INFLUENCE OF PALAEOENVIRONMENTAL CHANGES ON THE FORMATION OF THE VILKU BOG DEPOSITS

PALEOVIDES IZMAIŅU IETEKME UZ VILKU PURVA NOGULUMU VEIDOŠANOS

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Abstract

Vilku Bog is a small (about 95 ha) area of peatland formed in a glacial meltwater lake depression in the north-western part of the Lubāns Plain. The aim of this study was to investigate the influence of paleoenvironmental changes on the sedimentation of Vilku Bog. To achieve this aim, fieldwork was carried out – eight soundings were taken and three boreholes were drilled diagonally across the Vilku Bog. Multidisciplinary studies were carried out on deposit samples collected during fieldwork. The deposits were subjected to analyses of Loss on Ignition, plant macroremains, analyses of peat botanical composition and peat decomposition degree, spore-pollen analyses, and radiocarbon AMS ^{14}C dating.

The area where Vilku Bog is located was originally filled with lake clay and silt, but during the Middle Holocene, at the climatic optimum of 6160 cal BP, the lake began to accumulate gyttja and peaty gyttja as the number of aquatic plants increased. This contributed to the lake becoming completely overgrown and the start of peatland formation before 5810 cal BP in the second part of the Middle Holocene. The development of Vilku Bog started with the accumulation of peat deposits over the lake gyttja (fen-type *Hypnum*, grass and sedge peat, transition-bog-type grass peat and *Sphagnum*- cotton grass peat), followed by raised-bog-type peat (*Sphagnum* peat). The conditions (peat decomposition) of deposit accumulation were variable during the development of the bog. Peat botanical composition, which is affected by water-level fluctuations, indicate that Vilku Bog underwent the complete cycle of bog development, from fen to transitional bog and finally to raised bog. It has only been developing as a raised bog for the past 380 years.

Keywords: *Lubāns Plain, gyttja, peat, plant macroremains, AMS ^{14}C*

Introduction

The Lubāns Plain was formed as a result of the East Latvia glacial tongue of the last (Latvian, Weichselian) glaciation. It is an area in the central part of the east Latvian lowlands, the surface of which is lower than the surrounding area, and its altitude does not reach 96 m AMSL. The lowest place in the south-east part of the plain is occupied by Lake Lubāns, which is significantly overgrown and today only approximately a third of the original floodplain is preserved. Bogs have developed in overgrown lake bays. Many of these have been studied in detail (Stivriņš et al., 2014; Grūbe, 2006; Paparde et al., 2019). However, there were also several small lakes remaining in the depressions of the Lubāns Plain after drainage of glacier meltwater, but these later became overgrown and gradually developed as peatlands. The sediments of these small lakes turning into peatland in the Lubāns Plain have been relatively little studied (Stivriņš et al., 2014).

The results of research elsewhere (Grūbe, 2006; Paparde et al., 2019; Stivriņš et al., 2014), on the process of accumulation of sediments in small lakes, fluctuations of water levels, changes in the nature and sediment composition, their overgrowth, well reflect changes both in the climate and hydrological regime. They make it possible to reconstruct the sedimentation conditions and palaeoenvironment, and allow the development of the lake to be tracked from its formation to becoming overgrown and the development of peatland. One such site in the north-western part of the Lubāns Plain is Vilku Bog (about 95 ha), which became overgrown and gradually developed into peatland. Vilku Bog is located 12 km north of Lake Lubāns, on the left bank of the River Aiviekste, about 1.5 km from the nearest Stone Age settlement, Abora I (Reire, 2024).

The aim of this study was to investigate the influence of paleoenvironmental changes on the formation of the sediments of Vilku Bog. To find out about these changes, multidisciplinary studies were carried out on sediment samples collected in Vilku Bog on 15 and 16 August 2023.

Data and methods

This study draws on previous research (Kalniņa et al., 2024; Reire et al., 2024a; 2024b; Eberhards, 1969, 1985; Loze 1988; Loze et al. 2011), as well as on the results of the project LZP-2020/2-0032 “Subsistence strategy and the first demographic transition in the Lubans Wetland: the case of the Late Neolithic settlement of Abora,” developed

as part of a project by the Latvian Institute of History at the University of Latvia (Reire, 2022) and the Latvian Science Council project No. LZP-2022/1-0300 (Reire, 2024). In this case sediments were taken from Vilku Bog and laboratory methods were used.

