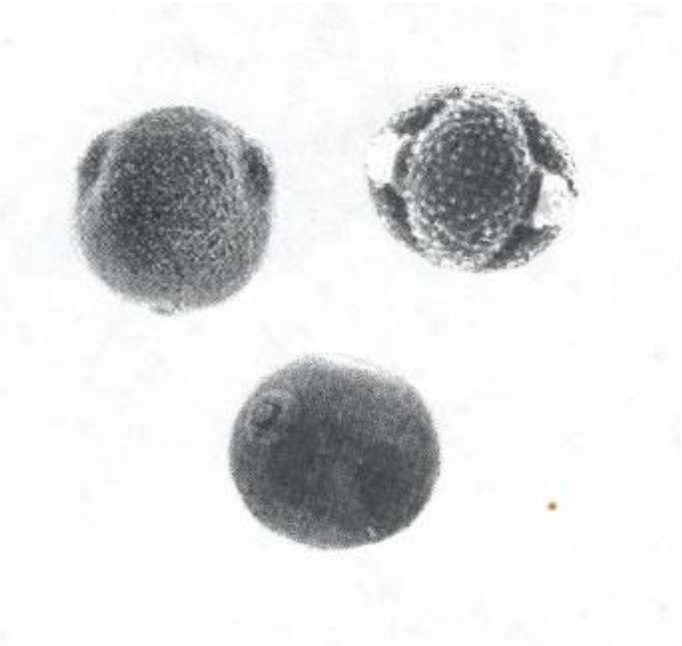
Palaeovegetation and environment during Weichselian stadials and interstadials at Mamontovaya Kurja and Sokolova in the Pechora basin, northern Russia.



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Forord

Det er flere som fortjener en takk (eller to).
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Abstract.

The vegetation and climate history of the Pechora area of northwestern Russia during the Early- and Mid Weichselian have been studied. Sediments from two sites have been analysed in this study; from Sokolova and Mamontovaya Kurja. The results show that the vegetation successional sequence found at Sokolova, most probably represent vegetation types of the Early Weichselian. The vegetation changed from an open shrub tundra, or grass tundra during the pre-Brörup stages, to an open birch forest, with some scattered spruce during the Brörup interstadial. The vegetation sequence at Mamontovaya Kurja possibly reflects two different warming periods (interstadials) of the Weichselian. The first one occurring around 37 ka BP, the second around 27- 30 ka BP (correlating to the Ålesund interstadial).
The vegetation at Mamontovaya Kurja showed minor changes throughout the studied section. The vegetation was probably an open grass steppe or steppe tundra throughout the time period studied. In the upper part of the section the vegetation seems to have changed to a drier type. This appears to reflect a climatic deterioration. Increased eolian activity is reflected in the sequence by almost complete disappearance of pollen grains in the uppermost layers.

The age of the lowermost pollen assemblage at Mamontovaya Kurja has not yet been resolved, but datings of these sediments are currently being undertaken.

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1.Introduction

This study is a part of the Norwegian-Russian interdisciplinary co-project PECHORA (Palaeo Environment and Climate History Of the Russian Arctic) which has recently been linked to the EU funded EIS (Eurasian Ice Sheet) project .

It is a multidisciplinary study involving archaeological, geological, palaeo-botanical and -zoological studies. The project was initiated in 1992, and its main objective is to study the glacial and environmental history of the European part of northern Russia during the last 150 000 years (Astakhov 1994).

The study region of this project is located between the Barents Sea shore and 65°N , and between 50° and 60°E , and is a part of the Pechora lowland, a major part of the Komi Republic in northern Russia (see figs. 2.1a and b).

The interpretations of the late-Quaternary stratigraphy in terms of the number, extent and timing of Weichselian ice advances in this region have been debated (*e.g.* Grosswald 1998, Mangerud *et al.* 1999). Evidence for an ice-dammed lake has been found at several sites within the area. There are finds of old shorelines at about 100 m a.s.l. (90 m a.s.l. in the south and 110 m a.s.l. in the north). This lake has been called Lake Komi, and is believed to have covered most of the Pechora lowlands. According to Mangerud *et al.* (1999), the shorelines are older than 36 ka, which dates this lake to Early or Middle Weichselian age. Possibly, Lake Komi was dammed by the ice that deposited the Markhida Line (Mangerud *et al*. 1999) (fig 2.1 b).

Previous studies of the vegetation history of northern Russia have usually been published in Russian, which makes them more or less inaccessible to non-Russian scientists. Other studies published in English have been concentrated in the Russian Plain (Faustova 1984, Velichko *et al.* 1984, Kabailene & Raukas 1987, Gaigalas *et al.* 1992, Davydova & Servant-Vildary 1996, Gribchenko & Kurenkova 1997, Zelikson *et al.* 1998), Central Siberia (Astakhov 1992, 1995, Ukraintseva 1993, Laukhin 1997) and the far Northeast of Siberia (Ukraintseva 1993, Anderson *et al.* 1997).

The two localities chosen for my thesis, Mamontovaya Kurja and Sokolova, are both situated within the Pechora area. The purpose of this pollen analytical study at these sites was originally to elucidate the Middle and Late Weichselian (Valdaian) climate and vegetation history for the northern part of the Pechora area. In addition, there was a possibility of finding traces of human activity reflected in the pollen record, as the Mamontovaya Kurja site was possibly a Palaeolithic dwelling site (Mangerud *et al*. 1999). From the reconstruction of the palaeovegetation, past climates are interpreted. The following forms the background for the reconstruction of the palaeoclimate in the Pechora basin:

Some authors refer to the term steppe-tundra, or periglacial steppe to explain the vegetation type occurring in northern Russia during the Weichselian (Astakhov 1992, Ukraintseva 1993). This 'steppe-tundra', which has no exact modern analogue, was an open herbaceous vegetation with an absence of thermophilous trees (Stuart 1991). Climatic ameliorations allowed the northwards spread of birch and conifer forest during interstadials (Stuart 1991). Elias *et al.* (1997) defined the steppe-tundra vegetation as an arid vegetation rich in grasses and other herbs, growing in relatively dry, well-drained soils. The herbs of the steppe-tundra included mesic-adapted species found in shrub tundra or tussock-tundra habitats today, and the vegetation was probably a mosaic of vegetation types (Khotinsky 1984, Elias *et al*. 1997). The herbaceous pollen types often associated with steppe-tundra vegetation are Poaceae, *Artemisia*, and Chenopodiaceae (Khotinsky 1984, Adams & Faure 1997). Other plants that occurred, but were less abundant, were Cyperaceae, *Cerastium*, *Rumex*, *Saxifraga*, *Juniperus*, and *Salix* (and others) (Adams & Faure 1997).

The Mamontovaya Kurja site was chosen because of its proximity to the Markhida Line (Mangerud *et al.* 1999), in addition to the Palaeolithic findings.

The analysis of the sediments at Mamontovaya Kurja would indicate if any ice had advanced over the site during the Weichselian.

In addition, the sediments would give evidence of the sedimentation regime at the site. If Lake Komi flooded this site during the time period in question, this would show in the sediments as lacustrine deposits, and a clearly lacustrine influenced pollen flora.

The Sokolova site was originally chosen because it was believed to be rather promising as a Weichselian site. A peat layer in an undisturbed sequence of lacustrine and alluvial sediments, and a distinct peat layer above a terrestrial lag seemed well suited for pollen analysis. When first encountered, it was believed that the Sokolova site was close to the Mamontovaya Kurja site in age. Later, when the datings from the two sites were available, an age difference became apparent. The analysed material from the Sokolova site seems to be much older than that of the Mamontovaya Kurja site, and datings of the Sokolova sediments suggests a pre-

Eemian or perhaps an Eemian-Early Weichselian age. The dates at Mamontovaya Kurja fall within the Mid-Weichselian.

2. Study area:

2.1 General description.

Both the Mamontovaya Kurja and Sokolova sites are situated within the Pechora basin in the Komi republic of northern European Russia. The area is named after the Pechora river (1809 km long), which has its source in the Urals and flows northwards until it reaches the polar circle. There it suddenly changes direction, and flows south-westwards before it again turns northwards and flows into the Barents Sea, creating an enormous delta (figure 2.1a and b). The Pechora basin is a low undulating plain (<200 m altitude) bordered by the Ural Mountains to the east, the Timan ridge to the west, and the Barents Sea to the north.

In the northern part of the area, conspicuous glacial landforms are present. These include hill-and-hole pairs, ice-pushed ridges, kames and till hummocks, interspersed with several small lakes. The southern part has a more even topography with larger swamps and occasional lakes. In this part one also find the Laya-Adzva Ridge (fig. 2.1b), a large glaciotectonic feature about 350 km long, elevated some 30-60 m above the swampy flatland (Astakhov 1994).

Just north of the Laya-Adzva Ridge, the Markhida-Sopkay Moraine (the Markhida Line *sensu* Mangerud *et al.* 1999) is situated (fig. 2.1b). This moraine is a broad zone of ice-marginal landforms and deposits running east-west across the Pechora lowland. It was formed along the southern margin of ice sheets advancing onto the coast from the Kara Sea from the NE, and from the Barents Sea from the N/NNW. No depositional metachronities from the Kara and the Barents ice sheet are indicated, so the moraines apparently constitute one continuous and synchronous morainic belt from the Timan Ridge in the NW through the Markhida, Harbei and Pai-Hoi moraines in the Pechora Basin (Mangerud *et al.* 1999).

As an ice marginal feature, the Markhida moraine was formed prior to 10-15 ka BP, probably during the Early or Middle Weichselian. This is indicated by TL dates in the range 58-63 ka BP for sediments just below the overlying moraine, and hence giving a maximum date for this ice advance (Mangerud *et al.* 1999). It is possible that Lake Komi was dammed by the ice advance creating the Markhida Line during the Middle or Early Weichselian. The Laya-Adzva moraine predates Lake Komi, and this moraine is probably of Saalian or Early Weichselian age.

Mamontovaya Kurja is situated southeast of the Laya-Adzva Ridge (site 23, figure 2.1 b) along the Usa river, which is a tributary to the Pechora river, at 66°34’N 62°25’E, near the northern limit of the boreal forest (the taiga). Sokolova is situated further to the south, ca. 4 km upstream along the Pechora river from Sokolovo village at 65°25’N 57°E, at a distance of ca. 225 km from the Markhida Line (figure 2.1b).

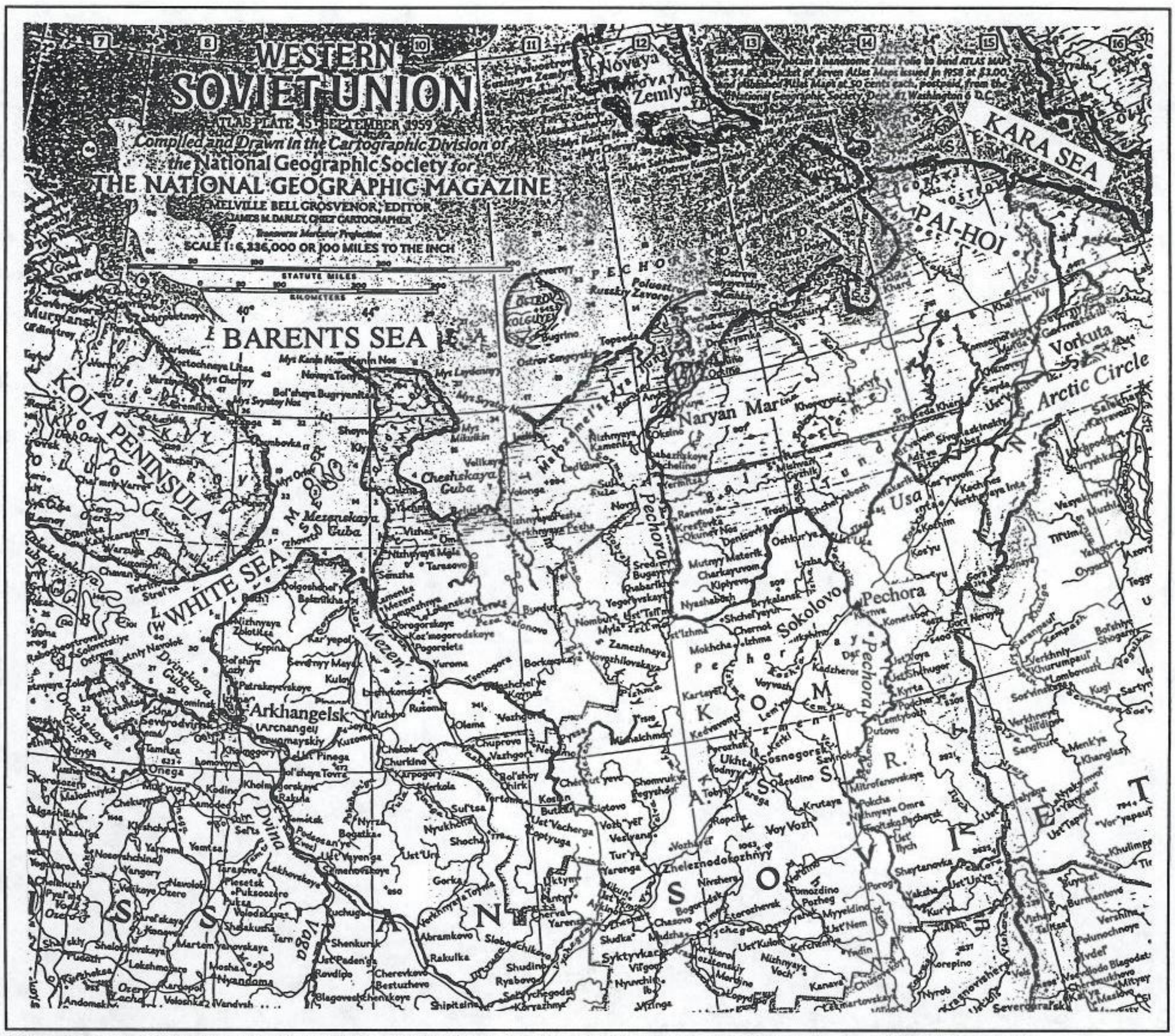


Figure 2.1a Map over north-east European Russia. The Pechora area is shown in detail in figure 2.1b

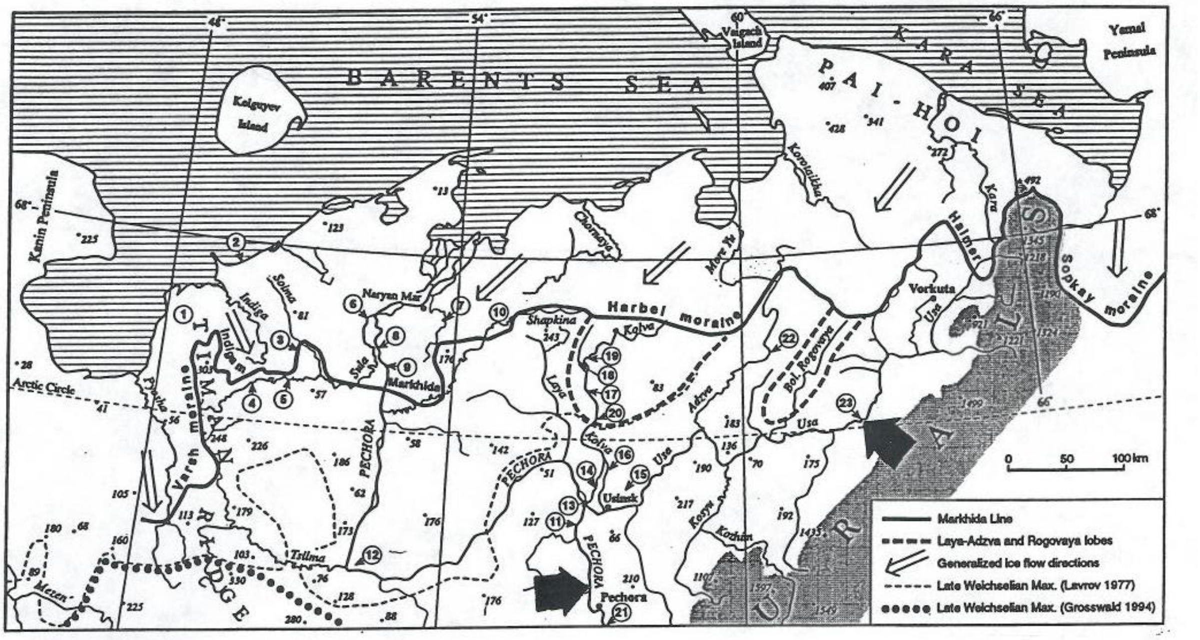


Figure 2.1b Detailed map over the Pechora area. The Mamontovaya Kurja site is marked 23, and with an arrow. The Sokolova site is situated at the arrow 30 km north of Pechora town. From Mangerud *et al.* 1999.

2.2 Climate.

Most of the Pechora area is today situated within the northern taiga zone of Northern Russia (Zelikson *et al.* 1998). The climate is of moist subarctic type. The annual precipitation is sparse, 400-600 mm, most of which falls during May - October (from 125 - 250 mm). From November to April there is much less precipitation, only 0 - 125 mm. However, due to low evaporation rate and melting of permafrost and subterranean ice during the summer, the ground is constantly moist (Chernov 1985). The winters in this region are harsh, and there are less than four months during the year with temperatures above 10°C. The January mean temperature is -10 to -20°C, and the July mean +10 to +20°C. The mean annual temperature is -5°C (0 to -10°C). The low summer and winter temperatures are due to high latitudes, the summer invasions of cold Arctic air, and cool and moist Atlantic air masses (Zelikson *et al.* 1998).

Climate data are from The Times Atlas of the World (1990).

2.3 Geology and the soils.

The soils in the Pechora area are primarily thick loess-like sediments from the Quaternary, including moraines, gravel, sand and clay. The loess sediments are up to 200 m thick in depressions, and cover the underlying Mesozoic rocks. Fresh glaciokarst features are common in the Lower Pechora catchment area (Astakhov 1997).

Eolian sand is widespread in the area, with thick accumulations most frequently occurring in the wide valleys of the Pechora and Usa rivers, and also on lowlands along the Barents Sea (Astakhov *et al.* 1999).

2.4 Present vegetation.

The vegetation in this area belongs to the northern taiga subzone, and includes discontinuous boreal forests changing to perennial frozen tundra north of 66°50’.

Mamontovaya Kurja is situated further to the north than Sokolova (figure 2.1b), and is thus affected by slightly cooler summers than Sokolova. In the European part of northern Russia, the northern tree limit more or less coincides with the July isotherm at 13°C, which undulates around the polar circle (Chernov 1985). The July isotherm along the polar circle is 13°C, while it is 15°C close to Pechora town. The forest is of mixed boreal type (Times Atlas of the World 1990), the most prominent constituents being *Picea, Pinus, Betula*, *Alnus* and *Alnaster*. *Alnaster (Alnaster fruticosa)* is the name used in the Russian literature for shrub alder (Ukraintseva 1993, Matveyeva 1994, Hahne & Melles, in press), which is *Duschekia fruticosa* (Rupr.) Pouzar. At Mamontovaya Kurja, the river is fringed by dense *Salix* scrub and the forest is made up of *Picea* and *Betula.* At Sokolova, the vegetation consists of dense *Picea obovata* forest with some birch and alder along the river.

2.5 The sites.

2.5.1 Site 1: Mamontovaya Kurja:

Mamontovaya Kurja (53 m a.s.l.) is situated on the left (northern) bank of the Usa river, and about 100 km south of the Markhida Line (site 23 in fig. 2.1b).

This is one of the sites within the Pechora area where several Palaeolithic stone artefacts have been found. In addition, large numbers of mammalian bones have been found during earlier excavations. These include horse, bison, and mammoth (Mangerud *et al.* 1999).
The bones and artefacts are found below a 12-15 m sequence of alluvial and eolian sediments from which most of the pollen samples have been collected. (See fig. 4.1 and table 4.1)

2.5.2 Site 2 : Sokolova.

The site Sokolova (site 29 in fig. 2.1b) is situated ca. 4 km upstream from Sokolova village, along the Pechora river. Here the low summer level of the river is 40 m a.s.l. . The entire sequence is about 18 m wide, and 15 m high (above river level). The pollen samples have been retrieved from sediments of alluvial origin and peat.
See figure 4.2 and table 4.6 for details.

3. Methods and material.

3.1 Fieldwork.

Most of the fieldwork at Mamontovaya Kurja was carried out during summer 1996. The samples from the cultural layer were collected during summer 1997.
The fieldwork at Sokolova took place in summer 1997.

The fieldwork was done by Dr J. I. Svendsen at Mamontovaya Kurja, and by Prof. J. Mangerud at Sokolova. In addition, other students working on the Pechora project participated. The samples were retrieved from the sediments after cleaning the horizons. The samples were then put in marked plastic bags and sealed. The samples were kept under cool conditions until prepared.

3.1.1 Lithostratigraphy.

The sediments and the stratigraphy were described in the field by Dr. J. I. Svendsen and Prof. J. Mangerud. I described the sediments in the laboratory according to Troels-Smith (1955), and used the field notes as background for the description, presented in tables 4.1 and 4.5.

3.2 Laboratory work.

3.2.1 Preparation techniques.

For pollen analysis, samples of 1 cm^3 were taken from the sediments with a calibrated brass-sampler. The samples were dissolved in boiling KOH and prepared (HF, acetolysis) following the standard procedure of Fægri & Iversen (1989).
2-3 tablets of *Lycopodium* spores were added to each sample in order to estimate the pollen concentration (Stockmarr 1971, Birks & Birks 1980).
Finally, the samples were stained with fuchsin and kept in small sealed vials until analysed. The samples were stored in glycerol oil.
The samples were prepared for analysis during 1997 and 1998.

3.2.2 Pollen analysis and identification.

The analyses were carried out using a Zeiss microscope equipped with phase-contrast objectives, 8x oculars and a blue filter. For counting, Planapo 40/1.0 Ph3 and 63/1.4 Ph3 objectives were used. For detailed examination, a Neofluar 100/1.3 Ph3 objective was used. Pollen types were determined using pollen keys in Fægri & Iversen (1989), supplemented by Moore *et al.* (1991), in addition to direct comparison with the reference collection at the Botanical Institute, University of Bergen.

Pollen grains that were corroded and/or crumpled, and possibly reworked pollen grains have been placed together in a group called ‘Unidentified’. Unknown, but well preserved grains were placed in a group called ‘Unidentified Unknown’.
All unidentified grains were excluded from the pollen sum.

3.2.3 Datings.

Twelve samples were prepared for ^{14}C dating by AMS (Accelerator Mass Spectrometry) from the Mamontovaya Kurja site, and several samples from Sokolova (8 for ^{14}C, 5 for OSL (Optically Simulated Luminescence) datings). The AMS samples were analysed at Beta Analytic, Inc (Miami), at the Swiss Federal Institute of Technology (ETH), Zurich, and at the Laboratory of Radiological Dating, University of Trondheim, Norway. Samples that are marked Tua, were prepared in Trondheim and measured in Uppsala, Sweden. In addition, conventional datings were carried out in Trondheim. The OSL samples were analysed at the Nordic Laboratory for Luminescence Dating, Risoe National Laboratory in Roskilde, Denmark.
All dates are shown in Tables 4.3 and 4.6. Terrestrial material for AMS-dating was picked out by hand after sieving the sediments through 2.00 mm, 500 μm and 250 μm meshes.
Material used for the OSL-datings was sampled separately in the field together with sediment samples to estimate the water content. The samples were kept in light-tight containers until analysed.

3.2.4 Pollen diagrams.

During most of the analysis, pollen grains were counted using a Psion Organizer. Otherwise a standard mechanical counter was used. From the Psion Organizer, the spectra were transferred to a PC and loaded into the Core Graphics 2.0 program (Kaland & Natvik 1993). The other spectra were transferred to the same program by hand.

This program converts pollen analytical data directly to a pollen diagram. The pollen results are presented as percentage, concentration, and influx diagrams.

The calculation basis (Σ P) is the sum of all terrestrial pollen types, excluding unidentified grains. Taxa within the groups spores, aquatics and reworked pollen and spores have been omitted from the total pollen sum, and have been calculated using the formula

$X (\Sigma P + X)^{-1}$ where X represents the taxon in question.

In the percentage diagrams (Figs. 1 and 4, Appendix D), the black curves are the percentages, and the shaded curves are x10 exaggeration. Within each group, the pollen and spore types are arranged in their stratigraphic order of occurrence.

In the percentage diagrams, Cyperaceae is obviously locally over-represented and have been omitted from the total pollen sum. Cyperaceae would otherwise have seriously affected the curves of the other taxa by its highly varying occurrence throughout the sequence.

Nomenclature of vascular plants follows Lid & Lid (1994).

3.2.5 Zonation.

The pollen data were transformed by TRAN version 1.7 (Juggins 1993) and then zoned by ZONE 1.2 (Juggins 1991). No taxa were deleted from the data set prior to the computations. Four zonation methods were used; CONSLINK (Birks and Gordon 1985) and CONISS (Grimm 1987), which are agglomerative methods, and SPLITLSQ and SPLITINF (Birks and Gordon 1985), which are divisive methods. The first two methods calculate the difference between each pair of spectra, based on the total composition of each. The divisive methods split a sequence into zones such that the variability in each zone is as small as possible.

The agglomerative methods did not give as clear results as the divisive methods. This can be seen in figures 4.3 and 4.6 as several zones proposed in the two first columns, compared to the two latter columns.

The various results from the numerical zonation were not always in agreement, so the zones of the two pollen diagrams were defined by subjective evaluation using the different numerical methods as a basis for this evaluation. This was done by comparing the diagram to the zones delimited by ZONE 1.2, and occasionally giving more weight to certain taxa as compared to others. An example of this is the upper limit of zone 4A at Mamontovaya Kurja. The numerical zonations show strong signals for a zone limit between spectra 19 and 20, and between 21 and 22 at Mamontovaya Kurja (see fig. 4.3). This was found to be caused by Cyperaceae, and as this taxon may reflect local occurrence, and has been placed outside ΣP, these two signals were overlooked. The signal for a zone limit between spectrum 13 and 14 (fig. 4.3) was thus followed. According to the numerically defined zonations, there should be a division of zone 4 (at Sokolova), and zone 4b (at Mamontovaya Kurja) see figs 4.3 and 4.6. But, since these two uppermost zones would comprise only 2 cm at Sokolova, and 5 cm at Mamontovaya Kurja, and include only two spectra each, the subjectively delimited upper zones were kept. The pollen diagrams do not show any major changes that contradict the final zonations, so the combination of subjectively and numerically defined zonation was retained. The zones are listed numerically from the bottom, and the spectra are numbered from the top.

3.2.6 Influx and concentration diagrams.

By adding tablets with known content of *Lycopodium* spores to the samples before preparation, pollen concentrations could be estimated (Stockmarr 1971).

Concentration diagrams are presented for both sites. Influx was estimated only at Mamontovaya Kurja, due to unreliable datings at Sokolova. Because of possible hiatuses inherent in the stratigraphic sequence at Mamontovaya Kurja, the influx estimates may be less than accurate.

3.2.7 Loss on ignition.

Loss on ignition (LOI) estimates the organic content of samples.

1 - 2 grams of sediment were weighed in glass beakers. The samples were dried for 48 hours at 105°C, and then re-weighed. The samples were then ignited for 6 hours at 550°C, left to cool for about an hour in a dessicator, and weighed again.

The results from the LOI measurements are shown on the pollen diagrams (Figures 1 and 4, Appendix D). The results from Mamontovaya Kurja are also shown in table 4.2, chapter 4.1.1.

3.2.8 Macrofossils.

During the preparation of the AMS-samples, the macrofossil content of some of the samples was checked. The macrofossil presence of a species, in addition to its pollen representation, confirms its local occurrence.

Dr Hilary Birks helped in the determination of the seeds and leaves, and Einar Heegaard identified the mosses.

Table 4.4 lists the macrofossils recorded at Mamontovaya Kurja.

3.2.9 Numerical methods.

The data were transformed for ordination in Canoco 3.12 (ter Braak 1991) by the TRAN 1.7 program (Juggins 1993). Prior to the analysis, some adjustments were made on the data sets. As terrestrial vegetation was focused, taxa of aquatic origin (not including *Sphagnum*), assumed long-distance transported taxa and reworked taxa were deleted.

No environmental variables have been measured, thus only indirect gradient analysis has been applied. In an indirect gradient analysis, responses or observations are distributed along axes which represent unknown gradients. The results are interpreted in terms of variations in environmental parameters (ter Braak & Prentice 1988).

Both PCA (principal components analysis) and DCA (detrended correspondence analysis) are indirect ordination methods. These can be used as tools for exploratory analysis of community data without having any prior information about the environment. PCA is a linear method, and DCA is a unimodal method (ter Braak & Prentice 1988).

In order to measure the variation of the species data, DCA was first applied. The length of the gradient of variation is measured in standard deviation (SD) units. When variation is small, the gradient length is short (1.5 - 2 SD), and the linear ordination method (PCA) is the appropriate method. Large variation in the species data results in long gradients (>2 SD), and unimodal methods such as CA and DCA are appropriate (ter Braak & Prentice 1988, Jongman *et al.* 1995).

As standard procedure in all of the analyses default settings were followed, only square root transformation was applied to reduce the effect of high percentages of a few pollen types.

The eigenvalue, λ, shows the maximum species score along the ordination axis, and is a measure of the importance of the axis. If $\lambda>0.5$, the species exhibit good spread along the axis (Jongman *et al.* 1995).

The resulting ordinations were plotted using CanoDraw 3.0 (Šmilauer 1993).

3.2.10 *Betula* pollen statistics.

At Sokolova, there is a distinct rise of *Betula* pollen in zone 4 (see the pollen diagram, fig. 4 Appendix D). To distinguish which species caused this rise, *Betula* pollen statistics was carried out. Pollen from *Betula nana* (dwarf birch) can be distinguished from tree-birch on the basis of; morphology, size measurements, and grain diameter/pore depth ratios. The last two are multivariate statistical approaches, and can provide a guide for objectively separating *Betula nana* from *B. pubescens* and *B. tortuosa* (Birks 1968).

For the *Betula* analysis, six previously counted slides that contained 100 or more grains of *Betula* pollen, were selected.

On each slide, 100 grains were measured (diameter and pore depth) using the 100x objective with a calibrated graticule, and followed the measuring techniques described in Kristiansen *et al*. (1988).

The results from the analysis are shown in figure 4.12. The measurements are given in tables A to F, Appendix B.

The slides were prepared some time before analysis with glycerol as the mounting medium. This could have caused the grain size to increase slightly (Fægri & Iversen 1989).

