

# Šafárka – first palaeobotanical data of the character of Last Glacial vegetation and landscape in the West Carpathians (Slovakia)

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Received 17 February 2002; accepted for publication 14 May 2002

**ABSTRACT.** Pollen analysis was used to study a sediment of Last Glacial age, buried beneath younger deposits. Radiocarbon dating indicates that the profile reflects events at least for the period 16 000 to more than 52 000 <sup>14</sup>C BP. Five vegetational-developmental phases are delimited: SF1 – larch stands under a very cold continental climate (analogy of forest tundra at the polar tree limit of today's Siberia); SF2 – birch – larch stands suggesting a cool continental climate (transition of forest tundra to the northern Siberian taiga); SF3 – pine – spruce stands with birch, larch and alder (analogy of the northern zone of middle Siberian taiga – climate with a higher humidity); SF4 – spruce stands with a greater contribution of alder and the continued presence of other tree species (analogy of natural forests of Carpathian basins during the Holocene climatic optimum); SF5 – pine stands with larch. Spruce is retreating (decrease in temperature and humidity).

The unique feature of the studied profile consists in its geographic position. It represents the first source of palaeobotanical data for the period of the Last Glacial in Slovakia. Unfortunately, exact age of individual profile layers is impossible to determine so far. Existing radiocarbon data were obtained from wood and cones collected at already disturbed profile. Small pollen-analytical samples, collected in the field during the salvage operation, were lacking material appropriate for the purpose of dating. Due to difficult conditions during the sampling of the profile, it was also impossible to perform detailed stratigraphic investigation directly in the field, but, according to overall geological context, the peat had accumulated in the fossil doline during the Last Glacial period.

**KEY WORDS:** pollen analysis, palaeoecology, Last Glacial, NE Slovakia

## INTRODUCTION

A layer of organic sediments was found in the course of activities associated with the preparations for gypsum mining in the locality Šafárka – Markušovce. As a result of notice given by workers of the Želba Co., who were clearing away the overburden a salvage operation – to take samples from the profile – was organized by the staff of the Museum of Spiš in cooperation with colleagues from the Nature Conservation Agency of the Slovenský Ráj area. There was no time available for any more extensive research since the mining company quickly destroyed the locality. In addition to the chronological samples taken from the still undestroyed profile in the remaining mining space, interesting plant macroremains

were collected from material released from the original organic strata. These comprised particularly large pieces of wood, cones and seeds of different tree species (*Picea* sp., *Larix* sp., *Pinus cembra*, and *P. sylvestris*) which once grew at the site. Pollen analysis and subsequent radiocarbon dating provided evidence of the considerable scientific value of the data obtained from this “natural archive”.

## SITE DESCRIPTION

Šafárka is situated 8 km south of Spišská Nová Ves (NE Slovakia), on the northern rim of the Slovenské Rudohorí Mts. (48°52'55"N;

20°34'30"E; 600 m asl.; Fig. 1). The bedrock beneath the Quaternary sediments is formed by gypsum strata of Upper Permian age (Jančura & Sasvari 1997). On clearing away

On the basis of the phytogeographical classification (Futák 1980) the site is situated within the area Carpaticum occidentale – Praecarpaticum. The geobotanical reconstruc-