A soft sediment corer with a chamber (5 cm diameter, 0.5 m long) was used for fieldwork, sediment exploration, and extraction. The investigated profile consisted of eight soundings taken and three boreholes drilled diagonally across Vilku Bog, with a distance of approximately 100 m between each point. Three sediment monoliths with a total length of 15 m were obtained from three boreholes in Vilku Bog. Sediment samples were taken from the 6-m-long borehole 2 (U2) (coordinates: x=675986.33; y=312170.26; borehole surface altitude: 95.76 m AMSL.). In this study the sediments were subjected to Loss on Ignition (Heiri et al., 2001), plant macroremain (Warner, 1987), peat botanical composition and peat decomposition degree, and spore-pollen analyses, as well as AMS ^{14}C dating. Terrestrial plant macroremains identified and collected during macroremain analysis were prepared for radiocarbon AMS ^{14}C dating technique at the Poznan Radiocarbon Laboratory, Poland. Altogether, five AMS radiocarbon dates of sediment age obtained from the Vilku Bog core sediment section were calibrated using the IntCal20 calibration dataset (Reimer et al., 2020).

Results

Vilku Bog has a gently undulating surface with no pronounced dome (Figure 1), which is usually characteristic of a raised bog's relief. This can be explained by the fact that the bog reached the raised bog development stage relatively recently (385 cal BP), when raised-bog-type *Sphagnum* peat began to accumulate. The lowest surface altitude measured was at the beginning of the profile, in the north-west of the bog (approximately 300 m from the River Abora): 95.15 m AMSL. In the middle of the bog, the altitude reaches 95.76 m AMSL. The relief of the mineral base of the bog is uneven, and the absolute altitude ranges between 91.54 and 92.26 m AMSL, reaching a maximum in the middle part of the profile. The lowest bed depth (91.54 m AMSL) is located in the central part of the bog, while the highest marker (92.26 m AMSL) is located 101 m from the deepest point, thus forming a relatively pronounced elevation. The surface of the gyttja deposits, parallel to the clay deposits, also undulates. The surface of the gyttja, including peaty gyttja, ranges from 92.30 to 92.98 m AMSL. The maximum thickness of the peat layer in Vilku Bog is 3.36 m, in the south-east of the

bog and at the end of the studied profile (Figure 1). The smallest peat layer thickness is 2.37 m, in the north-west of the bog and at the beginning of the profile. All peat types are present in Vilku Bog: fen, transition, and raised-bog-type peat.

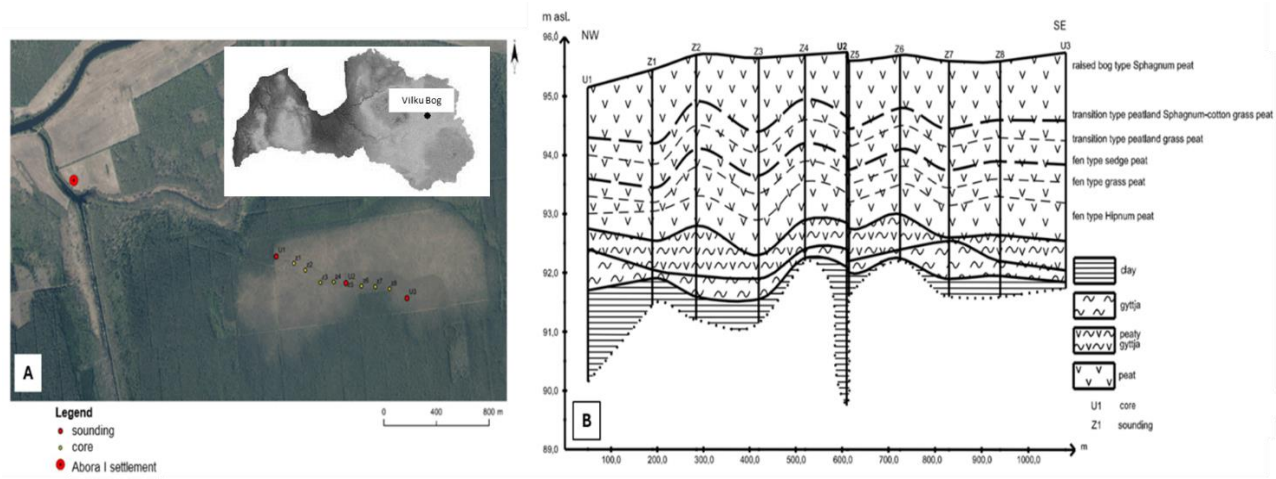

Figure 1. **Soundings and cores in Vilku Bog (A) and geological cross-section of Vilku Bog (B)** (authors' figure using basemap – Latvia 6th Cycle ortophoto map, LGIA)

