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THE APPLICATION OF POLLEN AND SPORES TO DETERMINE THE ORIGIN AND FORMATION CONDITIONS OF GROUND ICE IN WESTERN SIBERIA

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Abstract

Pollen and spore spectra from various types of ground ice and their host sediments were studied to obtain additional information about formation features. A new approach for the pollen analysis of ground ice samples was developed and applied. Pollen and spore spectra from Holocene and Late Pleistocene ice wedges and their host sediments (300 samples from ground ice and 800 samples from host sediments) in Western Siberia are discussed and compared with spectra from firn. Also considered are pollen and spore spectra of epigenetic segregation, injection and infiltrated-segregation ice from the Yamal and Gydan Peninsulas in relation to water source and freezing direction. Pollen analysis is unsuitable for dating and for determining ground ice type. However palynology can provide additional information about ground ice origin.

Introduction

Pollen and spores are common in ice bodies of different origin in permafrost areas. However their concentration is generally low (A. Vasil'chuk, 1987). To obtain sufficient data, a large volume of ice must be analysed. Pollen in ground ice was studied by B. Gorodkov as long ago as 1948. He sampled 20 kg of ground ice sampled from massive ice on Kotel'ny Island (Gorodkov, 1948). Long distance transported pollen and spores have been found together with local tundra species (Grichuk and Fyodorova, 1956). Pollen from massive ice bodies and overlying sediments has also been studied in the Mackenzie Delta (Fujino and Sato, 1985). We have investigated pollen and spores both in ground ice and host sediments in the permafrost areas of the Yamal Peninsula (Yu. Vasil'chuk and A. Vasil'chuk, 1979). In another study, different types of ground ice of Western Siberia and Yakutia were analyzed by pollen analysis (Yu. Vasil'chuk and A. Vasil'chuk, 1996). This paper reports on a palynological study of various kinds of ground ice (300 samples from ground ice and 800 samples from host sediments) in order to obtain information on ice formation, e.g., palaeoenvironmental conditions by studying syngenetic ice wedges together with host sediments; syngenetic ice layers to obtain information about their burial regime; epigenetic segregation, injection and infiltrated-segregation ice layers to determine the position of the water-bearing horizon and the direction of freezing.

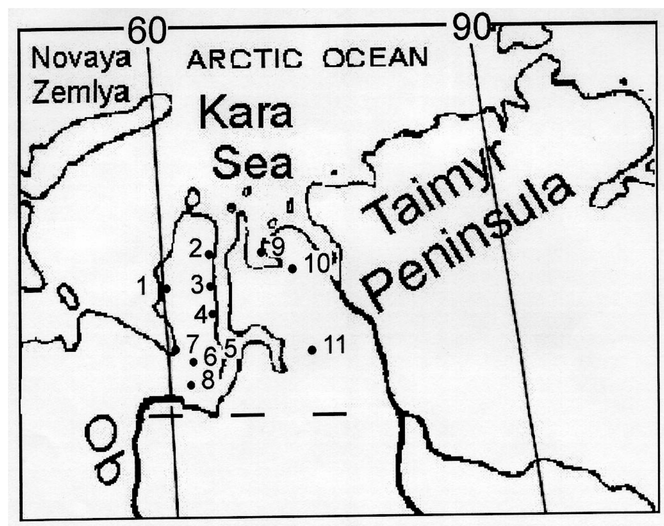

Figure 1. Location of sites, mentioned in the text: 1.Kharasavaya River; 2. Tambey River; 3. Seyaha Settlement; 4. Er'yakha River and Lyakkatosyo River; 5. Mys Kamenny Settlement; 6. Middle Yuribey River; 7. Lower Yuribey River; 8. Shchuch'ya River; 9. Matyujsale Settl.; 10. Gyda Settlement ; 11. Messoyakha River. Dotted line shows the northern limit of taiga.

Methods

There are some unusual aspects associated with ground ice sampling and treatment for pollen analysis. This is due to the low concentration of pollen grains and spores and to their excellent preservation in the ground ice. Our sampling strategy depended on the ground ice origin. During past investigations of

Table 1. Pollen spectra across a Late Holocene ice-wedge axis of Lyakkatosyo River flood-plain, Eastern Yamal Peninsula, Western Siberia in percents of total volume
D1 - distance (in meters) from the lateral boundary of the wedge at a depth of 0.8 m.

