# THE $^{14}C$ AGE OF PALSAS IN NORTHERN EURASIA

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ABSTRACT. We discuss results of $^{14}C$ dating peat of palsa of different regions of Northern Eurasia. We apply these dates to determine the age of active palsa growth during different periods of the Holocene in permafrost zone.

## INTRODUCTION

Palsas can be defined in several ways. Pissart (1983), in a review article on the origin of palsas, proposed that palsas be defined as perennial mounds caused by accumulation of ice in the ground, the ice resulting from "cryosuction", which attracts water toward the freezing front. In contrast, pingos are primarily caused by the accumulation of ice resulting from injection of water under pressure. Washburn (1983a) defined palsas as peaty permafrost mounds ranging from 0.5 to 10 m in height and exceeding 2 m in diameter, with typical forms caused by permafrost aggregation and degradation of peat. Palsas are classified into three types by Åhman (1977): 1. Esker palsas—long ridges, 2–6 m high and 50–500 m long with the long axis parallel to the bog slope; 2. String palsas—normally 1–2 m high and 25–100 m long with axis transverse to the bog slope; 3. Dome-shaped palsas—the classic type, 2–10 m high with a circular or oval circumference. Here, we define a palsa as a peat-covered permafrost mound (with frozen ice core), formed (and heaved) as a result of freezing high-humidity grounds. These palsas are usually dome-shaped.

Palsas are found most often in areas of discontinuous and sporadic permafrost (classic palsa type; Washburn 1983a), but they are also found in continuous (Washburn 1983b) permafrost. It is difficult to determine the development of a palsa by, for instance, structural features or paleotemperature curves. It is known that permafrost degraded during the Holocene optimum in vast areas of the southern permafrost zone. Palsas older than 5000 yr are quite rare in these areas (Yevseev 1976). With the help of radiocarbon dates, it is possible to gain insight into palsa formation and degradation processes through time. $^{14}C$ dating provides the estimation of the age of the lake and (later) of the peat-bog in palsa development, and the end of peat accumulation by sedimentation in the palsa surfaces. As a rule, the age of palsa growth is determined by $^{14}C$-dating the peat layers on the top of the peaty mounds.

The age of the peat mound can be approximately established only after $^{14}C$-dating has been performed on the younger layers—from the cross-section of a palsa, the time of heaving, and formation. We have analyzed almost all $^{14}C$ dates of palsas available for the Siberian permafrost. Most of the dates were obtained by $^{14}C$ laboratories at different institutes of the Russian Academy of Sciences, namely: the Geological Institute (GIN), the Institute of Geography (IGAN), the Institute of Forest and Wood (KRIL) and the Permafrost Institute (PI).

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## Results

The $^{14}C$ dates from peat in palsas from various locations in Siberia are shown in Table 1. They are supplemented by data from northern Norway and Arctic Canada.

