Paleopalinological survey of soils of the European north-east of Russia having complex organic profile

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Abstract. The genesis of the soils having second humus horizon in the North-East of the European part of Russia was considered in the paper. The theory of the relict origin of the second humus horizon in sod-podzolic soils was confirmed on the basis of paleopalynological analysis. Data of paleopalinological study of sod-podzolic soils with complex organic profile are presented. In these soils, the remains of the relict humus horizon, which formed in the warmer Atlantic period of the Holocene under broad-leaved forests, have been preserved. It was revealed that despite the significant degree of destruction of the relict horizon, paleomorphs (pollen and plant spores) were preserved in it, which formed phytocenoses of broad-leaved forests. During the optimal period of the Holocene, the northern boundary of the spread of phytocenoses of coniferous-deciduous forests within the borders of the modern Kirov region of Russia presumably passed north of 58 degrees north latitude. Currently, in the region, broad-leaved forests in natural conditions have been preserved south of 56 degrees north latitude. The results will clarify the species composition of vegetation and the history of landscape development in the Kirov region of Russia in the Holocene.

1. Introduction

Over the past few years climate change has become one of the most debated issues around the world. After the end of the last Valdai glaciation (about 12 thousand years ago), to date, the climate on the territory of the Russian Plain has changed several times. Periodic changes in climatic parameters led to regular changes in natural formations. Studying the features of vegetation distribution on the territory of the Russian Plain in the Holocene, it is possible, to a certain extent, to reconstruct the climatic conditions of the past, which is necessary to understand the dynamics of climate change and build climate change models in the modern era. Paleo-geographic research and, first, paleo-palinological research of soils, peats, and sedimentary rocks is one of the important sources of information about climate change in past eras. Pollen and plant spores (palinomorphs) can be preserved for a long time, being preserved in the soil rock mass and sedimentary deposits.

On the territory of the Russian Plain, within the taiga-forest and forest-steppe zones, there are unique relict natural formations - soils having a complex organic profile (with a second humus horizon). A distinctive feature of soils having a second humus horizon is the presence of a dark-colored second humus horizon (Ah) in the lower part of the arable horizon (Ap) or below the eluvial horizon (A2). Most researchers believe that the second humus horizon (Ah) was formed during the Holocene optimum period 6-8 thousand years ago, under steppe and forest-steppe vegetation and is the
remnant of a powerful black-earth humus-accumulative horizon. In connection with the cooling and humidification of the climate 4.0-4.5 thousand years ago, black-earth middle-Colocene soils underwent leaching and podzolization processes. That is, the pollen of plants that formed phytocenoses during the formation of this horizon should remain in the second humus horizon [1-4].

All higher plants (Bryophyta, pteridophytes, gymnosperm and angiosperms) produce pollen grains or spores, the outer seedcoats of which are rigid and almost do not break down, even when fossilized, withstand heating up to 300 °C, treatment with alkalis or concentrated acids. Due to its small size (tens, and in rare cases hundreds of microns) and special devices for transfer by wind and water, pollen and spores are spread over long distances. Therefore, spore-pollen complexes do not reflect local vegetation, but the vegetation cover of huge territories, allowing one to reconstruct the paleogeographic and paleoclimatic situation on a large scale [5, 6]. Spore-pollen products, which partially precipitate and become fossil, can be considered as a constant value due to the fact that it is a reflection of the formed plant groups that have existed for a long time.

The classic problem, in addition to the reconstruction of vegetation, which someone tries to solve using the palinological method, is the reconstruction of the climate. Thus, the use of the paleopalinological method in the study of soils with a second humus horizon allows to obtain reliable information on changes in vegetation cover and climate in the late Pleistocene-Holocene era.

