Pollen analyses of sediments from the summit of the Praděd range in the Hrubý Jeseník Mts (Eastern Sudetes)

Pylové analýzy z vrcholových poloh hřebene Praděda v Hrubém Jeseníku (Východní Sudety)

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Pollen diagrams, based on sediments from four small mires on the eastern summits of the Jeseníky Mts (the Praděd-Altvater group) in the Sudetes, the Czech Republic, show the development of vegetation in the area since the Subboreal period (ca 4700 B.P.). Stands of *Corylus avellana* with *Picea abies* and some *Tilia* cf. *platyphyllos* covered the eastern summits of the Jeseníky Mts between ca 5000 and 3000 B.P. *Corylus avellana* probably played the same role as *Pinus mugo*, common at similar altitudes in other Sudetes ranges. Between ca 3000 and 500–400 B.P. *Picea abies*, *Fagus sylvatica* and *Abies alba* dominated the natural precultural forests at the present alpine forest limit. An admixture of *Acer* (cf. *pseudoplatanus*) and *Ulmus* (cf. *glabra*) is very probable. Human impact (mountain summer grazing, hay making, selective beech cutting) influenced the summit vegetation and lowered the natural forest line from the beginning of the 17th century. The planting of spruce started at the beginning of the 19th century and is well expressed in the pollen diagrams. No traces of *Pinus mugo*, documented by *Pinus sylvestris* type of pollen or macroscopic material, were found.

Keywords: alpine forest line, Hrubý Jeseník Mts, pollen analyses, Sudetes, Upper Holocene, vegetation history

Introduction

This paper presents pollen analyses from the eastern Hrubý Jeseník Mts (Altvatergebirge), Czech Republic, an important range in the Sudetes Mts. Although several pre-war (Fahl 1926, Salaschek 1936, Fritz 1938) or early post-war (Firbas & Losert 1949, Opravil 1956, 1957, 1959) pollen analyses exist, we do not know much about the vegetation history of this region. Previous authors did not analyze the NAP elements of the pollen spectra and, therefore, the dating and interpretation of different pollen zones is very difficult, uncertain or even impossible. H. Salaschek (in litt.) recently analyzed two profiles from mires in the saddle between the Velký Máj (our HJ-2-A diagram) and Vysoká Hole, but unfortunately, his diagrams are not yet published. The objective of the pollen analysis of the present authors was to resolve not only palaeoecological, but also geobotanical and phytosociological problems: (1) What was the tree species composition, structure and distribution in stands at the upper forest (alpine) limit before man affected the area, and (2) how much can pollen analyses contribute to discussions about the effect of human activities on the altitudinal limit of the present-day forests.

In this investigation we used a modern standard pollen analyses. Two reference profiles were radiocarbon dated. By publishing the main results we fill one of the gaps in the basic reference pollen analytical data, which has made it difficult to summarize the vegetation history of the Czech Republic.