3.2.11 Rarefaction analysis.

Rarefaction analysis is a numerical method for comparing the palynological richness between samples within a single stratigraphic sequence or among sequences (Birks & Line 1992a). The estimate of expected species richness ($E(S_n)$), for a sample of size n, is dependent on both the number and the proportions of taxa in the sample. When n is large, rarefaction is the only richness estimate that is both unbiased and sensitive to rare species (Birks & Line 1992a). In the expression $E(S_n)$, n is the number of individuals taken from a collection of N individuals containing S species.

Most likely, changes in $E(S_n)$ reflect changes in floristic richness of the vegetation within the pollen source area. A floristically rich landscape often includes many vegetation types (many boundaries), and stable vegetation types have lower floristic richness (Seppä 1998). The “intermediate disturbance” hypothesis (Grime 1973, Odgaard 1994) postulates that maximum richness is reached at intermediate levels of disturbance. Unstable vegetation types often show high floristic richness, as long as the disturbances are not too severe. A low influx value together with low richness is often characteristic of severe environmental conditions (Seppä 1998). Estimation of the floristic richness in areas of tundra vegetation can be difficult, because of imprecise knowledge of the pollen catchment area (Seppä 1998). In addition, the transition from forested areas to open areas would increase the pollen catchment area, leading to potentially increased diversity (Birks & Line 1992a).

Focusing on the regional and local vegetation, aquatics and assumed long-distance transported (extra-regional) and reworked pollen were removed from the Mamontovaya Kurja and Sokolova data sets prior to the rarefaction analysis. Some taxa that were kept in the analysis may be long distance transported (*e.g. Ulmus*), and other taxa that were deleted might be locally present in some periods (*e.g. Picea*).

To compare the floristic richness of the two sites, the rarefaction analysis of each site was based on the same calculation sum, *n* = 182. Some spectra with a pollen sum lower than 182 were deleted before rarefaction analysis was done on the data sets.

The calculations were carried out by my supervisor Dr Aage Paus, using the RAREPOLL 1.0 program (Birks & Line 1992b).

4. RESULTS.

4.1 Site 1 : Mamontovaya Kurja.

4.1.1 Lithostratigraphy.

The stratigraphy at Mamontovaya Kurja is quite complex, and not all sedimentological features are yet fully understood. The assumed lithological interpretation of the different layers, and their sedimentary regime is discussed below.

The lithostratigraphy is shown in table 4.1, and an overview of the site with sediment description is shown in figure 4.1.

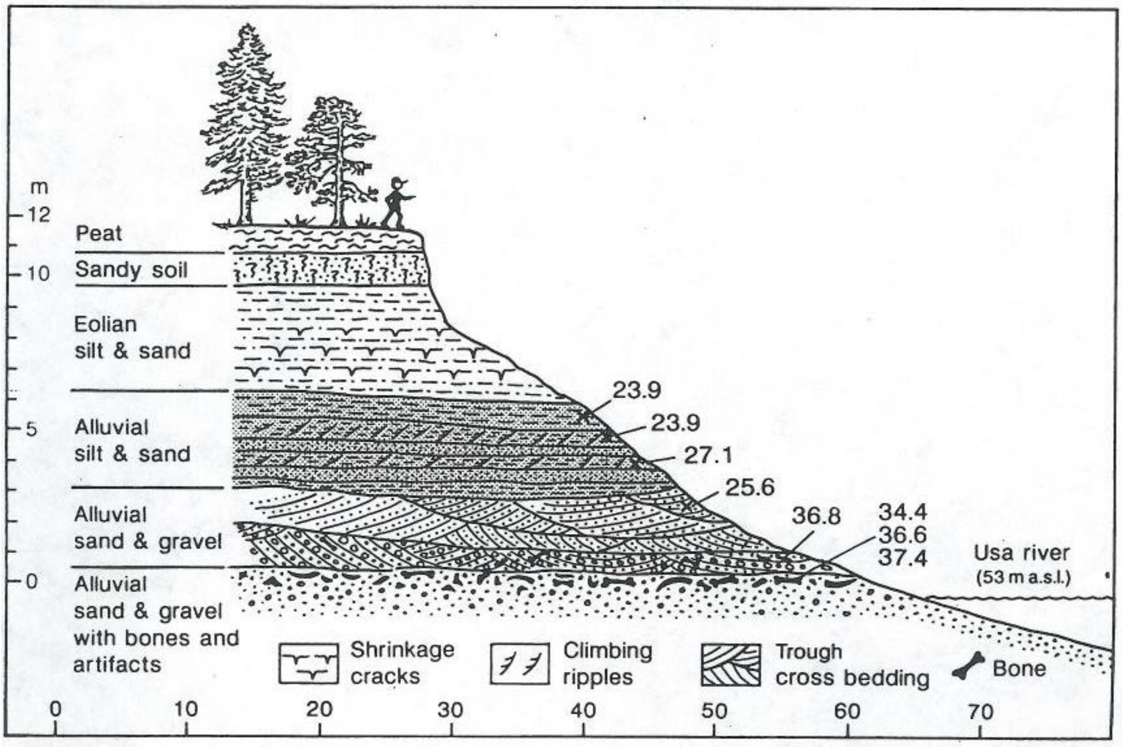


Figure 4.1 The excavated section at Mamontovaya Kurja. From Mangerud *et al*. 1999.

Table 4.1 Lithostratigraphic description of the sediments at Mamontovaya Kurja.
The description of constituents follows Troels-Smith (1955).

Layer number	Constituents	Description
3 (960 - 1090 cm)	Ag 4	Silt with deformation structures (eolian)
4 (1090 - 1130 cm)	Ag 2 Ga 2	Silt and sand (alluvial; climbing ripples)
5 (1130 - 1222 cm)	Ag 2 Ga 2	Silt and sand (alluvial; climbing ripples)
6 (1222 - 1240 cm)	Ag 2 Ga 1 Tb^{2}1	Laminated silt and sand with organic material
7 (1240 - 1290 cm)	Ag 2 Ga 2	Sand and silt (with ripples)
8 (1290 - 1300 cm)	Ga 4	Laminated sand
9 (1300 - 1330 cm)	Ag 2 Ga 2	Sand and silt
10 (1330 - 1350 cm)	Ag 2 Ga 1 Tb^{2}1	Laminated sand and silt with organic material
11 (1350 - 1370 cm)	Ag 2 Ga 2	Massive sand and silt
12 (1370 - 1400 cm)	Ag 2 Ga 1 Tb^{2}1	Crossbedded sand and silt with organic material
13 (1400 - 1410 cm)	Ga 3 Lf 1	Sand with a thin iron layer
14 (1410 - 1600 cm)	Ga 4	Crossbedded sand
15 (1600 - 1730 cm)	Gg$_{(\text{maj})}$ 2 Ga 2	Sand and gravel

Layer 3, the topmost layer, is eolian silt. The middle layers (layers 4 - 14) are alluvial silt and sand. Layer 15, the bottom layer, is alluvial sand and gravel. Most of the mammalian bones and anthropogenic artefacts were found in the upper part of layer 15. The lower part of layer 14 also contained some bones, though these probably are redeposited from layer 15.
Layers 4 - 12 were deposited in a partially isolated river bend/meander (an oxbow lake or river lagoon). These layers are all influenced by the same type of sedimentary environment, and constitute a floodplain sequence. Layers 13 and 14 consist of alluvial sand. These two layers were deposited as a migrating dune in the centre of the river, which must have had a fairly strong current. Clasts in these two layers may have been redeposited from the sides of the river, which could thus in principle be older than the sand layers. A hiatus representing 8-10,000 years may be present between layers 14 and 15. The spectra of p.a.z. 1 (40-47) are possibly from the same phase as the bones, thus being ca. 37 ka. Alternatively, the bones were redeposited around 27 ka BP and the silt clasts then deposited around the bones.
The topmost layers (layers 3 and 4) contained very little pollen. The pollen sum was in the range 0-30 grains (at least 4 slides counted, and a sum of added *Lycopodium* spores in the range of 1000 - 2000). For statistical reasons, these spectra were deleted from the diagram. The pollen and spore content of layer 3 and 4 are listed in Appendix E.

Loss on ignition (LOI) was only measured in layers 3 to 10, plus 15. Samples from layers 11-14 had been given away for grain size analysis, and were not available for LOI tests.

The LOI curve is shown in the pollen diagram, Appendix C, and the measurements are given in Table 4.2.

Table 4.2 Results from loss on ignition measurements at Mamontovaya Kurja

Layer no.	Depth (cm)	LOI (%)
3	1040	1.15
4	1100	1.34
5	1172	1.88
6	1236	5.86
7	1270	1.38
8	1290	0.84
9	1310	1.22
10	1335	4.32
15	1615	4.71
15	1635	3.98

LOI of all the layers is quite low, indicating low organic content in the sediments (Røsberg 1984).

4.1.2 Datings.

Radiocarbon dates from the cultural layer (layer 15) yielded ages around 34-37 ka. AMS dates from the alluvial sediments yielded ages around 25-27 ka, whereas AMS dates of material from the eolian sediments yielded 23-24 ka. Comparing the dates versus depths, it seems apparent that there was a fairly rapid sedimentation in the upper part of this sequence (fig. 4.1).

The results of the twelve datings from this site are shown in table 4.3.

Table 4.3 Datings from the Mamontovaya Kurja site. AMS dates are marked *.
The laboratory reference abbreviations are as follows; Beta = Beta Analytic Inc., ETH = Swiss Federal Institute of Technology, Zurich, LU = St. Petersburg University, T = Trondheim and Tua = sample where target was prepared in Trondheim, and AMS-dated at Uppsala University.

Layer number	Depth (cm)	^{14}C age BP	δ ^{13}C ‰	Laboratory ref.	Object dated
4	1109-1111	24,080 ± 220	-25.9	ETH - 20830*	Terrestrial moss
5	1191-1193	23,860 ± 120	-25.8	Beta - 119501*	Terrestrial moss
6	1234-1236	23,890 ± 140	- 26.0	Beta - 119502*	Terrestrial moss
7	1269-1271	24,890 ± 210	- 25.1	ETH - 20831*	Terrestrial moss
10	1339-1341	27,130 ± 180	- 26.4	Beta - 4072*	Terrestrial moss
12	1384-1386	27,090 ± 240	- 24.4	ETH - 20832 *	Terrestrial moss
14	1509-1511	25,650 ± 535	- 28.2	Tua - 1514*	Terrestrial plants
15	1604-1606	36,770 +2620 / - 1980		T - 11503	Bone of horse
15	1644-1646	36,630 + 1310 / - 1130		T - 11403	Tusk of mammoth
15	1644-1646	34,360 ± 630		T - 11504	Bone of mammoth
15	1654-1656	37,360 ± 970		LU - 4001	Tusk of mammoth
15	uncertain level	34,920 ± 1040		LU - 3994	Tusk of mammoth

There are several possible sources of error inherent in the different dating procedures (Olsson 1979, 1986, Fægri & Iversen 1989, Björck *et al.* 1998, Wohlfart *et al.* 1998).

The dated samples from Mamontovaya Kurja are of two types. Some samples are plant remains (moss or herbaceous plant debris), and some are mammalian bones. There are some uncertainties related to the age of the pollen assemblage in layer 15. Datings of the pollen bearing sediments are currently being undertaken, to resolve whether the mammalian bones are *in situ* or not, i.e. whether the bones are of similar age to the pollen assemblage.

For the plant material, different errors may occur due to contamination etc. (Fægri & Iversen 1989, Wohlfart *et al.* 1998). Terrestrial plant material from layers 3, 5, 6, 7, 10 and 12 was picked out by hand, cleaned and air-dried immediately after being sieved out of the sediments, in order to reduce the possibility of fungal growth on the macro remains (Wohlfart *et al.* 1998).

4.1.3 Sedimentation rates.

The sedimentation rates based on dates from levels 4, 7, 10, and 15 (T-11504, and LU-4001) in the Mamontovaya Kurja profile are calculated using the depths and ages shown in figure 4.2. The sedimentation rates were used as basis for the influx estimates.

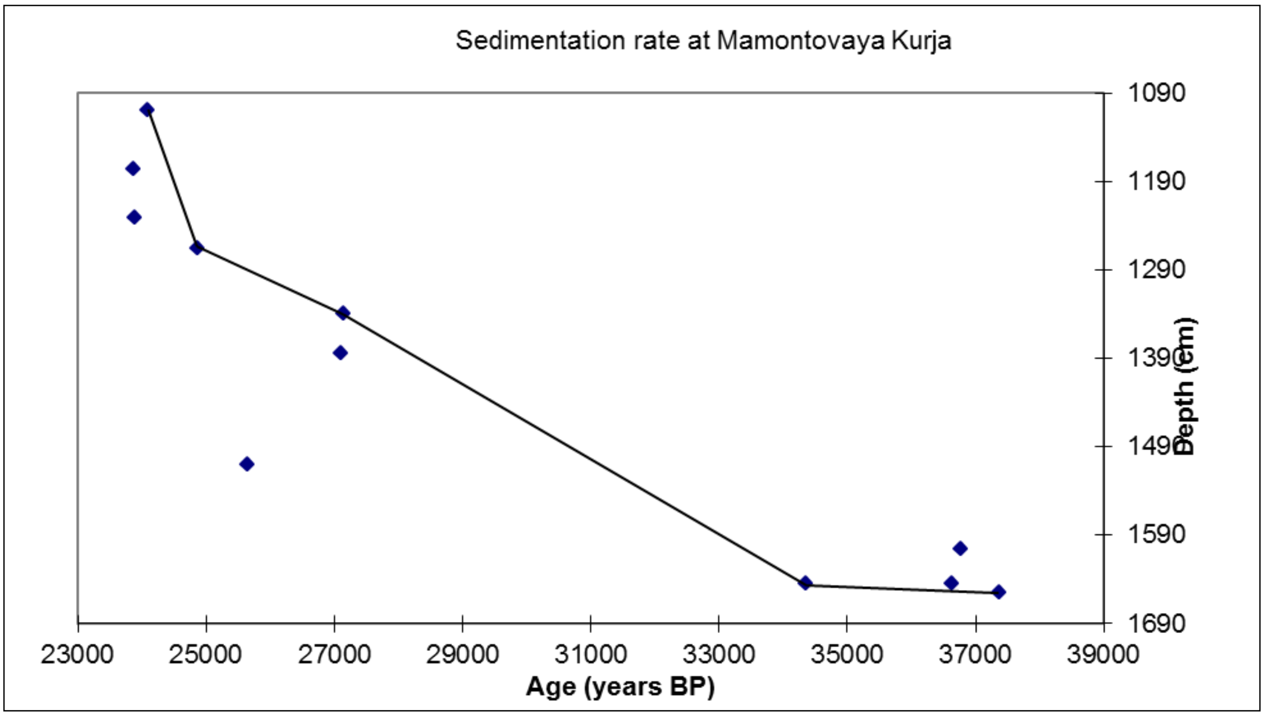


Figure 4.2 Graphic display of age versus depth at Mamontovaya Kurja. The line is drawn between the datings used for sedimentation rates, and for the influx estimates.

Due to the possible dating errors involved and interpolations across layer boundaries, estimates of the sedimentation rates are tentative. The sedimentation rate appear to be more rapid between 1090-1290 cm and seem to reflect the change in sediment environment in the topmost layers from alluvial sedimentation to eolian sedimentation.

Datings not considered in sedimentation-rate calculations are Beta-119501, Beta-119502, ETH-20832, Tua-1514, T-11503, T-11403, and LU-3994 (table 4.3).

There are two reasons why sample Tua-1514 is not included in the calculations. Firstly, this sample gives an age which is younger than the layer above. Secondly, it has a fairly large standard deviation compared to the other AMS-dates. It might be that sample Beta-4072 is wrong too, but I consider this date to be reliable as its standard deviation is half that of Tua-1514. In addition, ETH-20832 further supports this, as it is of similar age to Beta-4072. Samples T-11503 and T-11403, were not considered because of the relatively large standard deviations for both samples. Sample LU-3994 was not considered, as this was taken from an uncertain level within layer 15. Beta-119501, Beta-119502 and ETH-20832 were not used because influx calculations based on these dates gave highly unreliable results.

4.1.4 Pollen diagram from Mamontovaya Kurja.

The basis for the zonation in the percentage diagram is shown in figure 4.3.

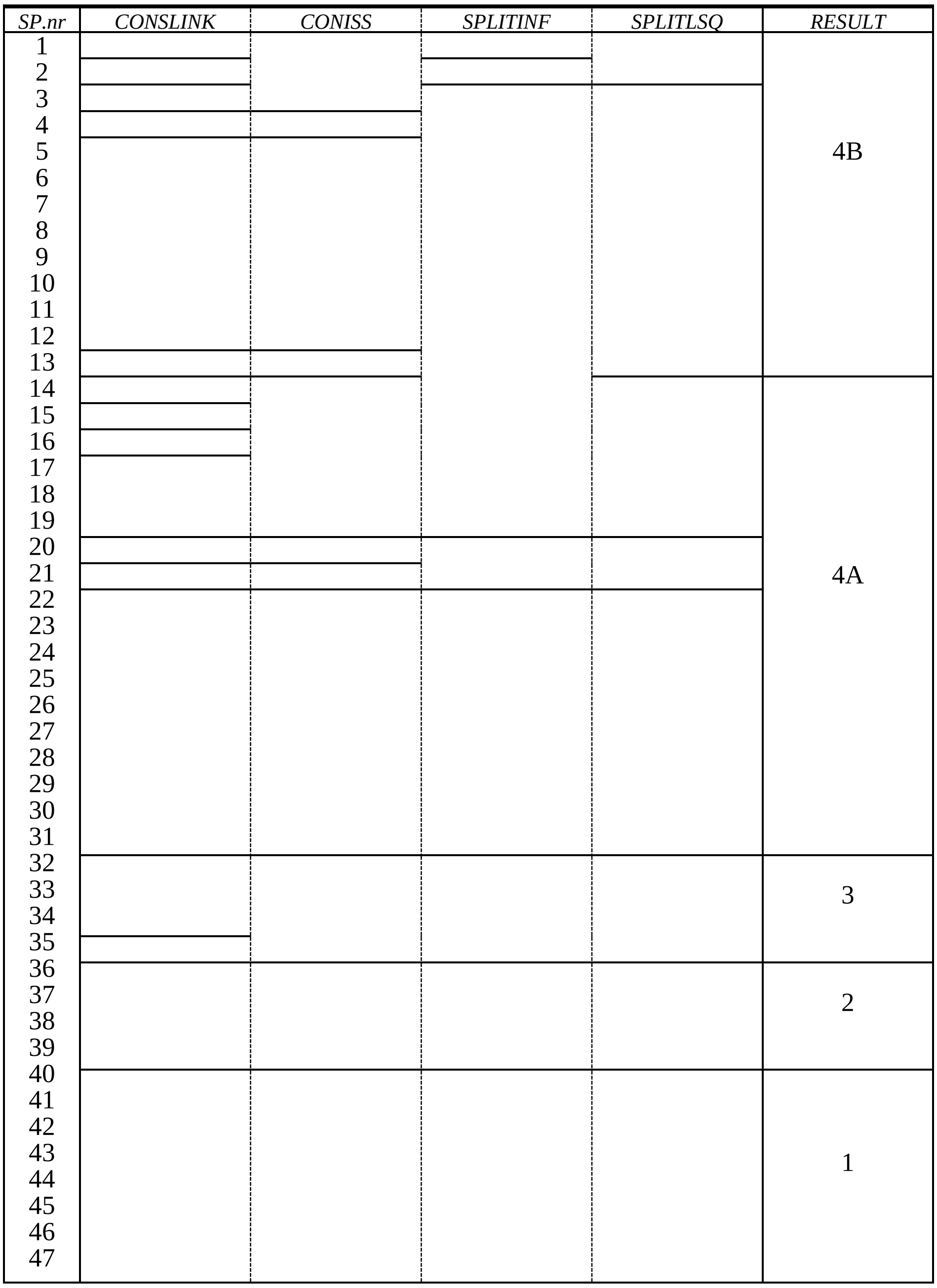


Figure 4.3 The basis for the zonation of the Mamontovaya Kurja diagram. The result column shows the zonation used on the diagram.

A short description of the pollen assemblage zones follows below.

For further details see the percentage, concentration, and influx diagrams (figs. 1, 2 and 3 Appendix D) and chapter 5.

Zone 1 : *Betula*- Poaceae-*Artemisia* pollen assemblage zone (P.a.z.)

In this zone the *Betula* curve reaches almost 20 %, and *Salix* and Chenopodiaceae reach their maxima. *Artemisia* and Poaceae show consistently high values, while Cyperaceae and *Pediastrum* show high peak values. The upper boundary is placed at the decrease in *Betula*, Cyperaceae and *Pediastrum* and the simultaneous Brassicaceae increase.

The concentration diagram shows similar trends. In addition, *Dianthus* shows an increase in the middle part of the zone. The influx diagram also show similar trends, in addition to peaks in Polypodiaceae and *Pteridium*.

Zone 2 : Poaceae-*Artemisia*-Brassicaceae p.a.z.

This zone starts with a rise in the *Papaver* and Brassicaceae curves, and the decline of *Betula* and *Salix*. In the middle of the zone, the amount of Dianthus and Brassicaceae slowly rises, and *Dianthus* reaches its maximum towards the end of

the zone. *Picea* increase towards the end of the zone and has a small peak here.

The increase of *Picea* is not shown as well in the concentration diagram. The concentration data show similar trends. The influx diagram is similar to the percentage diagram.

Zone 3 : *Betula*-*Pinus*-Cyperaceae p.a.z.

This zone is recognised by the sudden increase in *Pinus, Betula,* Cyperaceae, *Pteridium,* Polypodiaceae and *Pediastrum*. *Cerastium*-type is frequent, Artemisia remains stable, but the Poaceae and *Dianthus* curves distinctly drop.

In the concentration diagram, the increase in *Betula* is less pronounced, and Cyperaceae and Polypodiaceae hardly show any increases at all. In addition, the *Artemisia* curve drops in the concentration diagram, contrasting with the stable *Artemisia* percentages. The influx diagram shows similar trends to the concentration diagram, with a vague increase in *Pinus*.

Zone 4 Poaceae-*Artemisia* p.a.z. Divided into two subzones, a and b.

Subzone 4a : Poaceae - *Lychnis* p.a.z.

This subzone starts with an abrupt decrease in *Betula, Pinus,* Cyperaceae, *Pediastrum,* Polypodiaceae and *Pteridium*. Simultaneously, the *Artemisia* and Poaceae curves increase in addition to a marked re-occurrence of *Lychnis*.

Both the concentration, and the influx diagram give the same information as the percentage diagram in this subzone.

Subzone 4b : *Salix-Dianthus-Papaver* p.a.z.

The *Papaver, Dianthus* and *Salix* curves increase again. The amount of Chenopodiaceae, *Picea, Pinus, Ranunculus acris* type slightly increase.

The increases in *Picea, Pinus, Ranunculus acris* and Chenopodiaceae shown in the percentage diagram, are not detectable in the concentration diagram. Apart from that, the concentration and percentage diagrams give the same information in this subzone. The influx diagram shows large increases in several of the curves, especially in *Betula, Pinus, Picea, Salix,* Poaceae, *Artemisia,* Chenopodiaceae, and Brassicaceae.

4.1.5 Macrofossils from Mamontovaya Kurja.

Samples prepared for AMS-dating were collected from layers no. 3/4, 4, 6, 7, 9, 10, 11, 12, 14 and 15 (table 4.4).

Table 4.4 Macrofossils at Mamontovaya Kurja. + refers to presence, (+) refers to presence as corroded fragments. Abbreviations used in the table; s = seed, l = leaf, m = moss.

Macrofossils	**3/4**	**4**	**6**	**7**	**9**	**10**	**11**	**12**	**14**	**15**
Brassicaceae (s)	+	+	+	+		+	+	+		+
***Carex* (s)**						+		+		
Caryophyllaceae (s)						+		+		
***Oxyria* (s)**		+	+	+	+	+	(+)			
***Papaver* (s)**		+	+	+	+	+	+	(+)		+
Poaceae (s)	+	+	+	+	+	+	+	+	+	+
***Salix herbacea* (l)**						+				
Terrestrial moss	+	+	+	+	+	+	+	+	+	(+)
***Calliergon* cf. (m)**								+		
***Calliergon cuspidata* (m)**			+							
***Homalothecium lutescens* (m)**								+		
***Scorpidium* cf. (m)**							+			
***S.revolvens* (m)**								+		
***Warnstorfia exannulata* (m)**	+	+	+	+			+	+		

The mosses are typical of marshes, fens, bogs, and margins of lakes and ponds. The most common species is *Warnstorfia exannulata*. In layer 12, the find of *Homalothecium lutescens* indicates different environmental conditions. The species grows on lime-rich soils, on cliffs or on dry ground, and it usually only grows in open, sunny localities. This moss has only been found as a small fragment, which may reflect long distance river transport and/or redeposition. The herb macrofossils found all indicate an open habitat of quite unstable soils. Several of the taxa identified have recent distributions in mountainous and arctic habitats (*Salix herbacea, Oxyria* and *Papaver)*. Poaceae, *Carex,* Caryophyllaceae and Brassicaceae all include taxa indicative of both moist and dry soils. *Papaver* and *Oxyria* are often associated with unstable soils or gravel. *Oxyria* and *Salix herbacea* often grow in snow beds. *Papaver* most frequently grows on recent morainic deposits, gravel and disturbed soils.

4.2 Site 2 : Sokolova .

4.2.1 Lithostratigraphy.

Figure 4.4a, and 4.4b shows the lithological section at the site.

Figure 4.4a The excavated section at Sokolova, showing the lacustrine basin with the lower peat layer.

Figure 4.4b The excavated section at Sokolova, the picture shows the upper peat layer.

A description of the sediments is given in table 4.5.

Table 4.5 Lithostratigraphic description of the sediments at Sokolova.
The description of the constituents follows Troels-Smith (1955).

Layer number	Constituents	Description
0 (600 - 724 cm)	Ga 4	Alluvial sand
1 (724 - 726 cm)	Ag 4	Silt layer above the upper peat layer
2 (726 - 730 cm)	Tb^2 4	Peat (the upper peat layer)
3 (730 - 800 cm)	Gg $_{(maj)}$ 2 Ag 2	Sand and gravel
4 (800 - 818 cm)	Ag 3 Lf 1	Rust coloured silty sand
5 (818 - 829 cm)	Ag 4	Pure grey silt on top of the lower peat layer
6 (829 - 863 cm)	Tb^2 4	Peat (the lower peat layer)
7 (863 - 866 cm)	Ga 4	Light grey sand
8 (866 - 890 cm)	Ag 4	Brownish silt layer
9 (890 - 897 cm)	Ag 2 Ga 2	Sandy silt with some organic material
10 (897 - 900 cm)	Ga 4	Sand (with some organic material)
11 (900 - 913 cm)	Ag 3 $Tb^2$1	Silt with organic material
12 (913 - 919 cm)	Ga 4	Pure sand
13 (919 - 922 cm)	Ag 4	Pure silt
14 (922 - 925 cm)	Ga 4	Pure sand
15 (925 - 931 cm)	Tb^2 4	Seam of peat
16 (931 - 934 cm)	Ag 2 Tb^2 2	Silty sediments with peat
17 (934 - 936 cm)	Ag 3 Tb^2 1	Silty sediments with some peat
18 (936 - 938 cm)	Tb^3 4	Seam of peat
19 (938 - 966 cm)	Ag 2 Ga 1 $Tb^2$1	Sandy silt with peat remains

The pollen samples were taken from alluvial and sandy sediments with peat remains. Above the basal till there is a lacustrine sand layer (layers 19 - 7), with the lower peat layer (layer 6) on top. Above this there is a sand layer (layer 4), before there is a layer (layer 3) containing crossbedded sand and gravel (fluvial sediments). This layer is cut by a gravely lag (terrestrial origin), and above this the upper peat layer (layer 2) is situated. Above this there are alluvial sediments (layer 1 and 0) and on top, eolian sediments are situated.

Although the uppermost sediment samples were quite small, there was enough material for LOI measurements. The loss-on-ignition curve is shown in the percentage diagram, figure 4, Appendix D.

4.2.2 Datings.

Previous datings at this site gave ages around 20 ka BP for the upper peat layer (layer 2), and infinite ages for the lower peat (layer 6). The latter were believed to be less reliable, and several samples were retrieved for new datings (both AMS and OSL- datings).

The new ^{14}C-dates (AMS) at Sokolova all gave infinite ages which, according to Aalbersberg & Litt (1998), indicate ages older than 60 000 BP.

The OSL - dates are shown in table 4.6.

Table 4.6 Datings from Sokolova. [1)] Sample extracted above layer 1, ca. 20 m above river level. [2)] Sample extracted above layer 1, ca. 14 m above river level (immediately above the upper peat layer). Samples marked * have yielded ages at the limit for this dating method (see text).

Layer number	Depth (cm)	OSL dates (ka BP)	Laboratory ref.	Object dated
0 [1)]	~ 650	86 ± 7	982528 97-108	sand
0 [2)]	~ 700	92 ± 10	982526 97-87	sand
3	730 - 800	115 ± 9 *	982527 97-102	sand
7	863 - 866	132 ± 12 *	982524 97-83	sand
8	866 - 890	115 ± 8 *	982525 97-85	sand

The dates from layers 3, 7 and 8 are close to the Eemian interstadial in age (ca. 127 - 115 ka BP, Mangerud *et al.* 1979, Woillard & Mook 1982), showing standard deviations of longer duration than the Eemian itself. Hence, whether the dates reflect pre-Eemian, Eemian or post-Eemian ages cannot be decided, judging purely from the dates (J. Mangerud, *pers. comm.* 1999).

4.2.3 Pollen diagram from Sokolova.

Figure 4.5 shows the basis for the zonation of the percentage diagram.