Organic matter, carbonate matter and mineral matter results of the sediment Loss on Ignition analysis provide information on the sediment composition and changes in accumulation conditions shown in the diagram (Figure 2), where three zones based on changes in sediment composition are subdivided manually: VP LOI 1, VP LOI 2, and VP LOI 3.

The lower zone (VP LOI 1) in the depth range of 368–600 cm has the highest amount of minerals and carbonates, but the lowest amount of organic matter and natural moisture. Minerals in this interval average 90%, while organic matter varies between 2 and 5% (average 4%), moisture averages about 28%, and carbonate content average less than 9%, except for the peak at 512 cm, where carbonate content reaches 80%. The high mineral content was due to the accumulation of clay in this interval. The high carbonate content in the interval 511–512 cm is due to the leaching of carbonate rocks from the moraine abrasion plain close to the shore of Lake Lubāns. Its sediments (moraine clayey sand) are carbonatic, so as the lake water level rose, they washed away, thus leaching carbonate substances into the lake sediments.

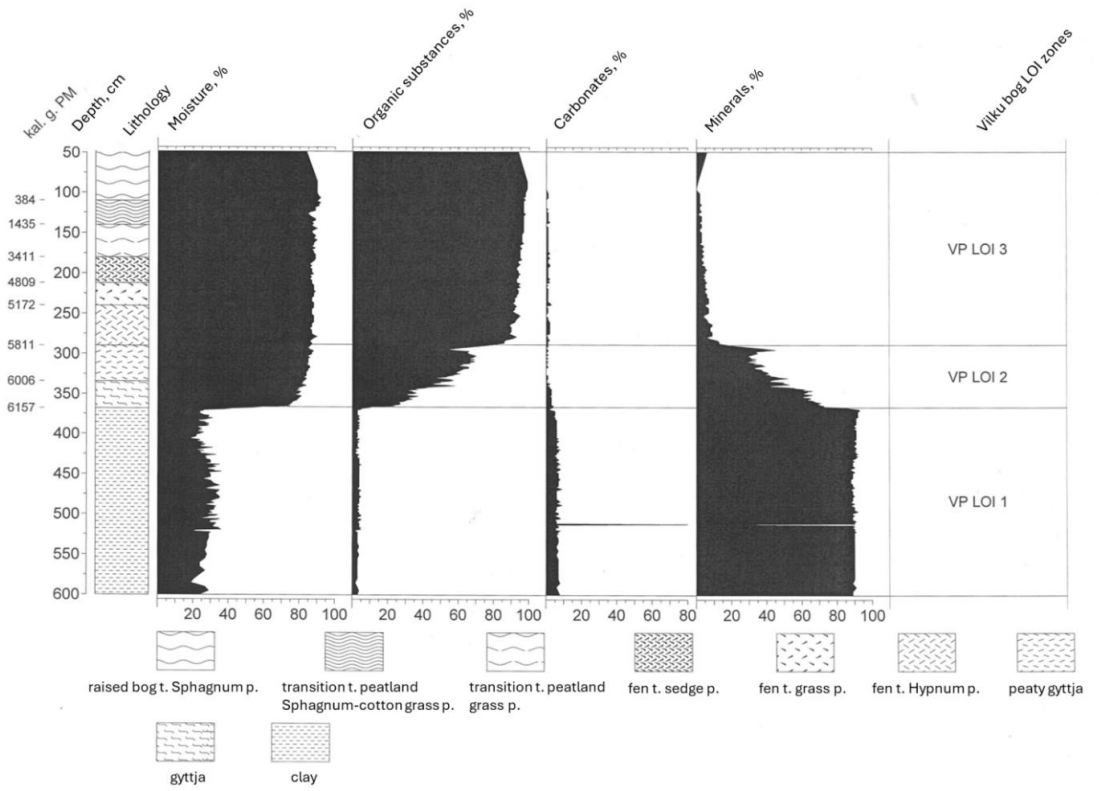

Figure 2. **Diagram of changes in the percentage of natural moisture, organic, carbonate and mineral matter in the sediments of Vilku Bog borehole 2 (U2) according to results of LOI analysis** (authors' figure)