D[1]	Trees	Pines	Dwarfed Shrubs	Herbs	Spores	number of pollen and spores
0.1	12	9	19	41	28	188
0.2	20	12	11	34	35	282
0.4	28	19	11	35	26	190
0.7	8	6	12	32	48	130
1.1	2	-	26	30	42	147

Holocene ice wedges from exposures and from bore holes in the north of Western Siberia, the ice wedges were sampled both along the axis and across the ice-wedge body. The results indicated varying pollen spectra across the wedge (Table 1), with the same oscillations fixed along the ice wedge axis from top to the bottom of the wedge. At a depth of 0.7-1.4 m, the tree pollen was about 20%, at 1.4-1.5 m, about 10-15%, and from 1.6 to 2.1 m – 25-30% (A. Vasil'chuk, 1987). It follows from these results that sampling across the ice wedge axis provides adequate representation. However, if a temporal distribution of pollen and spores is required, sampling along the ice wedge axis is preferable. In thick syngenetic ice wedges, which formed over many thousands years and became very large in vertical extent, it is possible to sample across the ice wedge axis, but age determinations in this case are very difficult. In order to follow a sequence of ice wedge formation, we determined that most representative results could be obtained if sampling was undertaken along the vertical axis of such ice wedges. In order to follow the axis of the wedge it is preferable to take samples at an outcrop, where it is possible to collect large volume samples. When sampling takes place across the vertical axis, it is very difficult to obtain a temporal sequence of samples, taking into account that it is not possible to define exactly where and when cracking took place within the ice-wedge body. As a rule, samples from thick ice wedges were taken over 0.5 m, and for special methods, ice monoliths were taken.

We typically obtained 1 kg of ice per sample (0.1 m deep into ice-wedge body). After thawing, three quarters of the melt water was passed through filter paper. Due to ice melting an ice-pollen grain communication is destroyed. The pollen was concentrated using centrifuging and filtering. Because of the relatively high concentration of pollen grains and low concentration of mineral particles, it was usually possible to study pollen and spores without any additional procedures. Some samples required routine treatment with sodium hydroxide and acetolysis. However as the pollen grains tended to swell, we strictly limited the length of time for acetolysis and did not heat the samples during this procedure.

Special study was required for the identification of birch pollen (*Betula sect. Albae* and *B.sect. Nanae*) for the northern regions of Western Siberia (Petrova and Vasil'chuk, 1982). Pollen of many varieties of *Betula sect. Nanae* from different areas were examined.

In order to gain insight into pollen spectra formation in ground ice, we sampled winter snow, the water of rivers, lakes and bays, ice aprons, firn, surface ice (floes) of rivers, lakes and bays. We consider the pollen spectra of firn to be a possible analogue to that of ice-wedge ice because both are similarly formed (Table 2). Floe ice of rivers, lakes, and bays can be considered as a possible analogue of buried ice.

Pollen spectra from surface ice are different from those of ice-wedges, because they contain much more tree pollen, possibly because of a potentially more southerly place of origin for the floe. If surface ice is formed to the south of the sampling place (as is typical for the northern regions of Western Siberia), the pollen spectra should contain pollen and spores that differ from the pollen spectra of the area where the floe was

Table 2. Pollen spectra from the surface of ice aprons and from the sea, bay and river floes in the North of Western Siberia: tree pollen (T), pollen of *Pinus sibirica* and *Pinus silvestris* (PP) included in the tree pollen, shrubs (Sh), herbs (H), spores (S) in percents of total volume.

Site	Snow					Surface ice				
	T	PP	Sh	H	S	T	CP	Sh	H	S
Matyujsale Factory	16	12	16	56	12	46	43	14	32	8
Kharasavaya River	28	21	9	48	15	55	49	13	37	9
Gyda River	27	20	18	44	11	42	34	12	37	9
Mys Kamenny Settlement	19	15	15	55	11	34	23	17	37	12

buried. Pollen spectra that form in large water reservoirs represent the pollen rain of the whole drainage system.

High percentages of tree pollen are present not only in the pollen spectra of fast-ice but in those of iceberg ice. It is known that pollen and spores are relatively abundant in polar glacier ice as, for example, in ice sheet of the Devon Island (McAndrews, 1984) and in the ice of glaciers of the Polar Ural Mountains (Surova, 1982).

Syngenetic ice wedges form from meteoric water (Yu.Vasil'chuk and A.Vasil'chuk, 1995a, 1997). Snow accumulates during the winter and in the early spring and snowmelt water penetrates into open frost cracks at thaw (in spring). Pollen spectra from firn should represent the regional features of vegetation cover.

Pollen and spores penetrate (are deposited) into ice wedges differently in relation to the ice origin. They may enter the ice-wedge body immediately from the air, or in flood water when they are trapped together with mineral particles. We obtained information about pollen rain in different seasons. Pollen grains penetrate into open frozen cracks in early spring only, when snow still covers the ground surface. The pollen grains come from more southerly areas, thus pollen spectra from ice wedges represent the regional pollen background level.