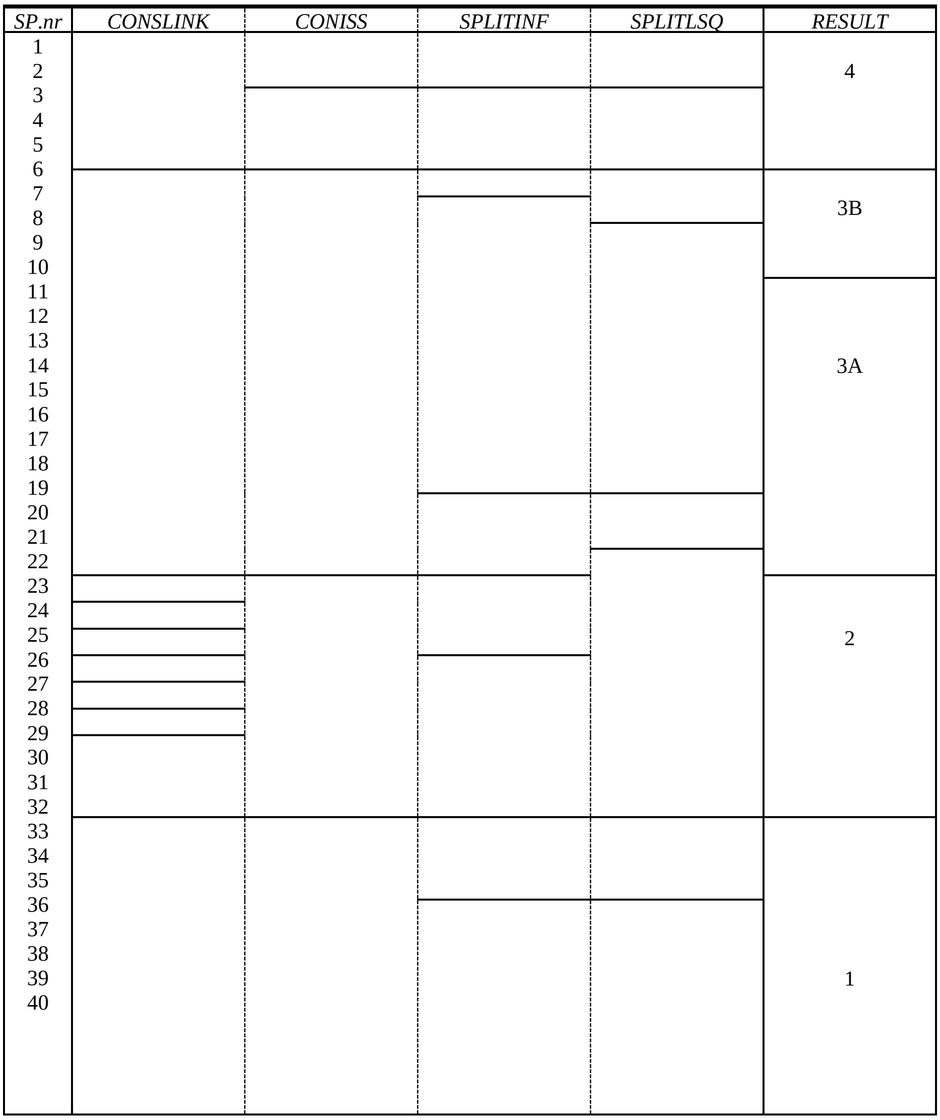


Figure 4.5 The basis for the zonation of the Sokolova diagram. The result column shows the zonation used on the diagram.

The following is a short summary of the local pollen assemblage zones. For further details see the percentage and concentration diagrams (figs. 4 and 5, Appendix D), and also chapter 5.

Zone 1 : Poaceae-*Artemisia*- Cyperaceae p.a.z.

This zone shows high values of Poaceae and *Artemisia*, together with well-represented Cyperaceae and Polypodiaceae. *Betula* decreases from about 21 % to below 5 % during the zone.

The concentration diagram shows quite even values for *Betula* throughout this zone, with *Pinus* slightly increasing. Cyperaceae, Polypodiaceae, *Salix, Picea,* and *Filipendula* all show increased concentration values towards the end of the zone.

Zone 2 : *Betula* - *Pinus* - Polypodiaceae p.a.z.

Betula, Pinus, and *Picea* values increase distinctly together with Polypodiaceae and *Filipendula*. The representation of *Artemisia*, Poaceae, and Cyperaceae are lower than in the previous zone. As in the previous zone, Chenopodiaceae and Asteraceae sect. *Aster* show stable values.

The concentration diagram gives the same information as the percentage diagram in this zone.

Zone 3 : Poaceae-*Artemisia* p.a.z.

This zone has been divided in two subzones, a and b.

Subzone 3a : Chenopodiaceae-Cyperaceae

The Poaceae curve reaches its maximum, and the *Artemisia* curve remains stable. A drop occurs in all the AP- curves, though the *Betula* decline is weaker than those of *Pinus* and *Picea*. *Ranunculus acris* type and *Dianthus* show peaks in the lower part, whilst there is an increase of Chenopodiaceae towards the end of the subzone.

The concentration diagram shows steadily increasing Poaceae values.

The percentage peaks in *Dianthus* and *Ranunculus acris* have no parallels in the concentration diagram.

Subzone 3b : *Betula*- *Ranunculus acris* p.a.z.

This subzone is only represented by four spectra, of which three are concentrated in the lower part. *Artemisia* has a peak at the onset of this subzone, whilst *Betula* and Poaceae both have moderately high values. There is a slight drop in the Polypodiaceae curve and a slow increase in the *Sphagnum* curve. Both *Pediastrum* and *Botryococcus* have peaks at the beginning of the subzone.

The concentration diagram shows approximately similar patterns to the percentage diagram.

Zone 4 : *Betula* - *Picea* - *Potentilla* p.a.z.

AP rises, and especially *Betula* increases abruptly. Simultaneously, Poaceae and *Artemisia* curves drop markedly. In this zone there are also the first appearances of *Trientalis,* Scrophulariaceae, *Linnaea* and *Vicia cracca* type. Cyperaceae has a small peak at the beginning of this zone, but then quickly drops.

In the concentration diagram *Picea, Pinus, Salix,* Poaceae, *Artemisia, Potentilla*, Cyperaceae, and Chenopodiaceae all increase in the beginning of this zone, and then suddenly drop concurrent with a bimodal increase of *Betula*.

4.3 Numerical analysis.

The results from the DCA ordination for both localities and the merged dataset are shown in table 4.7.

Table 4.7 DCA results for both the sites, including the merged dataset.
λ = eigenvalues, Grad.l. = gradient length

DCA	**Mamontovaya K.**		**Sokolova**		**Merged dataset**	
Axes	**λ**	**Grad.l.**	**λ**	**Grad.l.**	**λ**	**Grad.l.**
1.axis	0.104	1.007	0.093	1.172	0.174	1.321
2.axis	0.048	1.031	0.037	0.743	0.050	1.317
3.axis	0.021	0.711	0.022	0.662	0.033	0.880
4.axis	0.013	0.603	0.014	0.502	0.019	0.927

The lengths of all gradients show linear response curves (ter Braak & Prentice 1988, Jongman *et al.* 1995). Hence PCA was chosen as the ordination technique.

The eigenvalues and the cumulative percentage variation for the first four axes from the PCA ordination of both localities are given in table 4.8. To reveal any major differences in the vegetation development between the two sites, their data were merged. A PCA analysis on this merged dataset was run.

The eigenvalues and cumulative percentage variation of this dataset are also shown in table 4.8.

Table 4.8 PCA results for both sites and the merged dataset. The table shows the eigenvalues, λ, and the cumulative % variation, V %, for the datasets.

PCA	**Mamontovaya K.**		**Sokolova**		**Merged dataset**	
Axes	**λ**	**V %**	**λ**	**V %**	**λ**	**V %**
1. axis	0.441	44.1	0.371	37.1	0.524	52.4
2. axis	0.140	58.1	0.264	63.5	0.132	65.6
3. axis	0.111	69.2	0.126	76.1	0.101	75.7
4. axis	0.081	77.2	0.046	80.6	0.048	80.5

The distribution of species in the ordination space and their ecological demands indicate the latent environmental variables correlated with each axis (Kershaw & Looney 1985). To avoid their influence, assumed long-distance transported *Pinus* and *Picea* were deleted from the Mamontovaya Kurja data set prior to the analysis. Only *Pinus* was deleted from the Sokolova data set, as the percentage and concentration values of *Picea* indicate that it could have been locally present. Both *Pinus* and *Picea* were deleted from the merged dataset, although there was no discrepancy between the results with spruce included, and the results without spruce. Assumed reworked pollen and spores, unidentified grains, and aquatics (excluding *Sphagnum*) were also deleted.

In the plots, species distributed far from origin are the most important for indicating site differences, whereas species near origin are less important (ter Braak & Prentice 1988). Hence, species situated close to the centre are of little importance for the interpretation of the PCA ordination.

The results from the PCA ordination of the Mamontovaya Kurja site are shown in figs. 4.6 and 4.7, and from Sokolova in figs. 4.8 and 4.9. The PCA plots for the merged dataset are shown in figs. 4.10, 4.11a and 4.11b.

Only the scores on the first two axes are shown.

Abbreviations of the pollen and spore taxa shown in the PCA plots are shown in Appendix A.

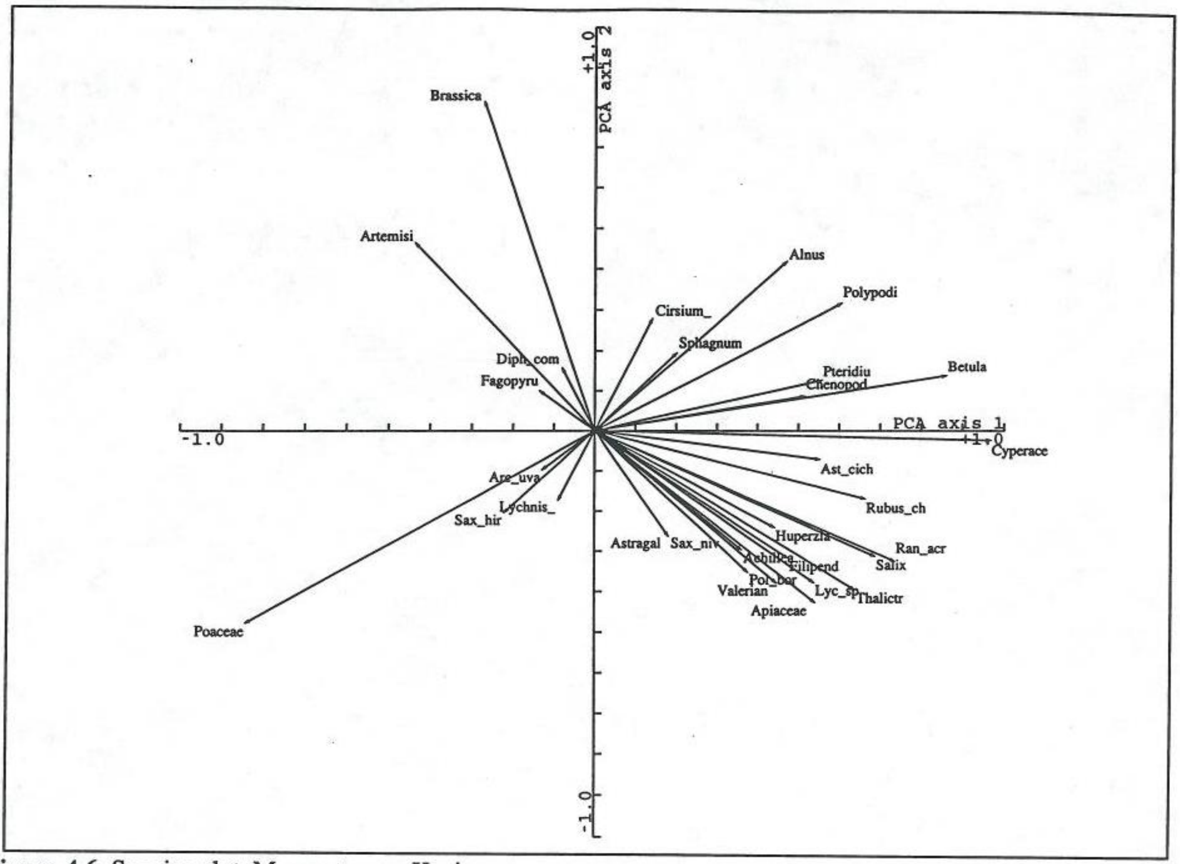


Figure 4.6 Species plot, Mamontovaya Kurja.

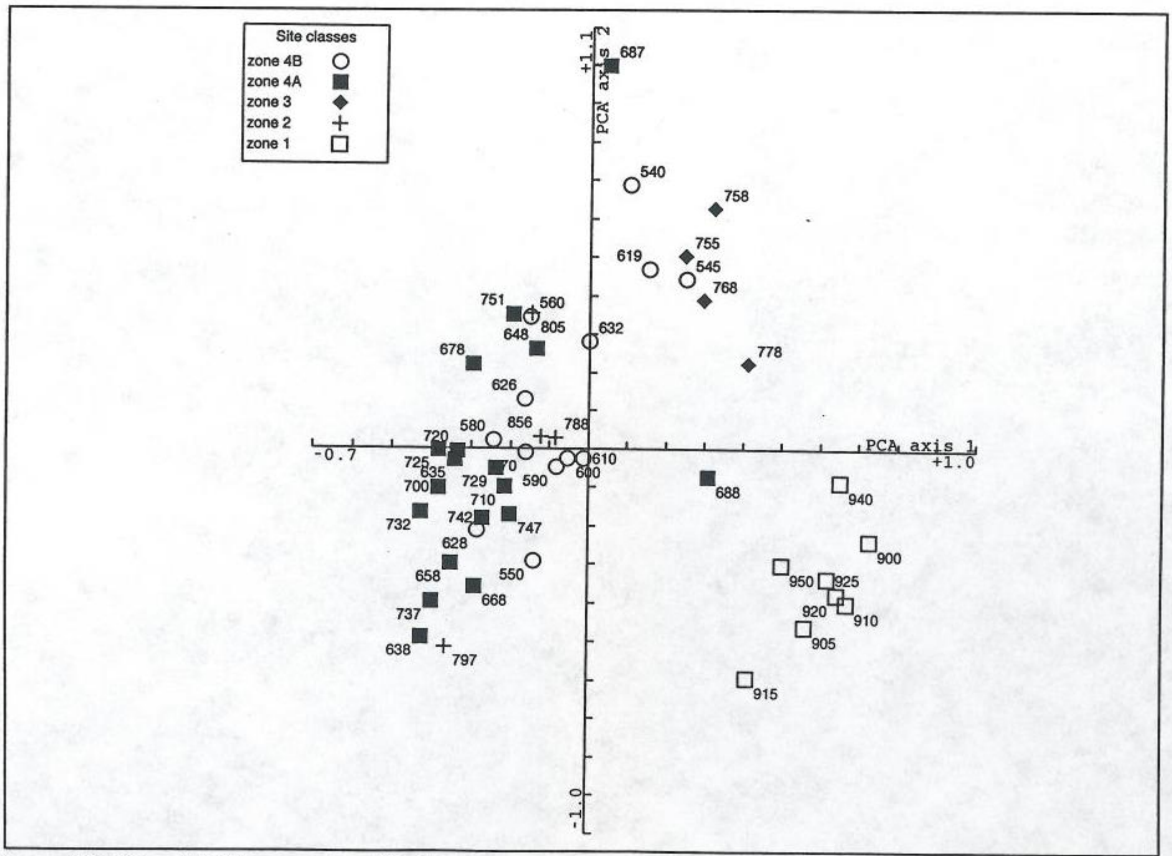


Figure 4.7 Sites plot, Mamontovaya Kurja.

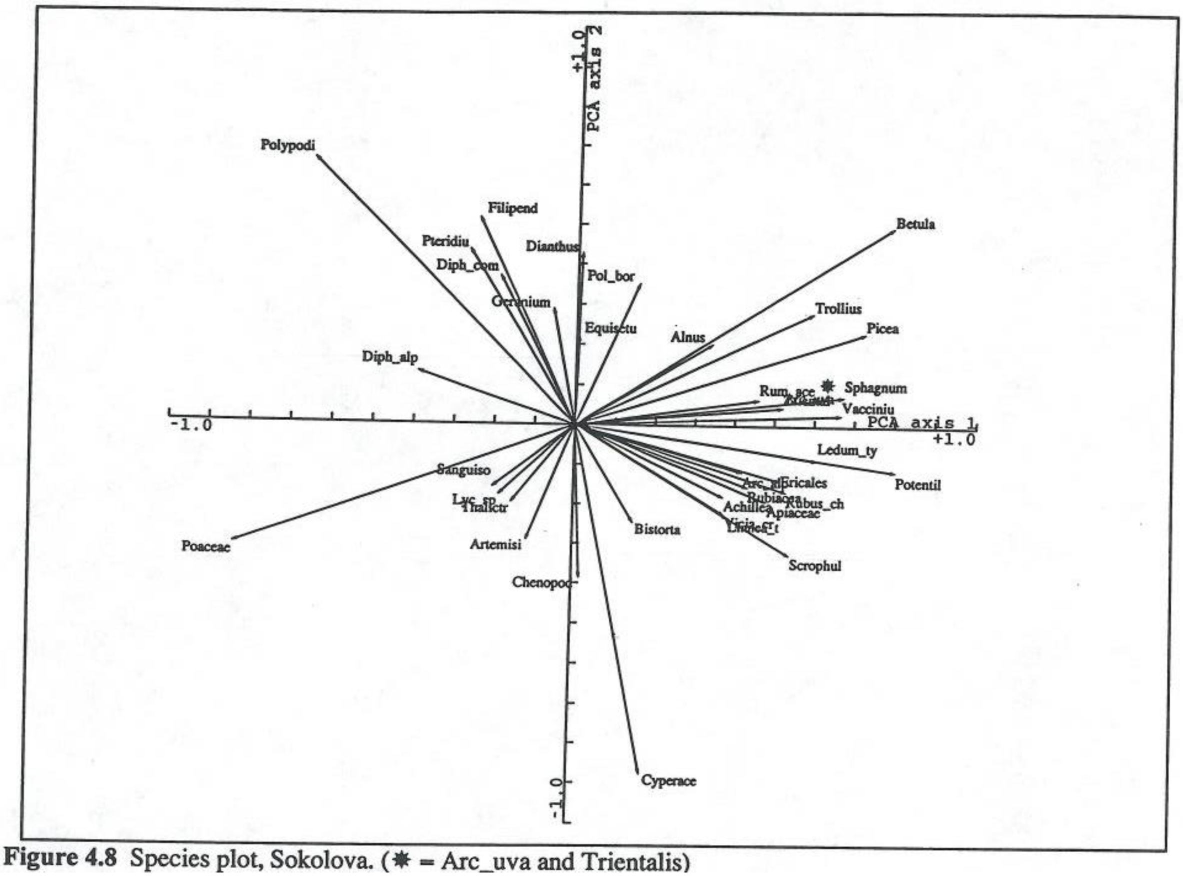


Figure 4.8 Species plot, Sokolova. (✸ = Arc_uva and Trientalis)

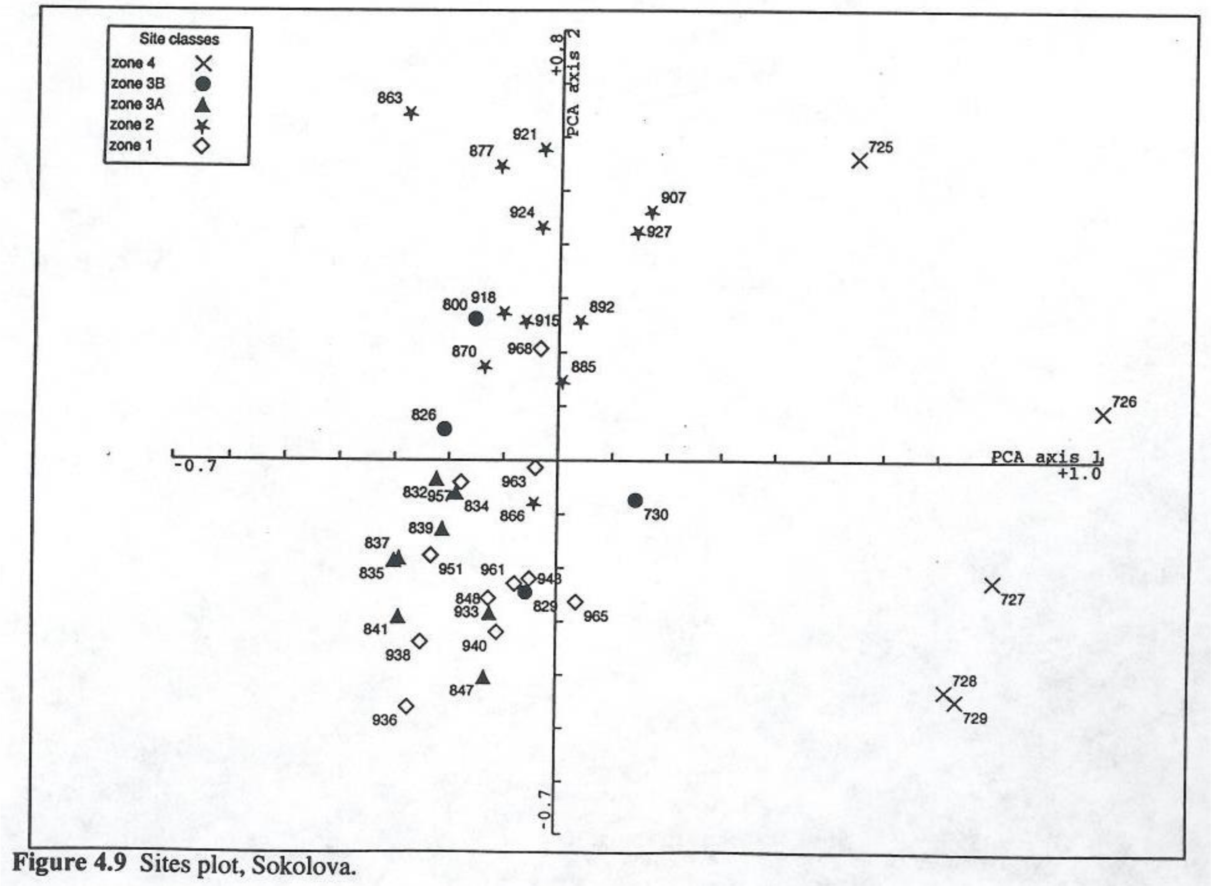


Figure 4.9 Sites plot, Sokolova.

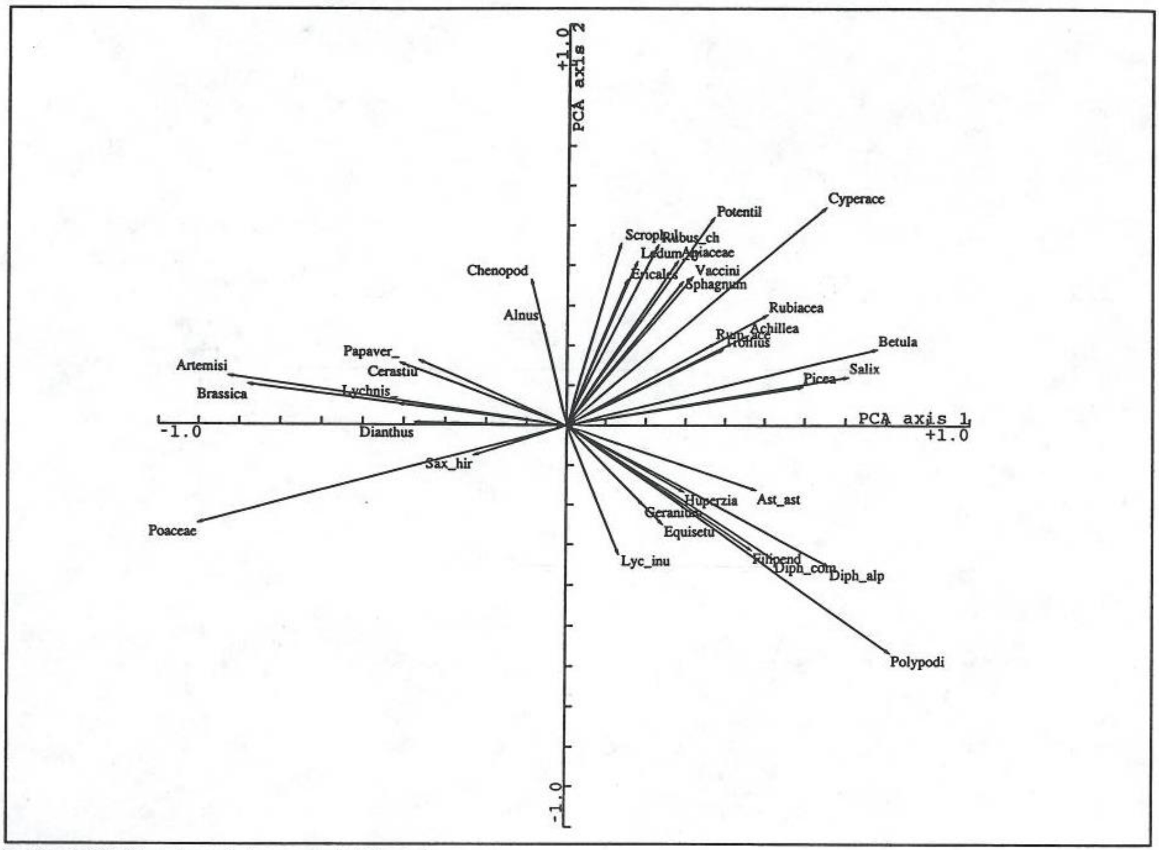


Figure 4.10 Species plot, merged data set.

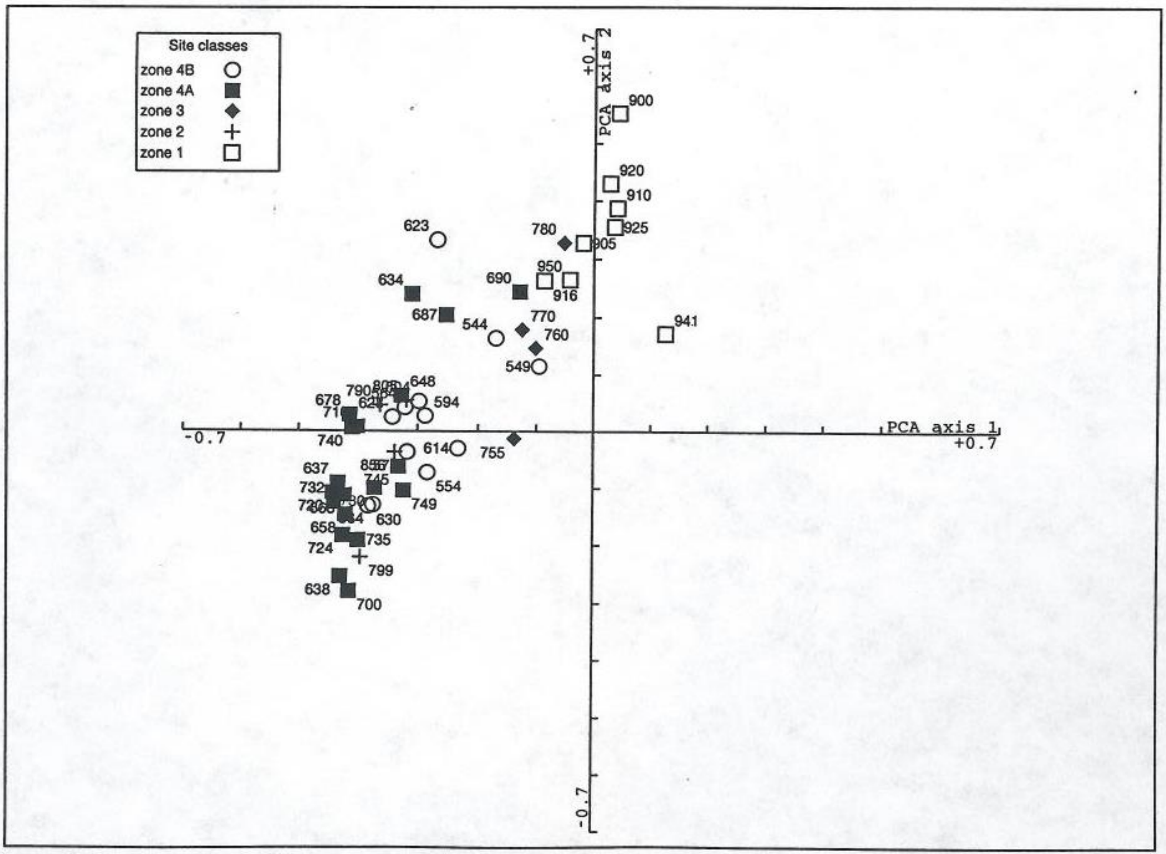


Figure 4.11a Sites plot of Mamontovaya Kurja, merged data set.

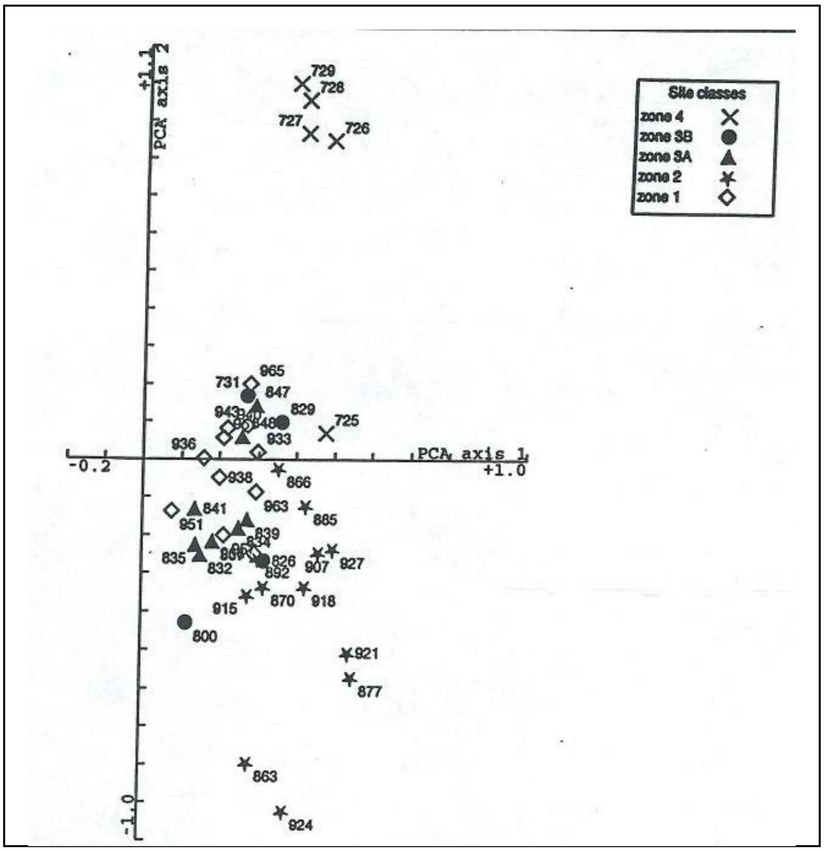


Figure 4.11b Sites plot of Sokolova, merged dataset.