The depth interval 278–368 cm in the middle zone (VP LOI 2) is characterised by a relatively rapid increase in organic matter and a decrease in carbonates and minerals in the sediments. The mineral content gradually decreased from 90% to 6%, while the carbonate content decreased from 9% to 1–2%. The moisture content averages 82% over this range. The organic matter increased rapidly to 93%. This indicates that the lake became overgrown during the accumulation of this sediment. This also evidenced by the fine detritus gyttja (335–368 cm) and peaty gyttja (290–335 cm) in this interval.

The upper zone (VP LOI 3) in the depth range 48–278 cm is characterised by high natural moisture and organic matter, and low carbonate and mineral content. The average natural moisture content of the sediments in this zone was 88%. Organic matter increased slowly and gradually from 93 to 99% between a depth of 278 and 85 cm, and then decreased, reaching 94% at a depth of 48 cm. Mineral content, on the other hand, decreased from 6% to 1% up to a depth of 85 cm, and then increased again to a level of 6%. The carbonate content in this zone varied between 0% and 3%. The sediments in

this zone are peat. In general, the results of the Loss on Ignition analysis reflect changes in the conditions of sediment accumulation. It is possible to identify the point (the depth) at which aquatic conditions give way to coastal and terrestrial conditions, that is, where the lake begins to become overgrown and a bog starts to develop. The scale of the mineral content is inversely proportional to that of the organic matter. The changes in sediment lithology coincide with the changes in the composition of the sediments (moisture, organic matter, carbonates, and minerals) in Vilku Bog.

Based on the data collected and summarised from the plant macroscopic analysis, four plant macroremain zones (MA zones) characterising the changes in the vegetation composition of the lake were identified. In the lower part of the sediments analysed in the section at a depth of 454–368 cm, which consists of clayey sediments deposited in a calm basin with conditions unsuitable for vegetation development, only *Equisetum* sp. and *Sphagnum* spp. macroremains were found. Only one leaf of *Oxycoccus microcarpus* and a few small charcoals were found.

In the section above 368–282 cm depth, 6160–5715 cal BP accumulated in gyttja and peaty gyttja. This is characterised by the highest number of macrofossils found and the greatest diversity of species. There is a relatively high abundance of shallow-water and flooded coastal plants, and aquatic plant remains. Diversity of plants and other macroremains are evident in the gyttja sediments of this zone, where the first macroremains of aquatic plants, peatland plants, and wet meadow plants appear. Among the aquatic plants were found *Stratiotes aloides*, *Myriophyllum spicatum*, *Trapa natans*, and *Nymphaea alba*. Shallow water plants such as *Sagittaria sagittifolia*, *Alisma plantago-aquatica*, *Phragmites* sp., and *Rumex maritimus* have been recorded. Bog plants include *Sphagnum* spp., *Thelypteris palustris*, *Rhynchospora alba* and *Trichophorum cespitosum*. Sediments in the depth interval 282–258 cm were accumulated during 5715–5405 cal BP and are represented by fen-type *Hypnum* peat. Plant macroremains are no longer of aquatic plants; only *Phragmites* spp. macrofossils are found in coastal plants. Among bog-specific plants, only *Sphagnum* spp. and *Eriophorum vaginatum* macroremains were found. Macroremains of *Scirpus* spp. were found, and the amount of *Equisetum* sp. decreased. This sub-area had a high abundance of wood fragments and tree/shrub leaf fragments. The plant species found in the gyttja indicate that vegetation had developed and the lake had begun to become overgrown, but that conditions were still waterlogged.

In the depth interval of the 258–174 cm section a fen-type *Hypnum* peat layer accumulated before 5405–3115 cal BP, overlain by fen-type grass peat, while the upper part of the interval is composed of fen-type sedge peat deposits. From a depth of 258 cm upwards, the sediments showed a decrease in tree and shrub leaf macroremains, with an increase in *Phragmites* sp. remains, and *Scirpus* sp., and *Equisetum* sp. m and *Poaceae* spp. macroremains. In the upper part of the zone, the number of plant *Scheuchzeria palustris*, *Eriophorum* spp., *Rhynchospora alba*, and *Carex* spp. macroremains decreases. Fragments of insect chitin were also found throughout the zone, as in the upper part of the zone was charcoal.