2. Materials and methods
As a part of this study, sod-podzolic medium-loamy soils with a second humus horizon on cover loams located in the northeastern part of the Russian Plain on the territory of the Chepetsk-Kilmez watershed in the Kirov region were studied. Six soil sections were made in a wood sorrel spruce forest with a mixed herb, and three more on an agricultural field. In soil samples, according to the Grichuk method [7], a study was conducted of the palinomorphs (pollen and plant spores, plant stomata, algae cells, etc.), after which spore-pollen spectra were compiled for each soil section.

3. Results and discussion
In the examined profiles of sod-podzolic soils, the second humus horizon is diagnosed most often as separate fragments or spots of different degrees of blur of dark gray color. Its remains are better preserved in the soil sections under forest phytocenoses (figure 1).

![Figure 1. Profiles of sod-podzolic soil under spruce tree (a) and on arable land (b).](image-url)
In profiles of arable sod-podzolic soils, the relict horizon either completely disappeared as a result of mixing it with the arable horizon, or its remains are observed in the form of grayish eroded spots in the underground soil layer (figure 1). Accordingly, the preservation of the palinomorphs is better in forest soil profiles.

In modern climatic conditions, a wood sorrel spruce forest with a mixed herb was formed on the territory under study. The forest stand is represented by European spruce (Picea abies (L.) H. Karst.), Siberian pine (Pinus sibirica Du Tour), Siberian fir (Abies sibirica Ledeb.), downy birch (Betula pubescens Ehrh.) with rowan-berry (Sorbus aucuparia L.) and fly honeysuckle (Lonicera xylosteum L.) in undergrowth. The grass layer is presented by European wild ginger (Asarum europaeum L.), wood sorrel (Oxalis acetosella L.), oval sedge (Carex leporine L.) and male fern (Dryopteris filix-mas (L.) Schott). There are also spores of sphagnum and green mosses. Tables 1 and 2 summarize the results of the study of spore-pollen spectra across all soil sections.

Table 1. Spore-pollen spectrum of sod-podzolic medium-loamy soil having second humus horizon under wood sorrel spruce forest.

| Horizon | Depth, cm | Spore-pollen spectra |
|---------|-----------|----------------------|
| A0      | 0-3       | Abies sibirica; Betula pubescens; Picea abies; Pinus sylvestris |
|         |           | Asarum europaeum; Campanula spp.; Carex spp.; Dryopteris spp.; Equisetum sylvaticum; Maianthemum bifolium; Sphagnum spp.; a lot of spores of sphagnum and green mosses, horsetail, ferns |
| A0A1    | 3-7       | Abies sibirica; Juniperus communis; Picea abies; Pinus sylvestris; |
|         |           | Asarum europaeum; Carex spp.; Equisetum sylvaticum; Festuca pratensis; Fumaria officinalis; Maianthemum bifolium; Sphagnum spp.; Vicia cracca; |
| A2(1)   | 7-14      | Alnus fruticosa; Betula pubescens; Quercus robur; Tilia platyphyllos; single exemplars of Picea abies and Pinus sylvestris |
|         |           | Angelica sylvastis; Aristolochia clematitidis; Asarum europaeum; Cephalanthera damasonium; Chenopodioidaeae; Cynanchum acutum; Dennstaedtiaceae; Dicranum polysetum; Dioscorea communis; Filipendula ulmaria; Frangula alns; Glyceria fluviatilis; Meesia triquetra; Schoenoplectus lacustris; Scilla autumnalis; Scirpus sylvaticus; Sphagnum spp.; Tulipa spp.; Vincetoxicum hirundinaria; |
| A2b     | 15-23     | Acer campestre; Alnus spp.; Hippophae rhamnoideae; Pinus sylvestris; Quercus pubescens; Sambucus nigra; Tilia platyphyllos; |
|         |           | Adoxa moschatellina; Aristolochia clematitidis; Asarum europaeum; Avenella flexuosa; Bromopsis inermis; Carex spp.; Convalaria spp.; Convallaria spp.; Eritrichium spp.; Gramineae; Hieracium spp.; Paris quadrifolia; Scilla autumnalis; Vinca herbacea |
| A2c     | 23-30     | Acer campestre; Alnus alnobetula; Tilia platyphyllos; |
|         |           | Agropyron repens; Allium spp.; Centaurium erythraea; Narcissus angustifolius; Pteridium tauricum; Pulmonaria mollis; Vincaher bacea; |
|         |           | a lot of spores of mosses and ferns; some residues of conifers' pollen; in some profiles there are not any spores or pollen |
| A2B     | 32-41     | Pinus sylvestris |
|         |           | Carex spp.; Lycopodium annotinum |
|         |           | Plant residues and spores of mosses and ferns; some residues of conifers' pollen |
| B1      | 44-65     | Single spores of sphagnum mosses, residues of lichens and algae |
|         |           | Some residues of conifers' pollen grains |