Discussion of the figures:

The datasets representing the two localities are quite small, and may represent coincidental patterns. This may be a source of error for this analysis.

Mamontovaya Kurja:

In the species plot from Mamontovaya Kurja (fig. 4.6), taxa associated with open habitats on fairly dry and disturbed soils (*Artemisia, Fagopyrum, Lychnis,* Poaceae, Brassicaceae) are positioned on the left of the plot. To the right are taxa that demand more moisture, and/or represent taller and denser vegetation (Cyperaceae, *Ranunculus acris* type, *Salix, Alnus, Thalictrum, Betula,* Polypodiaceae, Apiaceae etc.). The first axis represent 44 % of the total variance in the data set, which indicates one major environmental gradient in the plot; namely a gradient representing increasing organic content in the soils and decreasing disturbance. The first gradient indicates a division between dry, open vegetation to the left, and more closed, moister vegetation to the right.

The second axis represent only 14 % of the variation of the dataset, and the third and fourth axis are of similar values (11 % and 8 % respectively). The environmental variable inherent in the second gradient has not been accurately distinguished. Probably, this gradient could hold a combination of different environmental variables, but it has not been possible to decide which variable or variables. Plots showing the third and fourth axis were made in order to reveal the latent environmental variable(s), but as none of the plots gave any clear indications of such, these plots are not shown. It appears that species found in the lowermost spectra (p.a.z. 1), are found in the lower right hand part of the PCA plot. Species common in the other zones are found in the middle or upper part of the plot. The eigenvalues of both axes are less than 0.5, indicating that the species do not exhibit a good spread along the axes (Jongman *et al.* 1995). In the sample plot (fig. 4.7), the spectra are fairly well spread. The ordination separates between the pollen assemblage zones. Most distinctly separated are p.a.z. 1 and 3. It appears to be the gradients inherent in both the second, third and fourth axis that separates the two zones 1 and 3. The first axis, which may represent increasing organic content of the soils, a closing of vegetation, more moisture, and less disturbance, seems to separate zones 1 and 3 from the other zones.

Sokolova:

In the species plot for the Sokolova site (fig. 4.8), there is a concentration of taxa that prefer an open habitat in the bottom left of the plot (Poaceae, Chenopodiaceae, *Artemisia, Thalictrum* etc.). At the top left, taxa like *Diphasiastrum alpinum, Diphasiastrum complanatum, Filipendula, Geranium, Pteridium,* Polypodiaceae etc., are situated. These indicate sheltered and moister habitats. Situated at the right of the plot are taxa that could indicate low pH (*Ledum, Potentilla, Sphagnum, Vaccinium, Rubus chamaemorus* etc.). Taxa like *Betula, Picea* and *Trollius* which indicate a more closed vegetation, are also situated in this part of the plot. The PCA scores show that the two first axes contain 37.1 and 26.4 % of the variation in the data set, and thus seem to be almost equally important (table 4.8). The eigenvalues at Sokolova are lower than 0.5, indicating that the species are not too well spread along the axes.

This indicates two main environmental gradients in the plot; namely a gradient representing decreasing pH along the first axis, and a gradient representing increasingly organic soils and decreasing disturbance, and perhaps closing of the vegetation along the second axis.

In the sample plot (fig. 4.9), the spectra belonging to the different zones have been fairly well separated. Spectra belonging to p.a.z. 4 are quite distinct from all the other spectra in the right of the plot. Zones 1 - 3b are less distinctly separated from each other in the plot. It seems that p.a.z. 4 is affected by low pH, as well as closing of the vegetation. P.a.z. 2 seems to be most affected by increased organic soils, and maybe closing of the vegetation. P.a.z. 1 and 3 seem to be more associated with open vegetation, higher pH, and more disturbed soils.

Merged dataset:

In the PCA species plot for the merged data set (fig. 4.10), there is a concentration of species that belong to dry communities of the tundra or steppe tundra type, like Poaceae, *Artemisia, Papaver, Lychnis,* Brassicaceae, Chenopodiaceae etc. to the left of the plot. To the right, there are species associated with humidity and moister soils. Some of the species are associated with a semi-closed or shrubby vegetation (*Betula, Salix, Picea,* Apiaceae etc.) that also grow on moister soils. Bottom right are species associated with vegetation of moist and fairly stable soils, with taxa like Polypodiaceae, *Huperzia selago, Lycopodiella inundata, Diphasiastrum alpinum, D. complanatum, Geranium, Equisetum etc*. Top right are taxa like *Rubus chamaemorus, Ledum* type, Ericales, *Potentilla, Sphagnum* etc., which are all associated with lower pH. The PCA scores show that the first axis represent 52.5 % of the total variation in the data set (table 4.8), which indicates that there is one main environmental gradient present in the plot; namely a gradient from left to right representing increasingly organic soils that are moist and stable, and also increasing density of the vegetation.

The gradient along the second axis could represent decreasing pH. This gradient contains only 13.2 % of the total variation of the data set, and thus is of slighter importance for the arrangement of the species and samples in the plots.

The eigenvalues for the first axis is >0.5, thus the species are spread fairly well along this axis.

In the sample ordination, the Mamontovaya Kurja spectra and the Sokolova spectra have been figured in two separate plots (figs. 4.11a and 4.11b, respectively), although situated in the same ordination space. This was done to better show the distribution of the spectra from the two sites. As can be seen, most of the Mamontovaya Kurja spectra are found in the left of the plot, and are closely clustered. The Sokolova spectra fall in the right of the plot, displaying a greater separation than Mamontovaya Kurja.

When comparing with the presumed environmental gradients found in the species plot, the Sokolova site is characterised by moist and stable soils, and high vegetation density, whereas the Mamontovaya Kurja site is characterised by unstable, dry soils in a disturbed habitat.

4.4 *Betula* pollen statistics from Sokolova.

The results from the *Betula* pollen statistics are shown in figure 4.12. The measurements are given in tables A - F, Appendix B.

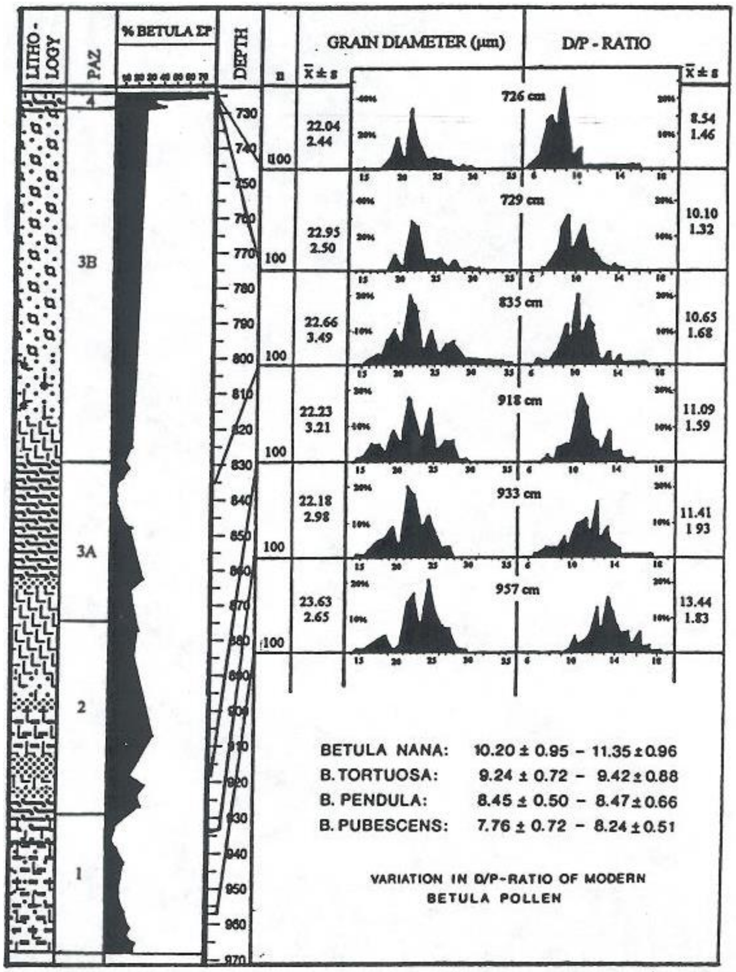


Figure 4.12 Results of the *Betula* pollen statistics. The D/P ratio of modern *Betula* pollen is shown in the bottom right (from Birks 1968, van Leeuwarden 1982, Paus 1988)

When comparing the diameter measurements of my analyses (see tables A - F, Appendix A) with those in earlier studies, it is apparent that my results give larger sizes (especially for *B. nana*) than reported by others (Birks 1968, van Leeuwarden 1982, Paus 1988). The larger diameter measurements may be due to swelling during or after preparation (Cushing 1961, Fægri & Iversen 1989), and/or the grains may have swollen because of sedimentary processes (Praglowski 1966, Fægri & Iversen 1989). The tree-birch grains found in the two topmost samples contradict this general idea, being smaller than previous studies has reported. This could be because the birch-pollen was underdeveloped, for instance as a response to climatic factors, or perhaps being unripe and deposited within the catkin (not obvious when counting), that disintegrated during sedimentation. Of these reasons, the diameter measurements were not used in the interpretations of the results. My interpretations are based on the size independent D/P-ratio.

When comparing the fossil D/P-ratio results with modern results (Birks 1968, van Leeuwarden 1982), tree-birch apparently comprises 65-70 % of measured *Betula* at 726 cm, and ca. 35 % at 729 cm (see fig.4.12). Most of the tree-birch grains were quite small (small measured diameter) compared to the grains of *Betula nana*, and also compared to tree-birch grains of other studies (Birks 1968, van Leeuwarden 1982, Paus 1988, 1995). It was nevertheless apparent, during analyses, that the small *Betula* grains were of morphological tree-birch type. Although small, the grains were more triangular in shape, and also of a brighter colour than the other *Betula* grains present (Terasmäe 1951, Florin 1969). The D/P-ratio showed normal differentiation between tree-birch and dwarf-birch. At 835 cm, tree-birch constitutes 30 % of measured *Betula* as judged by the D/P ratio. At 918 cm and 933 cm, the D/P ratio indicates a total of ca. 15 % tree-birch pollen, and at 957 cm, the D/P ratio indicate less than 15 % tree-birch pollen.

4.5 Rarefaction analysis.

Rarefaction analysis was made in order to obtain an estimate of the floristic richness of the two sites, and to compare the result of the two sites with each other.

The results of the rarefaction analysis are shown in figures C1 and C2, Appendix C.

A synthesis of the results is as shown in table 4.9.

Table 4.9 Results of the rarefaction analysis. P.a.z. = pollen assemblage zone, $E(S_{182})$ = Estimated species richness of a sample of 182 species.

Sokolova			Mamontovaya Kurja		
P.a.z.	**$E(S_{182})$**	**Pollen Concentration**	**P.a.z.**	**$E(S_{182})$**	**Pollen Influx**
4	10 - 14	high	4 b	9 - 14	low
3 b	12 - 17	low	4 a	7 - 11	low
3 a	10 - 13	low	3	12 - 14	low
2	11 - 15	low	2	10 - 13	low
1	10 - 13	low	1	14 - 17	low

In total, the estimate of species richness is fairly low (Birks & Line 1992a), with some fluctuations in the values from one zone to another.

Mamontovaya Kurja:

At this site, the species richness estimates show low values throughout the entire sequence. The lowermost zone (p.a.z. 1) has the highest species richness (14 - 17), but the influx values are low. This could indicate that the vegetation was influenced by a less severe climate (less disturbance) than the following zones (Birks & Line 1992a), or there could be much long-distance transported pollen. These zones seem to be characterised by an open vegetation disturbed by harsh climates preventing the establishment of a species rich vegetation. However, a slightly increasing species richness estimate in p.a.z. 3 could reflect a fluctuating environment towards ameliorating conditions and intermediate disturbance in this zone (Grime 1973, Birks & Line 1992a, Odgaard 1994).

Sokolova:

The species richness is generally low and of similar values in all zones. In the three lowermost zones (1,2, and 3a), low pollen concentrations occur together with low species richness. However, low concentrations are usually associated with higher species richness (Seppä 1998). The deviating Sokolova results could indicate that the vegetation in this period was influenced by a harsh environment, for instance a very cold climate (Seppä 1998). The results seem to indicate that the vegetation in these three zones was relatively open. In zone 3b, the species richness increases, and this may indicate that the vegetation was less disturbed (Birks & Line 1992a), although the vegetation probably was still rather open. Thus, this may reflect a period with optimal level of disturbance (Grime 1973, Odgaard 1994). In zone 4 there is a rapid increase in the concentration values, although the species richness is still fairly low. This could reflect a closing of the vegetation, increased competition and hence decreased species richness (Birks & Line 1992a).

Sokolova has slightly higher species richness estimates than Mamontovaya Kurja. Disregarding the age differences, these differences in species richness could perhaps in part be explained by the differences in geographical position of the two sites. Mamontovaya Kurja is ca. 125 km north of Sokolova, and the higher latitude may have experienced harsher climates than Sokolova. Another explanation is that these differences could be due to differences in aspect. Most likely, however the slight difference in species richness is due to climatic differences between the different time periods. All interpretations indicate that the climate at

Mamontovaya Kurja was harsher (colder and possibly more arid) than what was the case at Sokolova.

5. Discussion:

5.1 Palaeoecological interpretations of the pollen diagrams.

5.1.1. Mamontovaya Kurja.

Data from the percentage, concentration and influx diagrams (figure 1, 2 and 3, Appendix D), with LOI measurements (table 4.2 and percentage diagram, Appendix D), rarefaction analysis (fig. C1, Appendix C), PCA analysis (figs. 4.6 and 4.7), and macrofossil content (table 4.4) have been used in the following interpretation.

Pollen assemblage zone 1 : *Betula*-Poaceae-*Artemisia* (ca. 36 ka BP).
Depth : 1730 - 1555 cm

The sediments in this zone consist of alluvial sand and gravel. The pollen samples were retrieved from a silt-block, and also from a small peat lens. The sand and gravel layer contains the Palaeolithic artefacts and the mammalian bones (Mangerud *et al*. 1999).
The low LOI measurements in this zone (below 5 %) indicate a low organic content of the sediments, which in turn could indicate unstable soils, erosion, and sparse vegetation cover. As the sediments are of alluvial origin, there is a possibility that the sediments may have been subject to fractionation (Fægri & Iversen 1989). This is not indicated by the influx values, as these are relatively high. Total pollen influx is between 500-2100 grains/cm²/yr. The datings made in this zone are still somewhat uncertain, which makes the influx calculations highly unreliable. The concentration diagram indicates a total concentration of ca. 51,000 grains/cm³, which is fairly low. Analysing lake sediments, Gajewski *et al.* (1993) found a shrub tundra site to yield total concentration of 50,000 to 100,000 grains/cm³. As alluvial sediments often contain a smaller portion of the total pollen rain (West *et al*. 1993), the concentration values at Mamontovaya Kurja may indicate a vegetation type similar to shrub tundra. There is a possibility that the pollen samples are taken from alluvial sediments that may have been deposited before or early in the flowering season (deposited after a spring nival peak), thus the low pollen concentrations could be due to this (West *et al.* 1993). The pollen assemblage though, can be interpreted as open dry tundra. This is indicated by pollen taxa containing dry-soil elements like *Artemisia,* Chenopodiaceae, Poaceae, and *Rumex* (Khotinsky 1984), and (arctic-alpine) tundra elements like *Betula nana, Cerastium, Saxifraga, Salix, Papaver, Astragalus, Polemonium* and *Thalictrum* (Cwynar & Ritchie 1980, Khotinsky 1984). The influx diagram indicates a total influx around 2100 grains/cm²/yr with a maximum of 2300

grains/cm^2/yr in the middle of the zone. These values are fairly high and reflect influx values found for forest tundra or mountain birch woodlands (Ritchie & Lichtie-Federovich 1967, Hicks 1994).

In both the percentage and in the concentration diagram, the most abundant taxa are Poaceae, *Artemisia*, and Chenopodiaceae. Judging from the low concentration values, and low percentages for most of the trees, it is likely that most of the tree-pollen is long-distance transported. The percentages of both *Pinus* and *Picea* (a concentration of 1200 - 1600 grains/cm^3 for *Pinus*, and 650 grains/cm^3 for *Picea*, both with percentages below 10 %) are too low to indicate local presence (Hyvärinen 1976, Birks & Birks 1980, Ritchie 1984, West *et al*. 1993). *Betula* shows higher concentration and influx values than the other tree taxa, with a maximum value in the range of 6300 - 6500 grains/cm^3 and 260 - 270 grains/cm^2/yr. The influx values indicates that tree birches may have been present (Hicks 1994, Paus 1995), but most likely, as indicated by fairly low concentrations and percentages, the elevated *Betula* curve mostly represents dwarf birch, and long distance transport of tree-birch pollen. Considering the low percentage and concentration values, *Salix* might only be represented by dwarf species with limited pollen dispersal. The herbs found as macrofossils in this zone (table 4.4) are also registered with pollen occurrences in the pollen diagram, namely Brassicaceae, Poaceae and *Papaver sp.* Of these, *Papaver sp*. has the most restricted habitat requirements, demanding fairly disturbed and open habitats in a cool climate.

The high percentage, concentration, and influx values of Poaceae, *Artemisia*, and Chenopodiaceae in comparison with the overall values, indicate a treeless type of vegetation. Estimated species richness of this zone is somewhat higher than of the following zones (table 4.9). This may be due to lower level of disturbance in this zone (as compared to the other zones), which would increase $E(S_n)$ (Grime 1973, Birks & Line 1992a).

The spectra of this zone cover a range of organic content and hence disturbance of the soils, as shown in the PCA plot of samples (fig. 4.7).

The Usa river is believed to have had a normal fluvial drainage until at least 26 ka BP (Mangerud *et al*. 1999), perhaps creating an oxbow lake, which would explain the slightly elevated influx values of *Pediastrum*. The relatively high percentages shown for Cyperaceae, *Sphagnum* and *Rubus chamaemorus* probably represents local peat formation at or near the river edge.

As mentioned earlier, the spectra of this zone may be of a different age than the dated bones. Further dating of the sediments of layer 15 will hopefully solve this problem.

Pollen assemblage zone 2 : Poaceae-*Artemisia*-Brassicaceae (ca. 34 ka BP to ca. 30 ka BP)
Depth : 1555-1385 cm

There is possibly a hiatus of 8-10,000 years between layer 15 (p.a.z. 1) and layer 14 (p.a.z. 2), meaning that the spectra of zone 1 are ca. 36 ka, whilst the spectra of this zone are ca. 27 ka. Alternatively, the spectra of the previous zone are slightly older than the spectra of this zone. As in the previous zone, the sediments of p.a.z. 2 are of alluvial origin and consist mainly of crossbedded sand. Both total influx and total concentration are quite low, which indicates that fractionation (Fægri & Iversen 1989) may have occurred. In the upper part of the zone, the sediments consist of sand and silt with organic material. There are no LOI data for this zone. At the transition between p.a.z. 1 and 2, there is a marked drop in almost all pollen percentage curves except Brassicaceae, *Artemisia, Papaver* and *Dianthus*, which increase. *Betula* concentration decrease to only 230-300 grains/cm^3, and Betula influx reaches only 17 grains/cm^2/yr, which indicates an almost complete disappearance of *Betula*. The other tree taxa are most likely only represented by long-distance-transported pollen. Total concentration amounts to 16-17,000 grains/cm^3, which also indicate a sparse and open vegetation type (Hyvärinen 1976). Total influx averages 670 - 1170 grains/cm^2/yr, and thus indicate tundra or forest tundra vegetation (Ritchie & Lichtie-Federovich 1967, Hicks 1994).

Salix distinctly drops at the beginning of the zone, and disappears towards the end. Rarefaction analysis shows a decrease in estimated species richness for this zone compared to the previous zone (table 4.9). This could be due to increased disturbance caused by deteriorating climate (Birks & Line 1992a). The only macrofossils found here are seeds of Poaceae, and stems and leaves of terrestrial mosses (undiff.) (table 4.4). Thus the macrofossil content also shows a decrease in species diversity.

Judging from the PCA plots (figs. 4.6 and 4.7), this zone seems to represent increased disturbance and less organic content of the soils, which support the vegetational development proposed above.

Towards the end of the zone there are slight increases in the pollen curves of several of the species. Most distinct are the increases in Poaceae and *Cerastium*, though there are slight increases in *Betula, Pinus,* and Cyperaceae as well. These increases may be explained by the arrangement of spectra in this zone. There is only one spectrum in the lower part of this zone, and only four spectra in all. The three others are concentrated in the top of the zone. So the apparent increase in some of the pollen curves towards the end of the zone could thus be coincidental, and not caused by environmental changes.

Judging from the species composition, the percentages, and the concentrations, in addition to the results from PCA and the macrofossils, the vegetation was probably treeless. The environment was probably cooler and perhaps drier than in p.a.z. 1. This is indicated by the disappearance of different taxa, like *Filipendula*, which can tolerate a minimum July temperature of 10°C (*F. ulmaria* 8°C) (Aalbersberg & Litt 1998). Its disappearance could indicate that the July mean temperature sank below 10°C in this zone.

Pollen assemblage zone 3 : *Betula*-*Pinus*-Cyperaceae (ca. 30 ka - ca. 27 ka BP)
Depth : 1385-1354 cm

The sediments in this zone consist of sand and silt with some organic material. The sediments are still of alluvial origin.

In addition to being of alluvial origin, the sediments also consist of sand, which further promotes fractionation (Fægri & Iversen 1989). Low total concentration in this zone (7500 grains/cm^3) suggests that fractionation may have had an effect on the sediments. The total influx of this zone is lower than in the previous zones (333 grains/cm^2/yr), and may indicate fractionation. The influx of this zone seems to be more reliable than for the other zones, by a better correlation with the pollen-assemblage interpretation.

The percentage curves for plants indicative of dry vegetation, like *Artemisia*, Chenopodiaceae, and Poaceae (Khotinsky 1984), all decrease in this zone. In contrast, pollen-types indicative of moister soils have a peak (*Rubus chamaemorus*), or their first (and only) occurrence (like Onagraceae, *Cirsium*). *Pediastrum*, Polypodiaceae, *Pteridium* and *Botryococcus* also show increasing values in the percentage and the concentration diagram. The influx diagram shows a decrease in almost all curves.

The total tree-pollen curves increase, and reaches a maximum of 35 %. *Betula* and *Pinus* show the most marked increases. *Pinus* reaches about 30 %, and concentration values for *Pinus* increase to values similar to those in p.a.z. 1 (1200-1600 grains/cm^3), but this is too low to indicate local presence of pine (Hyvärinen 1976). The pine influx only reaches 80 grains/cm^2/yr, which is too low to indicate local presence (Hyvärinen 1976, Birks & Birks 1980, Hicks 1994). Similarly, low concentration, percentage, and influx values for *Picea* and *Betula*, indicate that neither *Picea* nor *Betula* trees were present (Ritchie 1984, Paus 1988). Macrofossils found in this zone show greater species diversity than in the previous zone. Some of the taxa present indicate moist soils (*Carex*, *Calliergon*, *Scorpidium*, and *Warnstorfia* *exannulata*), whilst others are indicative of drier ground (*Papaver*, Caryophyllaceae, and *Homalothecium lutescens*).

Rarefaction analysis show slightly higher estimated species richness for this zone (table 4.9, fig. C1, Appendix C), compared to zone 2, although the value is still fairly low (Seppä 1998). The low concentration together with moderately low estimated species richness indicates that the site was under influence of a fairly harsh climate. The species composition indicates wetter conditions, at least moister soils, than in the preceding zone. In the PCA plot (fig. 4.7), the spectra of this zone are situated close to those of zone 1. This means that the zone possibly shows increased soil stability and organic content of soils compared to zone 2. There might have been a slight amelioration of the climate, which could have involved increased precipitation and/or increased melting of permafrost. Another explanation for this could be that the river changed its course, which could explain the increased moisture in this zone. The peak in *Pediastrum* indicates the presence of a still water, perhaps that the river level increased somewhat. This could have led to increased moisture content of the soils fringing the river.

Even though no trees were present at Mamontovaya Kurja at this point, trees probably grew nearer than previously, thus causing the increased *Pinus* percentages in the pollen diagram.

Pollen assemblage zone 4 : Poaceae-*Artemisia* (ca. 27 - ca. 23.8 ka BP)
Subzone 4a : Poaceae-*Lychnis* (ca. 27 - ca. 24 ka BP)
Depth : 1354-1237.5 cm

The sediments here are of alluvial origin, mostly laminated sand and silt with some organic material. Layer 8, which is situated in the middle of this subzone, consists of pure laminated sand. This is reflected quite sharply in the pollen diagram in the following way: There is a sudden decrease in the concentration of all major pollen types, and the pollen sum (Σ P) is low compared to spectra above and below it. This is most likely due to the effects of fractionation (Fægri & Iversen 1989). LOI values are very low in this zone. After a maximum of 4 % in the very beginning, LOI drops to around 1 %. These low values suggest low organic content of the sediments. Total concentration increases averaging 27,000 grains/cm^3, with a maximum of 43,000 grains/cm^3, and total influx increase to a maximum of 6300 grains/cm^2/yr in the top of the zone (an average of 1100 - 1400 grains/cm^2/yr in the lower and middle parts). Both Poaceae and *Artemisia* increase rapidly in this zone, whilst *Pinus* and *Betula* decrease. These changes are shown quite well both in the percentage and in the concentration diagram, but the influx diagram is less clear. As in the previous zones, the tree-pollen is probably long-distance-transported. This is indicated by low percentages, concentrations, and influxes of *Picea, Pinus,* and *Betula* (Hyvärinen 1976, Birks & Birks 1980, Ritchie 1984, Paus 1988). Although the *Betula* concentrations only amounts to 900 - 1000 grains/cm³, and the influx only to 30 grains/cm²/yr, *Betula nana* could be locally present. Other shrubs, like *Salix* and *Alnus* show low percentages, concentrations, and influx values. Even so, at least *Salix herbacea* was present at the site in the beginning of this subzone, as confirmed by a leaf found in layer 10. Otherwise, the macrofossils (table 4.4) show approximately the same species composition as in the previous zone, with the addition of *Oxyria*, which presently grows in moist habitats like snow beds and edges of brooks and rivers, on lakesides, moist gravel or peaty soils or meadows (Lid & Lid 1994).

The PCA plot indicates that the spectra in this subzone reflect dry vegetation, thus the spectra seem to reflect increased disturbance and decreasing organic content of the soils (fig. 4.7). The spectra of this zone are situated close to those of p.a.z. 4B and 2, and far away from those of p.a.z. 1.

The estimated species richness decreases somewhat, which could possibly be due to increased dominance of *Artemisia* and Poaceae, in addition to increased disturbance (Grime 1973, Seppä 1998). Species that indicated moister soils in p.a.z. 3, all drop in this zone. *Sphagnum* is the only moisture demanding species that increases, and this together with Cyperaceae might have inhabited moister areas, e.g. depressions or river margins. The increase in steppe-indicating species *sensu* Khotinsky (1984) and Adams & Faure (1997), indicate that the soils again turned drier. Both influx and concentration values are higher than reported for tundra areas today, the influx value indicate a shrub tundra, forest tundra or subalpine birch forest (Ritchie & Lichtie-Federovich 1967, Hicks 1994, Plouffe & Jetté 1996). The relative percentages for the different species do however contradict this as none of the trees have representations above 10 %. In addition, Poaceae and *Artemisia* together hold 70-85 % of the total pollen percentage.

The vegetation was still open, probably a grass tundra or tundra steppe. After a slight climatic improvement in the preceding zone, there was probably a return to cooler and more arid conditions.

Subzone 4b : *Salix-Dianthus-Papaver* (ca. 24 - ca. 23,8 ka BP)
Depth : 1237.5 - 1130 cm

The sediments in this subzone are similar to subzone 4A, i.e. alluvial sand and silt with organic material. As in the previous zones, the alluvial sediments may indicate that fractionation has occurred (Fægri & Iversen 1989). There is a LOI peak at the very beginning of almost 6 %, but this value decreases to about 1 % further up in the sequence as in p.a.z. 4A. This indicate a very low organic content of the sediments.
The total concentrations in this zone decrease slightly, from 34,000 grains/cm^3 in zone 4a to 29,000 grains/cm^3 in this zone, mostly because of slight decreases in Poaceae and *Artemisia*. The influx in this zone increase from about 1800 grains/cm^2/yr to 6600 grains/cm^2/yr in the top of this zone (fig.3, Appendix D). These influx estimates are quite high, indicating dense forests, and may be erroneous due to unreliable ^{14}C-dates. Hence, the influx estimates of this zone are avoided in the palaeoecological interpretation. Either the dates of this zone are wrong, or there has occurred an enrichment of the sediments caused by the large catchment area of the Usa river. The latter explanation is probably not the case, as the catchment area of the Usa river is further north where the vegetation most likely were more sparse than at Mamontovaya Kurja at this point. The low concentrations also contradict this enrichment theory. Otherwise, there are only minor changes in the pollen composition in the diagram. *Papaver* and *Dianthus* increase in this zone, possibly indicating even drier conditions than previously. The macrofossils (table 4.4) in this zone include the same taxa as in the previous subzone, thus indicating similar conditions as in p.a.z. 4A. Estimated species richness increase slightly compared to the preceding subzone. This could be because of the decrease in Poaceae and *Artemisia* as dominating pollen producers (Seppä 1998). The PCA ordination (fig. 4.7) shows that the spectra of this zone are close to subzone 4A, thus displaying affinities towards disturbance and low organic content of the soils.
As in subzone 4A, the vegetation at Mamontovaya Kurja seems to be of a steppe or steppe tundra type. The species composition, indicate as dry conditions as in 4A. The percentage and concentration values support this interpretation (Allen *et al.* 1998). The pollen representation seems to indicate grasslands or periglacial steppe vegetation (Khotinsky 1984, Adams & Faure 1997).

Summary Mamontovaya Kurja:

Mamontovaya Kurja was situated close to the Usa river throughout the time sequence that is spanned by the pollen diagram. The riverbank would have yielded moist habitats, even if the surrounding vegetation was rather dry. In general, the vegetation at the site was probably a periglacial steppe or steppe tundra throughout the pollen-analysed sequence. Zones 1 and 3 seem to represent more humid periods.