Table 1. Radiocarbon Dates of Peat in Palsas of Northern Eurasia

| Depth (m) | $^{14}C$ age (yr BP)* | Lab no. |
|---|---|---|
| *Tazovski Peninsula, Western Siberia, at Lake Kuryngvoilor, 2.5-m-high palsa* | | |
| 0.2 | 4900 ± 50 | GIN-2292 |
| 1.0 | 7910 ± 120 | GIN-2293 |
| 2.6 | 9380 ± 150 | GIN-2294 |
| *Tazovski Peninsula, Western Siberia, at Lake Kuryngvoilor, peat in depression near 2.5-m-high palsa* | | |
| 0.2 | 2490 ± 50 | GIN-2295 |
| *Tazovski Peninsula, Western Siberia, Kur'ekh River valley, 5-m-high palsa* | | |
| 0.4 | 3800 ± 40 | IGAN-392 |
| 1.0 | 5740 ± 40 | IGAN-391 |
| 1.5 | 7800 ± 50 | IGAN-390 |
| 2.0 | 8600 ± 50 | IGAN-389 |
| 2.3 | 9100 ± 50 | IGAN-388 |
| 2.5 | 9000 ± 50 | IGAN-387 |
| 3.2 | 9000 ± 50 | IGAN-386 |
| *Western Siberia, Ob River valley near settlement Azovy, 4-m-high palsa* | | |
| 0.4 | 550 ± 50 | GIN-2659 |
| 1.0 | 4580 ± 150 | GIN-2658 |
| *Western Siberia, Ob River valley near settlement Azovy, 2-m-high palsa* | | |
| 1.6 | 8570 ± 70 | GIN-2657 |
| *Western Siberia, Tazovski Peninsula, near settlement Pangody, three 2-m-high palsas* | | |
| 1.0 | 750 ± 60 | TA-745 |
| 1.5 | 2870 ± 60 | TA-743 |
| 2.0 | 6680 ± 70 | TA-744 |
| *Western Siberia, Tazovski Peninsula, near settlement Pangody, 8-m-high palsa* | | |
| 3.0 | 5610 ± 70 | TA-746 |
| 3.5 | 5810 ± 70 | TA-752 |
| *Western Siberia, Tazovski Peninsula, near settlement Pangody, peat in depression near 8-m-high palsa* | | |
| 4.5 | 6680 ± 80 | TA-742 |
| *Yenisey River valley near town Igarka, 3-m-high palsa* | | |
| 0.5 | 3930 ± 50 | KRIL-125 |
| 0.5 | 5140 ± 60 | KRIL-119 |
| 0.6 | 5200 ± 60 | KRIL-120 |
| 1.0 | 5410 ± 60 | KRIL-122 |
| 1.3 | 5450 ± 60 | KRIL-123 |
| 1.5 | 7330 ± 80 | KRIL-118 |
| *Yenisey River valley near town Dudinka, 3-m-high palsa N1* | | |
| 0.4 | 5410 ± 60 | KRIL-129 |
| 0.5 | 5515 ± 60 | KRIL-130 |
| 0.6 | 5890 ± 60 | KRIL-131 |
| 0.7 | 6280 ± 70 | KRIL-132 |
| 0.8 | 6800 ± 70 | KRIL-133 |
| *Yenisey River valley near town Dudinka, 3-m-high palsa N2* | | |
| 0.5 | 6170 ± 70 | KRIL-136 |
| 1.2 | 7060 ± 70 | KRIL-138 |
| 1.2 | 7050 ± 70 | KRIL-135 |

