$ AR from about 1.09 in the butt-end to about 1.34 in the upper portion of the trunk (**Table 3**) may reflect this U penetration in the upper part of the trunk, with preferred mobility of ^{234}U. At that time, U remained in the sapwood, which gradually turned into heartwood. Uranium uptake in wood continued during burial and could have a long-term or discrete history. Very likely, horizontal transport of U dominated at this time as the largest amount of U accumulated in the outer and intermediate layers of trunk. Apparently, a similar history of Th (including ^{232}Th and non-authigenic ^{230}Th) infiltration into the larch trunk took place.

Following this initial uptake, the lower pieces 2 and 3 and the outer and intermediate layers of whole trunk acted as geochemical barriers with respect to U and Th. In addition, the relatively compressed larch heartwood limited hydraulic permeability and associated isotope uptake. Within this scenario, the uppermost sample from the trunk heartwood can be considered as a more or less closed geochemical system.

The direct $^{230}Th/U$ age of 39.1 ± 5.7 ka obtained for the uppermost heartwood sample LUU-441 (**Table 3**) overlaps the confidence interval of the ^{14}C age of 36.4 - 37.9 cal ka BP (sample LU-6026, **Table 1**) for the same larch trunk. Both of these ages agree within analytical uncertainty with the $^{230}Th/U$ age 40.3 ± 3.9 ka obtained for the lowermost trunk heartwood sample LUU-559. The high $^{230}Th/^{232}Th$ AR ~10.9 indicates that the sample has very low detrital (or Th**)** contamination, and a slightly older $^{230}Th/U$ age was calculated.

The remaining five $^{230}Th/U$ dates for the intermediate and outer layers of the larch trunk were significantly younger and varied from approximately 12–27 ka. Most likely, these samples were open geochemical systems during flood events and subsequent burial of the larch trunk, particularly with respect to U. We propose that this open-system behavior has led to the apparently young $^{230}Th/U$ ages for the samples.

Environmental materials containing ^{232}Th require, in principle, a detrital correction for this contamination. A number of correction methods can be applied to impure material (e.g., Kaufman, 1993; Ludwig and Titterington, 1994; Geyh and Müller, 2005). In the case of our study, however, geochemically open behavior in 5 samples precluded the application of these corrections. Comparison between the uncorrected and corrected ages of fossil wood indicates that the magnitude of the correction is often less than the analytical errors derived for samples contained negligible Th contamination (Allard *et al.*, 2012).

Nonetheless, both the $^{230}Th/U$ ages of 39.1 ± 5.7 ka obtained for the uppermost heartwood sample LUU-441 and 40.3 ± 3.9 kyr for the lowermost trunk heartwood sample LUU-559 can not be considered completely reliable dates because of post-depositional uranium uptake.

6. CONCLUSIONS

Based on the radioisotope data, as well as specific burial and environmental conditions, we propose a model for the incorporation and distribution of U and Th in the buried wood/larch trunk from Western Siberia during aging. Complications related with the recognition of geochemical closed systems with respect to U did not allow obtaining completely reliable $^{230}Th/U$ age. Despite this the $^{230}Th/U$ age of 39.1 ± 5.7 ka obtained for the uppermost heartwood sample overlaps the confidence interval of ^{14}C ages in the range from 35.3–38.0 cal ka BP obtained for the same larch trunk and other wood and vegetation remnants within the stump layer. These age data in combination with previously obtained pollen data testify the stump layer formation during the late cooling stage (33–30 ^{14}C ka BP, ca. 37.5–34.2 cal ka BP) of the Karganian time (MIS-3, Middle Valdai, 57–24 ka). A thorough assessment of the degree of opened/closed system relatively U and Th requires further geochronological study of buried wood. Results reported in the paper can be considered as promising steps for the development of $^{230}Th/U$ method for dating fossil wood as well as for solving the problems of Quaternary chronology.

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