The species composition of the palinomorphs of the litter and horizon A0A1 corresponds to the modern composition of the phytocenosis. A large number of pollen of coniferous plants was found: European spruce, Siberian pine, Siberian fir, juniper. In addition, there was pollen of downy birch,
European wild ginger, Meadowsweet (*Filipendula ulmaria* (L.) Maxim), May lily (*Maianthemum bifolium* (L.) F.W.Schmidt), cereals, sedges, spores of shield fern, sphagnum and green mosses. This composition is characteristic of phytocenoses of a significant part of the south taiga subzone, formed in a temperate climate, with relatively low average annual temperatures and high humidity.

In the upper part of the eluvial horizon A<sub>2</sub>Ah, changes in the spore-pollen spectrum are observed, expressed in the appearance of pollen grains of large-leaved linden, alder, European birthwort (*Aristolochia clematitis* L.), white swallow-wort (*Vincetoxicum hirundinaria* Medik.), *Cynanchum acutum* L., poet's daffodil (*Narcissus angustifolius* L.). Currently, the natural range of these species includes the forest-steppe and steppe bands of European Russia, Crimea, and the Caucasus. At the same time, spores of sphagnum and green mosses, coniferous pollen are present in the horizon in a small number. This set of spores and pollen is characteristic of the vegetation cover of the subboreal beginning of the subatlantic period of the Holocene [8]. At this time, there was a decrease in average air temperatures and humidity compared to the Holocene optimum, but they were higher than at present [9]. Conifers prevailed in phytocenosis, mainly Scots pine. The northern boundary of the spread of broad-leaved forests shifted south, as indicated by the low amount of pollen in the spectrum. Cereals and sedges were found in the herbaceous, less heat-loving species, mainly European birthwort and white swallow-wort. Probably, the phytocenosis of the subboreal period was represented by coniferous-broad-leaved forest with a predominance of Scots pine. Perhaps the strengthening of eluvial processes in the soil during this period contributed to more active destruction or removal of pollen grains.

The spore-pollen spectrum of the horizon A<sub>2</sub>Ah is dominated by pollen of broad-leaved species: large-leaved linden, field maple, downy oak, forest beech; many pollen grains of representatives of the *Chenopodioidae* family were found. There are pollen grains of European birthwort, herbaceous periwinkle (*Vinca herbacea* Waldst. & Kit), European wild ginger, *Hieracium* spp., moschatel (*Adoxa moschatellina* L.), herb-paris (*Paris quadrifolia* L.), wavy hair-grass (*Avenella flexuosa* (L.) Trin.), bladder-senna (*Colutea arborescens* L.). There is pollen of shrubs: alder buckthorn (*Frangula alnus* Mill.), sea-buckthorn (*Hippophae rhamnoides* L.), elderberry (*Sambucus nigra* L.). Obviously, this period in the development of the vegetation cover of the territory corresponds to the Atlantic period - the optimum of the Holocene [9]. The woodland was dominated by a large-leaved linden with an admixture of oak, field maple, and forest beech. On the spurs of the Vyatka Uvals, downy oak probably grew. In the undergrowth there was an elderberry, alder buckthorn and sea-buckthorn. The grass cover was represented by cereal grass, species of the lily family. Grass forest-steppe and steppe species grew along the edges of forests. Plant species whose pollen was found in this horizon most closely correspond to the phytocenosis of modern deciduous forests [10]. Under the canopy of broad-leaved forests and in stepped areas, with a favorable combination of hydrothermal factors, soils with a thick humus horizon were formed. The remains of this particular horizon are currently present in sod-podzolic soils.