TABLE 1. Radiocarbon Dates of Peat in Palsas of Northern Eurasia *(Continued)*

| Depth (m) | $^{14}C$ age (yr BP)* | Lab no. |
|---|---|---|
| 1.5 | 7260 ± 80 | KRIL-137 |
| 1.6 | 7940 ± 80 | KRIL-134 |
| *Palsa near southern limits of Western Siberia permafrost zone* | | |
| 0.0–0.25 | 1370 ± 30 | KRIL-499 |
| 0.25–0.50 | 2620 ± 45 | KRIL-500 |
| 1.25–1.5 | 6170 ± 70 | KRIL-501 |
| 1.97–2.0 | 6080 ± 70 | KRIL-502 |
| 2.45–2.5 | 6815 ± 80 | KRIL-503 |
| 2.85–2.9 | 6700 ± 80 | KRIL-504 |
| *Polar Ural near Lake Malaya Khadata, 3–4-m-high palsa* | | |
| 0.5 | 5680 ± 120 | Tln-56 |
| 1.0 | 6315 ± 70 | Tln-64 |
| 1.5 | 7960 ± 100 | Tln-86 |
| *Polar Ural in valley of the River Bol'shaya Lagorta, 1–2-m-high palsa* | | |
| 0.4 | 1760 ± 60 | Tln-42 |
| 0.5 | 3300 ± 110 | Tln-55 |
| 1.5 | 4385 ± 60 | Tln-41 |
| 6.5 | 7790 ± 80 | Tln-40 |
| *Taimyr Peninsula, River Novaya valley, Ary Mas area, 3–4-m-high palsa* | | |
| 0.3 | 5495 ± 80 | PI |
| 1.2 | 5860 ± 60 | PI |
| 2.1 | 6670 ± 90 | PI |
| 2.2 | 6695 ± 80 | PI |
| *Southern Yakutia, peat plateau "Suollakh" in Aldan-Timpton River junction 4–6-m-high palsa* | | |
| 0.2 | 3420 ± 50 | GIN-4355 |
| 2.3 | 8950 ± 70 | GIN-4356 |
| 2.5 | 10,750 ± 80 | GIN-4357 |
| 2.7 | 9940 ± 60 | GIN-4358 |
| 2.9 | 9990 ± 90 | GIN-4359 |
| 3.3 | 9910 ± 80 | GIN-4360 |
| 3.5 | 10,120 ± 120 | GIN-4361 |
| 3.9 | 10,610 ± 70 | GIN-4362 |
| *Northern Norway, Kautokeino, 2.3-m-high palsa 0.3 m* | | |
| 0.3 (+391.0) | 770 ± 105 | HV-10604 |
| 0.7 (+390.6) | 1325 ± 150 | HV-9969 |
| 1.3 (+390.0) | 2080 ± 50 | HV-9172 |
| 1.3 (+390.0) | 2100 ± 50 | HV-9970 |
| 1.3 (+390.0) | 3215 ± 60 | HV-9971 |
| 2.3 (+389.0) | 5420 ± 70 | HV-9973 |
| 2.3 (+389.0) | 6400 ± 80 | HV-9170 |
| 3.3 (+388.0) | 7700 ± 55 | HV-9171 |
| 4.3 (+387.0) | 9000 ± 95 | HV-9974 |
| *Northern Norway, Kautokeino, inter-mound depression, near 2–3-m-high palsa* | | |
| 0.5 | 475 ± 100 | HV-10605 |
| *Arctic Canada, Cornwallis Island area, resolute area, "Five Mile Lake", palsa* | | |
| 0.2 | 1680 ± 60 | QL-1739 |
| 0.7 | 2430 ± 60 | QL-1740 |
| 1.2 | 5410 ± 50 | QL-1741 |

*After Vasil'chuk and Lakhtina (1986) with addition from Surova, Troitski and Punning (1975); Belorusova and Ukraintseva (1980); O. S. Turkina, personal communication (1980); Starikov and Zhidovlenko (1981); Washburn and Stuiver (1985); F. Z. Glebov, personal communication (1990); Ospennikov (1991).

In Western Siberia, Holocene palsas are located in the south of the Tazovski Peninsula, at Lake Kuryngvoilor (66°N, 72°E). The palsa forms with $^{14}C$ ages are shown in Figure 1a and Table 1. The central part of the 2.5-m-high palsa is dated from 9700 to 4900 BP. Peat found in a depression at this palsa (0.2-m depth, see Fig. 1a) is dated at 2400 BP. The palsa is younger than 4900 BP. A palsa in the valley of the Kur'ekh River in the Tazovski Peninsula (65°N, 66°E) (Fig. 1b) has dates ranging from 3800–9100 BP. This palsa must be younger than 3800 BP (Vasil'chuk and Lakhina 1986). At the same area of Tazovski Peninsula, at the upper Arkatabyakha River, and in the Plokhoi Yurga River valley, there are palsas formed *ca.* 5000 and 8000 BP (Fig. 1c,d).