It is believed that the Usa river was large and quite deep during most of the time period covered by the pollen diagram (J. I. Svendsen, *pers. comm.* 1999). The river was probably meandering, and had large flood basins. Only towards the top of the sequence (in layer 4 and 3) the river seems to have diminished (or changed its course), and windblown (eolian) sediments accumulated. The amount of moisture demanding species found, could reflect local habitats near the river edge or by an oxbow lake.

5.1.2 Sokolova.

Data from the percentage and concentration diagrams (Appendix D), with LOI measurements (see the percentage diagram, fig. 4 Appendix D), rarefaction analysis (fig. C2, Appendix C), PCA analysis (figs. 4.8 and 4.9), and *Betula* pollen statistics (fig. 4.12, and tables A - F, Appendix B) have been used in the interpretations.

Pollen assemblage zone 1: Poaceae-*Artemisia*-Cyperaceae (probably post-Eemian age, see 6.2)

Depth : 968 - 929 cm

The sediments in this zone consist of sandy silt or silty sediments with peat remains. A small peat lens in layer 17 causes the LOI measurements to rise abruptly (to 12 %). Otherwise, LOI shows stable values around 4 %, which is fairly low. Low LOI indicates low organic content of the sediments, which may indicate unstable or disturbed soils, and a fragmented vegetation cover.

The species composition shows high percentages of Poaceae, *Artemisia*, Cyperaceae, and Polypodiaceae. This trend is also obvious in the concentration diagram. The pollen types represented in this zone, such as *Artemisia*, Poaceae, Chenopodiaceae, *Betula*, Cyperaceae and Salix, indicate a steppe tundra or perhaps an open shrub tundra (Khotinsky 1984, Serebryanny & Malaysova 1998). Poaceae has a concentration peak in the upper part of the zone, reaching 90,000 grains/cm³. Total concentrations reach a maximum of 103,000 grains/cm³ at the Poaceae maximum, but otherwise total concentration averages 23,000 grains/cm³. This is lower than reported for shrub tundra (Gajewski *et al.* 1993), thus indicating that trees (and perhaps also shrubs) were absent at Sokolova in this zone.

After a peak of 40 % AP in the lowermost spectrum, the AP curve recedes to 20-30 %. *Picea* and *Pinus* both reach approximately 6 %, and their concentrations reach ca. 4000 grains/cm³ in this zone. These low values indicate that neither of these trees was present at Sokolova (Hyvärinen 1976, Ritchie 1984, Gajewski *et al.* 1993, Plouffe & Jetté 1996), and so their pollen representation reflects long-distance transport and possibly some redeposition.

The main tree-pollen contributor is *Betula*, which reaches almost 20 %. *Betula* pollen statistics show that tree-birch pollen amounts to less than 15 % of measured *Betula* pollen (fig. 4.12). This, together with the low concentration values for *Betula*, indicates that most of *Betula* pollen originates from local *Betula nana*. The tree-birch pollen most probably reflects long-distance transport, and/or redeposition. Forests may have developed at a closer range towards the end of the zone, as there are increases in the curves for both *Pinus* and especially *Picea*.

The estimated species richness in this zone is fairly low (Seppä 1998), and the low total pollen concentration indicates a relatively sparse vegetation. From the PCA plot (fig. 4.9), it is evident that this zone has been placed along the first environmental gradient, and that it is affected by relatively dry and disturbed soils with low organic content, thus indicating an open vegetation.

Pollen assemblage zone 2 : *Betula*-*Pinus*-Polypodiaceae (post- Eemian age, see 6.2)
Depth : 929 - 875 cm

The sediments in this zone consists of silt and sand layers with some organic content (peat-remains), and the sediments of this zone are from the lower part of the lacustrine sequence. LOI measurements are low in this zone, with a maximum in layer 13 of 5 %. The mean value though, is only ca. 2 %.

The species composition of this zone exhibits quite large differences from the previous zone. *Artemisia* and Chenopodiaceae remain stable, Poaceae drops quite significantly, whilst *Filipendula*, Polypodiaceae, *Rumex acetosa* type and tree-pollen increase. The increase in moisture demanding species like *Filipendula*, *Lycopodiella inundata*, *Equisetum*, *Ranunculus* *acris* type, and *Rumex acetosa* type, indicates increased humidity of the soils, probably caused by increased precipitation, and/or increased melting of permafrost. The increase in moisture demanding species like *Filipendula, Equisetum, Lycopodiella inundata, Potentilla* and the aquatic *Potamogeton* could be reflecting local vegetation around (and in) the lake.

Total AP percentages reach 65 - 70 % in this zone, and *Picea, Pinus* and *Betula* show distinct increases. This is also shown in the concentration diagram. *Pinus* reaches 20 - 25 %, and a concentration of maximum 10,700 grains/cm³. *Picea* reaches 13 % and a concentration of 3000 grains/cm³. Although both taxa increase markedly from the previous zone, it is probable that neither was actually present at the site. *Pinus* concentrations are generally too low to indicate local presence of the tree (Hyvärinen 1976). Some authors have considered *Picea* to be locally present when reaching over 10 % (Ritchie 1984, Plouffe & Jetté 1996), whilst others have reported *Picea* to reach 10-20 % without being locally present (Gajewski *et al.* 1993). In this pollen diagram, there is no suppression of the *Betula* curve concordant with the *Picea* and *Pinus* increases. This could indicate that neither *Picea* nor *Pinus* were locally present. If locally present, their presence should have suppressed the *Betula* representation (Hyvärinen 1976). The increase in AP pollen in this zone is therefore probably due to increased long-distance transport, though *Picea* was probably regionally present.

The *Betula* curve reaches more than 30 % in this zone, but *Betula* pollen statistics shows that tree-birch pollen is less than 15 % of measured *Betula* (fig. 4.12). This, together with the low concentrations (8000 grains/cm³), indicates that *Betula nana* is the only *Betula* species locally present at Sokolova.

Rarefaction analysis shows an increase in estimated species richness, compared to the preceding zone (table 4.9). This is caused by the increases of tree pollen (including *Salix*) and by increased influence of the local vegetation, and could indicate a slight climatic amelioration in this zone (Birks & Line 1992a).

Total concentration averages around 40,000 grains/cm³, which is slightly lower than for shrub tundra today (Gajewski *et al*. 1993). In the PCA ordination (fig. 4.9), the spectra are spread as if they are affected by the first proposed environmental gradient, which suggests less disturbance, and increased organic content of the soils. Less disturbance is also suggested by the rarefaction analysis, whilst increased organic content of the soils is contradicted by the LOI measurements. However, decreasing LOI could indicate a cessation of erosion and less eroded organic material washed into the basin.

The vegetation in this zone was probably a tundra or shrub tundra (*Betula nana* and *Salix* present). The increased amount of tree pollen reaching the site, mostly reflect increasing amounts of long-distance-transported pollen, although some may be redeposited. In all, the vegetation was denser and growing on moister soils compared to zone 1.

Pollen assemblage zone 3 : Poaceae-*Artemisia* (Dates ranging from 132 ka to 115 ka BP)
Depth : 875 - 730 cm
Subzone 3a : 875 - 830 cm

The sediments in this subzone consist of peat with silt (the lower peat layer (layer 6)), which is the upper part of the lacustrine sequence at Sokolova. This is reflected in the LOI measurements, as the values increase to a mean of 6-8 % (a maximum at 10 %).
Total concentration decreases in this zone, from 40,000 grains/cm³ to 23,000 grains/cm³. Apart from a decline in the tree pollen, the only major change in the species composition as compared to the previous zone is an increase in Poaceae. An increase in Cyperaceae and stable high values of Polypodiaceae and *Filipendula* indicate areas of moist soils.
Both *Picea* and *Pinus* decrease to about 5 %, whilst Poaceae, *Artemisia* and also *Ranunculus acris* type increase. *Betula* decreases at a slower rate than the other tree types, and has a peak before decreasing. *Betula* pollen statistics show that tree-birch amounts to 30 % of measured *Betula* (fig. 4.12), but low percentages and concentrations of *Betula* indicate that tree-birches were not present at Sokolova (Paus 1988). On the other hand, the increase in tree-birch pollen suggests tree-birch presence within the region.
Estimated species richness drops to values comparable to those of p.a.z. 1, which could be reflecting a climatic deterioration (table 4.9 and figure C2, Appendix C). This is also indicated by the decline in tree pollen. A harsher climate could have increased the disturbance of the vegetation, which would manifest itself as lowered estimated species richness (Birks & Line 1992a, Odgaard 1994).
The spectra of this subzone are situated close to the spectra of p.a.z. 1 in the PCA ordination (fig. 4.9), thus indicating influence of disturbed soils of low organic content. This supports the interpretation of rarefaction analysis and also the species composition shown in the pollen diagram.
The vegetation was probably still of tundra type, perhaps shrub tundra. Shrubs like *Betula nana* and *Salix* was present, whilst *Ephedra* probably was represented only by long-distance transport.

Subzone 3b : 830 - 729,5 cm

The sediments of this subzone consist of layers of silt and silty sand at the bottom, a layer of fluvial origin consisting of crossbedded sand and gravel above this, and at the top is a lag consisting of sand and gravel (layer 3). The lag is of terrestrial origin, and it is not believed to be a large age discrepancy between the layers below and above this lag. LOI measurements are very low in this subzone, with a maximum of less than 3 %. This reflects the type of sediments found in this subzone.

This subzone consists of only four spectra. The uppermost spectrum is situated 70 cm above the next (in the upper part of layer 3), which in turn is 25 cm above the next one (upper part of layer 4). It is only the two lowermost spectra that are situated close together (both in layer 5). These large gaps, together with the low ΣP of the third spectrum (no. 7) make a vegetational interpretation fairly unreliable. At the uppermost spectrum, the total concentration slightly rises to 31,000 grains/cm³ that could show a possible start of an ameliorating trend.

Total pollen concentration decreases somewhat in this zone, to about 26,000 grains/cm³; one spectrum has a minimum value of 1700 grains/cm³. This low value is due to the sand and gravely sediments that comprise most of this zone (layer 4 and 3). There is only one spectrum present in layer 4, and its low pollen sum indicates that extensive fractionation might have occurred (Fægri & Iversen 1989). To interpret the vegetation development would be meaningless as the pollen curve changes could be coincidental and reflect changes in sedimentation regime, rather than any vegetational change. However, the average pollen composition should point to some characteristics of the vegetation and the environment. Throughout the zone, the species composition shows relatively high proportions of Poaceae and *Artemisia* as well as *Betula*, Cyperaceae and Polypodiaceae. *Ranunculus acris* type and *Sphagnum* show increasing values, as do the two *Diphasiastrum* taxa.

Total AP amounts to 30 %, with *Pinus* and *Picea* both decreasing to 3 %, whilst *Betula* increases slightly to 20 %. No *Betula* pollen measurements have been carried out in this subzone, but the fairly low percentages and concentrations for *Betula* indicate that tree-birches were still absent from Sokolova. *Alnus* increases in this subzone, and remains stable around 3 %. The concentrations are however low and do not suggest local presence.

Estimated species richness rises markedly in this subzone (table 4.9), which could be an effect of less severe vegetational disturbance, as a result of a climatic amelioration (Birks & Line 1992a). The spectra of this subzone are a bit scattered in the PCA plot (fig. 4.9), all situated approximately in the middle of the plot. In general, this subzone seems affected by medium disturbance and slightly decreasing pH. Thus, both rarefaction analysis and the PCA ordination seem to indicate medium (or intermediate) levels of disturbance (*sensu* Grime 1973) for the vegetation.

The species composition (*Betula*, *Salix*, Cyperaceae, Poaceae, *Ranunculus acris* type, etc.) seems to indicate a tundra, or shrub tundra type of vegetation, possibly affected by slightly ameliorating climate compared to subzone 3a.

Zone 4 (post - Eemian age, see 6.2)

Depth : 729.5 - 725 cm

This is the uppermost zone in the diagram, and the sediments consist of peat with some silt. This is reflected in the LOI-curve, which increases suddenly from 1.7 % in the previous zone to a maximum of 69 % in this zone. The peat is situated on the top of the lag in layer 3, and contains a small soil profile. It is not believed to be any large time gap between the lag and this peat, as there for instance are no ice-wedge casts in the sediments beneath the peat (J. Mangerud, *pers.comm.* 1998). Total pollen concentrations also increase abruptly, and reach over 2.7 x 10^5 grains/cm³.

Species like *Artemisia*, *Papaver*, Chenopodiaceae, and Cyperaceae show distinct decreases percentages at the beginning of this zone. The concentration diagram though display small peaks in *Artemisia*, Poaceae and Chenopodiaceae before these curves recedes.

These decreases occur simultaneously with rapid increases especially in *Betula* and *Sphagnum*. In addition, both *Picea* and *Pinus* peak in this zone, leading to an increase in total AP to more than 90 %. *Pinus* peaks at 10 %, and 2 x 10^4 grains/cm³, but this peak occurs as *Betula* has its first peak, and is probably not an evidence of local occurrence of *Pinus* (Hyvärinen 1976). *Picea* reaches over 25 %, and 3,5 x 10^4 grains/cm³. At this peak, *Betula* percentages and concentrations fall, thus indicating local occurrence of *Picea* (Ritchie 1984, Plouffe & Jetté 1993, Gajewski *et al.* 1993). *Betula* has two peaks in this zone, as can be seen in both diagrams. The decrease in between occurs as *Picea*, *Pinus* and *Salix* peak, though the increase in *Pinus* is not shown in the concentration diagram. *Betula* reaches 40 % at the beginning of the zone, and over 70 % at the second peak. *Betula* pollen statistics (fig. 4.12) show that tree-birch amounts to 30 % of measured *Betula* at the first peak, and to 65-70 % at the second peak. This, together with relatively high concentrations indicate that tree-birch had reached the site at the second peak in this zone. Rarefaction analysis shows decreasing estimated species richness for this zone (table 4.9). Together with the high concentrations, a closing of the vegetation is indicated (Birks & Line 1992a). In the pollen diagram, species indicating a closed type of vegetation (*Linnaea* and *Trientalis*), and species indicating more mesic areas (*Trollius, Vicia cracca, Potentilla,* Apiaceae and Rubiaceae) are present.

The almost complete disappearance of the algae *Pediastrum* and *Botryococcus* indicates the absence of running water. Alternatively, the closing of the vegetation resulted in more acidic, and thus uninhabitable waters for these algae. The increase of *Sphagnum*, Cyperaceae, *Potentilla* and the occurrence of *Potamogeton* may indicate local mire formation at Sokolova. The regional vegetation in this zone probably consisted of an open birch forest, possibly with some scattered spruce growing in the vicinity of the site.

Summary Sokolova:

During the period of sedimentation at Sokolova the vegetation changed from an open steppe tundra or shrub tundra in p.a.z. 1-3, to a more closed vegetation (open birch forest) in p.a.z. 4. Lake Komi, which is believed to have originated during the early parts of the Weichselian (50 - 70 ka BP, Mangerud et al. 1999), most likely transgressed over the Sokolova site. Within the sediments of layer 3 is a gravely lag, which may possibly reflects a hiatus caused by the transgression of Lake Komi over the site (Mangerud *et al*. 1999).

6. Correlations with other sites.

Following (table 6.1) is a brief synthesis of the different Eurasian stadials and interstadials, and their correlations as indicated in the literature.

Table 6.1 Brief synthesis of the different stadials and interstadials, and their correlations. The names follow Mangerud (1989), Duraghina & Konovalenko (1993), Möller *et al.* (1999), and Mangerud *et al.* (1999).

Europe	European Russia	NE European Russia	Siberia
Late Weichselian	Late Valdaian	Polarnaya	Upper Zyryansk
Middle Weichselian	Middle Valdaian	Byzovaya	Karginsk
Early Weichselian	Early Valdaian	Laya	Lower Zyryansk
Eemian	Mikulino	Sulinskaya	Kazantsevo
Saalian	Moscowian	Vychegdskaya	Bakhtan
Mangerud (1989)	**Mangerud *et al.* (1999)**	**Duraghina & Konovalenko (1993)**	**Möller *et al.* (1999)**

6.1 Mamontovaya Kurja.

At Mamontovaya Kurja, the ^{14}C dates all indicate Middle Weichselian (Middle Valdaian) ages for this locality. The pollen diagram from Mamontovaya Kurja shows what might be climatic ameliorations in two zones of the diagram; in p.a.z. 1, dated at 34 - 37 ka BP, and in p.a.z. 3, ca. 30 ka BP (a date of 27 ka BP has been recorded just above this zone; see 4.1.2 and the percentage diagram, figure 1, in Appendix D). The vegetation of these zones seems affected by a slightly better climate (less harsh) than the other zones.

Faustova (1984) characterised the Middle Valdaian of European Russia as a nonglacial interval, which was made up of three warm phases separated by relatively short cool phases. Isayeva (1984) reported the same from Central Siberia, where three interstadials were distinguished and dated (50-44 ka BP, 42-33 ka BP, and 30-24 ka BP). The vegetation consisted of tundra-steppe associations with thin birch forests alternating with increased conifer-birch forest cover. Periglacial flora persisted even during periods of relative warming (Faustova 1984). Duraghina & Konovalenko (1993) also report three warm periods for the Middle Valdaian in NE European Russia. The cold intervals of Middle-Valdaian were characterised by periglacial flora with some birch. In the South Komi republic, the warm intervals were characterised by shrubby vegetation (birch shrubs) and xerophytes (Duraghina & Konovalenko 1993). During the Middle Valdaian, the most significant warming seem to have occurred ca. 39-38 ka BP (Faustova 1984). A cooling period followed, before the Dunaevo (Bryansk) warming which has been dated to 30-24 ka BP (Faustova 1984, Velichko & Nechayev 1984). The warm periods of the Middle Valdaian were probably only warm in comparison with the very cold conditions of most of the Valdaian (Velichko & Nechayev 1984, Duraghina & Konovalenko 1993). The Bryansk warming for instance, was probably only slight. Although there was an increase in moisture (Velichko *et al.* 1984), the climate was still cool, and the warming did for instance not greatly affect the faunal composition of the Russian Plain (Markova 1984).

A marked cooling followed the Dunaevo (Bryansk) warming lead to the appearance of arctic and arctic-alpine (periglacial) floras in European Russia (Faustova 1984, Duraghina & Konovalenko 1993). This was the start of the maximum cold of the late Valdaian/Weichselian, thought to have occurred 25-15 ka BP in Western Europe (Gaigalas *et al.* 1992), and 24-14 ka BP in Russia (Velichko 1984).

According to Faustova & Velichko (1992), Dunaevo (Bryansk) correlates with the Ålesund Interstadial in Northern Europe (Mangerud *et al.* 1981b, Larsen *et al.* 1987), Upper Karginsky Interstadial of West Siberia (Möller *et al.* 1999), and the Denekamp Interstadial of Western Europe (Kolstrup & Wijmstra 1977, Kryszkowski *et al.* 1993).

At Ivanovo (ca. 250 km NE of Moscow) Grichuk (1984) reports a Middle Valdaian vegetation made up of spruce and pine-birch forests during the Dunaevo period, which changes to insular spruce forest and then a steppe-tundra in the post-Dunaevo period. In the southern part of the Siberian Plain, herb grass-steppe and mixed coniferous and birch forests has been assigned to the transition to the post-Dunaevo period which was characterised by periglacial *Artemisia*-herb steppe, insular spruce forests, and pine-cedar forests in the mountains (Grichuk 1984).

Gribchenko *et al.* (1997) report findings of Upper Palaeolithic sites in the Russian Plain which correspond to the end of the Middle Valdaian mild interstadial (30-24 ka BP) co-incident with the Bryanskian fossil soil (Faustova 1984, Faustova & Velichko 1992).

The period between 30 and 27 ka BP yielded relatively good conditions for both plant growth and preservation in southern Scandinavia and north-western and central Europe (Kolstrup 1993). The winters may have become colder between 27 and 24 ka BP, giving rise to permafrost conditions (especially after 24 - 20 ka BP). In all there is evidence for much eolian activity during the period between 30 and 20 ka BP, with the vegetation on the unstable soils being made up by dwarf shrubs, herbs, grasses and sedges (Kolstrup 1993).

An ice free period at about 30 ka BP (33 - 28 ka BP), has been recorded at Skjonghelleren (near Ålesund, western Norway) (Larsen *et al*. 1987). This period was subsequently correlated with the Ålesund interstadial (Mangerud *et al.* 1981b). The vegetation was open with some birch present (*Pinus* and *Alnus* possibly also occurred). At about 28 ka BP the ice advanced into the area, and the ice cover lasted until ca. 12.5 ka BP (Larsen *et al.* 1987).
In Poland at the Belchatow outcrop, Kryszkowski *et al*. (1993) found evidence of an improvement in the vegetation at around 33 ka BP (33-28 ka BP). The vegetation changed from a sub-polar desert to a grass tundra. After 28 ka BP, sub-polar deserts spread again. This improvement of the climate has been correlated with the Denekamp interstadial (dated 33-28 ka BP) of the Netherlands (Kolstrup & Wijmstra 1977, Kryszkowski *et al.* 1993).

The vegetation types at Mamontovaya Kurja seem to correlate fairly well with the vegetation types reported by Duraghina & Konovalenko (1993) for the middle Valdaian.
The apparent vegetation improvement shown in p.a.z. 3, may thus correlate with the third Middle Valdaian interstadial (or warm phase) reported by Isayeva (1984) and Faustova (1984). This warm period possibly correlates with the early phases of the Ålesund Interstadial in Norway (Mangerud *et al.* 1981, Larsen *et al.* 1987), and the Bryansk/Dunaevo warming shown in parts of Russia. In the diagram from Mamontovaya Kurja the following period seems drier (possibly colder). This development is also shown for the post-Dunaevo period in European Russia (Faustova 1984, Duraghina & Konovalenko 1993).
The period indicated in p.a.z. 1 is uncertain, as the age of the pollen-bearing sediments are not yet known. One alternative is that the pollen sequence is concordant with the mammalian bones, i.e. ca. 36-37 ka BP. This age could fit with the second warm phase reported by Isayeva (1984). Another alternative is that the pollen-bearing sediments were deposited some time after the mammalian bones, thus being deposited shortly before 27 ka BP, and p.a.z. 1 to 3 would more or less be describing the same period. The pollen assemblage of p.a.z. 2 would in that case represent material that were slumped into the sediments, and could be older (or younger) than that of both p.a.z. 1 and 3.

6.2 Sokolova.

At Sokolova the OSL-dates yield ages referring to either a pre-Eemian, post-Eemian, or Eemian age for the site. Sediments close above the topmost pollen-bearing peat layer yield Early Weichselian ages (86 ± 7 and 92 ± 10 ka BP). Comparisons with both pre-Eemian, Eemian, and post-Eemian sites will be made in order to delimit the age of the Sokolova site as closely as possible. See map (figs. 2.1a, and 2.1b) for the position of sites included in the correlation.

The Eemian Interglacial lasted about 10,000 years, from 130-117 ka BP (Mangerud *et al.* 1979, 1981a, Woillard & Mook 1982, van Andel & Tzedakis 1996) and correlates with the Mikulino Interglacial of European Russia and Kazantsevo of Siberia (Grichuk 1971, 1984, Arkhipov 1984, Astakhov 1992, Faustova & Velichko 1992).

The Mikulino Interglacial of European Russia was characterised by vegetation zones similar to the present ones, only with polar desert and tundra areas more limited than today (Grichuk 1984). In southern Komi Republic a spruce and pine forest was present at the Mikulino optimum (Duraghina & Konovalenko 1993). The area between Pechora river and Usa river (65-67^o N, 59-60.5^o E, abutting the Urals) was covered by spruce forests with some birch. Otherwise, the Pechora area was covered by birch forests with some conifers and a small component of broad-leaved species (Duraghina & Konovalenko 1993).

According to Lavrushin & Spiridonova (1995), the dominant role of birch in the forests in the Pechora area was due to wide expansion of bogs during the Mikulino optimum.

Further to the west, at Pasva along the river Vaga, broad-leaved species amounted to only 25 % of AP, whilst spruce and alder constituted the major portion of the tree pollen (Lavrushin & Spiridonova 1995). Spruce and birch dominated the Mikulino period in the Severnaya Dvina basin, where broad-leaved species amounted to ca. 20 % of AP. In the Vorkuta region, spruce taiga with a small admixture of broad-leaved species (oak, elm and hazel) was present at the Mikulino optimum (Lavrushin & Spiridonova 1995).

At Sokolova, the pollen diagram has been interpreted as reflecting an open vegetation, namely tundra or shrub tundra, which changed to an open birch forest at the top of the section. This gives no indications to whether the vegetation development shown at Sokolova is of pre- or post-Eemian age. The vegetation developement does however indicate that the Sokolova diagram is not of Eemian age. This because Sokolova is situated south of Vorkuta, where taiga and decidious forest was found during the Mikulino optimum.

The pre-Mikulinian period belongs to the Moscowian glaciation of European Russia (Grichuk 1971, 1984). This correlates with the Saalian glaciation of Central and NW Europe (see fig. 6.1, Grichuk 1971, Litt *et al.* 1996, Drescher-Schneider & Papesch 1998).

The final stages of the Moscowian glaciation on the East European/Russian Plain was characterised by insular forests of *Picea obovata* and elements of periglacial vegetation (Poaceae, Cyperaceae, Chenopodiaceae, *Artemisia, Betula nana* and mosses) (Grichuk 1984). In Central Siberia insular spruce forests and periglacial steppes with *Artemisia* and Polemoniaceae, were replaced by coniferous forest and open birch forest with *Artemisia* and species of Plumbaginaceae (Grichuk 1984). In the NE European part of Russia, the end of the Vychegdskaya glacial was characterised by a transition from arctic tundra, through tundra steppe, shrub tundra and forest tundra to the taiga of the Mikulino optimum (Duraghina & Konovalenko 1993). At the Pasva section, the transition to the Mikulino interstadial is shown as an increase in *Betula* sect. Albae, and a slight decrease in *Picea* (Lavrushin & Spiridonova 1995).

In central and western Europe the transition from the Saalian late glacial and the Eemian warming (interstadial) is placed at the beginning of re-afforestation. This is shown in pollen diagrams as a marked recession in the NAP-curves (particularly for *Artemisia* and other heliophytes), together with a rise in especially *Betula* (Menke 1970, de Beaulieu & Reille 1992b) and *Pinus* (de Beaulieu & Reille 1984, 1992a, Zagwijn 1996, Robertsson *et al.* 1997). In Europe, the final stages of the Saalian glaciation were characterised by an open vegetation consisting of grasslands and heliophyte communities, with some *Pinus* (perhaps insular forests), and a little *Betula* and *Salix* (Grüger 1979, de Beaulieu & Reille 1984, 1992a, 1992b).

The post-Mikulino period belongs to the Early Valdaian glaciation of European Russia (Velichko 1984, Hahne & Melles in press), and the Lower Zyryansk glaciation in Siberia (Grichuk 1971, Velichko 1984), which correlates with the Weichselian glaciation of central and western Europe (Menke 1970, Mangerud 1989, Möller *et al.* 1999).

In East Siberia the transition to the Early Valdaian stadial is marked by a decrease in AP, whilst *Betula* increases (*B. nana*- type) together with *Alnus*/*Alnaster* (Grichuk 1984). Davydova & Servant-Vildary (1996) report vegetation consisting of sparse pine and birch forests with tundra shrubs for the Early Valdaian glaciation (95-52 ka BP) in the Central region of the East European Plain (north of Moscow). This is also reported by Grichuk (1984) for the same region. In north European Russia, at Pasva, the vegetation at the beginning of the post-Mikulino time was characterised by open woodlands of birch, along with abundant *Sphagnum*. A slight warming followed, which led to an increase in dense coniferous pine and spruce forests. The cooling which followed, led to a decrease in coniferous trees. Birch (including dwarf species) gained in importance, and *Selaginella selaginoides* became abundant. The following and second Valdaian warming has been correlated with the Brörup interstadial, and in its beginning spruce forests with a considerable amount of tree-birch (and some dwarf species) prevailed. Ericaceae were abundant, as well as mesic herbs and sedges (Lavrushin & Spiridonova 1995).

In Europe, the transition between the Eemian and the Weichselian is placed at the start of the development of mineral soils, often shown as a rise in light-demanding herbs, especially *Artemisia* (Menke 1970). During the Weichselian glaciation, several climatic oscillations have been recorded (Menke 1970, de Beaulieu & Reille 1984, 1992a, 1992b, Larsen *et al.* 1987, Dansgaard *et al.* 1993, Litt *et al.* 1996, Hoffmann *et al.* 1998). The Eemian is followed by the Herning stadial (115 - 105 ka BP , Hoffman *et al.* 1998) which was characterised by Ericales, Gramineae and heliophytes (*Artemisia, Thalictrum, Plantago, Betula nana* etc.) in Oerel (Behre & Lade 1986). The transition to the Brörup interstadial (105 - 95 ka BP, Hoffmann *et al.* 1998) is marked by an increase in *Betula* pollen, together with *Pinus, Alnus*, some *Picea* and large amounts of *Calluna*. At Bispingen (Central Germany) the transition from Herning to Brörup is marked by a decrease in NAP, and an increase in *Betula* and *Pinus* (sparse woodlands) (Litt *et al.* 1996). At Mondsee (Austria), the transition from Herning to Brörup is marked by an increase in *Betula*, *Pinus*, and *Picea* (Drescher-Schneider & Papesch 1998). In France (La Grande Pile, de Beaulieu & Reille 1992a, Ribains maar, de Beaulieu & Reille 1992b, Les Echets, de Beaulieu & Reille 1984) the period after the Eemian interglacial was characterised by mixed or deciduous forests during the warm phases St Germain I and II, and by taiga or cold steppes during the cold phases Melisey I and II (de Beaulieu & Reille 1984, Faquette *et al*. 1999).

The vegetation development at Sokolova, shows a transition from tundra or shrub tundra vegetation to an open birch forest, probably with some spruce. In addition there are increasing amounts of different ericads in the topmost layers. This vegetation development seem to fit quite well with the vegetation development shown for the post Mikulino/Eemian period in Russia. In addition, this seems to fit better with the datings as well. The two dates from sediments right above the upper peat layer (86 ± 7 and 92 ± 10 ka BP), apparently fall within the Brörup interstadial, or slightly after this (105-95 ka BP, Hoffman *et al.* 1998). This could mean that the vegetation development shown in the upper peat layer at Sokolova, refers to the beginning of the Brörup interstadial. The vegetation development shown in the lower part of the diagram (p.a.z. 1 to 3b), may thus represent post-Eemian vegetation, perhaps correlating with the Melisey I cold phase of central Europe (Faquette *et al*. 1999) and Herning stadial of northern Europe (Litt *et al*. 1996, Drescher-Schneider & Papesch 1998).