At a depth of 174–102 cm, before 3115–350 cal BP fen-type sedge peat was replaced by transition-type peatland grass peat. This zone is characterised by a high number of wood fragments and charcoal, as well as *Sphagnum* spp., *Calamagrostis canescens*, and *Pinus sylvestris* macroremains. This indicates that the bog was receiving fewer nutrients from groundwater, and the herbaceous vegetation typical of fens was slowly being replaced by vegetation typical of raised bogs.

When Vilku Lake became overgrown with *Phragmites* spp., *Equisetum* spp., *Carex* spp. and *Hypnum* spp., around 5600 cal BP mosses (mainly *Meesia* sp.) began to accumulate on the peaty gyttja of the fen-type *Hypnum* peat, having a high degree of decomposition – 45%. Before 5200 cal BP, the composition of the main peat-forming plants changed: *Hypnum* spp. mosses, *Typha*, and *Carex dioica* disappeared, and the amount of *Carex lasiocarpa* increased slightly. The degree of decomposition decreased slightly, but a well-decomposed (30%) fen-type grass peat still formed. This was the case when, 4800 cal BP ago, the fen-type sedge peat dominated by *C. lasiocarpa* macroremains, started to increase, coming to cover 45% of the total remains.

At a depth of 1.8 m in the bog section, the composition of the main peat-forming plants changed, with a significant decrease in *C. lasiocarpa* and the disappearance of deciduous remains, which were present (5–10%) in the fen peat. Such changes in the botanical composition of the peat allow us to determine that transitional bog peat accumulated. In the section above, at the depth interval 1.2–1.4 m (385–1435 cal BP), significant changes occurred in the composition of the bog vegetation and peat-forming plants. Groundwater-feeding plants (sedges, rushes) still grew in the bog, but *Sphagnum* species – *Sphagnum fuscum* and *Sph. Magellanicum* – which feed on precipitation were

also becoming established. This combination of plant remains is indicative of a transitional bog type during the accumulation of the peat layer described above.

The upper, 1.15-m-thick peat layer of Vilku Bog has accumulated over the last 380 years. Its main peat-forming plants are *Sphagnum* sp., *Eriophorum vaginatum* and *Ericaceae*., which are characteristic of raised bogs. The peat characteristics identified suggest that the upper layer of Vilku Bog is composed of *Sphagnum* peat of the raised bog type with low decomposition (15–20%). The nature of the botanical composition shows that Vilku Bog has undergone the complete cycle of bog development, from fen to transitional bog, and finally to raised bog.

The regional vegetation is characterised by changes in tree composition in the whole of the vicinity of the northern part of the Lubāns wetland, according to the results of the spore-pollen analysis (Reire, 2024). The pollen curves in the diagram indicate a change in the composition of the surrounding forests since the Middle Holocene and the end of the climatic optimum between 6100 and 5100 cal BP, when forests with a significant presence (10–15%) of broad-leaved trees (*Ulmus*, *Tilia*, *Quercus*) developed in the vicinity of Vilku Bog area; in the present day, there is a distribution of mixed-tree forests, with a significant proportion of *Pinus* in the forest composition. The fluctuations in herbal plant pollen and changes in the composition of aquatic plant pollen and spores indicate the lake becoming overgrown and the development of the peatland from a fen to a raised bog over the last 380 years, with a significant proportion of *Sphagnum* in the peat composition. The results of the pollen analysis reveal changes in vegetation composition between 6100 cal BP and the present day, which have been influenced by changes in climatic conditions and possibly by human activities conditionally indicated by the presence of ruderal plants, mainly *Urtica*, Chenopodiaceae, Plantaginaceae pollen and charcoal dust. They were found in the bog section interval, the sediments of which formed in the period from 3000 to 1430 years ago and are probably not related to the Abora I settlement existed time since 4520 cal BP.

The dynamics of sediment accumulation during the development of Vilku Bog have not been uniform up to the present day. Relative to the other sediments of Vilku Bog, the slowest sediment accumulation occurred when environmental conditions in Vilku Bog changed from fen to transitional bog from 4810 to 3410 cal BP, with an average annual accumulation of 0.02 cm. The fastest rate of sediment accumulation is

in the last section, accumulating 0.23 cm per year during the raised bog development stage since 380 cal BP.