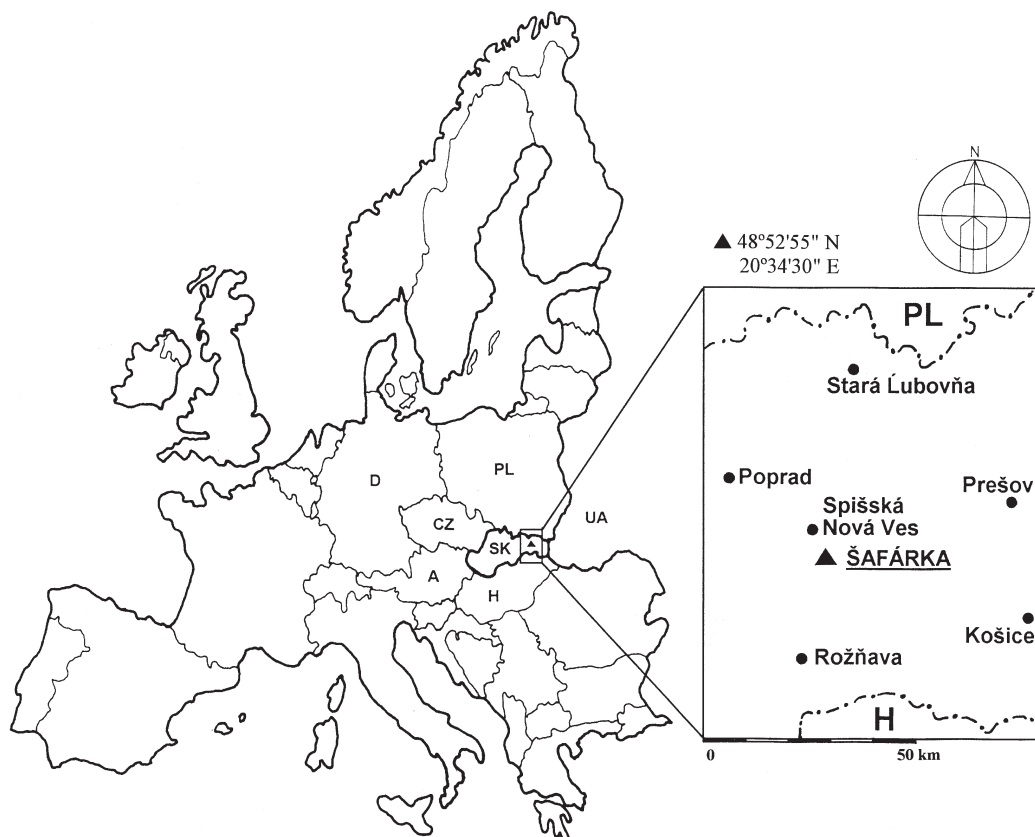


Fig. 1. Site location map. Triangle – position of the locality Šafárka

the surface Quaternary sediments, fossil dolines ("sink holes") from older periods of the Quaternary were revealed in the gypsum bedrock (Novotný 2002). In such dolines sedimentation of humolite took place which forms the object of this palaeoecological study. According to geological map of Novotný (2002) some other fossil dolines with the peat sediments existed in this area (Fig. 2). The doline in which the sediment of studied profile (S3) was produced, was about 20 m wide, 30 m long and nearly 50 m deep, (personal communication of L. Novotný). They were found and destroyed in the course of gypsum mining.

The locality falls climatically into the "mildly warm and humid district with a cold winter" (July 17°C, January -5°C, average yearly precipitation 880–1100 mm). The area belongs hydrogeographically to the catchment of the Hornád river.

tion map of potential vegetation (Michalko et al. 1987) indicates fir and fir-spruce forests for this locality (*Abieton* auct. and *Vaccinio-Abieton* Oberd. 1962 p.p.) and *Alnenion glutinoso-incanae* Oberd. 1953 on alluvial areas. Deforested areas (pastures) have a vegetation classified as *Polygalo-Cynosurenion* Jurko 1974. The recent doline contains swamp phytocoenoses *Caricion fuscae* Koch 1926 em. Klika 1934 and associations *Calthion* R. Tx. 1937 em. Bal.-Tul. 1978. *Picea abies* and *Abies alba* are dominants in the neighbouring forests with an admixture of *Pinus sylvestris*, *Larix decidua*, *Sorbus aucuparia*, and *Acer pseudoplatanus*.

#### METHODS

(a) **Field work:** Samples for pollen analysis were taken primarily from the organic sediment of profile S3 on 5<sup>th</sup> May 2000, directly from the wall of strata

above the gypsum bedrock. The organic strata were overlain by about 5 meters of strata composed mostly of inorganic clayey material. Samples for pollen analysis were mostly taken at intervals of 5 cm. At the same time, whenever it was possible, samples of plant macroremains were collected from the collapsed organic section regardless of chronological order. Such material, i.e. wood, cones, later served as sources for the first information about the age of the profile obtained through being of radiocarbon dated.

**(b) Laboratory work:** All samples used for pollen and other microfossil analyses were prepared by the modified acetolysis method (Erdtman 1960). They were pre-treated with hydrofluoric acid (HF) for 24 hours (Faegri & Iversen 1989, Moore et al. 1991). In each sample at about 400–700 pollen grains were counted, but only 186 grains were found in sample 95 cm. For pollen identification, the following keys and atlases were used besides a reference collection: Faegri & Iversen (1989), Moore et al. (1991), Punt (1976–1996), Reille (1992, 1995, 1998). Pollen nomenclature follows mostly the ADABA (Alpine Palynological Data – Base). Pollen frequency was in most cases very good and pollen grains were also usually easily identifiable.

**(c) Pollen diagram:** The results of the pollen analysis are illustrated in a pollen diagram compiled by the modified program TILIA (Grimm 1990, 1992). A simplified pollen diagram is given in Fig. 3 where the majority of the herb types are grouped as “other herbs”. The percentages of individual taxa including Pteridophyta, Bryophyta and Algae, have been calculated from the basic sum AP + NAP = 100%. The left hand side of pollen diagram shows the lithology. Radiocarbon data are contained in the next column (Age) only informative. A coarse geological period (Last Glacial) is presented in the column “Period”, and the remaining column contains the division of the pollen diagram into the “Local pollen assemblage zones”. The description of the individual LPAZ is presented in the section “Pollenanalytical results and their interpretation”.

## RADIOCARBON DATING

Immediately after the sampling was finished (profile S 3, position R 2 – see Fig. 2), a piece of wood (No. 1) was sent for radiocarbon dating with the aim of finding out the approximate age of the organic layers. Since the pieces of wood came from the already disturbed profile, it is impossible to estimate their original location exactly. Three other samples from collapsed material near profile S 3 – cones of *Picea* and *Larix* were also dated. The original position of these three samples in the profile also remains unknown. The age of wood sample No. 2 and unidentified cone from the collapsed material on position R 4 – see Fig. 2 is after radiocarbon dating about

30 000 BP. It means that radiocarbon dating of wood samples from several nearby-situated fossil dolines (Fig. 2) gave the age between 18 000 – 32 000 BP (see dating). The dating was performed by Dr. J. Melková, and Ing. P. Jílek at the <sup>14</sup>C laboratory, Chair of Hydrogeology, Faculty of Natural Sciences, Charles University, Prague.