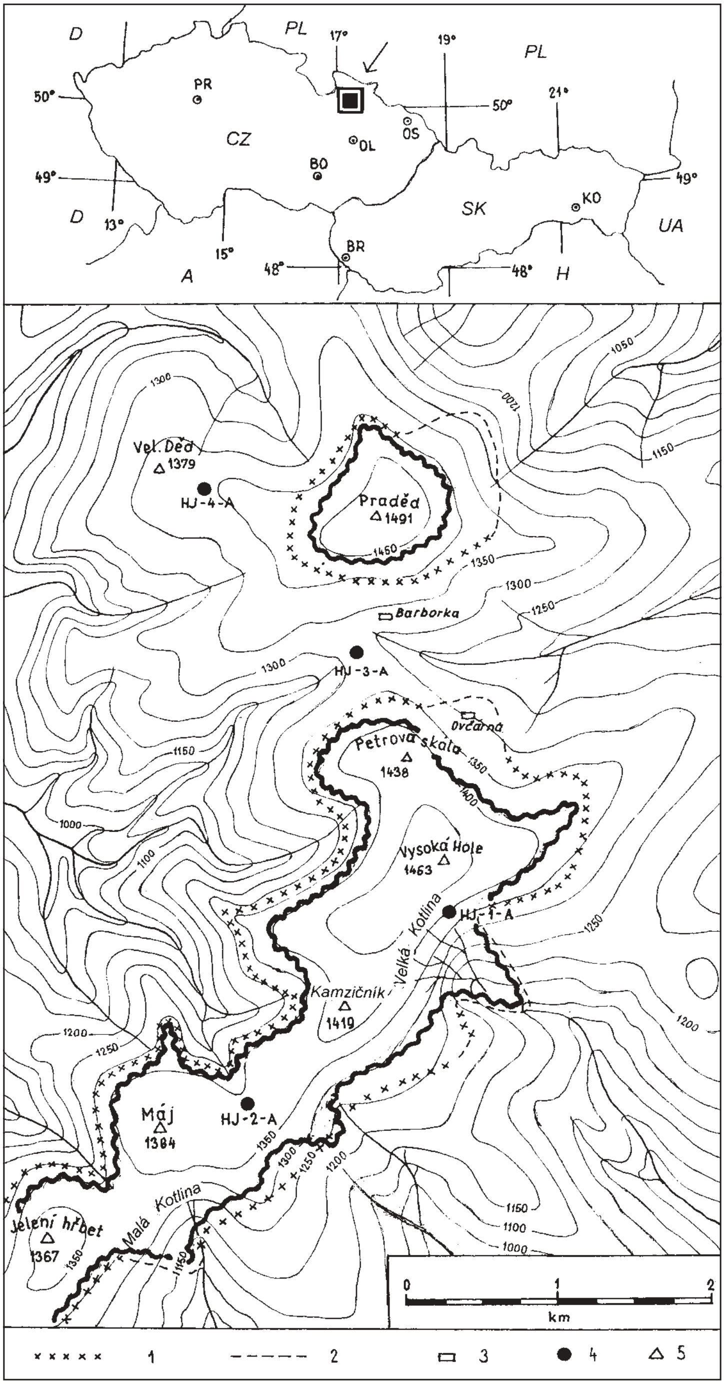


Fig. 1. – Map of the area with location of study sites. 1. Present mean alpine forest line. 2. Artificially or naturally lowered forest limit (according to Alblová 1970, Rypl 1980, Plesník 1984). 3. Mountain chalets. 4. Location of mire sites used in the pollen analyses. 5. Topographic points. The wary line indicates our conception of the reconstructed forest limit before man affected the vegetation ca. 1000 years B.P.

Three pollen diagrams (HJ-1-A, HJ-2-A and HJ-3-A) were analysed by a former student of the Forestry Faculty, University of Agriculture, Brno under the supervision of E. Rybníčková; two were used in his diploma thesis (Rypl 1980). Later on, E. Rybníčková analysed the reference profile HJ-4-A and chose samples for radiocarbon dating. K. Rybníček, who collected the samples in the field, is responsible for the stratigraphic descriptions and together with E. Rybníčková for the interpretation of the results.

Study region

The Hrubý Jeseník Mts are the highest orographic range of the Eastern Sudetes. Our investigations were concentrated on the highest ridges, close to the present forest line in the eastern part of the mountains. This more or less treeless ridge runs in a N–S (SW) direction at an altitude between approx. 1300 m and has the highest point, 1491 m, Praděd (Altvater) Mt (Fig 1).

The climate is very cold and humid. The meteorological observatory on Praděd recorded the following data: mean annual temperature of 9° C, annual precipitation of 1330 mm; continuous snow cover with a mean of over 150 cm is from the beginning of October to the middle of May (Tejnská & Tejnský 1972, Lednický et al. 1973). The humidity is increased by very common fogs at the summit. Strong winds from the west are locally regulated and accelerated according to anemo-orographic principles (Jeník 1961) and significantly affect the forest tree limit.

The summit ridge is broad and more or less flat with scattered blocks of schists. Migmatitic and other gneisses are the main rocks. The vegetation in the area is generally poor, mostly acidophilous, represented first of all by *Carici fyllae-Nardetum* Jeník 1961, *Festuco supinae-Nardetum* Šmarda 1950, *Thesio alpini-Nardetum* Jeník, Bureš et Burešová 1980, *Crepido-Calamagrostietum villosae* (Zlatník 1925) Jeník 1961 and *Calamagrostio villosae-Piceetum* (Tx.1937) Hartmann 1953 close to, below and above the present forest limit. Existing stands of *Pinus mugo* agg. are of secondary origin, introduced at the end of the 19th century (Hošek 1963, 1973).