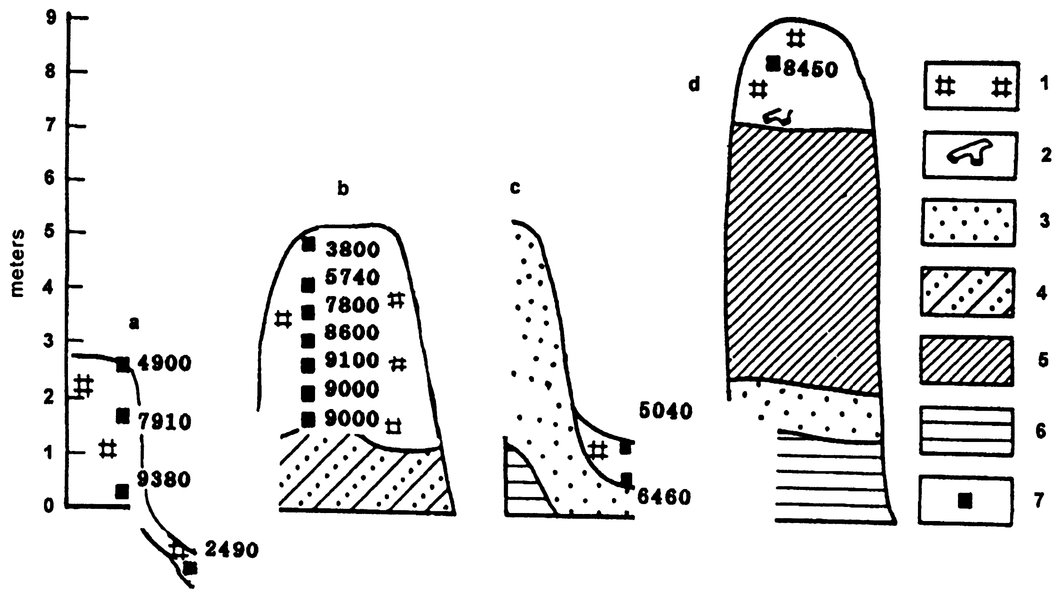


Fig. 1. $^{14}C$ dated palsas at Lake Kuryngvoilor (a), near Kur'ekh River (b), in upper Arkatabyakha River (c) and in Plokhoi Yunga River valley (d), Tazovski Peninsula, Western Siberia. 1. peat; 2. wood; 3. sand; 4. sandy loam; 5. loam; 6. clay; 7. sampling points of organic matter and $^{14}C$ dates.

A 4-m-high palsa located in the Ob River valley near the settlement Azovy, Western Siberia (65°N, 66°E) has been investigated (Vasil'chuk 1983). The $^{14}C$ dates for the peat from this palsa range from 500 to 4500 BP (Fig. 2a, Table 1). Peat from the bottom of a 2-m-high palsa (Fig. 2b) has been dated to 8,500 BP. In this case, several palsas are younger than 500 BP, whereas others are considerably older (Vasil'chuk 1982).

We have investigated the structure of many palsas in this area by boring 7–10-m bore-holes (Vasil'chuk 1982, 1983). Figure 2a shows a typical vertical cross-section of a palsa consisting of alternating peat varieties, from bottom to top: low moor (grass, *Scheuchzeria palustris*) peat is overlapped by high moor (cotton grass or *Sphagnum fuscum*) peat, above low moor (often wood) peat is covered by high moor (cotton grass or *Sphagnum fuscum*) peat again. Apart from the mounds near the Azovy settlement shown in Figure 2, we describe palsas with peat layers including sandy loam laminas under icy clay at a depth of 1.5–2.0 m.

Near the Pangody settlement in the southern Tazovski Peninsula (66°N, 75°E), several $^{14}C$ dates were obtained for three palsas with a height of 2 m. We obtained three dates ranging from 6600 to 750 BP. For a 8-m-high palsa, we have two dates: 5810 and 5610 BP. Peat in a depression is dated at

6680 BP (O. Turkina, personal communication 1980). The low palsa is younger than 750 BP, and the high palsa is younger than 5600 BP (Vasil'chuk and Lakhtina 1986).

In the Yenisey River valley near the town of Igarka (67°N, 86°E) one 3-m-high palsa peat has been dated between 7330 and 3900 BP (Table 1, Fig. 4a). At two 3-m-high palsas near the town of Dudinka (70°N, 86°E) (Fig. 4b,c) (lower Yenisey River valley), two series of dates have been obtained: from 6800 to 5410 BP, and from 7940 to 6170 BP (Table 1, dates by Starikov and Zhidovlenko 1981). The ages of these palsas are *ca.* 3900 BP, 5400 BP and 6100 BP, respectively.