## Results:

Wood sample (No. 1): 16 565 ± 415 BP (CU 1600) – position R2 – see Fig. 2

*Larix* cones (No. 1): 30 186 ± 1 935 BP (CU 1655) – position R2 – see Fig. 2

*Picea* cones: 26 509 ± 480 BP (CU 1656) – position R2 – see Fig. 2

Wood sample (No. 2): 31 883 ± 3 091 BP (CU 1761) – position R4 – see Fig. 2

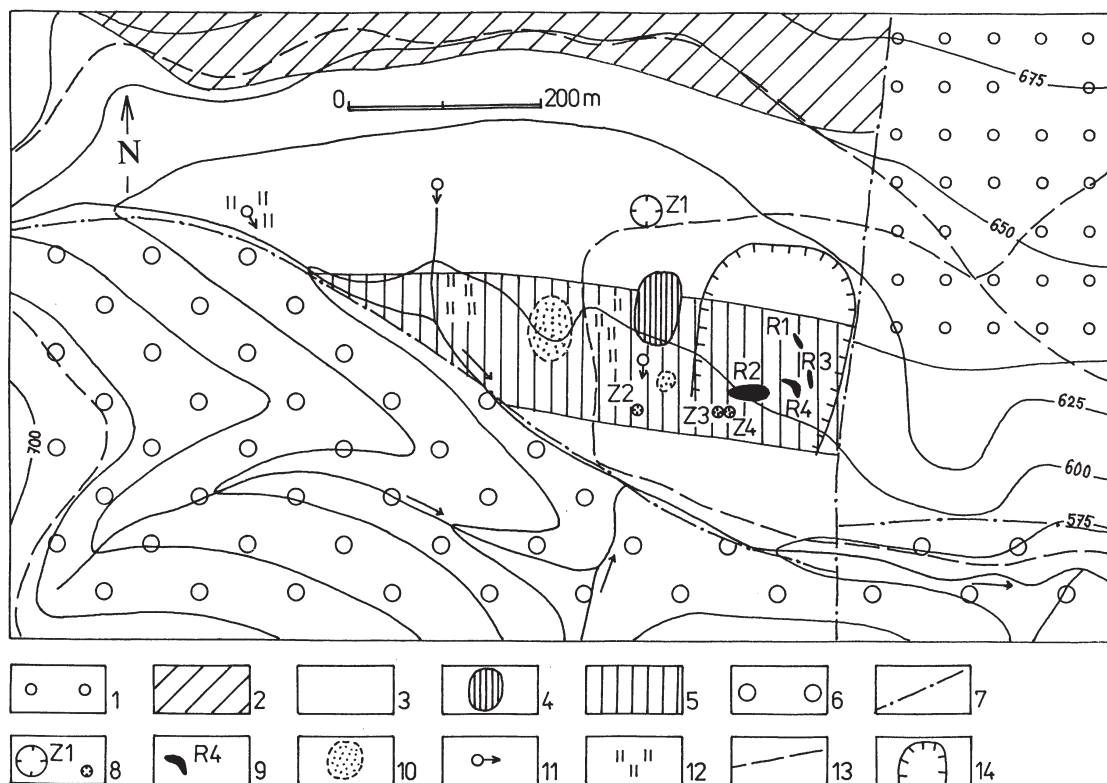
Indeterm. cone: 32 008 ± 3 593 BP (CU 1762) – position R4 – see Fig. 2

*Larix* cones (No. 2): 18 287 ± 1 512 BP (CU 1763) – position R2 – see Fig. 2

Notice: After the manuscript was in the editorship of *Acta palaeobotanica* already two AMS radiocarbon dates were obtained (Dr. G. Morgenroth, Physikalisches Institut des Universität Erlangen-Nürnberg). From samples lying at 90 and 115 cm in the analysed profile (S3), the age beyond the limit of radiocarbon measurement – older than 52 000 BP – was determined (ERL-4532, ERL-4533). These data had further shifted our ideas about the profile age back to the past, at least for the bottom part of the sequence.

## POLLENANALYTICAL RESULTS AND THEIR INTERPRETATION

The organic material taken from the exposed profile wall contained large amounts of plant macroremains, particularly in the lowermost part of the section. Their preservation was so good that at first sight it was not possible to distinguish the peat-like sediment from analogous materials of Holocene age. A greater age was, nevertheless, indicated by the thick layers of inorganic sediments which were present on top of the organic layers. The overburden layers possessed some features of solifluction material, which can be considered as indicating a Pleistocene age of the layers below. The first results of the pollen analysis also suggested that the character of vegetation



**Fig. 2.** Geological and karst situation at the gypsum and anhydrite deposit Šafárka at Markušovce (north-eastern Slovakia), according to Novotný (2002). **1** – multiple layers of Borovany type – Palaeogene; **2** – calstone and slate – Triassic; **3,4,5** – multiple layers of Nová Ves type – upper Perm; **6** – multiple “knol” (basal) layers – lower Perm; **7** – tectonic fractures; **8** – karst dolines; **9** – layers of fossile peat; **10** – raised peat bog; **11** – springs; **12** – wetlands; **13** – forest roads; **14** – rough outline of the quarry in 1999

development differed from that known for the Late Glacial and Holocene from other localities within the area under consideration (Jankovská 1984, 1988, 1991, 1998). However, only with the first  $^{14}\text{C}$  data was objective confirmation for the hypothesis of a Pleistocene age for the samples obtained. The pollen diagram from the profile (Fig. 3) is divided into five “local pollen assemblage zones” (LPAZ, SF 1 – 5).