An exception to the more or less monotonous mountain vegetation is that in the areas of the Velká and Malá Kotlina glacial cirques. Their geomorphic, mesoclimatic and hydrologic characteristics, and nutrient rich environment result in a rich local flora and fauna. Regular avalanches depress the forest limit to about 1100 m and keep the site free of forest. Jeník et al. (1980) describe 29 phytosociological associations for the Velká Kotlina area and over 500 species of vascular plants and mosses are found there (see also Šmarda 1950).

Methods

The material for pollen analyses was collected from the sites of freshly dug pits at all the mire sites and stored in metal boxes 10 × 10 × 50 cm. The physical properties of the sediments were described in the field and components of the the sediment determined later in the laboratory, in both cases using the method of Troels-Smith (1955). Colour of sediment refers to Munsell Soil Color Charts (Munsell Color Company, Baltimore 1954). The peat samples for pollen analysis (mostly collected at 5 cm intervals) were treated by acetolysis. Samples with a high content of mineral particles were pretreated with HF. At least 500, but usually over 700 pollen grains were counted per sample. Pollen diagrams are based on total pollen (AP + NAP = 100%). The percentages of spores are related to the total pollen.

The samples for radiocarbon dating were taken from the material stored in the metal boxes after all visible roots and other macroscopic remains were removed. The dating was done in the C14 Labor der Niedersächsischen Landesamt für Bodenforschung in Hannover (at that time headed by Mebus Geyh). Conventional uncalibrated 14C dates in years B.P. are placed on particular diagrams. Data in brackets are the approximate ages derived either from peat accumulation curves or from synchronization of pollen curves. The time zoning follows the chronozones proposed by Mangerud et al. (1974).

The nomenclature of vascular plants and mosses follows that of Neuhäuslová & Kolbek (1982). Nomenclature of sporomorphs is conventional and does not need to correspond to present names of the plant producers.

Study sites

The material for pollen analyses is from four small mires located along the summit parts of the mountain range between Praděd (Altvater) and Velký Máj (Maiberg) Mts. All of them are situated close to the present forest limit in the sections Velká Kotlina (HJ-1-A) and Máj (HJ-2-A) representing the treeless areas, and Barborka (HJ-3-A) and Velký Děd (HJ-4-A) within present upper forest stands.

Velká Kotlina, HJ-1-A, 1400 m a.s.l. (Fig. 2)

The fen peat is deposited on and around the outflows of springs at many sites in the Velká Kotlina cirque. One of the small sloping mires in an area of about 50 m^2, situated below the NW margin of the cirque, not on a avalanche route, was chosen for sampling the material. Rich fen and spring vegetation cover the mire and consists of *Molinia caerulea* (dominant), *Eriophorum latifolium, Parnassia palustris, Carex flava, C. echinata, C. nigra, Equisetum limosum, Pinguicula vulgaris, Viola biflora, Bartsia alpina, Polygonum bistorta, Sellaginella sellaginoides, Trollius altissimus, Caltha palustris, Chaerophyllum hirsutum, Deschampsia cespitosa, Alchemilla* sp.*, Nardus stricta, Potentilla erecta, Salix capraea, S. silesiaca*; among mosses *Cratoneuron commutatum, Philonotis seriata, Anisothecium squarrosum, Campylium stellatum* and *Bryum* sp. are the most common.

The fen peat is of 40 cm maximum depth, humified and with no macroscopic remains except for small twigs of *Salix* and roots of present plant cover (see Table 1). Comparing this section with the neighbouring radiocarbon dated profiles, it was estimated that the beginning of fen peat accumulation was ca 1200 years B.P. The preceding minerogenic sediments of sand and clay were deposited in and around an active spring and are estimated to be ca 1800–2000 years old.

Velký Máj (Maiberg), HJ-2-A, 1350 m a.s.l. (Fig. 3)

A small peat deposit of about 1 ha in size is part of a discontinuous mire complex situated in the saddle between the Máj and Kamzičník Mts. It originated in the outflow of springs and accumulation of rain and melt waters that collected in the saddle between the slopes. The deposition of peat is retarded by erosion in several places due to the sparse snow cover and exposure of the surface to strong wind and frost, especially during winter. The present vegetation of the mire consists of acidophilous and oligotrophic plants with dwarf shrubs and *Sphagnum* moss. *Vaccinium myrtillus, V. vitis-idaea, V. uliginosum, Calluna vulgaris,* *Oxycoccus palustris, Eriophorum vaginatum, E. angustifolium, C. nigra, C. pauciflora, C. limosa, Deschampsia flexuosa, Calamagrostis villosa, Trientalis europaea, Homogyne alpina, Molinia caerulea, Nardus stricta* and among mosses *Sphagnum capillifolium, S. fallax, S. magellanicum, Polytrichum strictum* and lichens *Cladonia* sp., occur there.