7. Summary.

The study of the palaeovegetation and environment at the two sites, Mamontovaya Kurja and Sokolova, shows that the conditions at the two sites were quite different from present. Mamontovaya Kurja, being a Middle Weichselian site, was affected by a fairly cold and dry climate during the period depicted in the pollen diagram.

The vegetation at Mamontovaya Kurja was a dry steppe tundra or periglacial steppe, throughout most of the sequence, only interrupted by two periods, which seem to have harboured vegetation demanding slightly moister soils. These two periods seem to correlate with two previously recognised Weichselian interstadials. The first of the “warmer” periods (in p.a.z.1) seems to correlate with the second warm period of the Valdaian, which correlates with the Hengelo interstadial. The second of the “warmer” periods at Mamontovaya Kurja (in p.a.z. 3) correlates with the Bryansk warm period, which correlates with the Denekamp interstadial.

The two zones both show dates that fits well with the interstadials they have been correlated with. In addition, the vegetation sequences also fits with this scheme, as the Weichselian interstadials only were warm in relation to the overall harsh climate of the Weichselian in Northern European Russia.

Sokolova, being an Early Weichselian site, was affected by a climatic amelioration in the latter stages of the sequence shown in the pollen diagram.

The vegetation at Sokolova was tundra or shrub tundra that changed to an open birch-forest with some spruce. The three lower zones at Sokolova probably represent a part of the Early Weichselian before the Brörup interstadial, possibly the Herning stadial (correlates with Melisey I). This is indicated not only by the OSL dates obtained, but also from the vegetation development. The vegetation is probably reflecting the later stages of the Herning stadial, when the climatic conditions had started to ameliorate towards the Brörup interstadial. The upper zone (p.a.z. 4), represent the transition to the Brörup interstadial proper. This is indicated by the rapid increase of tree-birch found in the top of the diagram.

Literature references:

Aalbersberg, G. & Litt, T. (1998) Multiproxy climate reconstructions for the Eemian and Early Weichselian. *Journal of Quaternary Science* **13 (5),** 367-390.

Adams, J. M. & Faure, H. (1997) (eds.) QEN members. Review and Atlas of Palaeovegetation: Preliminary Land Ecosystem maps of the world since the last glacial maximum. Oak Ridge National Laboratory, TN, USA. *http://www.esd.ornl.gov/ern/qen/adams1.html*

Allen, J. R. M., Huntley, B. & Watts, W. A. (1998) The Weichselian palaeovegetation record at Lago Grande di Monticchio, Italy. Terra Nostra 98/6: 3rd ELDP Workshop, Ptolemais, 25- 30.

Anderson, P. M., Lozhkin, A. V., Belaya, B. V., Glushkova, O. Yu. and Brubaker, L. B. (1997) Lacustrine pollen record from near altitudinal forest limit, Upper Kolyma Region, Northeastern Siberia. *The Holocene* **7(3)**, 331-335.

Arkhipov, S. A. (1984) Late Pleistocene Glaciation of Western Siberia. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union. Longman, London. pp. 13-19.

Astakhov, V. I. (1992) The last glaciation in West Siberia. *Sveriges Geologiska Undersökning,* **Ser. Ca 81**, 21-30.

Astakhov,V. I. (1994) The last glaciation in Russia's European Arctic - A review of scientific investigations on Quaternary stratigraphy and shoreline displacement. *SMR report*, **13/94**, 81 pp.

Astakhov, V. I. (1995) The mode of degradation of Pleistocene permafrost in West Siberia. *Quaternary International*, **vol. 28**, 119-121.

Astakhov, V. I. (1997) Late Glacial events in the Central Russian Arctic. *Quaternary International,* **Vols. 41/42,** 17-25.

Astakhov, V. I., Svendsen, J. I., Matiouchkov, A., Mangerud, J., Maslenikova, O. and Tveranger, J. (1999) Marginal landforms of the last Kara and Barents ice sheets in northern European Russia. *Boreas*, **28**, 23-45.

Beaulieu, J.-L. de & Reille, M. (1984) A long Upper Pleistocene pollen record from Les Echets, near Lyon, France. *Boreas* **13**, 111-132.

Beaulieu, J.-L. de & Reille, M. (1992 a) The last climatic cycle at La Grande Pile (Vosges, France). A new pollen profile. *Quaternary Science Reviews,* **vol.11**, 431-438.

Beaulieu, J.-L. de & Reille, M. (1992 b) Long Pleistocene pollen sequences from the Velay Plateau (Massif Central, France). I. Ribains maar. *Vegetation History and Archaeobotany* **1**, 233-242.

Behre, K.-E. & Lade, U. (1986) Eine Folge von Eem und 4 Weichsel-Interstadialen in Oerel/Niedersachsen und ihr Vegetationsablauf. *Eiszeitalter und Gegenwart* **36**, 11-36.

Birks, H. H. & Birks, H. J. B. (1980) Quaternary Palaeoecology. Edward Arnold, London. 289 pp.

Birks, H. J. B. (1968) The identification of *Betula nana* pollen. *The New Phytologist* **67,** 309-314.

Birks, H. J. B. & Gordon, A. D. (1985) Numerical methods in Quaternary pollen analysis. London: Academic Press. 317 pp.

Birks, H. J. B. & Line, J. M. (1992a) The use of rarefaction analysis for estimating palynological richness from Quaternary pollen-analytical data. *The Holocene* **2(1)**, 1-10.

Birks, H. J. B. & Line, J. M. (1992b) RAREPOLL 1.0 - Rarefaction diversity measures and their variances. Computer programme.

Björck, S., Bennike, O., Possnert, G., Wohlfart, B. and Digerfelt, G. (1998) A high - resolution ^{14}C dated sediment sequence from southwest Sweden : age comparisons between different components of the sediment. *Journal of Quaternary Science* **13(1)**, 85-89.

Chernov, Yu. I. (1985) The living tundra. Cambridge University Press. 213pp.

Cushing, E. J. (1961) Size increase in pollen grains mounted in thin slides. *Pollen et Spores* **3(2)**, 265-274.

Cwynar, L. C. & Ritchie, J. C. (1980) Arctic Steppe-Tundra: A Yukon Perspective. *Science*, **vol 208**, 1375-1377.

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahl-Jensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S., Steffensen, J. P., Sveinbjörnsdottir, A. E., Jouzel, J. and Bond, G. (1993) Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature*, **vol 364**, 218-220.

Davydova, N. & Servant-Vildary, S. (1996) Late Pleistocene and Holocene history of the lakes in the Kola Peninsula, Karelia and the north-western part of the East European Plain. *Quaternary Science Reviews*, **vol. 15**, 997-1012.

Drescher-Schneider, R. & Papesch, W. (1998) A contribution towards the reconstruction of Eemian vegetation and climate in central Europe : first results of pollen and oxygen-isotope investigations from Mondsee, Austria. *Vegetation History and Archaeobotany* **7**, 235-240.

Duraghina, D. A. & Konovalenko, L. A. (1993) Pleistocene Palynology of the North-East European part of Russia. (Palinologia Pleistocena Severo-Vostoka Evropeiskoi chasti Rossii). Sankt-Peterburgh, Nauka. 124 pp. (in Russian).

Elias, S. A., Short, S. K. and Birks, H. H. (1997) Late Wisconsin environments of the Bering land Bridge. *Palaeogeography, Palaeoclimatology, Palaeoecology* **136**, 293-308.

Faquette, S., Guiot, J., Menut, M., de Beaulieu, J.-L., Reille, M. & Guenet, P. (1999) Vegetation and climate since the last interglacial in the Vienne area (France). *Global and Planetary Change* **20**, 1-17.

Faustova, M. A (1984) Late Pleistocene glaciation of European USSR. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union, Longman, London. pp. 3-12.

Faustova, M. A. & Velichko, A. A. (1992) Dynamics of the last glaciation in northern Eurasia. *Sveriges Geologiska Undersökning*, **Ser. Ca 81**, 113-118.

Florin, M.-B. (1969) Late-Glacial and pre-Boreal vegetation in Central Sweden. *Svensk Botanisk Tidsskrift* **63**, 142-187.

Fægri, K. & Iversen, J. (1989) Textbook of pollen analysis. 4.ed. By: Fægri, K., Kaland, P. E. & Krzywinski, K. John Wiley & Sons. 328 pp.

Gaigalas, A., Serebryanny, L. and Valueva, M. (1992) Middle Valdaian forest environments at Birzai, northern Lithuania. *Boreas* **21**, 289-293.

Gajewski, K, Payette, S. and Ritchie, J. C. (1993) Holocene vegetation history at the boreal - forest - shrub-tundra transition in north-western Québec. *Journal of Ecology* **81**, 433-443.

Grichuk, V. P. (1971) The analysis of zonal structure of the Pleistocene vegetational cover across USSR. *Pollen et Spores* **13(1)**, 101-116.

Grichuk, V. P. (1984) Late Pleistocene Vegetation History. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union, Longman, London. pp.155-178.

Gribchenko, Yu. N. & Kurenkova, E. I (1997) The main stages and natural environmental setting of late Palaeolithic human settlement in Eastern Europe. *Quaternary International*, **vols. 41/42**, 173-179.

Grime, J. P. (1973) Competitive exclusion in herbaceous vegetation. *Nature*, **vol. 242**, 344-347.

Grimm, E. C. (1987) CONISS - A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Computers and Geosciences*, **Vol. 13, No. 1**,13-35.

Grosswald, M. (1998) Late - Weichselian ice sheets in Arctic and Pacific Siberia. *Quaternary International*, **vol. 45/46**, 3-18.

Grüger, E. (1979) Spätriss, Riss/Würm und Frühwürm am Samerberg in Oberbayern - ein vegetationsgeschichtlicher Beitrag zur Gliederung des Jugpleistozäns. *Geologica Bavarica* **80**, 5-64.

Hahne, J. & Melles, M. (1999) Climate and Vegetation history on the Taymyr Peninsula since middle Weichselian time - palynological evidence from lake sediments. In : Kassens, H., Bauch, H. A., Dmitrenko, I.A, Eicken, H., Hubberten, H.W., Melles, M., Thiede, J. & Timokhov, L.A. (eds.) Land-Ocean Systems in the Siberian Arctic: Dynamics and History. Springer Verlag, Berlin/Heidelberg, New York. pp. 407-423.

Hicks, S. (1994) Present and past pollen records of Lapland forests. *Review of Palaeobotany and Palynology* **82**, 17-35.

Hoffmann, M. H., Litt, T. and Jäger, E. J. (1998) Ecology and climate of the early Weichselian flora from Gröbern (Germany). *Review of Palaeobotany and Palynology* **102**, 259-276.

Hyvärinen, H. (1976) Flandrian pollen deposition rates and tree-line history in northern Fennoscandia. *Boreas* **5**, 163-175.

Isayeva, L. L. (1984) Late Pleistocene Glaciation of North-Central Siberia. In : Velichko, A. A. (ed.) Late Quarternary Environments of the Soviet Union. Longman, London. pp.21-30.

Jongman, R. H. G., ter Braak, C. J. F. & Tongeren, J. F. R. (eds.) (1995) Data analysis in community and landscape ecology. Cambridge University Press. 299 pp.

Juggins, S. (1991) ZONE ver. 1.2 Unpublished computerprogr.

Juggins, S. (1993) TRAN ver.1.7 Unpublished computerprogr.

Kabailene, M. & Raukas, A. (1987) Stratigraphy of lake and bog deposits and climatic changes in the late-glacial and Holocene in the Soviet Baltic Republics : a review. *Boreas* **16,** 125-131.

Kaland, P. E. & Natvik, Ø. (1993) Core 2.0 Unpublished computerprogr.

Kershaw, K. A. & Looney, J. H. H. (1985) Quantitative and Dynamic Plant Ecology. 3. ed. Edward Arnold (Publishers) Limited, London. 282 pp.

Khotinsky, N. A. (1984) Holocene Vegetation History. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union, Longman, London. pp. 179-200.

Kolstrup, E. (1993) Periglacial environmental developments between 30 and 20 ka BP in Denmark. *Geologie en Mijnbouw* **72**, 159-166.

Kolstrup, E. & Wijmstra, T. A. (1977) A palynological investigation of the Moershoofd, Hengelo, and Denekamp Interstadials in the Netherlands. *Geologie en Mijnbouw* **56,** 85-102.

Kristiansen, I. L., Mangerud, J. and Lømo, L. (1988) Late Weichselian/Early Holocene pollen- and lithostratigraphy in lakes in the Ålesund area, western Norway. *Review of Palaeobotany and Palynology,* **53**, 185-231.

Krzyszkowski, D., Balwierz, Z. and Pyszynski, W. (1993) Aspects of Weichselian Middle Pleniglacial stratigraphy and vegetation in central Poland. *Geologie en Mijnbouw* **72,** 131-142.

Larsen, E., Gulliksen, S., Lauritzen, S.-E., Lie, R., Løvlie, R. and Mangerud, J. (1987) Cave stratigraphy in western Norway; multiple Weichselian glaciations and interstadial vertebrate fauna. *Boreas* **16**, 267-292.

Laukhin, S. A. (1997) The environmental changes of Gorny Altai (Western Siberia) during Mousterian/Late-Palaeolithic transition : Data from Kara-Bom site section. *CRP* **14**, 128-131.

Lavrushin, Yu. A. & Spiridonova, E. A. (1995) The late Pleistocene events in the North of European Russia: Geology and Palaeoenvironments. In Velichko, A.A.(ed.): Climate and Environment Changes of East Europe during Holocene and Late-Middle Pleistocene, 63-68. IGU conference on Global changes and geography. Moscow August 14-18, 1995.

Lid, J. & Lid, D. T. (1994) Norsk flora. Det Norske Samlaget. Oslo.

Litt, T., Junge, F. W. and Böttger, T. (1996) Climate during the Eemian in north-central Europe - a critical review of the palaeobotanical and stable isotope data from central Germany. *Vegetation History and Archaeobotany* **5,** 247-256.

Mangerud, J. (1989) Correlation of the Eemian and the Weichselian with deep sea oxygen isotope stratigraphy. *Quaternary International* **3/4**, 1-4.

Mangerud, J., Sønstegaard, E. & Sejrup, H.-P. (1979) Correlation of the Eemian (interglacial) Stage and the deep-sea oxygen-isotope stratigraphy. *Nature* **vol.277**, 189-192.

Mangerud, J., Sønstegaard, E., Sejrup, H.-P. and Haldorsen, S. (1981a) A continuous Eemian-Early Weichselian sequence containing pollen and marine fossils at Fjøsanger, western Norway. *Boreas* **10**, 137-208.

Mangerud, J., Gulliksen, S., Larsen, E., Longva, O., Miller, G.H., Sejrup, H.-P. and Sønstegaard, E. (1981b) A Middle Weichselian ice-free period in Western Norway : the Ålesund Interstadial. *Boreas* **10**, 447-462.

Mangerud, J., Astakhov, V. & Svendsen, J. I. (1999) Age and extent of the Barents and Kara ice sheets in Northern Russia. *Boreas* **28**, 46-80.

Markova, A. K. (1984) Late Pleistocene mammal fauna of the Russian Plain. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union, Longman, London. pp. 209-218.

Matveyeva, N. V. (1994) Floristic classification and ecology of tundra vegetation of the Taymyr Peninsula, northern Siberia. *Journal of Vegetation Science* **5**, 813-828.

Menke, B. (1970) Ergebnisse der Pollenanalyse zur Pleistozän-Stratigraphie und zur Pliozän-Pleistozän-Grenze in Schleswig-Holstein. *Eiszeitalter und Gegenwart* **21**, 5-21.

Moore, P. D., Webb, J. A. & Collinson, M. E. (1991) Pollen Analysis. 2.ed. Oxford : Blackwell Scientific Publications. 216 pp.

Möller, P., Bolshiyanov, D. Yu. & Bergsten, H. (1999) Weichselian geology and palaeoenvironmental history of the central Taymyr Peninsula, Siberia, indicating no glaciation during the last global glacial maximum. *Boreas* **28**, 92-114.

Odgaard, B. V. (1994) The Holocene vegetation history of northern West Jutland, Denmark. *Opera Botanica* **123**, 1-171.

Olsson, I. U. (1979) A warning against radiocarbon dating of samples containing little carbon. *Boreas* **8**, 203-207

Olsson, I. U. (1986) Radiometric dating. In : Berglund & Ralska - Jasiewiczowa (eds.) : Handbook of Holocene Palaeoecology and Palaeohydrology.. John Wiley, Chichester. pp. 283-287

Paus, Aa. (1988) Late Weichselian vegetation, climate, and floral migration at Sandvikvatn, North Rogaland, southwestern Norway. *Boreas* **17,** 113-139.

Paus, Aa (1995) The Late Weichselian and early Holocene history of tree birch in south Norway and the Bölling Betula time-lag in northwest Europe. *Review of Palaeobotany and Palynology* **85**, 243-262.

Plouffe, A. and Jetté, H. (1996) Middle Wisconsinan sediments and palaeoecology of central British Columbia: sites at Necoslie and Nautley rivers. *Canadian Journal of Earth Sciences* **34**, 200-208.

Praglowski, J. (1966) On pollen size variations and the occurence of *Betula nana* in different layers of a bog. *Grana Palynologica* **6 : 3,** 528-543.

Ritchie, J. C. (1984) Past and present vegetation of the far northwest of Canada. University of Toronto Press. 251 pp.

Ritchie, J. C. & Lichti-Federovich, S. (1967) Pollen dispersal phenomena in arctic - subarctic Canada. *Review of Palaeobotany and Palynology*, **3**, 255-266.

Robertsson, A.-M., Svedlund, J.-O., Andrèn, T. and Sundh, M. (1997) Pleistocene stratigraphy in the Dellen region, central Sweden. *Boreas* **26**, 237-260.

Seppä, H. (1998) Postglacial trends in palynological richness in the northern Fennoscandian tree-line area and their ecological interpretation. *The Holocene* **8,1**, 43-53.

Serebryanny, L and Malaysova, E. (1998) The Quaternary vegetation and landscape evolution of Novaya Zemlya in the light of palynological records. *Quaternary International*, **vol. 45/46**, 59-70.

Stockmarr, J. (1971) Tablets with spores used in absolute pollen analysis. *Pollen et Spores*, **13(4),** 615-621.

Šmilauer, P. (1993) CanoDraw 3.0 .Microcomputer Power, Itacha, New York.

Stuart, A. J. (1991) Mammalian extinctions in the late Pleistocene of Northern Eurasia and North America. *Biological Reviews*, **66**, 453-562.

Terasmäe, J. (1951) On the pollen morphology of Betula nana. *Svensk Botanisk Tidsskrift* **45**, 358-361.

ter Braak, C. J. F. (1991) CANOCO - a FORTRAN program for canonical community ordination by (principal) (detrended) (canonical) correspondence analysis, principal components analysis and redundance analysis (version 3.12). TNO Institute of Applied Computer Science, Statistics Department, Wageningen.

ter Braak, C. J. F. & Prentice, I. C. (1988) A theory of gradient analysis. *Advances in ecological research,* **18** , 271-317.

The Times Atlas of the World, 1990. London.

Troels-Smith, J. (1955) Characterization of unconsolidated sediments. *Danm. Geol. Unders. Ser.IV*, **Rk. 3, no 10**, 73 pp.

Ukraintseva, V. V (1993) Vegetation cover and environment of the “ Mammoth Epoch “ in Siberia. Agenbroad, L.D., Mead, J.I., Hevly, R.H. (eds.) The Mammoth Site of Hot Springs, South Dakota Inc, S. Dakota. 309 pp.

van Andel, T. H. & Tzedakis, P. C. (1996) Palaeolithic landscapes of Europe and environs, 150,000 - 25,000 years ago : An overview. *Quaternary Science Reviews*, **vol. 15**, 481-500.

van Leeuwarden, W. (1982) Palynological and macropalaeobotanical studies in the developement of the vegetation mosaic in eastern Noord-Brabant (The Netherlands) during Lateglacial and early Holocene times. *Dr Thesis, University of Utrecht*. 204pp.

Velichko, A. A. (1984) Introduction. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union, Longman, London. pp. xxiii-xxvii.

Velichko, A. A., Isayeva, L. L., Makeyev, V. M., Matishov, G. G. and Faustova, M. A. (1984) Late Pleistocene Glaciation of the Arctic Shelf, and the Reconstruction of Eurasian Ice Sheets. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union, Longman, London. pp. 35-41.

Velichko, A. A & Nechayev, V. P. (1984) Late Pleistocene Permafrost in European USSR. In : Velichko, A.A. (ed.) Late Quaternary Environments of the Soviet Union, Longman, London. pp. 79-86.

West, R. G, Andrew, R. and Pettit, M. (1993) Taphonomy of plant remains on floodplains of tundra rivers, present and Pleistocene. *The New Phytologist*, **123**, 203-221.

Wohlfart, B., Skog, G., Possnert, G. and Holmquist, B. (1998) Pitfalls in the AMS radiocarbon-dating of terrestrial macrofossils. *Journal of Quaternary Science* **13(2)**, 137-145.

Woillard, G. M. & Mook, W. G. (1982) Carbon-14 dates at Grande Pile: Correlations of Land and Sea Chronologies. *Science*, **vol. 215**, 159-161.

Zagwijn, W. H. (1996) An analysis of Eemian climate in western and central Europe. *Quaternary Science Reviews*, **vol. 15,** 451-469.

Zelikson, E. M., Borisova, O. K., Krementsky, C. V. and Velichko, A. A. (1998) Phytomass and carbon storage during the Eemian optimum, late Weichselian maximum and Holocene optimum in Eastern Europe. *Global and Planetary Change* **16-17**, 181-195.

APPENDIX A :

Abbreviations of pollen and spore taxa used in the ordination plots.

Achillea	*Achillea*	Lyc_sp	*Lycopodium sp.*
Alnus	*Alnus*	Papaver_	*Papaver type*
Apiaceae	Apiaceae	Picea	*Picea*
Arc_alp	*Arctostaphylos alpina*	Poaceae	Poaceae
Arc_uva	*A. uva-ursi*	Pol_bor	*Polemonium boreale*
Artemisi	*Artemisia*	Polypodi	Polypodiaceae
Ast_ast	Asteraceae sect. Aster	Potentill	*Potentilla*
Ast_cich	Asteraceae sect. Cichor.	Pteridiu	*Pteridium*
Astragal	*Astragalus alpinus*	Ran_acr	*Ranunculus acris type*
Betula	*Betula*	Rubiacea	Rubiaceae
Bistorta	*Bistorta type*	Rubus_ch	*Rubus chamaemorus*
Brassica	Brassicaceae	Rum_ace	*Rumex sect. acetosa*
Cerastiu	*Cerastium*	Salix	*Salix*
Chenopod	Chenopodiaceae	Sanguiso	*Sanguisorba officinale*
Cirsium_	*Cirsium*	Sax_hir	*Saxifraga hirculus*
Cyperace	Cyperaceae	Sax_niv	*S. nivalis*
Dianthus	*Dianthus*	Scrophul	Scrophulariaceae
Diph_alp	*Diphasiastrum alpinum*	Sphagnum	*Sphagnum*
Diph_com	*D. complanatum*	Thalictr	*Thalictrum*
Equisetu	*Equisetum*	Triental	*Trientalis*
Ericales	*Ericales*	Trollius	*Trollius*
Fagopyru	*Fagopyrum*	Vacciniu	*Vaccinium*
Filipend	*Filipendula*	Valerian	*Valeriana*
Geranium	*Geranium*	Vicia_cr	*Vicia cracca type*
Huperzia	*Huperzia selago*		
Ledum_ty	*Ledum type*		
Linnea_t	*Linnaea type*		
Lychnis	*Lychnis type*		
Lyc_inu	*Lycopodiella inundata*		

APPENDIX B.

Abbreviations used in the tables; D = Grain diameter (in μm), P = Pore depth (in μm), D/P ratio = Grain diameter:Pore depth ratio.

Table A : Betula analysis : sample 726 cm.

	D	**P**	**D/P ratio**			**D**	**P**	**D/P ratio**
1	22,94	3,1	7,4		**51**	21,08	2,48	8,5
2	21,7	3,1	7		**52**	23,56	3,1	7,6
3	19,22	2,48	7,75		**53**	21,08	2,17	9,71
4	21,08	3,1	6,8		**54**	21,7	3,1	7
5	22,32	3,1	7,2		**55**	24,18	1,86	13
6	21,08	2,48	8,5		**56**	21,7	1,86	11,67
7	24,18	3,41	7,1		**57**	26,66	2,79	9,55
8	21,7	2,79	7,78		**58**	18,6	2,17	8,57
9	19,84	3,1	6,4		**59**	20,46	2,48	8,25
10	22,94	3,1	7,4		**60**	19,84	2,48	8
11	21,08	3,1	6,8		**61**	19,84	2,17	9,14
12	21,7	3,72	5,83		**62**	21,08	2,48	8,5
13	27,9	3,72	7,5		**63**	18,6	2,48	7,5
14	18,6	2,48	7,5		**64**	21,7	2,17	10
15	22,94	3,41	6,72		**65**	19,84	3,1	6,4
16	21,7	2,79	7,78		**66**	24,8	2,48	10
17	23,56	3,1	7,6		**67**	21,7	2,48	8,75
18	21,7	3,1	7		**68**	21,08	2,17	9,71
19	27,9	3,1	9		**69**	29,14	3,41	8,55
20	22,94	2,48	9,25		**70**	19,84	2,48	8
21	19,84	2,48	8		**71**	21,7	2,48	8,75
22	21,08	2,48	8,5		**72**	22,32	2,17	10,29
23	21,08	2,79	7,55		**73**	22,94	2,48	9,25
24	28,52	3,41	8,36		**74**	21,08	2,48	8,5
25	21,08	3,1	6,8		**75**	24,18	2,48	9,75
26	21,7	2,79	7,78		**76**	22,94	2,48	9,25
27	26,66	3,1	8,6		**77**	24,8	2,48	10
28	22,94	3,1	7,4		**78**	24,8	2,17	11,43
29	22,32	2,79	8		**79**	19,84	2,79	7,11
30	21,7	3,1	7		**80**	22,32	2,17	10,29
31	23,56	3,72	6,33		**81**	20,46	2,48	8,25
32	18,6	2,48	7,5		**82**	19,22	2,17	8,86
33	20,46	2,48	8,25		**83**	19,22	2,17	8,86
34	21,7	2,48	8,75		**84**	21,7	2,48	8,75
35	19,84	2,79	7,11		**85**	26,66	2,48	10,75
36	21,08	2,48	8,5		**86**	17,98	2,48	7,25
37	22,94	3,1	7,4		**87**	22,32	2,48	9
38	23,56	3,1	7,6		**88**	22,94	2,48	9,25
39	20,46	2,79	7,33		**89**	23,56	1,86	12,67
40	19,84	2,48	8		**90**	29,14	1,86	15,67
41	19,84	2,48	8		**91**	19,84	2,48	8
42	21,7	2,48	8,75		**92**	21,08	2,48	8,5
43	21,7	2,48	8,75		**93**	18,6	2,48	7,5
44	22,32	2,48	9		**94**	21,08	2,48	8,5
45	21,08	2,48	8,5		**95**	18,6	2,48	7,5
46	22,32	2,48	9		**96**	26,66	3,1	8,6
47	21,7	2,48	8,75		**97**	19,84	2,17	9,14
48	26,04	3,1	8,4		**98**	19,22	2,17	8,86
49	23,56	3,1	7,6		**99**	19,84	2,17	9,14
50	24,8	2,48	10		**100**	20,46	2,17	9,4

Table B : Betula analysis : sample 729 cm

	D	P	D/P ratio			D	P	D/P ratio
1	22,32	2,17	10,29		**51**	25,42	2,48	10,25
2	24,8	2,48	10		**52**	22,94	2,48	9,25
3	21,08	2,48	8,5		**53**	27,28	2,17	12,57
4	31	2,17	14,29		**54**	22,94	2,17	10,57
5	25,42	2,17	11,71		**55**	21,08	2,48	8,5
6	22,32	2,17	10,29		**56**	24,8	2,48	10
7	29,76	2,17	13,71		**57**	22,94	2,17	10,57
8	21,7	1,86	11,67		**58**	21,7	2,48	8,75
9	27,28	2,17	12,57		**59**	25,42	3,1	8,2
10	21,08	1,86	11,33		**60**	22,94	2,48	9,25
11	21,08	2,17	9,71		**61**	23,56	2,17	10,86
12	22,94	2,48	9,25		**62**	22,32	2,48	9
13	22,32	2,17	10,29		**63**	18,6	2,17	8,57
14	21,7	2,17	10		**64**	22,32	2,17	10,29
15	27,9	2,48	11,25		**65**	21,7	2,48	8,75
16	22,94	2,17	10,57		**66**	21,08	2,48	8,5
17	23,56	2,17	10,86		**67**	29,14	2,48	11,75
18	21,08	2,17	9,71		**68**	21,7	1,86	11,67
19	24,8	2,48	10		**69**	26,66	2,17	12,29
20	25,42	3,1	8,2		**70**	22,32	1,86	12
21	21,7	2,48	8,75		**71**	19,84	1,86	10,67
22	25,42	2,48	10,25		**72**	20,46	2,17	9,43
23	27,9	2,48	11,25		**73**	22,94	2,48	9,25
24	21,7	2,17	10		**74**	21,7	3,1	7
25	22,94	2,48	9,25		**75**	25,42	2,48	10,25
26	23,56	2,48	9,5		**76**	22,32	2,48	9
27	21,7	2,17	10		**77**	19,84	1,86	10,67
28	21,08	1,86	11,33		**78**	20,46	1,86	11
29	22,94	2,48	9,25		**79**	24,8	2,48	10
30	23,56	2,79	8,44		**80**	28,52	2,17	13,14
31	19,22	2,17	8,85		**81**	21,7	1,86	11,67
32	21,08	2,48	8,5		**82**	22,32	2,48	9
33	22,32	2,48	9		**83**	21,7	2,48	8,75
34	23,56	2,17	10,86		**84**	22,94	2,79	8,22
35	21,7	2,48	8,75		**85**	21,7	2,48	8,75
36	21,08	2,17	9,71		**86**	22,94	2,17	10,57
37	22,32	2,48	9		**87**	26,04	2,48	10,5
38	22,32	2,48	9		**88**	27,9	2,48	11,25
39	21,08	2,17	9,71		**89**	24,8	2,48	10
40	21,7	2,17	10		**90**	19,84	1,86	10,67
41	19,84	1,86	10,67		**91**	22,32	2,17	10,29
42	19,22	1,86	10,33		**92**	23,56	2,79	8,44
43	19,22	1,86	10,33		**93**	19,22	1,86	10,33
44	21,7	2,17	10		**94**	21,7	1,86	11,67
45	21,7	2,17	10		**95**	22,32	1,86	12
46	25,42	1,86	13,67		**96**	23,56	2,17	10,86
47	24,8	2,48	10		**97**	21,08	2,17	9,71
48	27,9	2,79	10		**98**	20,46	2,17	9,43
49	21,08	2,17	9,71		**99**	19,84	2,48	8
50	22,94	2,48	9,25		**100**	22,32	2,17	10,29