Late Pleistocene and Holocene syngenetic ice wedges were studied at exposures and bore holes in the North of Western Siberia. Radiocarbon dating of their host sediments indicates the time of ice wedge formation (Yu.Vasil'chuk and A.Vasil'chuk, 1997). A comparison of pollen spectra from ice wedges and host sediments gives an additional possibility to synchronize separate fragments of ice wedges and host sediment layers.

There are two stages of ice wedge complex formation (Yu. Vasil'chuk, 1992; Yu. Vasil'chuk and A. Vasil'chuk, 1995a): subaerial and subaqueous. The most intensive ice wedge growth is observed during the subaerial stage as during peat accumulates (Yu.Vasil'chuk and A.Vasil'chuk, 1997). At this stage, local components of the pollen spectra dominate: pollen of insect-pollinated herbs, tree pollen (*Larix sp*.) and shrub pollen (*Salix sp*.). At the subaqueous stage, re-deposited elements are abundant in pollen spectra. The formation features of pollen spectra in ice-wedge ice were indicated by the appearance of willow and larch pollen. These pollen types are infrequently preserved in host sediments and generally indicate the local occurrence of these plants in the vegetation cover. Comparisons of recent and fossil pollen (A. Vasil'chuk, 1982, 1983, 1987) with the modern vegetation seasonal temperature limits makes it possible to reconstruct mean summer and mean July temperatures with reasonable precision; winter temperatures have been reconstructed from the oxygen isotope record of ice wedge ice (Yu. Vasil'chuk and A. Vasil'chuk, 1995b; Yu. Vasil'chuk et al., 1997).

Results

Analysis of the pollen spectra of Holocene and Late Pleistocene ice wedges, together with pollen spectra of

Table 3. Pollen spectra of Holocene (H) and Late Pleistocene (LP) ice wedges and their syngenetic host sediments in Yamal-Gydan Province of the Western Siberia: tree pollen (T), pollen of *Pinnus sibirica* and *Pinus silvestris* (PP), shrubs (Sh), herbs (H), spores (S) in percents of total volume

Site	Ice-wedge ice					Host sediments				
	T	PP	Sh	H	S	T	PP	Sh	H	S
Shchuch'ya River (H)	36-66	1-25	10-27	10-32	5-22	22-47	1-9	1-30	10-55	8-54
Messoyakha River (H)	30-49	1-12	31-37	10-27	3-17	2-64	1-44	1-48	2-21	8-95
Tambey River (H)	52-86	2-48	3-11	6-33	2-18	27-69	6-16	11-34	12-41	1-29
Matyujsale Settl. (H)	3-11	0-1	29-35	27-44	20-33	1-22	0-12	2-43	18-68	6-54
Seyaha Settl. (LP)	23-46	13-40	4-20	21-37	15-35	12-82	6-68	0-35	2-64	8-70
Gyda Settl. (LP)	4-19	3-10	21-39	11-34	36-43	1-48	0-31	9-87	7-47	2-52

their host sediments (Table 3) in the north of Western Siberia, shows that percentages of tree pollen are higher in ice wedges of the southern region (66%) of the Shchuch'ya and Messoyakha Rivers than in northern areas (less than 10%). However, most of the tree pollen is long distance wind-transported; this is evidenced by more than 20% pine *(Pinus silvestris, P. sibirica*) pollen, which was absent on the Yamal and Gydan Peninsulas during the Holocene (Yu. Vasil'chuk, 1992). The pine limit was at 66.5°N and this provided an abundance of pine pollen in the southern region in early spring. Comparison of spectra from ice wedges and host sediments shows that the pine pollen rain influx was more noticeable in spring, when frost cracks were open, than later in summer when the atmospheric content of pine pollen diminished. In a section of flood-plain sediments in the mouth of the Tambey River, tree pollen dominates in ice wedges (86%) and pine pollen is about 48%. In host sediments, percentages of tree pollen are also high (27-69%), while pine is relatively low (6-16%). Evidently, the tree pollen from the host sediment (pollen of *Picea sp*. and *Betula sect*. *Albae*) is water-transmitted due to repeated oscillation of Ob Bay level. The tree pollen from the ice wedges are air-transmitted. The same situation took place during formation of Seyaha ice-wedge complex (Yu. Vasil'chuk et al., 1984) at the mouth of Seyaha River. Tree pollen dominates (46% - with 29% cedar pine – *Pinus Sibirica*) in the upper part of ice wedges. In the host sediments, tree pollen represent 17-60%, pine increases to 50%, and in overlapping subaqueous sand, pine dominates (68%).