Radiocarbon dating indicates that the peat started to accumulate ca 1900–2000 years B.P. In the very beginning it was herbaceous *(Carex)* and ligneous *(Picea alba)* peat, but then *Sphagnum (S. capillifolium, S. fallax,* later also *S. magellanicum), Vaccinium* spec. div. and *Eriophorum vaginatum* became the main component of the peat (Table 1).

Barborka, HJ-3-A, 1315 m a.s.l. (Fig. 4)

A small ombro-oligotrophic mire (about 0.8 ha) situated in the western part of the saddle between the Praděd (Altvater) and Petrova skála (Petrstein) peaks, just below the present forest limit. Its existence is dependent on springs and accumulation of surface rain water, which flows down the slopes.

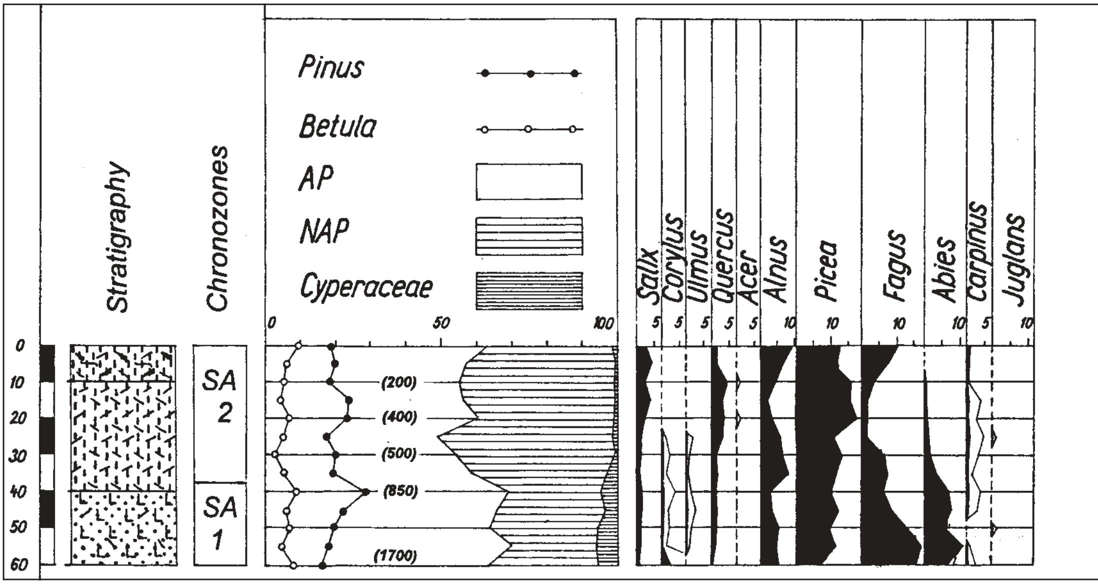
The margins of this treeless peat deposit are covered by waterlogged open spruce stands which are surrounded by spruce forest. The following plants cover the central part of the site: *Eriophorum vaginatum, E. angustifolium, Carex rostrata, C. nigra, C. canescens, C. limosa, Oxycoccus palustris, Empetrum hermaphroditum, Vaccinium myrtillus, V. vitis-idaea, V. uliginosum, Juncus filiformis, Molinia caerulea, Nardus stricta, Potentilla erecta, Trientalis europaea, Deschampsia flexuosa, Calamagrostis villosa, Picea abies* and mosses *Sphagnum fallax, S. balticum, S. capillifolium, S. magellanicum, Polytrichum strictum, Calliergon stramineum, Drepanocladus fluitans.*