In the lower part of the eluvial horizon A<sub>2</sub>B and in the horizon A<sub>3</sub>B there is a decrease in the number of palinomorphs. Pollen grains of pine and spruce prevail, there are a lot of spores of mosses and ferns. There are single exemplars of large-leaved linden and field maple. This change in the paleopalinological spectrum indicates a change in the harsh cold climate of the boreal period to the soft and warm of the Atlantic [8, 9]. It is likely that the phytocenosis of the boreal period in species composition was close to modern and was a dark coniferous forest with an admixture of broad-leaved species.

The spore-pollen spectrum of arable sod-podzolic soil by the nature of the distribution of the palinomorphs is close to that of the soil under the forest. Peculiarities are the presence of spores of fewer species in all horizons, which is probably due to their faster destruction with active agricultural use of soils. Nevertheless, in the A<sub>2</sub>Ah horizon there is pollen of species characteristic of broad-leaved forests: common beech, field maple, oak, *Convallaria transcaucasica* and *Convallaria majalis*, *Pteridium taericum*, representatives of the families *Cornaceae* Bercht, and *Iridaceae* Juss.
Table 2. Spore-pollen spectrum of sod-podzolic medium-loamy soil having second humus horizon under arable land.

| Horizon | Depth, cm | Spore-pollen spectra |
|---------|-----------|----------------------|
| A₀      | 0-25      | Abies sibirica; Picea abies; Pinus sylvestris; Artemisia spp.; Asarum europaeum; Chenopodioideae; Sphagnum spp. |
| A₂Ah    | 25-34     | Acer campestre; Alnus subcordata; Fagus sylvatica; Hippophae rhamnoides; Pinus sylvestris; Quercus spp. |
|          |           | Aristolochiaceae; Asphodeline spp.; Briza media; Campanula glomerata; Centaurea cyanus; Chenopodioideae; Cirsium spp.; Convallaria majalis; Convallaria transcaucasica; Cornaceae; Fumaria officinalis; Iridaceae; Jasione montana; Maianthemum bifolium; Pteridium tauricum; Vincetoxicum hirundinaria. |
|          |           | Abandon of cereals' pollen |
| A₂B     | 34-43     | Alnus incana; Betula spp.; Picea abies; Pinus sylvestris; Taxus baccata |
|          |           | Asarum europaeum; Atrichum undulatum; Carex spp. |
| B₁      | 43-60     | Picea abies |
|          |           | Agropyron desertorum; Gramineae; Notholaena marantae; Pteridium tauricum; Vincetoxicum hirundinaria. |

4. Conclusions

Thus, using paleopalynological analysis methods for soils having complex organic profile it is possible to assume the composition of phytocenoses and try to reconstruct the landscape conditions of the end of the Pleistocene-Holocene.

Based on the data obtained, it can be concluded that during the optimal period of the Holocene, the northern boundary of the distribution of phytocenoses of coniferous-deciduous forests within the borders of the modern Kirov region of Russia presumably passed north of 58 degrees north latitude. Currently, in the region, broad-leaved forests in natural conditions have been preserved south of 56 degrees north latitude. Most species of shrub and grass vegetation, represented in the spore-pollen spectra of the horizons A₂Ah currently does not grow in the region at all.

The data obtained as a result of this study are fully consistent with the data of other researchers on the distribution of natural zones on the Russian Plain in the Holocene. Nevertheless, a study of the paleopalynological spectrum of sod-podzolic soils having second humus horizon made it possible to clarify the species composition and history of vegetation development in the Kirov region of Russia in the Holocene.

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