#### **SF-1: “*Larix* – *Poaceae*”: 115–120 cm and probably even deeper**

The pollen spectrum is dominated by 23% pollen grains of *Larix* accompanied by half that quantity of *Betula alba* t. and a still fewer pollen of *Pinus sylvestris* t., *P. cembra* t. and *Betula nana* t. The ratio AP/NAP is nearly 1:1. Poaceae, Cyperaceae and *Artemisia* dominate amongst the herbs. *Pleurospermum austriacum*, *Polygonum bistorta* t., *Sanguisorba officinalis*, *Pimpinella major* t., *Phyteuma*, *Gentiana* t., *Centaurea scabiosa* and some other herbs pollen types occur sporadically.

#### **Interpretation of LPAZ “SF-1”**

Pollen spectrum “SF-1” represents a vegetation formation which existed under a very cool, continental climate. The absolute dominance of *Larix* pollen grains, always considerably undervalued in the pollen spectrum, confirms the dominant role of *Larix* amongst the tree species. *Betula*, most likely *B. pubescens*, and *Pinus cembra*, along with *P. sylvestris* occurred sporadically within the *Larix* stands. *Betula nana* was growing in the undergrowth. An analogy for such boreal forest merging into forest tundra can be observed at the present day in some areas of continental Siberia. *Larix* is a tree species which, today, forms the polar tree limit in western Siberia, e.g. in the eastern foreground of Polar Ural Mts. and on the Jamal peninsula, as well as further to the east around the Arctic circle. It also forms the alpine tree limit on the Polar Ural Mts. Larch is thus able to grow in regions with a considerable areal extent of deep permafrost. Extensive areas covered by larch stands also reappear many kilometers to the north of the larch



polar tree limit, i.e. on the alluvial areas of great rivers, within the typical tundra zone. This is due to a decrease in the depth of permafrost in such situations (field observation by the first author on the Jamal peninsula). *Larix* thus belongs among the tree species most resistant to an extremely cold climate.

Closed stands of larch with stone pine can be seen in central Europe right at the tongue of the Aletsch glacier in Switzerland at an altitude of about 2000 m. It is possible that a similar larch stands with stone pine with a taiga-like character were present in intracarpathian basins in the Last Glacial. Relicts of this vegetation formation were last extensively distributed below the High Tatra Mts. in the Late Glacial. They were destroyed by the rapid expansion of spruce at the beginning of the Holocene (Jankovská 1984, 1988, 1991, 1998). Interesting palaeoecological results have been presented by Magyari et al. (1999) from the locality of Nagy-Mohos Lake in Hungary, at the border with Slovakia. From samples at the basis of profile ( $^{14}\text{C}$ - 21 756±247 BP) they have reconstructed: “a boreal parkland forest dominated by *Pinus cembra* and *Pinus sylvestris* in the canopy layer and with a sporadic admixture of *Larix* sp. and probably *Picea abies*”. The studies of our Hungarian colleagues, of Bennet et al. (1991) and Willis et al. (2000) perfectly match the results of palaeoecological research in Slovakia from the Late Glacial (Jankovská op.cit.) as well as the results presented here from Šafárka.

The pollen identifications support the possibility of the occurrence of *Betula nana* bushes. Nevertheless, this assumption can only be fully corroborated by findings of their macroremains. Light larch stands would have enabled the existence of a rich herb layer. Herbs must have been completely dominant in smaller treeless enclaves whose existence was dependent on local conditions (wetlands, natural meadow biotopes, biotopes formed after natural catastrophes – fire, wind damage, landslides, etc.). Even in the case of this type of vegetation, an analogy can be seen in the contemporary vegetation of continental Siberia. This is illustrated by the occurrence of *Pleurospermum austriacum* whose typical pollen grains have been recorded throughout the whole of the profile. A high occurrence of Cyperaceae and Poaceae is similarly recorded as is the case at the present time within both

the forest tundra and tundra zones. The indication is of extensively distributed wetlands – the initial stadia of future peat-bogs, moist pristine meadows, thermokarst lakes, depressions, etc. The taxa found include *Sanguisorba officinalis*, *Thalictrum*, *Polygonum bistorta*, *P. viviparum*, *Pleurospermum austriacum*, *Phyteuma*, *Gentiana*, *Cardamine* and species of several other families. Characteristic for this cold period is the enhanced occurrence of *Artemisia* pollen. Species of this genus could either be growing in this landscape or their pollen grains could have been transported from places of their high occurrence, e.g. from contemporary Hungary. The sporadic presence of pollen grains of some climatically more demanding trees such as *Corylus*, *Ulmus*, *Quercus* and *Carpinus* is also interesting. It is possible to hypothesize that these tree species existed in refuges on the southern slopes of the Carpathians and in Pannonia, even at times when boreal forests were dominant both in the Carpathians and even some parts of contemporary Hungary. As Willis et al. (2000) state, thermophilous trees (*Carpinus*, *Quercus*, *Ulmus*, and *Tilia*): “must have survived in microenvironmentally favourable pockets”.