Near the southern limits of the Western Siberia (62°N) permafrost zone, F. Z. Glebov (personal communication 1990) dated palsa peat from 6700 to 1300 BP (KRIL 499-504, Table 1)—this palsa must be younger than 1300 BP.

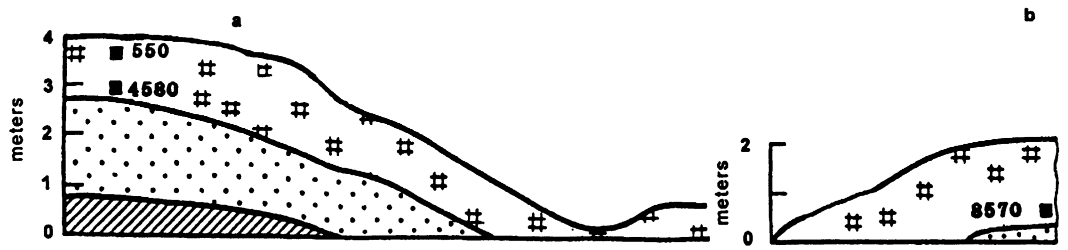


Fig. 2. $^{14}C$-dated palsas at Azovy settlement, Ob River valley, Western Siberia. Symbols as in Fig. 1.

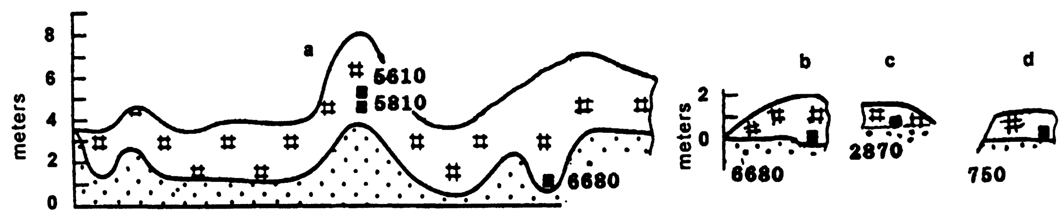


Fig. 3. $^{14}C$-dated palsas at settlement Pangody, Tazovski Peninsula, Western Siberia. Symbols as in Fig. 1.

## Polar Ural

A peat in a 3–4-m-high palsa located in the northern part of the Polar Ural near Lake Malaya Khadata (68°N, 66°E) has been dated between 5680 and 7960 BP; a peat in a 1–2-m-high palsa in Polar Ural in the valley of the River Bol'shaya Lagorta has been dated between 1760 and 7790 BP. The dates (Tln) are shown in Table 1 (Surova *et al.* 1975). The first palsa is younger than 5600 BP, whereas the second one is younger than 1700 BP. The coordinates for these Ural sites are 66°N, 65°E.

## Taimyr Peninsula

Peat in a 3–4-m-high palsa located in the Taimyr Peninsula, River Novaya valley, Ary Mas area has been dated between 5495 and 6695 BP (Belorusova and Ukraintseva 1980). The age of this palsa is younger than 5500 BP. The coordinates for this site are 72°N, 102°E.