Table C : Betula analysis : sample 835 cm

	D	P	D/P ratio			D	P	D/P ratio
1	22,94	1,86	12,33		**51**	22,32	2,48	9
2	21,7	1,86	11,67		**52**	24,8	1,86	13,33
3	22,32	2,17	10,29		**53**	18,6	1,86	10
4	25,42	1,86	13,67		**54**	27,9	2,48	11,25
5	22,94	1,55	14,8		**55**	21,08	1,86	11,33
6	24,8	2,48	10		**56**	21,7	1,86	11,67
7	27,28	2,48	11		**57**	25,42	2,17	11,71
8	29,14	3,1	9,4		**58**	21,7	2,48	8,75
9	24,8	2,17	11,43		**59**	17,36	2,17	8
10	20,46	2,17	9,43		**60**	24,18	1,86	13
11	26,66	2,17	12,29		**61**	19,84	1,86	10,67
12	22,32	1,86	12		**62**	16,74	1,55	10,8
13	22,94	2,17	10,57		**63**	24,8	2,48	10
14	18,6	2,79	6,67		**64**	19,22	2,17	8,86
15	34,1	3,1	11		**65**	18,6	2,17	8,57
16	21,7	2,48	8,75		**66**	18,6	1,86	10
17	27,9	3,1	9		**67**	21,7	2,17	10
18	21,7	2,17	10		**68**	26,66	2,79	9,56
19	21,08	2,17	9,71		**69**	21,7	1,86	11,67
20	22,94	2,48	9,25		**70**	19,22	1,86	10,33
21	15,5	1,55	10		**71**	27,9	2,17	12,86
22	22,94	2,48	9,25		**72**	23,56	2,48	9,5
23	24,18	2,48	9,75		**73**	27,9	2,48	11,25
24	21,7	1,86	11,67		**74**	21,7	2,17	10
25	20,46	3,1	6,6		**75**	26,66	2,48	10,75
26	35,96	2,17	16,57		**76**	22,32	2,17	10,29
27	22,32	2,17	10,29		**77**	21,7	1,86	11,67
28	22,32	1,55	14,4		**78**	19,84	1,86	10,67
29	17,36	1,55	11,2		**79**	21,7	1,86	11,67
30	16,74	1,55	10,8		**80**	24,8	2,17	11,43
31	26,04	1,86	14		**81**	19,84	2,17	9,14
32	23,56	2,17	10,86		**82**	24,18	2,17	11,14
33	20,46	1,86	11		**83**	19,22	1,86	10,33
34	24,18	2,48	9,75		**84**	21,08	1,86	11,33
35	25,42	2,17	11,71		**85**	21,7	2,17	10
36	26,04	2,79	9,33		**86**	27,9	2,17	12,86
37	22,94	2,79	8,22		**87**	21,7	1,86	11,67
38	19,22	2,17	8,86		**88**	20,46	1,86	11
39	20,46	2,17	9,43		**89**	29,14	2,17	13,43
40	24,8	1,86	13,33		**90**	23,56	2,79	8,44
41	22,94	2,17	10,57		**91**	18,6	2,17	8,57
42	21,7	2,79	7,78		**92**	17,98	1,55	11,6
43	20,46	2,17	9,43		**93**	21,7	2,17	10
44	23,56	2,79	8,44		**94**	18,6	1,86	10
45	22,32	2,17	10,29		**95**	19,84	2,17	9,14
46	27,9	2,48	11,25		**96**	21,7	1,86	11,67
47	21,08	1,86	11,33		**97**	19,22	1,86	10,33
48	18,6	1,86	10		**98**	22,94	2,17	10,57
49	22,94	2,48	9,25		**99**	25,42	2,17	11,71
50	26,04	1,86	14		**100**	19,22	1,86	10,33

Table D : Betula analysis : sample 918 cm

	D	P	D/P ratio			D	P	D/P ratio
1	15,5	1,86	8,33		**51**	22,32	1,86	12
2	23,56	2,48	9,5		**52**	27,9	2,48	11,25
3	24,18	1,86	13		**53**	18,6	1,86	10
4	24,8	1,86	13,33		**54**	23,56	1,86	12,67
5	23,56	2,17	10,86		**55**	16,74	1,55	10,8
6	27,1	2,17	10		**56**	24,8	1,86	13,33
7	22,94	1,86	12,33		**57**	19,84	1,86	10,67
8	22,32	2,17	10,29		**58**	22,94	1,86	12,33
9	26,04	2,48	10,5		**59**	14,26	1,55	9,2
10	20,46	1,86	11		**60**	21,7	1,86	11,67
11	22,94	1,86	12,33		**61**	26,04	1,86	14
12	21,7	1,86	11,67		**62**	20,46	1,55	13,2
13	17,98	1,86	9,67		**63**	16,12	1,24	13
14	18,6	1,55	12		**64**	25,42	2,48	10,25
15	23,56	2,48	9,5		**65**	19,84	1,86	10,67
16	21,08	1,55	13,6		**66**	16,74	1,55	10,8
17	23,56	2,17	10,86		**67**	24,18	3,1	7,8
18	19,84	1,86	10,67		**68**	21,7	1,86	11,67
19	19,84	1,86	10,67		**69**	24,18	2,17	11,14
20	20,46	1,86	11		**70**	28,52	2,48	11,5
21	27,9	2,48	11,25		**71**	17,98	1,55	11,6
22	21,7	2,17	10		**72**	22,94	1,55	14,8
23	27,28	2,48	11		**73**	21,08	1,55	13,6
24	26,04	2,79	9,33		**74**	21,7	2,17	10
25	22,94	2,48	9,25		**75**	21,7	1,55	14
26	21,08	1,86	11,33		**76**	19,84	1,86	10,67
27	22,94	2,17	10,57		**77**	24,8	1,86	13,33
28	22,94	1,86	12,33		**78**	26,04	2,48	10,5
29	19,22	1,86	10,33		**79**	24,8	2,48	10
30	21,08	1,86	11,33		**80**	27,9	2,48	11,25
31	22,94	2,48	9,25		**81**	24,8	2,17	11,43
32	26,04	1,86	14		**82**	22,32	2,17	10,29
33	19,84	1,86	10,67		**83**	24,8	2,17	11,43
34	24,8	2,48	10		**84**	17,98	1,55	11,6
35	21,08	2,17	9,71		**85**	21,7	2,17	10
36	17,98	1,55	11,6		**86**	25,42	1,86	13,67
37	16,74	1,55	10,8		**87**	20,46	1,55	13,2
38	26,04	2,48	10,5		**88**	29,76	2,48	12
39	24,18	2,17	11,14		**89**	19,84	1,86	10,67
40	15,5	2,17	7,14		**90**	23,56	2,17	10,86
41	17,98	1,86	9,67		**91**	25,42	2,17	11,71
42	21,7	2,48	8,75		**92**	20,46	2,17	9,43
43	21,7	2,48	8,75		**93**	24,18	1,55	15,6
44	22,94	2,17	10,57		**94**	27,9	2,48	11,25
45	24,18	1,86	13		**95**	16,74	1,55	10,8
46	21,08	2,48	8,5		**96**	24,18	2,17	11,14
47	21,08	2,79	7,56		**97**	18,6	1,86	10
48	21,7	2,17	10		**98**	19,84	1,55	12,8
49	20,46	1,86	11		**99**	21,7	2,48	8,75
50	25,42	2,48	10,25		**100**	24,8	1,86	13,33

Table E : Betula analysis : sample 933 cm

	D	**P**	**D/P ratio**			**D**	**P**	**D/P ratio**
1	21,08	2,17	9,71		**51**	24,18	2,48	9,75
2	18,6	2,48	7,5		**52**	26,04	2,48	10,5
3	16,74	1,55	10,8		**53**	21,7	2,17	10
4	19,84	2,48	8		**54**	21,08	1,86	11,33
5	21,08	3,1	6,8		**55**	20,46	2,48	8,25
6	25,42	2,48	10,25		**56**	21,08	1,55	13,6
7	27,28	2,48	11		**57**	21,08	1,86	11,33
8	19,84	1,55	12,8		**58**	21,7	1,86	11,67
9	18,6	1,86	10		**59**	18,6	1,55	12
10	24,8	2,17	11,43		**60**	21,08	2,79	7,56
11	24,18	1,86	13		**61**	26,04	1,86	14
12	17,98	1,55	11,6		**62**	22,94	1,86	12,33
13	23,56	2,17	10,86		**63**	21,7	2,48	8,75
14	25,42	2,17	11,71		**64**	22,32	1,86	12
15	19,84	1,55	12,8		**65**	22,94	1,86	12,33
16	22,94	2,48	9,25		**66**	24,18	2,48	9,75
17	26,04	2,17	12		**67**	21,08	2,17	9,71
18	24,18	2,17	11,14		**68**	19,84	1,86	10,67
19	24,18	1,86	13		**69**	21,7	1,86	11,67
20	22,32	1,86	12		**70**	18,6	1,55	12
21	24,8	1,86	13,33		**71**	24,8	1,86	13,33
22	19,22	1,86	10,33		**72**	26,04	2,48	10,5
23	17,36	1,55	11,2		**73**	27,9	1,86	15
24	22,94	2,17	10,57		**74**	25,42	1,86	13,67
25	21,7	2,79	7,78		**75**	23,56	1,86	12,67
26	27,9	3,1	9		**76**	21,08	1,55	13,6
27	22,94	2,48	9,25		**77**	21,7	2,48	8,75
28	21,08	1,55	13,6		**78**	24,8	1,86	13,33
29	22,94	2,17	10,57		**79**	22,32	1,86	12
30	21,7	2,17	10		**80**	22,94	1,86	12,33
31	24,8	1,86	13,33		**81**	22,32	1,86	12
32	15,5	1,24	12,5		**82**	19,22	1,55	12,4
33	20,46	1,86	11		**83**	17,36	1,55	11,2
34	24,18	2,17	11,14		**84**	26,04	2,17	12
35	16,74	1,55	10,8		**85**	21,7	1,55	14
36	24,18	2,17	11,14		**86**	22,32	1,86	12
37	22,94	2,17	10,57		**87**	27,9	2,48	11,25
38	14,26	1,24	11,5		**88**	21,7	1,86	11,67
39	18,6	1,55	12		**89**	22,94	2,48	9,25
40	19,22	1,86	10,33		**90**	21,08	2,48	8,5
41	21,7	2,17	10		**91**	24,8	1,86	13,33
42	22,94	2,48	9,25		**92**	25,42	1,86	13,67
43	18,6	1,86	10		**93**	27,28	1,55	17,6
44	17,36	1,86	9,33		**94**	24,8	1,86	13,33
45	24,8	1,86	13,33		**95**	20,46	2,48	8,25
46	22,94	1,86	12,33		**96**	19,84	1,55	12,8
47	26,04	1,55	16,8		**97**	26,04	1,86	14
48	19,84	1,55	12,8		**98**	26,66	2,48	10,75
49	22,94	1,86	12,33		**99**	16,12	1,55	10,4
50	17,98	1,55	11,6		**100**	22,94	1,55	14,8

Table F : Betula analysis : sample 957 cm

	D	**P**	**D/P ratio**			**D**	**P**	**D/P ratio**
1	28,52	2,17	13,14		**51**	22,94	2,5	14,8
2	24,8	2,17	11,43		**52**	18,6	1,55	12
3	24,18	1,86	13		**53**	27,28	1,55	17,6
4	27,28	1,86	14,67		**54**	24,8	1,86	13,33
5	27,28	2,48	11		**55**	25,42	1,86	13,67
6	25,42	1,86	13,67		**56**	23,56	1,86	12,67
7	22,32	1,55	14,4		**57**	21,08	1,55	13,6
8	26,04	1,86	14		**58**	24,18	2,48	9,75
9	24,8	1,55	16		**59**	23,56	1,55	15,2
10	21,08	1,55	13,6		**60**	22,32	1,55	16
11	21,7	1,86	11,67		**61**	28,52	1,55	18,4
12	25,42	1,55	16,4		**62**	26,04	2,17	12
13	15,5	1,55	10		**63**	27,9	1,86	15
14	22,94	1,86	12,33		**64**	26,04	1,55	16,8
15	24,18	1,86	13		**65**	24,18	1,55	15,6
16	22,32	1,86	12		**66**	23,56	2,17	10,86
17	22,32	1,86	12		**67**	18,6	1,24	15
18	29,14	2,17	13,43		**68**	24,18	1,55	15,6
19	26,04	2,17	12		**69**	26,04	1,86	14
20	22,94	1,55	14,8		**70**	21,08	1,55	13,6
21	24,8	1,86	13,33		**71**	22,94	1,86	12,33
22	24,18	1,86	13		**72**	23,56	1,86	12,67
23	21,08	1,86	11,33		**73**	24,8	1,86	13,33
24	24,8	1,86	13,33		**74**	21,08	1,55	13,6
25	21,08	1,24	17		**75**	25,42	2,48	10,25
26	25,42	1,86	13,67		**76**	23,56	2,17	10,86
27	23,56	1,86	12,67		**77**	22,94	1,55	14,8
28	24,8	1,86	13,33		**78**	19,22	1,86	10,33
29	18,6	1,55	12		**79**	22,32	1,86	12
30	23,56	1,86	12,67		**80**	25,42	1,55	16,4
31	20,46	1,86	11		**81**	18,6	1,86	10
32	24,18	1,86	13		**82**	14,88	1,24	12
33	25,42	1,86	13,67		**83**	21,08	1,55	13,6
34	24,8	1,86	13,33		**84**	22,32	1,86	12
35	23,56	1,86	12,67		**85**	25,42	1,86	13,67
36	18,6	1,24	15		**86**	24,8	1,55	16
37	26,04	1,55	16,8		**87**	24,8	1,86	13,33
38	27,9	1,86	15		**88**	26,04	1,86	14
39	22,32	2,17	10,29		**89**	27,9	1,86	15
40	21,7	1,86	11,67		**90**	24,8	1,86	13,33
41	25,42	1,86	13,67		**91**	24,18	1,86	13
42	22,94	2,17	10,57		**92**	21,7	1,55	14
43	22,94	1,86	12,33		**93**	22,32	1,86	12
44	21,7	1,86	11,67		**94**	20,46	1,55	13,2
45	25,42	2,17	11,71		**95**	27,28	1,86	14,67
46	22,32	1,55	14,4		**96**	21,7	1,86	11,67
47	25,42	1,86	13,67		**97**	22,94	1,55	14,8
48	25,42	1,86	13,67		**98**	24,18	1,55	15,6
49	24,8	1,55	16		**99**	21,7	1,55	14
50	26,04	1,86	14		**100**	21,08	1,24	17

Appendix C: Rarefaction analysis.

The results from the rarefaction analysis are shown in figs. C1 and C2 (see below).

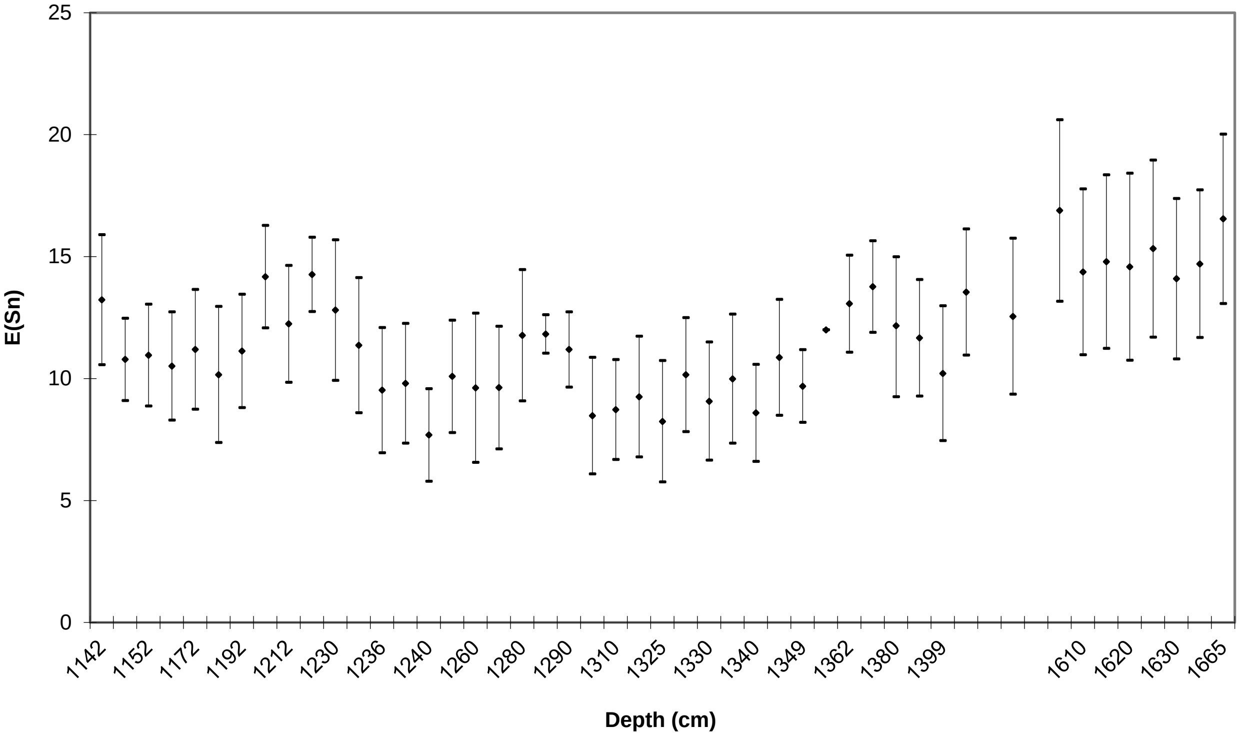


Figure C1 Rarefaction analysis of the Mamontovaya Kurja site, n=182.

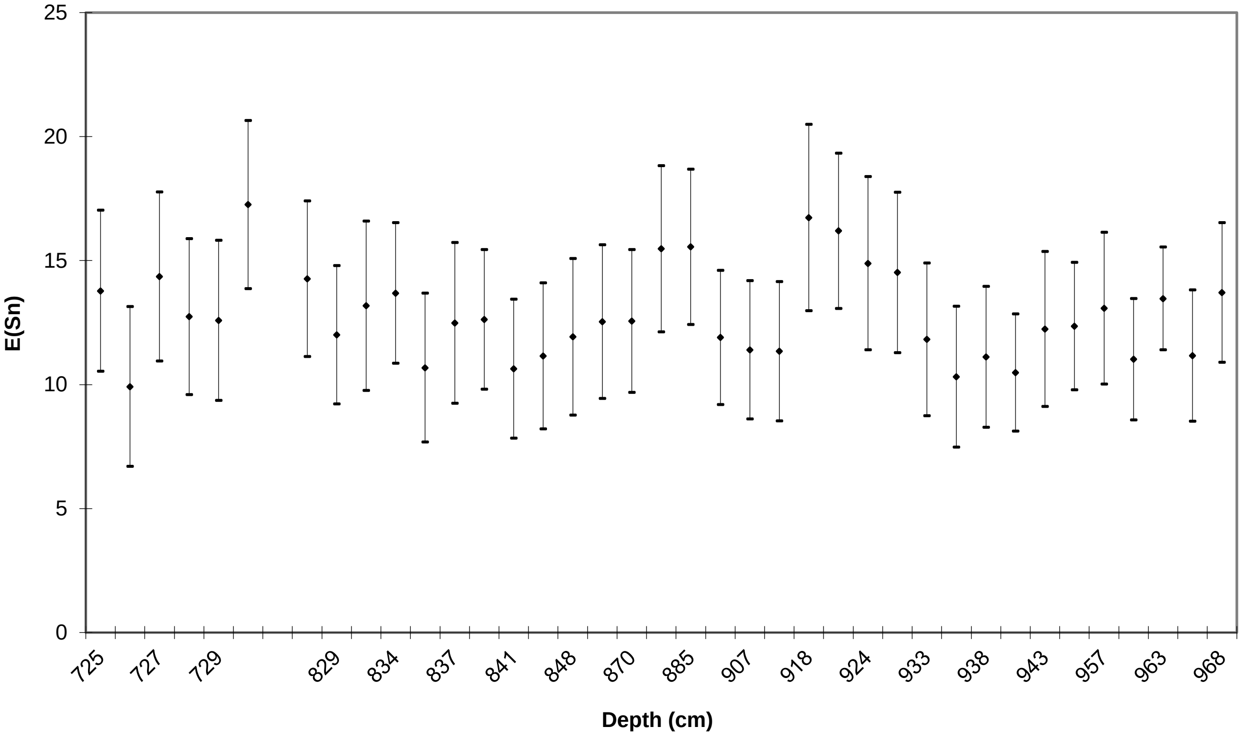


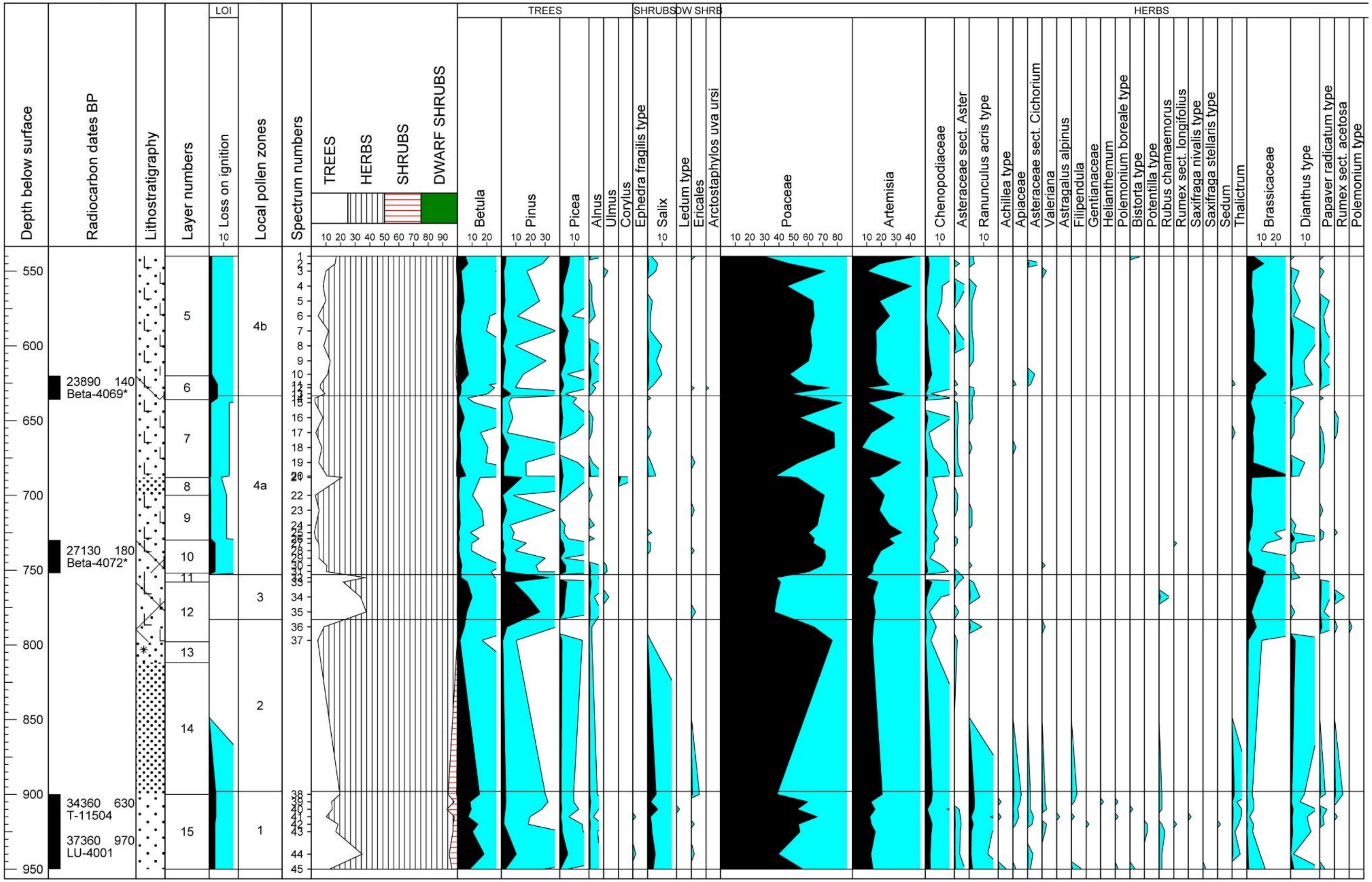
Figure C2 Rarefaction analysis of the Sokolova site, n=182.

Appendix E : Pollen and spore content of layers 4 and 3.

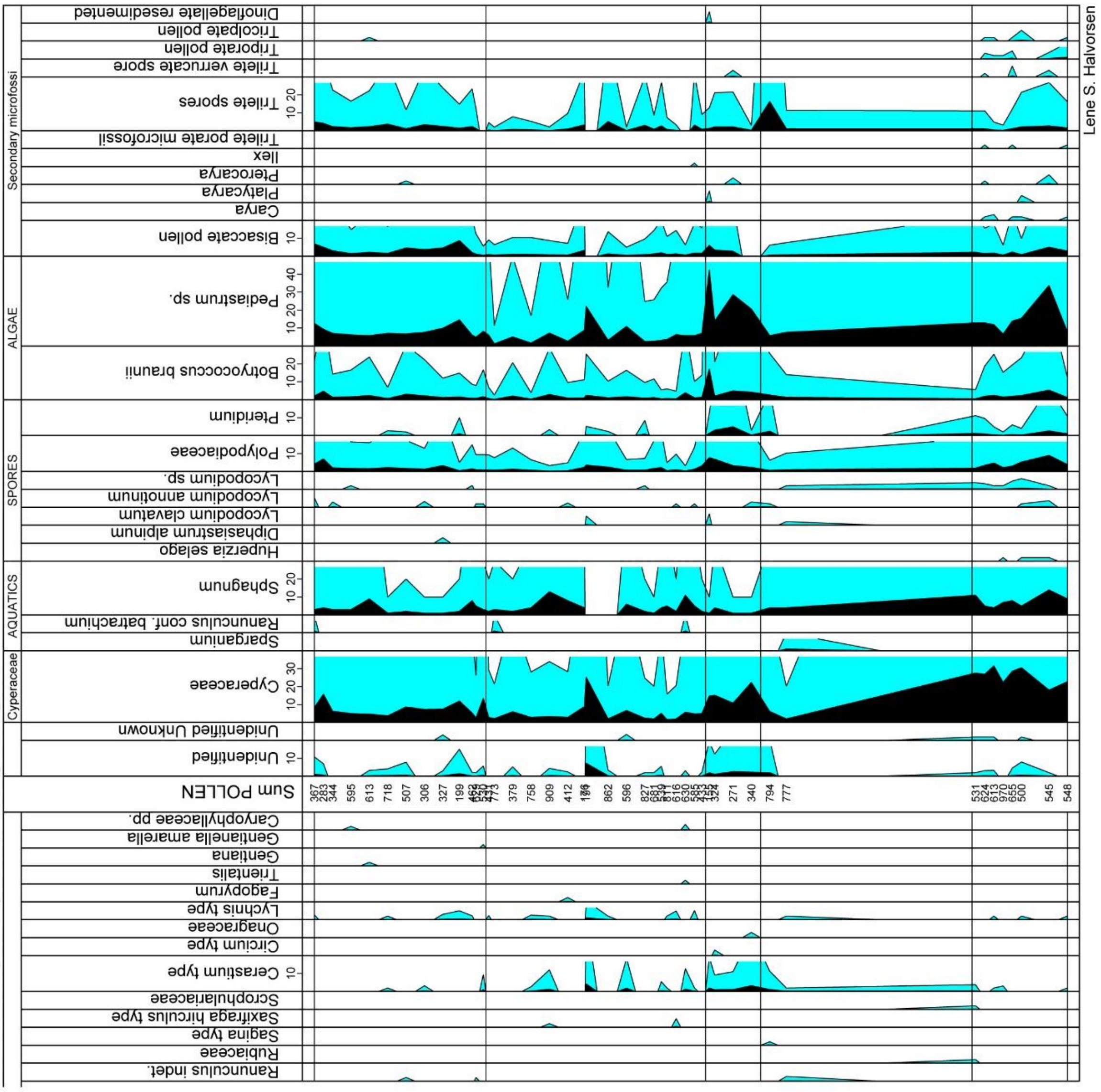
Table E.1 Pollen and spore content of layers 4 and 3 at Mamontovaya Kurja, not included in the pollen diagram.