The age of this very cold phase is so far unknown. A relatively high radiocarbon age more than 52 000 BP was obtained from the sample 115 cm (small piece of wood) – by AMS dating.

#### SF-2: “*Betula* – *Larix*”: 95–115 cm

The vegetation development of this period is represented in the profile by a distinct sediment layer dominated by large pieces of wood and with other remains of tree species. The pollen of *Betula alba* t., with average values of about 50%, prevails in the pollen spectra. *Larix* attains values of about 10%, which is high for this species. The continuous occurrence of pollen grains of *Betula nana* t. and *Salix* is observed, *Pinus sylvestris* t., *P. cembra* t. as well as *Picea*, *Corylus* and *Ulmus* have minimal values. The herb pollen is dominated by Cyperaceae, Poaceae and *Artemisia*. Continuous pollen curves characterize Daucaceae, Asteraceae Tubuliflorae, Rubiaceae, Rosaceae and Brassicaceae. A continuous pollen curve of *Pleurospermum austriacum* is typical of SF-2. Of the Pteridophyta spores, those of *Equisetum* and Polypodiaceae occur regularly, although at low values.

### Interpretation of LPAZ “SF-2”

The vegetational cover at the Šafarka area, as well as in its more distant surroundings, was larch forests with a high admixture of *Betula* cf. *pubescens* or, eventually, *B. alba*. *B. nana* and *Salix* were growing in the undergrowth. The very low pollen values of *Pinus sylvestris* t. and *P. cembra* t. do not indicate the occurrence of those species in the neighbourhood. The same holds true for *Picea*, *Corylus* and *Ulmus*. If these tree species really were growing in the area, then their occurrence was only sporadic.

Larch stands with birch provided favourable light conditions for both the brush and herb layers. Wetlands, i.e. enclaves of natural meadow and peat-bog formations, were still quite common. Small lakes and pools could have been formed due to the thawing of permafrost, as the consequence of landslides, etc., and also in karst dolines. The area can be assumed to have provided habitats for a number of plant taxa with a present arcto-alpine distribution, growing here along with elements of rocky steppes. The occurrence of *Artemisia*, *Campanula*, *Centaurea jacea*, *Cerastium*, *Heraclium*, *Pimpinella major*, *Pleurospermum austriacum*, and *Saxifraga granulata* should be mentioned, and also an increased occurrence of *Daucaceae*, *Ranunculaceae*, *Rubiaceae*, *Rosaceae*, *Brassicaceae* and *Asteraceae Tubuliflorae*. The vegetational situation of phase SF-2 at Šafarka is very similar to the situation in the Preboreal and Boreal at the locality Chornaya Gorka in the Polar Ural Mts. (67°05'N; 65°21'E; 170 m asl.; Jankovská & Panova in press). This locality was, at that time also dominated by stands of birch with larch, just before the spruce expansion during the rather moist, warm Atlanticum period. Phase SF-2 can be characterized by cool, continental climate and the age of it is so far unknown. After AMS radiocarbon dating is not only sample “115 cm” but also sample “90 cm” older than 52 000 BP.

### SF-3: “*Picea* – *Pinus* – *Betula*”: 40–95 cm

This phase is very distinctly expressed in the pollen spectrum. The lower limit is marked by a sudden increase in *Picea* (50%) and *Pinus sylvestris* t. (40%) pollen values and a similarly sudden decrease of those of *Betula* and *Larix*. From this time on *Alnus* has a con-

tinuous curve and also *Quercus* and partially *Tilia* but at lower values. Pollen values of *Corylus* and *Ulmus* remain mostly the same as in the preceding phases. Sporadic pollen finds of *Fagus* and *Abies* are recorded, while somewhat more pollen grains of *Carpinus* are present. The pollen curves of *Betula nana* t. and partly of *Salix* remain continuous until the end of the phase.

The values of *Artemisia*, *Cyperaceae*, *Poaceae*, *Asteraceae Tubuliflorae*, *Daucaceae* and other herb taxa show a strong decrease during the first, (older) part of the phase. Pollen grains of some herbs, e.g. *Pimpinella major* t. and *Pleurospermum austriacum*, are completely absent. However, the younger phase is marked by a sharp increase in *Cyperaceae* along with *Daucaceae*, *Filipendula* and *Polypodiaceae*. Simultaneously sporadic coenobia of some algal taxa of the genus *Pediastrum*, zygotes of *Spirogyra* t., and *Zygnema* t. (*Conjugatophyceae*) occur. High values are temporarily attained by *Sphagnum* spores shortly before an increase in *Polypodiaceae* spores.