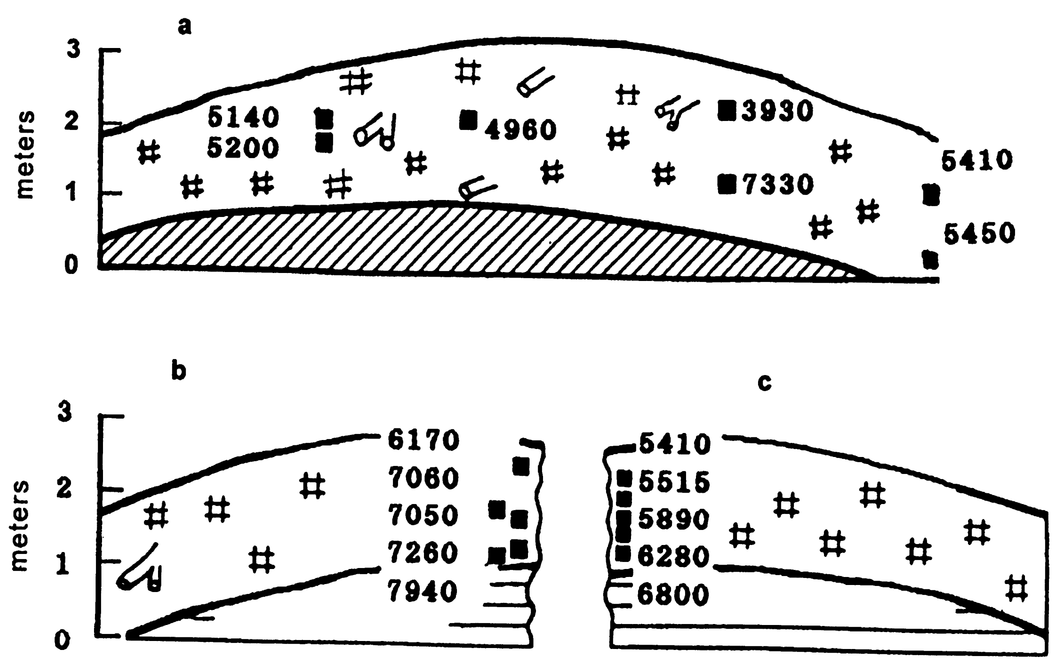


Fig. 4. $^{14}C$-dated palsas near the town of Igarka (a), Yenisey River valley; and near the town of Dudinka (b,c), lower Yenisey River valley, Western Siberia. Symbols as in Fig. 1.

## Yakutia

In Yakutia, Ospennikov (1991) described Holocene palsa in the peat plateau "Suollakh" (Aldan-Timpton River junction: 58°N, 126°E). The sequence of this palsa is 0.0–0.7 m: arboreous oligotrophic peat; 0.7–2.15 m: arboreous mesotrophic peat; 2.15–2.45 m: sphagnum mesotrophic peat; 2.45–2.6 m: hypnum mesotrophic peat; 2.6–2.9 m: arboreous-sphagnum mesotrophic peat; 2.9–3.95 m: hypnum eutrophic peat. There are a number of $^{14}C$ dates ranging from 3420 to 10,610 BP. These $^{14}C$ dates show that this palsa is not older than *ca.* 3000 BP.

## Scandinavia

Palsas in Scandinavia are typically $^{14}C$-dated between 5000 and 7500 BP (Åhman 1977; Åkerman 1982). In contrast, Göttlich *et al.* (1983) have studied a young (2.3 m high, 40 m long, 28 m wide) palsa at Kautokeino, northern Norway (69°N). The central part of the palsa cross-section was dated in Hannover, yielding dates ranging from 700 to 9000 BP. In a depression they obtained a date of 400 BP. These $^{14}C$ dates show that this palsa is younger than 700 yr, but peat accumulation in the depression persists up to the present.

## Canada

Many palsa and pingo sites were studied in Canada, and numerous $^{14}C$ dates were obtained. We discuss here only one selected palsa. $^{14}C$ dates from the "Five Mile Lake" (74°N), Cornwallis Island area, Arctic Canada, were measured at the University of Washington (Washburn and Stuiver 1985). They are shown in Table 1. Basal peat from a depth of 1.2 m was dated at 5400 BP, and peat from a depth of 0.2 m dated at 1600 BP. The dates are evidence that the palsa is young and formed no earlier than 1600 BP. Certainly in Canada, there are old palsas as well, for example *ca.* 8000–5500 BP in the Fourth of July Creek valley (59°N).

## Discussion

From the data shown here, we can see that palsas have developed during different times, even within the boundaries of single permafrost region. Almost all palsas (Figs. 1–4) belong to a single permafrost region. However, their age (based on $^{14}C$ dates from peat) ranges from 500 to 8000 BP. This depends on factors such as the local water supply, bog formation process, and peat sedimentation. Palsa sections with alternating oligotrophic and eutrophic peat are noted, suggesting cyclic processes. $^{14}C$ dating allows us to estimate the age of the lake and later peat-bog in palsa development, because palsa growth is also associated with the local water supply, bog formation and peat sedimentation.