Pollen Spectra of Sheet, Injection and Segregation Ice

Palynological studies of Late Pleistocene sheet ground ice have been carried out at natural exposures in the Yamal and Gydan Peninsulas. The pollen spectra have

Table 4. Pollen spectra of massive buried ice (Middle Yuribey River, Yamal Peninsula) and massive injection-segregation ice (Lower Yuribey River, Yamal Peninsula) and their host sediments: tree pollen (T), pollen of *Pinus sibirica* and *Pinus silvestris* (PP), shrubs (Sh), herbs (H), spores (S) in percents of total volume

Site	Massive ice					Hosting sediments				
	T	PP	Sh	H	S	T	PP	Sh	H	S
Upper part of river valley	35-67	4-32	1-15	13-57	4-13	40-93	21-44	1-11	2-25	2-24
Lower part of river valley	30-63	14-50	1-41	10-23	14-19	17-40	10-25	11-27	8-16	26-44

been investigated from sheet ice: buried syngenetic ice and distinct injection-segregation ground ice in the same area in the Yuribey River valley of Yamal Peninsula (Table 4).

A syngenetic buried ice sheet formed in coastal deposits, was immediately covered by sediments, and frozen. The pollen assemblages of the host sediments are represented by high percentages of tree pollen (up to 93%), mainly *Pinus sibirica*, *P.silvestris* and *Betula sect. Albae*. Pollen spectra from the ice are similar to those from the sediment, but are less abundant. Tree pollen also dominates (39-67%). There is a close similarity of buried pollen assemblages with the pollen spectra of present surface ice (see Table 2).

Pollen from the injection and segregation ice layers are quite variable. They are characterized by their similarity to those of the horizons of host sediments. This is a result of epigenetic freezing of deposits, of unlike origin.

Conclusions

Pollen analysis is unsuitable for dating and for determining ground ice type. However palynology can be used for additional information about ground ice origin. We have identified several varieties of pollen assemblages based on ground ice of different ages and origins in the North of Western Siberia.

These are:

1). The pollen spectra of Holocene syngenetic ice wedges are characterized by similarity with the pollen spectra of the host sediments. Tree pollen is more frequent in pollen spectra of ice wedges in southern areas especially of those which had been formed in the Holocene climatic optimum. This is long distance pollen of *Pinus sibirica, P.silvestris* and also pollen of *Picea* sp., *Betula sect. Albae*, B. *Sect. Nana*e, which can be local.

High percentages of tree pollen are commonly found in ice wedges of northern areas which have been formed in conditions of alternating subaerial-subaqueous regime, particularly in coastal sections of bays or large rivers. In the case of ice wedges which developed in elevated relief forms, the pollen is dominated by local pollen and the tree pollen percentage is low.

2). The pollen spectra of ice wedges of Late Pleistocene age are usually similar to their host sediments. Two pollen assemblages are noted in the Late Pleistocene ice wedges. The first, is characterized by long distance wind-transmitted pollen of Pinus sibirica and P.silvestris together with water-transmitted pollen of Picea sp. They are deposited at the subaqueous stage of ice-wedge complex development. The second group is represented by relatively low percentage of tree pollen, mainly wind-transmitted pollen from pines. The pollen of wind-pollinated herbs or *Betula sect. Nanae* is more often dominant and these pollen were deposited at the subaerial stage.

3). The pollen spectra of buried syngenetic massive ice are commonly characterized by a close similarity with the pollen of host sediments. High percentages of tree and herb pollen are accompanied by low spores and shrub percentages.

4). The pollen spectra of epigenetic massive ground ice are dissimilar to the host sediments. These are commonly represented by high pollen percentages of various tree species.

The present data are insufficient for the reconstruction palaeoecology or palaeotemperatures. More data are required to cover different temperature and landscape zones. The pollen spectra of ground ice could be used to refine the data of the host sediments. An estimation of wind-transmitted pollen also could be done on the basis of pollen spectra of ice wedges, as almost all tree pollen is wind-transmitted and penetrates into ice wedges in early spring. It would also be possible to determine *Larix* sp. and *Salix* sp. participation in vegetation cover as their pollen are preserved in the ice of ice wedges.

A distinction needs to be drawn between different types of ice. Pollen spectra of syngenetic ice, both ice wedges or massive ice, could indicate palaeo-environment, primarily temperature regime at the time of ice formation. Pollen spectra from epigenetic ice could aid in identification of water source location and direction of freezing.

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