### Interpretation of LPAZ “SF-3”

This very distinct change in vegetation composition indicates a similarly distinct and relatively sudden change in climate. The evidence is of a substantial increase in temperature. Linked to this increase in temperature was a favourable change in the hydrological situation. Thawing of the permafrost and glaciers, and an increase in liquid precipitation (in contrast to the previous – snow and ice) can be assumed to have followed the increase in temperature. The response to favourable soil moisture and temperature was a rapid spread over the area of *Picea*, *Alnus* and also *Pinus*. Shady spruce stands were the main competitor to the previous light stands of larch. The competitively weak *Larix* became gradually displaced from the undergrowth, as too were the birch trees. Climax forest stands must have developed under the prevailing climatic conditions in the course of this vegetation phase. Spruce forests with an admixture of other tree species developed in dependence of the variation in local conditions. *Larix* remained a stable component of the forest stands, and could even have been the dominant species, e.g. with *Pinus cembra*, in extreme localities. This seems to be quite likely, since a number of untypical *Pinus cembra* pollen grains, which

were difficult to determine, have probably been included in the pollen diagram as *Pinus sylvestris* t. *Alnus* (cf. *incana*) was spreading into the forested wetlands. *Betula nana*, and probably also *Alnus viridis*, could have been growing in the area. However, the climatically more demanding tree species probably did not grow locally. The source of their pollen is probably the climatologically more suitable region of southern Slovakia and Hungary.

Some changes have also taken place in the herb layer since the beginning of phase SF-3. The heliophyta have withdrawn but, nevertheless, could still occur as relicts in suitable localities. The restricted occurrence of wetland species during the older phase can probably be explained by the spread of spruce and alder on to the previously treeless wetlands. During the younger phase, a decrease can be observed in the occurrence of spruce and alder, and a new expansion of Cyperaceae, *Valeriana officinalis*, *Filipendula*, *Thalictrum*, Daucaceae, *Equisetum* and *Sphagnum*. The pollen of water plants (*Batrachium*, *Potamogeton*, *Typha latifolia*) indicates the existence of water actually at the locality. The findings of water algae are evaluated in a later section "Origin and evolution of the deposit". The forests represented by LPAZ SF-3 have an analog in the contemporary continental middle to northern spruce taiga with an undergrowth of ferns.

#### **SF-4: "Picea and Alnus": 10-40 cm**

This phase is characterized by maximum pollen values of *Picea* and *Alnus*, minima of *Betula alba* t., low values of *Pinus sylvestris* t., and regular occurrence of *Tilia* pollen. A decrease in the number of pollen of all the herb taxa of wetland communities is noticeable along with the maximum occurrence of the spores of *Lycopodium (annotinum, clavatum and selago)*.

#### Interpretation of LPAZ "SF-4"

LPAZ "SF-4" probably represents the maximum of the climatic optimum within this so far imprecisely delimited Last Glacial period. Spruce stands attained their maximum distribution and the vegetation of the region was probably very similar to that of the submontane basins of the High Tatra Mts. in the first part of the Atlantic period (Jankovská 1991). A further increase in temperature, favourable soil-hydrological conditions and probably also

increased precipitation are indicated by the spread of spruce and alder. Shady closed spruce stands limited the distribution of *Pinus sylvestris* and there are minimum numbers of *Betula* (tree species). *Betula nana* was practically forced out of the region. In contrast, *Larix* and *Pinus cembra* most probably remained as important components of the forest in those localities where spruce was unable to become adequately established. The suggestion of a temperature optimum within this period, is corroborated by the sporadic but regular occurrence of *Tilia* pollen. Despite being dispersed from a great distance, it indicates that the area of vegetation requiring higher temperatures had shifted northwards in response to improved climate conditions. Also of interest is the find of a single coenobium of the water alga *Pediastrum simplex*. On the basis of its contemporary ecology, this is considered to be a demanding taxon both in terms of climate and trophic status (Jankovská & Komárek 2000, Komárek & Jankovská 2001).

Spruce stands with alder and a abundant ferns (Polypodiaceae) had probably even colonized the remaining areas of the originally treeless wetland biotopes. This caused the retreat of Cyperaceae and conspicuously restricted the occurrence of *Filipendula*, an important element of the natural meadows and alluvial communities. *Equisetum*, *Heracleum*, *Peucedanum* and Ranunculaceae also disappeared. In addition to the ferns an important constituent of the herb layer in the spruce stands were the club-mosses (*Lycopodium annotinum*, *L. clavatum* and *L. Selago*). The forests in immediate vicinity and also in the wider surroundings probably possessed the character of coniferous middle taiga.