The palsa evolution during the Holocene can be used for indication of the paleoclimate and paleo-permafrost dynamics in the northern Eurasian permafrost. The palsas grew actively during different periods of the Holocene both in northern and in southern areas of northern Eurasia. Probably the forming of permafrost and palsa formation was more intensive after increasing thermokarst phenomena.

In areas of continuous permafrost, permafrost conditions existed during the whole Holocene, so that here palsa growth does not depend on climatic oscillations (Vasil'chuk 1982). In areas of discontinuous and sporadic permafrost, the permafrost degraded during the Holocene climatic optimum. The majority of palsas formed during the Late Pleistocene and Early Holocene melted. The relict palsas dating older than 5000 BP are rare in these areas. They are mostly found in southern continuous permafrost areas where melting did not occur. Substantial bog formation took place after thermokarst development led to intensive peat accumulation during the Holocene optimum. A decrease in summer temperatures after the Holocene optimum resulted in aggravation of the permafrost, mainly at places where peat accumulated.

Also, local conditions such as erosion, accumulation of sediments, and peat formation influenced the development of palsas. Erosion shows in two ways. The first is a degradation of inter-mound depressions, the second, a removal of cover deposits from the mounds. The latter most likely explains the structure of the mound in upper Arkatabyakha River, Tazovski Peninsula (Fig. 1c). This is a flat mound without peat cover, which was removed after the mound formation to the depression between mounds. Peat accumulation persisted, as indicated by the dates (6400 and 5000 BP). Most likely, it was a typical palsa, with ice-rich loam underlying sand and a convex shape of the sand roof. Also, other mounds from the same area are similar palsas (Fig. 1a,b,d).

Of special interest is a case where older dates occur in the upper part of palsa sections and much younger dates in the depressions. A clear example of such phenomena is the 3-m section of palsa near lake Kuryngvoilor (Fig. 1a). A non-inversion series of dates (9300–4900 BP) has been obtained along the mound axis, and a date (2400 BP) is obtained for the upper part of the depression between the mounds. This is evidence that peat accumulation persisted after palsa formation.

The $^{14}C$ dates shown in Figures 1–4, and also dates from other research (Table 1), suggest that the palsa age is almost independent from latitude and temperatures of the permafrost. Both in areas of discontinuous and sporadic permafrost, and in the continuous permafrost, old and young palsas are found. We recognize four different ways of permafrost mound formation:

1. Slow freezing under rapid drainage with relatively high ground temperature (0 to −3°C);
2. Slow freezing under gradual drainage with relatively high ground temperature (0 to −3°C);

3. Rapid freezing under rapid drainage with relatively low ground temperature (<–3°C);
4. Slow freezing under gradual drainage with relatively low ground temperature (<–3°C).

These four types result in considerably different distributions of $^{14}C$ dates. Under conditions of relatively high temperatures, a fast drainage (as a result of a lake burst, for example) causes slow freezing and the formation of palsas at randomly distributed locations in the lake depression. We expect here similar $^{14}C$ dates for the same depths in the upper sections. In addition, the slow freezing begins at the parts drained initially, which are more common inshore. As a result, palsas are located concentrically in the drained lake depression. The youngest $^{14}C$ dates should be found at the upper part of sections of a circumferential palsa, or in the central part depending on which area froze later. Bottom peat dates can be contemporaneous.

In conditions of low temperatures, lakes drain in a similar fashion to the disturbance of a bulldozed winter road crossing the outlet creek (Mackay 1988). There is a fast freeze and formation of one or more mixed pingo- and palsa-type mounds. Independent from mound location, a polygonal ice-wedge was found at the palsa sections near the Azovy settlement (Low Ob valley).