Layer 4 and 3 : Species composition								
Taxon	***1120 cm***	***1100 cm***	***1080 cm***	***1060 cm***	***1040 cm***	***1020 cm***	***1000 cm***	***980 cm***
Artemisia	6	-	-	-	-	-	-	-
Brassicaceae	2	-	-	-	-	-	-	-
Cyperaceae	3	-	-	-	1	1	-	-
Pinus	1	1	-	-	-	2	1	-
Poaceae	13	2	-	-	1	-	1	-
Saxifraga conf. *hirculus*	-	-	-	1	-	-	-	-
Polypodiaceae	-	1	-	1	-	-	-	-
Pteridium	-	-	-	-	-	-	1	-
Bisaccate (resed.)	-	2	-	1	-	5	1	-
Trilete spores (resed.)	-	1	-	2	-	6	1	-
Unidentified	-	-	-	-	-	1	-	-

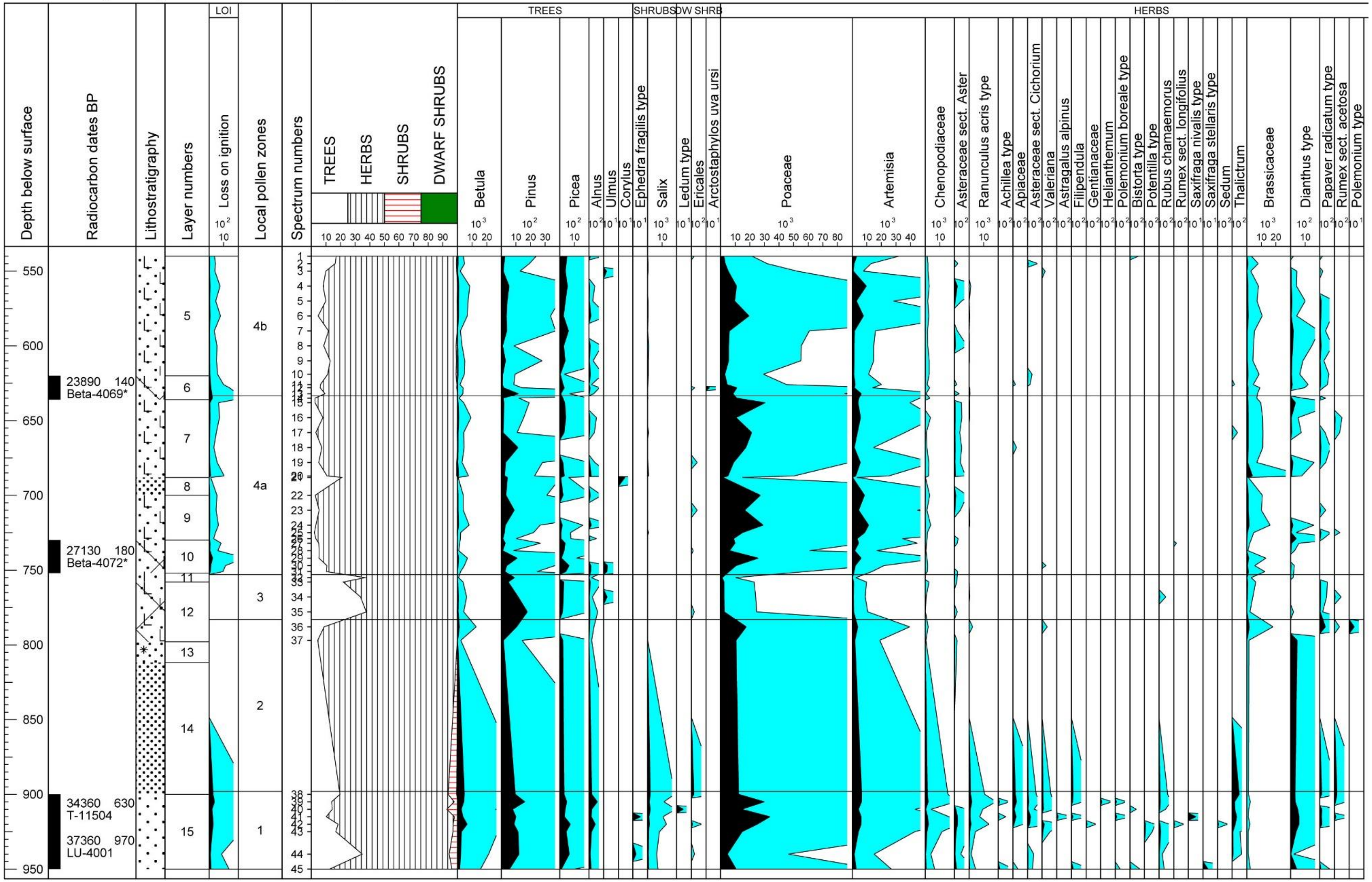
APPENDIX D. Figure 1.
Mamontovaya Kurja. Percentage diagram



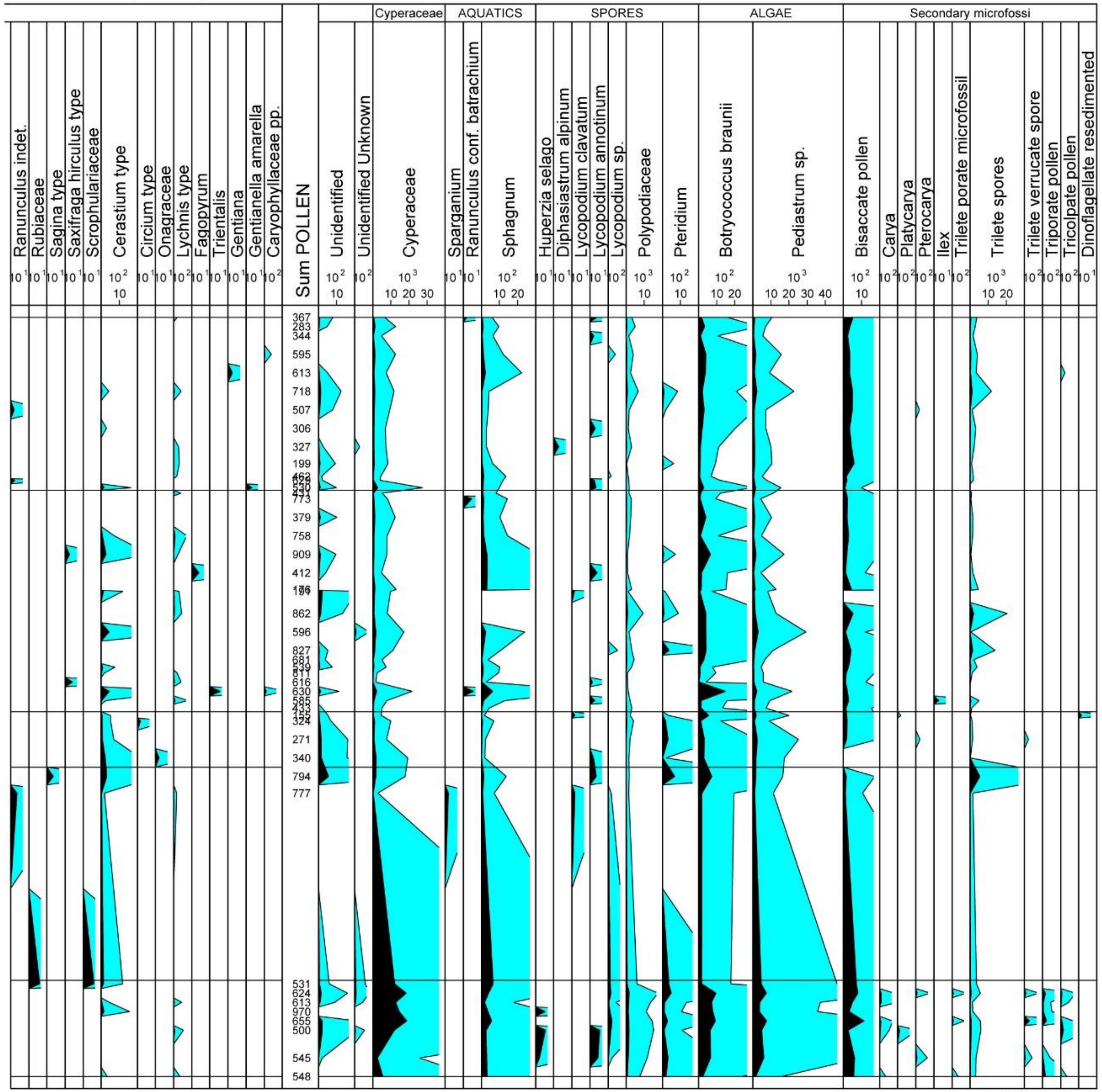
APPENDIX D. Figure 1, contd.
Mamontovaya Kurja. Percentage diagram



APPENDIX D. Figure 2.
Mamontovaya Kurja. Concentration diagram



APPENDIX D. Figure 2, contd..
Mamontovaya Kurja. Concentration diagram



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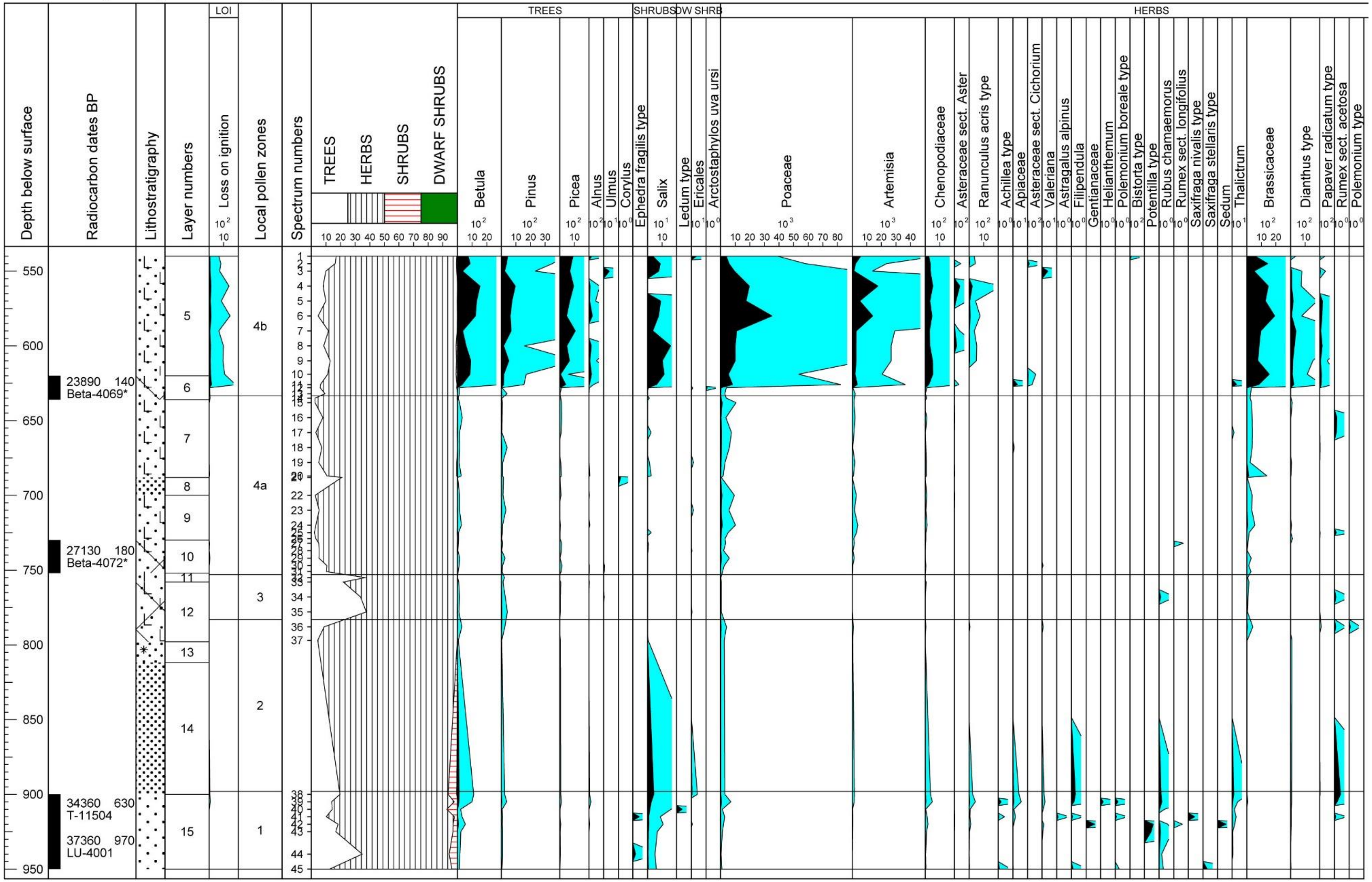
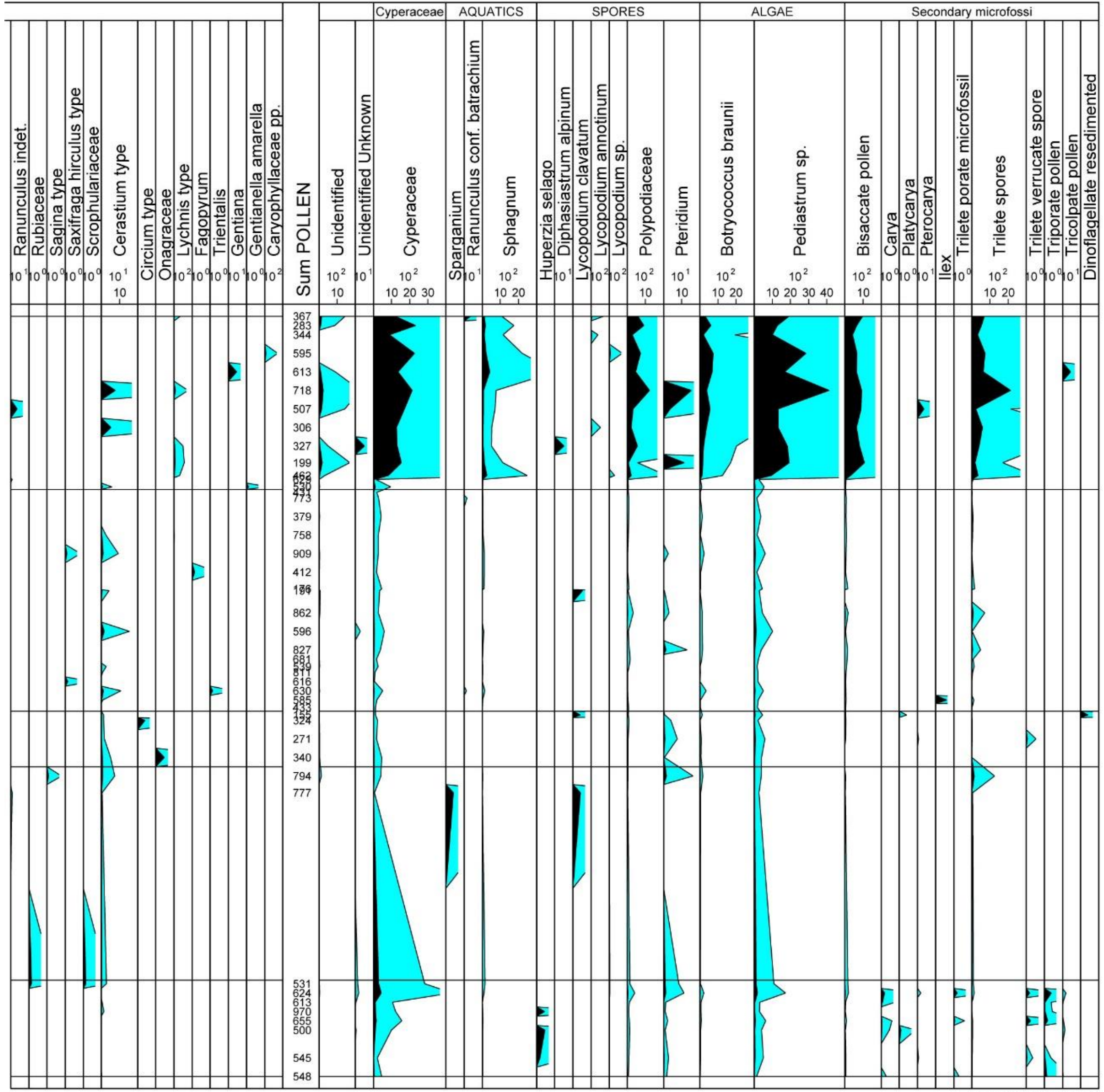
APPENDIX D. Figure 3.
Mamontovaya Kurja. Influx diagram



APPENDIX D. Figure 3, contd.
Mamontovaya Kurja. Influx diagram



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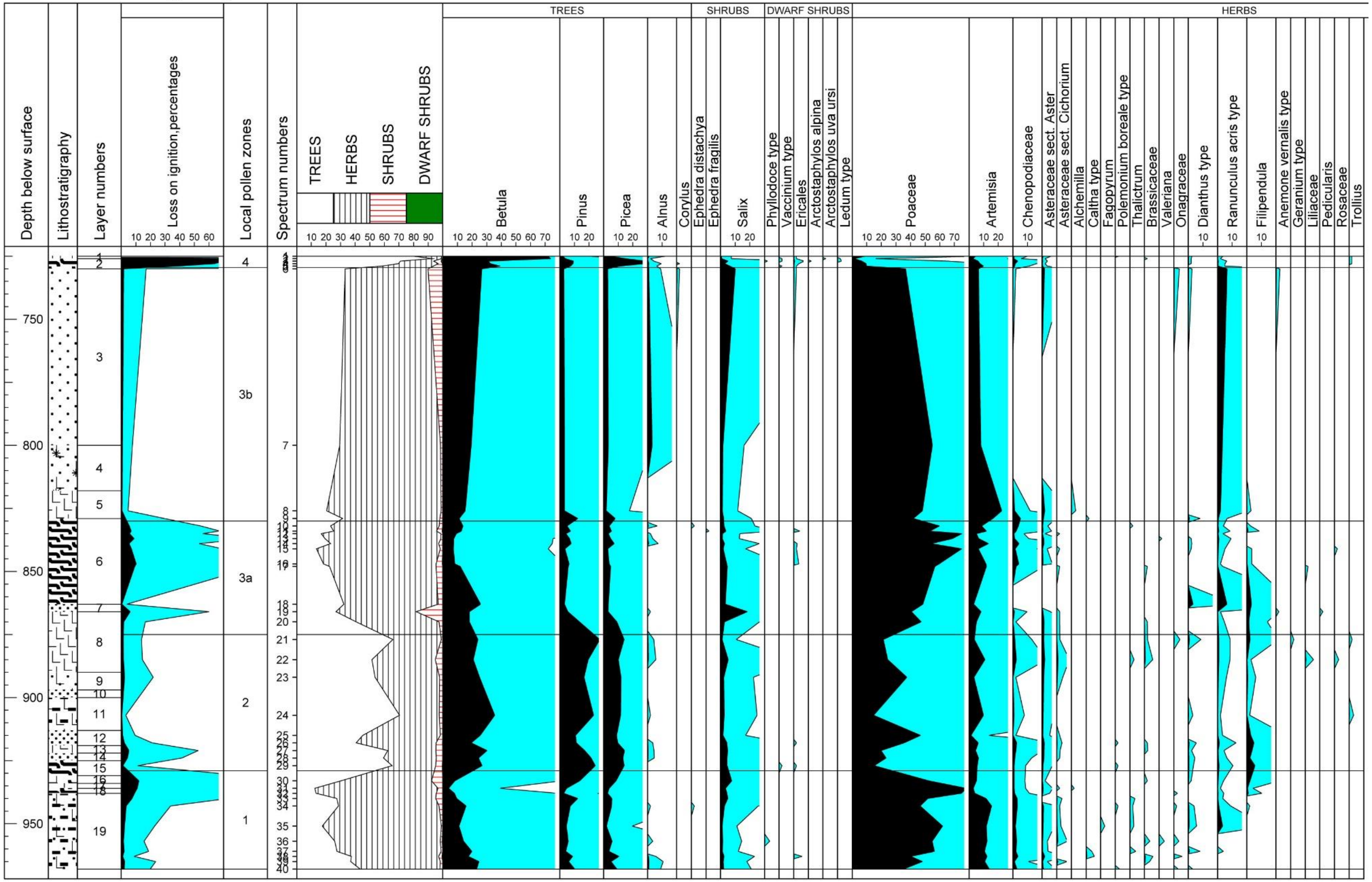
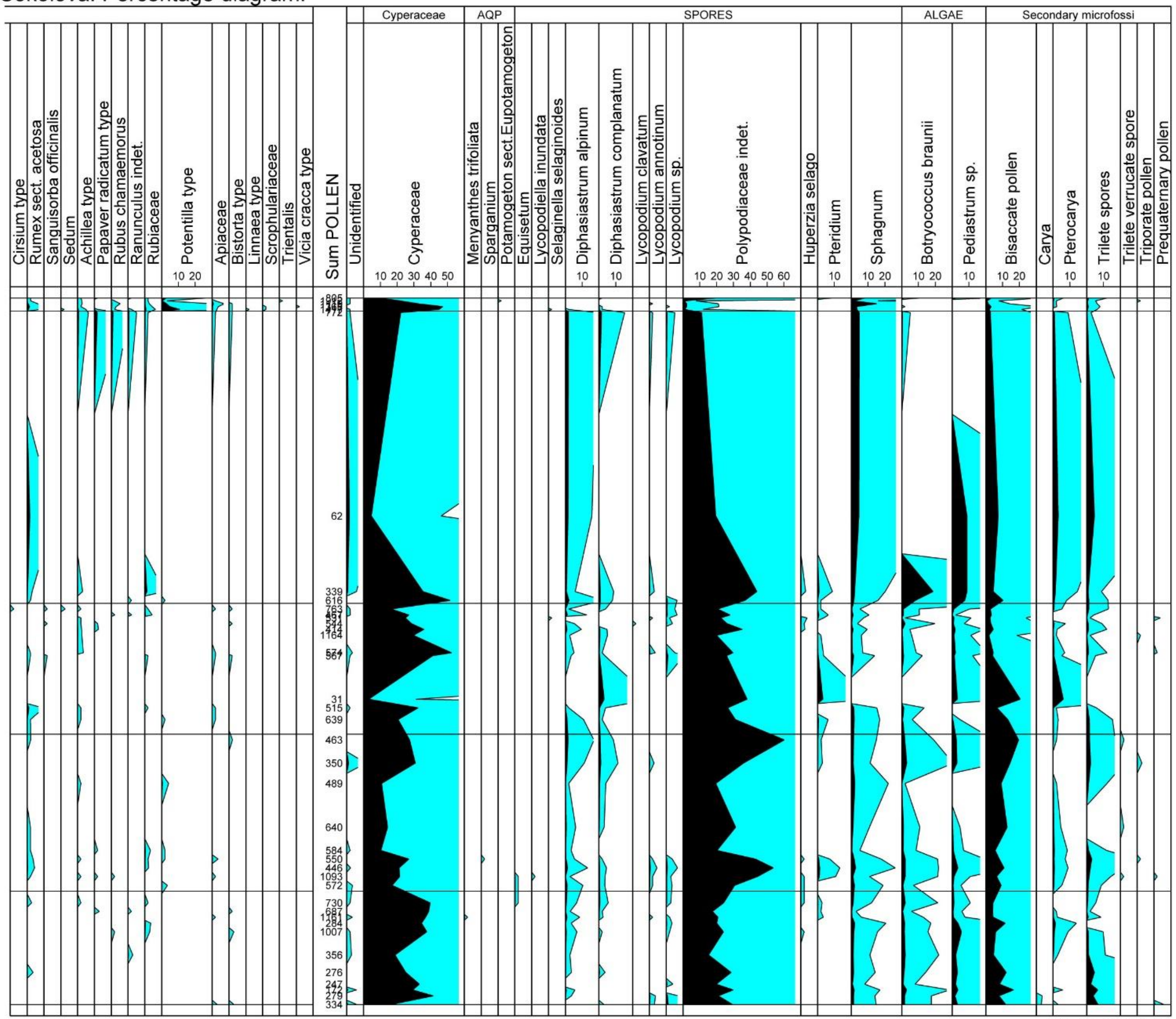
APPENDIX D. Figure 4.
Sokolova. Percentage diagram.



APPENDIX D. Figure 4, contd.
Sokolova. Percentage diagram.



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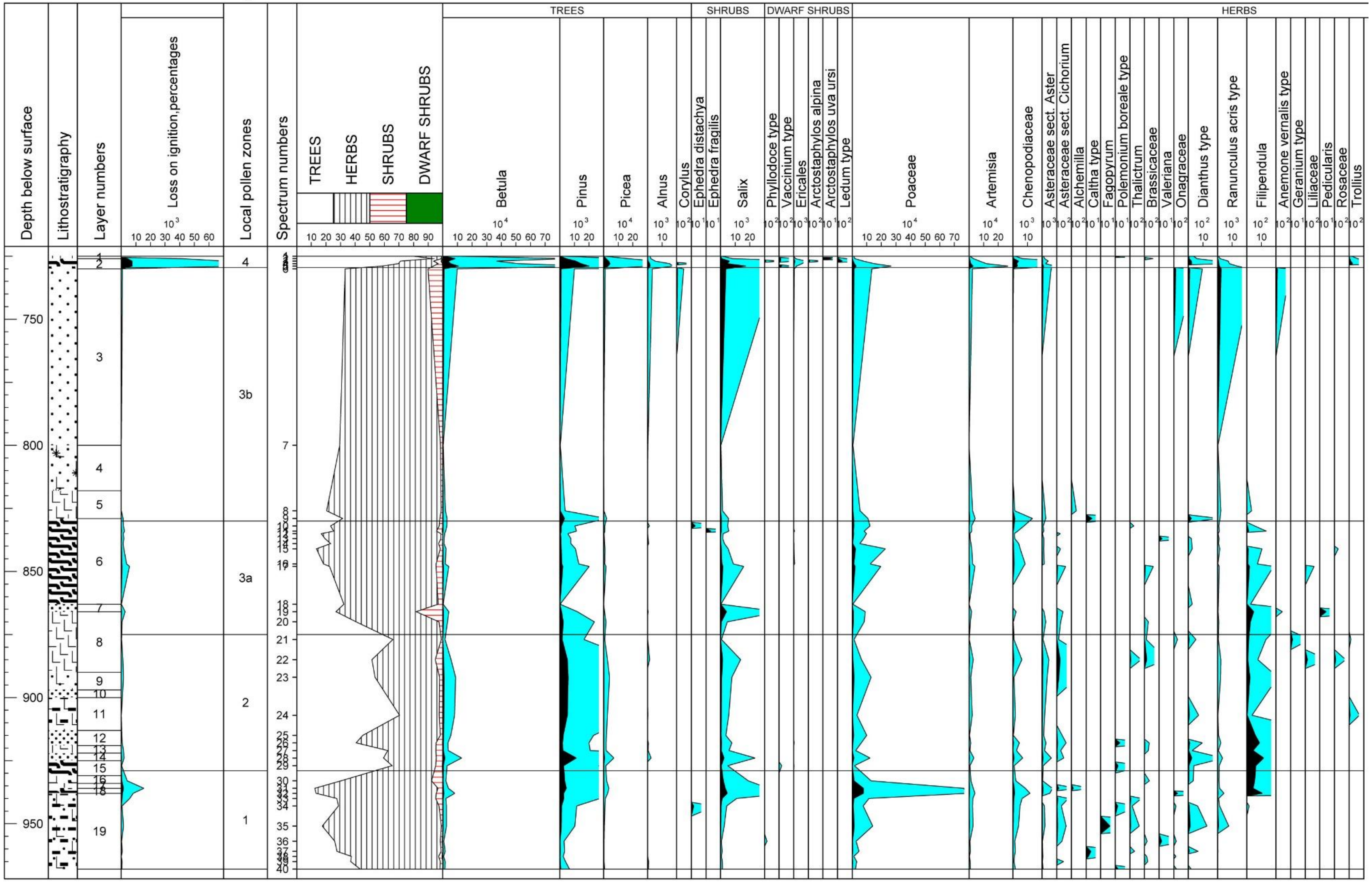
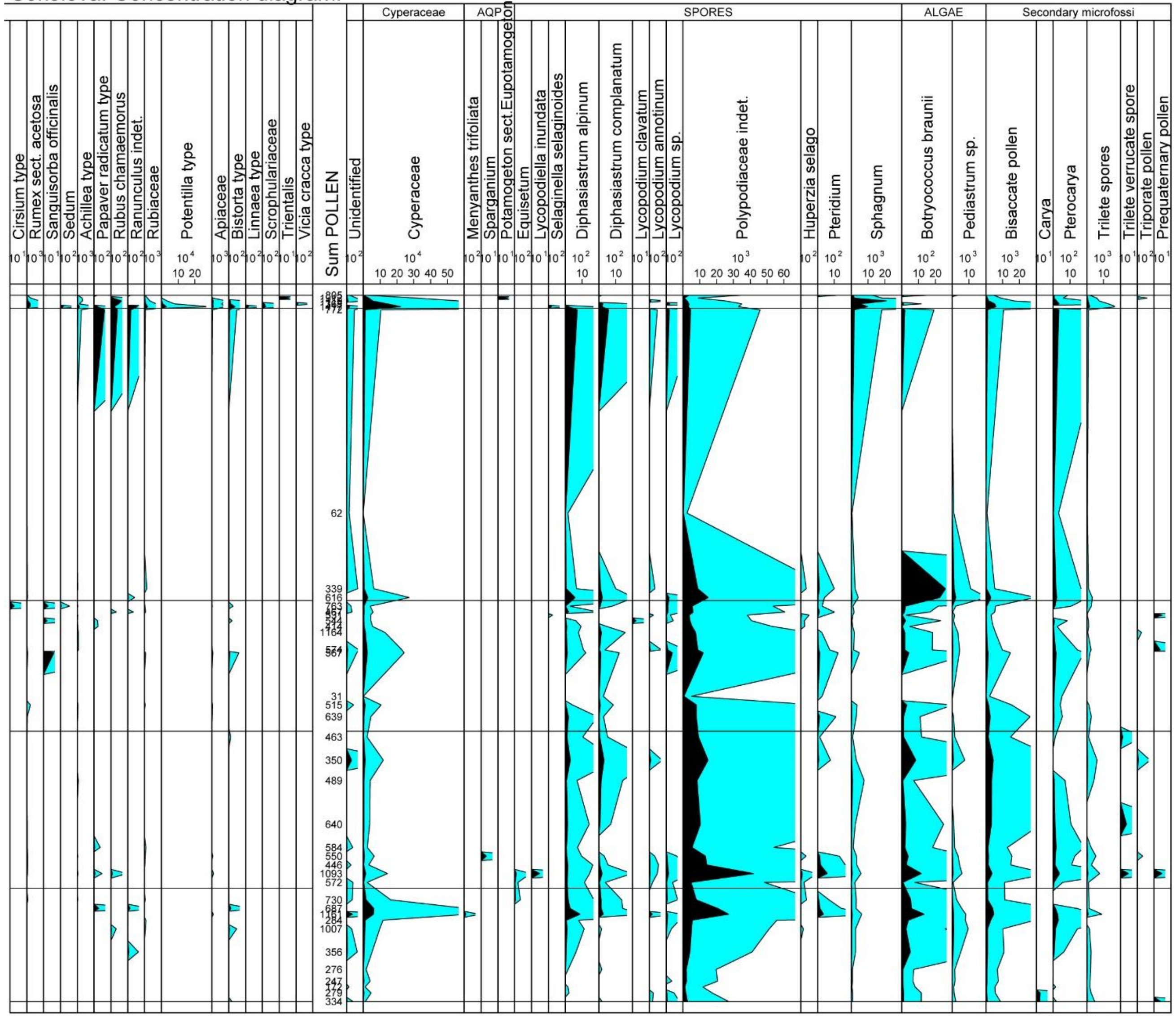
APPENDIX D. Figure 5.
Sokolova. Concentration diagram.



APPENDIX D. Figure 5, contd.
Sokolova. Concentration diagram.



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