#### **SF-5: "Pinus": 5-10 cm**

The last and, youngest LPAZ was delimited on the basis of a sharp decrease in both the *Picea* and *Alnus* pollen curves, and of an equally sharp increase in *Pinus sylvestris* t. The values of all the other forest tree species (*Larix*, *Betula alba* t. and *Pinus cembra*) remain low, and at the same level as in the previous LPAZ SF-4. AP reaches 80% being comprised mainly of *Pinus sylvestris* t. (60%). The NAP at 20%, is comprised of Cyperaceae, Poaceae, *Artemisia*, Asteraceae and Daucaceae. The occurrence of the pollen of water plants is sporadic (*Batrachium* t., *Myrio-*



*phyllum spicatum*, *Typha angustifolia* t.). The curve of Polypodiaceae spores has the same form as that of *Picea*, i.e., it falls sharply from about 45% to 5%. Coenobia of the algae *Botryococcus* sp. div. and of *Spirogyra* t. zygospores occur at the end of the zone.

#### Interpretation of LPAZ "SF-5"

Since this LPAZ is represented by a single pollen spectrum any interpretation has to be made with caution. It is only possible to speculate that the climate became worse – that temperatures fell. This is what could have caused the retreat of spruce, thus providing more space for pine with its greater light requirements. It is probable that during the period during which the sediments of phase SF-5 were being deposited the vegetation cover was formed by open stands of *Pinus sylvestris*, *Larix*, *Pinus cembra* and *Picea* with an admixture of *Betula* tree types. It cannot be excluded that the sediment between 5 and 10 cm depth represents the onset of a cool phase. The finds of the water algae *Botryococcus* sp. div. (coccal green algae) and zygospores *Spirogyra* t. (Conjugatophyceae) could indicate the existence of smaller pools directly at the site, as corroborated by the finds of *Batrachium*, *Myriophyllum spicatum* and *Typha angustifolia* (and *Sparganium* ?).

The predominantly inorganic material which caps the profile is, at the present state of the investigations, considered by geologists as resulting from solifluction.

### ORIGIN AND EVOLUTION OF THE DEPOSIT

There are very few pieces of evidence for explaining the situation which led to the sedimentation of organic material at the study site. The considerable accumulation of large pieces of wood and tree remains e.g. whole trunks, root systems, branches, cones, seeds, etc. could have been the result of some natural catastrophe. A wetland vegetation biotope could have originated behind a barrier of inorganic material which had accumulated as the result of a land-slip, solifluction or the presence of thermokarst. This could have been followed by sedimentation of autochthonous peat-like material. Novotný (2002) has demonstrated the presence of both recent and fossile

karst doline in the Šafárka locality. It, therefore, seems plausible to assume that the locality Šafárka where the sedimentation of humolite was taking place was such a doline. However, it is interesting that, despite the distinctive situation with large wood remains, pointing to their accumulation during a sudden catastrophe, the nature of the pollen curves do not suggest such a catastrophe. The development of all the curves in that part of the profile, i.e. between 95 and 120 cm, can be logically substantiated. They reflect the gradual transformation of larch stands of boreal character into birch-larch stands, probably with an admixture of stone pine. In the period represented in the sediment from 95 cm upwards, the locality had the character of wetlands with vegetation of wet and peaty meadows. The finds of water algae coenobia, although occurring somewhat sporadically, indicate the existence of a small water body.

In the sample from a depth of 90 cm, where the maximal amount of *Sphagnum* spores were found, the coenobium *Pediastrum boryanum* var. *cornutum* was recorded. This species is typical of biotopes of water bodies (Komárek & Jankovská 2001). The isolated finds of coenobia of *P. duplex* var. *asperum*, *P. duplex* var. *rugulosum* and *P. simplex* lead to a similar conclusion. The last mentioned taxon prefers a eutrophic environment and, according to its contemporary distribution, higher temperatures (Komárek & Jankovská 2001). Since it occurs at the climatic optimum of the studied profile, its presence could indicate higher summer temperatures, typical for the otherwise harsh continental climate of present day Siberia. Zygospores of water algae of the group Conjugatophyceae (*Spirogyra* t., *Zygnema* t.) mostly indicate the presence of small pools which are gradually being overgrown. Even water plants could grow as evidenced by the pollen finds of *Batrachium*, *Potamogeton* and *Typha latifolia*. In addition, the pollen of *Myriophyllum spicatum* and *Typha angustifolia* (or *Sparganium*) was found in the uppermost sample, which was deposited an already cooler period. The existence of water body is demonstrated by a higher number of coenobia finds of the alga *Botryococcus* sp. div. and zygospores of *Spirogyra* t. The former taxon is often found among the palaeobotanical remains in sediments from very cold periods where even taxa of the genus *Pedias-*

*trum* are totally missing. The zygospores of *Spirogyra* t. were found by the first author in the sediment of a small pool in northern Spitsbergen under a high-arctic climate.