Conclusion

In the Vilku Bog area, which is a small depression in the Lubāns Plain, clays and silt initially accumulated under lake conditions. During the Middle Holocene, at the climatic optimum before 6155 cal BP, the lake began to accumulate sediments rich in organic matter (gyttja and peaty gyttja) as the number of aquatic plants increased. The calm hydrological conditions of the lake are evidenced by the water chestnut fragments *Trapa natans* found in the gyttja; the seeds of *Nymphae alba* are also well preserved. Vilku Bog began to develop before 5810 cal BP in the Middle Holocene, in the second half of the climatic optimum, as the lake overgrew and fen type *Hypnum* peat accumulated. The peatland bed is relatively flat, with occasional undulations, above which other sediments accumulated almost in parallel: lake sediments, gyttja, and peaty gyttja, bog deposits, fen-type *Hypnum*, grass, sedge peat, transition-type peatland grass, *Sphagnum*- cotton grass peat; and raised-bog-type *sphagnum* peat. The conditions of sediment accumulation have been variable, with the aquatic environment at a depth of 2.98 m being replaced by peatland conditions as the palaeolake becomes overgrown. The botanical composition of the Vilku Bog peat shows that Vilku Bog, formed by the overgrowth of the Vilku palaeolake, has undergone a complete bog development cycle from fen to transitional bog and, finally, to raised bog, which has only developed as a raised bog over the last 380 years. As the Vilku paleolake became overgrown, the macroremains found in its sediments include a large diversity of plant remains, both aquatic plants and plants that usually grow in shallow water and on the coast, as well as in wet meadows. As the raised bog developed the number and diversity of plant macroremains decreased.

Peat accumulation in Vilku Bog varied, from 0.02 cm/year in the period 4810–3410 cal BP to 0.23 cm per year before 380 cal BP, when the bog reached the stage of raised bog.

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Kopsavilkums

Vilku purvs ir viens no maziem (aptuveni 95 ha), ledāja kušanas ūdeņu palikšņu ezeriņiem Lubāna līdzenumā ziemeļrietumu daļā, kurš ir pārpurvojies. Lai noskaidrotu paleovides izmaiņu ietekmi uz Vilku ezera/purva nogulumu veidošanos, tika veikti multidisciplināri pētījumi nogulumu paraugiem, kuri tika iegūti lauka darbos, veicot 8 zondējumus un 3 urbumus pa profilu diagonāli pāri Vilku purvam. Nogulumiem tika veiktas: karsēšanas zudumu, augu makroatlieku, kūdras botāniskā sastāva un kūdras sadalīšanās pakāpes, sporu–putekšņu analīzes, kā arī AMS ^{14}C datēšana.

Vilku purva teritorijā sākotnēji ezera apstākļos uzkrājās māli un aleirīti, bet vidējā holocēnā, klimatiskā optimuma laikā, pirms 6160 kal. g. PM, ezerā, palielinoties ūdensaugu daudzumam, sāka uzkrāties gitija un kūdraina gitija. Ezeram aizaugot, Vilku purvs sāka veidoties pirms 5810 kal.g.PM vidējā holocēnā, klimatiskā optimuma otrajā pusē, virs gitijas uzkājoties purvu nogulumiem – zemā tipa hipnu, zāļu, grīšļu kūdrai, pārejas tipa zāļu un sfagnu-spilvju kūdrai un augstā tipa sfagnu kūdrai. Nogulumu uzkrāšanās apstākļi bijuši mainīgi – ūdens vidi 2.98 m dziļumā nomaina purva apstākļi, paleoezeram aizaugot. Vilku purva kūdras botāniskā sastāva raksturs liecina, ka Vilku purvs, kas izveidojies aizaugot Vilku paleoezeram, ir izgājis pilnu purva attīstības ciklu no zemā purva uz pārejas purvu un, visbeidzot, uz augstā tipa purvu. Kā augstā tipa jeb sūnu purvs, tas attīstās tikai pēdējos 380 gadus. Nogulumu uzkrāšanās Vilku purvā ir bijusi mainīga no 0.02 cm gadā laika posmā 4810–3410 kal.g.PM līdz 0.23 cm gadā pirms 380 kal. g. PM, kad purvs sasniedz augstā purva stadiju.

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