The alternation of peat, water-saturated loam and clay, and occurrence of underlying water-bearing sand is the most important prerequisite of a potential large increase in thickness. This is also the case after thawing as both peat and loam do not drain and have a high moisture content. We observe here a repeated cyclic heave and subsidence at the same place (Vasil'chuk 1983). Cyclic permafrost peatland development has been described by Zoltai (1993) in northwestern Alberta, Canada. Cyclic pingo formations in the Northwest Territories of Canada have been described by Mackay (1977). Kullman (1989) also noted cyclic processes in permafrost development in Northern Sweden. At 15 sites, a new permafrost expansion (and palsa formation) after exceptionally late thawing has been observed. In Norrbotten Province, mires with palsa-like mounds were found. A few low birch trees grow on these mounds. In Vasterbotten Province, peat mounds with a height of 1 m occur. In 1976, they were completely thawed, but in 1987 frozen peat with segregated ice was found at a depth of 0.6 m.

Palynologic studies of palsa sections could be useful as an additional method for the study of palsa development. Palsa growth stages can be distinguished by pollen analysis. It is very important to select a local signal from pollen spectra for these aims. Pollen and spores spectra from palsa sections near the Azovy Settlement show a paradoxical situation at first glance. As a rule at the low part of the palsa section spores and grass pollen (more often this is pollen of sedge and spores of horsetail) dominated, at the upper part tree pollen prevailed. These results probably imply that pollen and spores spectra are representative for a local succession of vegetation, but they only partially reflect climatic changes. Mosses and herbs formed peat layers in low areas before freezing. When heaving takes place, the site becomes dry and tree vegetation appears, forming woody peat with the corresponding pollen spectra.

Worsley *et al.* (1995) performed palynologic analysis in northern Quebec palsas, resulting in a division into the same stages of palsa formation which we have obtained for the Western Siberia palsas. Pollen and spores data show the abundance of sedge pollen (60% from total land pollen) and spores of horsetail (23%) at the first stage. The second stage is dominated by tree pollen (up to 82%) with a large part of heather pollen (12%).

Seppälä (1971) obtained a $^{14}C$ date for the frozen silt from the core of Suttisjoki palsa bog 9740 ± 280 BP, Hel-33). This is evidence for the beginning of palsa formation in eastern Lapland in the Preboreal. Pollen analysis of that section shows both climatic changes and landscape ones. The lower part of the section (depth 2.0–2.9 m), a low moor bog stage is characterized by prevailing sedge pollen (up to 70%) and also spores of horsetail (8–25%). The upper part is a high moor bog, characterized by the absence of sedge pollen and prevailing peat-moss spores (*ca.* 100%) with participating heather pollen (up to 25%).

We note that the pollen and spore content in the mounds in the central part of Eastern Yamal Peninsula have another distribution—the domination of tree pollen in the lower part of the cross section (re-deposition of tree pollen) and prevailing grass pollen in the upper part (Vasil'chuk *et al.* 1983). The low content of local components does not provide information about vegetation succession in relation to mound formation in this case.

## Conclusion

We reviewed the permafrost palsas in northern Eurasia in terms of $^{14}C$ dates of the peat layers. Climatic conditions are important for permafrost and palsa formation. However, the local environment (especially conditions of sediments and peat accumulation) leads to varying palsa ages even within uniform climatic and geocryologic region. $^{14}C$ dating has shown that the palsa age is almost independent of latitude and temperatures of the permafrost. Both in areas of discontinuous, sporadic permafrost and in continuous permafrost, ancient and young palsas are found. Palsas develop within the boundaries of a single permafrost region at different times. Even palsas belonging to the same climatic region can have ages differing by 8000 yr or more. It is difficult to find ancient palsas in the discontinuous permafrost zone (especially in sporadic permafrost zone), but they can be found in southern continuous permafrost areas where no melting occurred. We recognize at least four different ways of permafrost mound formation, depending on temperature and drainage conditions. This defines the $^{14}C$ date distributions. The cyclic character of the palsa thickness is a result of their "pulsating" development: repeated freezing with heaving and repeated melting with subsidence.

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