## DISCUSSION

The results of palaeobotanical studies of peat-bog sediments of Late Glacial age have already proved that the development of vegetation in the region of the Slovakian Carpathians took quite a different path than in the Czech Hercynicum (Pokorný & Jankovská 2000). Striking were the findings of high pollen values of *Larix* and numerous seeds of *Pinus cembra* in the Late Glacial deposits. The two tree species were shown to have been growing eastwards and south-eastwards of the High Tatra Mts. (localities Hozelec and Sivárňa) towards the end of the Last Glacial period (Jankovská 1984, 1988, 1991). Stands with the character of the light stone pine – larch Siberian taiga were extensive in area, particularly in the climatically warm period of the Alleröd. They evidently covered the bottoms of basins from 500–600 m upwards, forming the alpine tree limit. *Picea* and *Pinus sylvestris* were also sporadically present in these stands. Finds of macroremains of *Larix* and *Pinus cembra* from the Late Glacial, and those of *Picea* and *Pinus sylvestris* from the Early Holocene, provided the basis for the theory that all these species survived the Last Glacial period in the area. The newly discovered organic sediments, buried under a nearly 5 m thick capping layer of inorganic material at the locality Šafárka, add extra evidence to clarify the situation. According to the results, analysed so far, a “natural archive” in the form of the profile studied, discovered at Šafárka, covers at least the period between about 16 000 and more than 52 000 BP. The palaeobotanical findings prove that forest stands formed the vegetation cover of basins and lower mountain ranges even during the coldest phases of the Last Glacial. Their dominant species was *Larix* with *Pinus cembra*. During the climatically cold amplitudes, *Betula* cf. *pubescens* was the more common species while in warmer and moist conditions it was *Picea*. At present, no typical analog to this Pleistocene stone pine – larch forest can be found in Slovakia. An analog can be seen, however, in Siberia and, partly, in the

Alps. Stands with *Picea*, prevailing since the warm amplitudes of Last Glacial, can have an analog in the present submontane spruce forests at the foot of the Tatra Mountains. However, *Abies* and *Fagus* and other more temperature dependent species were absent there in the Last Glacial.

In terms of archaeology, the time span reflected by the Šafárka profile corresponds partly with the Gravettian – the period of mammoth hunters. Their nearest localities are situated to the south and north of Šafárka (Kamińska & Kozłowski 2002, Sobczyk 1995). Our palaeobotanical results provide some information about the vegetation and landscape of the period in which the Gravettian people and the big Glacial fauna were living and moving. According to Kamińska and Kozłowski (2002), Slovakia and southern Poland were peripheral regions of the major Gravettian centres between 30–25/24 Kyr. B.P. Only short-term hunting camps were situated there and they differed distinctly from the long-term base camps situated in Moravia and Austria.

Information on the past of the Carpathian landscape has only been obtained with great difficulty and often only by chance. Very interesting data on the vegetation, climate and other environmental features has been provided by palaeobotanical studies from neighbouring Hungary. The vegetation situation from at least 14 000 to 22 000 BP was revealed in a profile of sediments of the earlier Nagy-Mohos Lake (Magyari et al. 1999). Other results from Hungary (Willis et al. 2000) also correspond well with the results we have obtained so far. Their studies contain data on the palaeoclimate, evolution of the deposit proper, etc. (see also Stewart & Lister 2001). The discussion on the occurrence of permafrost is in accordance with the conclusions of the Czech authors (Czudek 1986, Jankovská 1997).

## CONCLUSIONS

Chronologically the pollen profile from Šafárka covers at least between 16 000 and more than 52 000 <sup>14</sup>C years BP. It, therefore, involves the period of the younger part of the Last Glacial. Within the time span and in a wider context it contains the period of the Gravettien represented by the culture of mammoth hunters.

Pollen analysis of the base of the profile showed a very cold period marked by larch forests, probably similar in character to continental forest tundra or park like northern taiga. The subsequent warming was reflected in the spread of birch-larch stands. Increased moisture availability due to the thawing of snow, surface ice and permafrost, resulted in the rapid spread of spruce. Its expansion at first caused the stagnation and then the retreat of the larch stands. In the warm and moist phase of the Last Glacial, the region was covered by spruce stands with an admixture of larch, stone pine, scots pine and tree birch. Alder was spreading into the alluvia of brooks and in wetlands. The area of climatically more demanding vegetation was shifted northwards. Later a decrease in temperature and humidity caused the rapid retreat of spruce and spread of pine.

The wetland (water body, peat bog?) in witch the organic material at Šafárka were deposited could have originated in several ways (land-slip, solifluction, thermokarst processes, etc.). It seems very likely that a karst doline had been formed there (Novotný 2002) which led to the accumulation of plant material under anaerobic conditions. This process could have taken place in a peaty wetland, a peaty meadow or a small water body.

This contribution provides the first, preliminary palaeobotanical results for this site. A more detailed interpretation is expected from the analysis of other similar profiles.

#### ACKNOWLEDGEMENTS

We are grateful to Dr. L. Novotný for all information about the geological situation of the site and Dr. L. Kamińska for the archaeological remarks. Our thanks must be expressed to Dr. J. Úlehla for the translation of this article in English and to Mrs. Z. Formánková and Ing. P. Jankovský for technical assistance. Prof. Dr. S. Hicks, Dr. W. Granoszewski and Dr. P. Pokorný are gratefully acknowledged for their constructive suggestions for improving the manuscript and special for the language correction. We are also grateful <sup>14</sup>C laboratory, Faculty of Natural Sciences, Charles University, Prag and <sup>14</sup>C (AMS) laboratory, Institute of Physik, University, Erlangen-Nürnberg, Germany for all radiocarbon datings. The radiocarbon dating was only possible through the support of the Grant Agency of the Academy of Sciences of the Czech Republic no. A 6005904/1999.

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