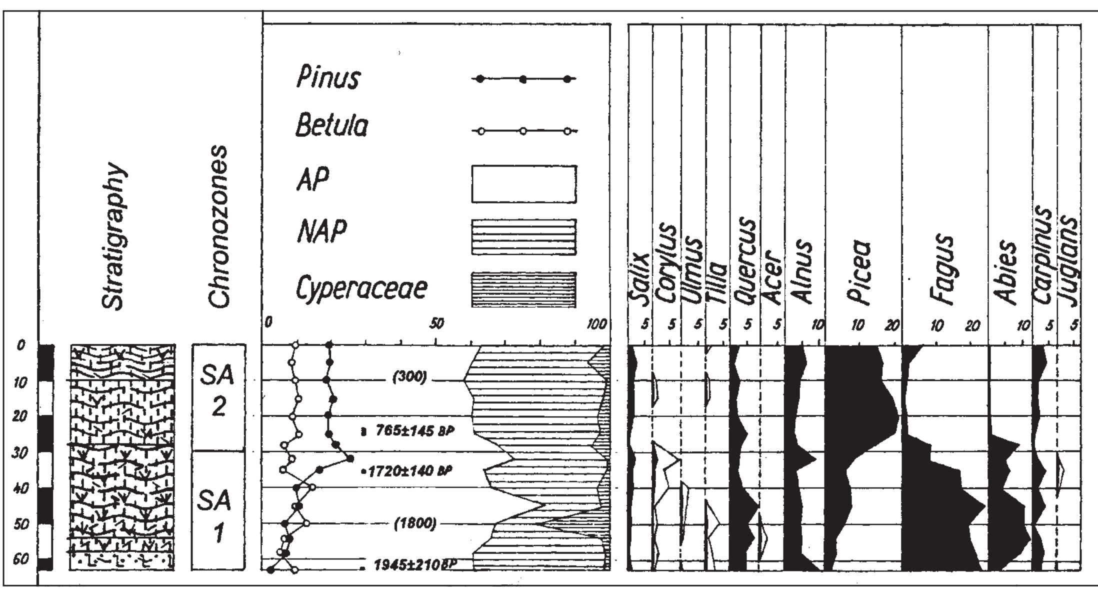
Based on the 14C dated pollen diagram for Velký Děd (HJ-4-A), some 1.5 km to the west, peat growth started here between 4000–4200 years B.P. on minerogenic spring sediments. First organogenic sediments with spruce remains were formed mostly by low-sedge communities. Typical ombrotrophic *Eriophorum vaginatum-Shagnum* peat appears between 1000–1200 years B.P. For the description of the sediments see Table 2.

Velký Děd (Grossvaterberg), HJ-4-A , 1395 m a.s.l. (Fig. 5)

A complex of small ombro-oligotrophic mires is situated in a mountain spruce forest on the flat broad ridge of the Praděd Mt, denoted on maps as Velký Děd. The biggest and deepest peat deposit was sampled. Spring outflows caused the waterlogging of the surrounding forest and resulted in peat formation in the wettest places.

The present vegetation is similar to that at the previous site, Barborka: *Eriophorum vaginatum* (dominant), *E. angustifolium, Carex nigra, C. canescens, Vaccinium myrtillus, V. vitis-idaea, V. uliginosum, Oxycoccus palustris, Potentilla erecta, Equisetum sylvaticum, Homogyne alpina, Doronicum austriacum, Trientalis europaea, Calamagrostis villosa, Picea abies, Salix caprea, Sorbus aucuparia* and the mosses *Sphagnum magellanicum, S. capillifolium, S. fallax, S. girgensohnii, Polytrichum strictum, P. commune* are common there. Though the mire is not the deepest studied, it is the oldest one. The date of the lowest peat layer is 4620 ± 175 years B.P. The peat is similar to that at the previous sites: the oldest minerogenic and mixed minero-organogenic spring sediments are about 4500 and 3000–3200 years B.P., respectively. *Carex-Sphagnum* peat with some wood remains (*Picea abies, Salix)* was laid down up to ca 200 years B.P., when *Eriophorum vaginatum-Sphagnum* peat started to accumulate. For the description of the sediments see Table 2.


Stratigraphy
Chronozones
Pinus
Betula
AP
NAP
Cyperaceae
SA 2
SA 1
(200)
(400)
(500)
(850)
(1700)
Salix
Corylus
Ulmus
Quercus
Acer
Alnus
Picea
Fagus
Abies
Carpinus
Juglans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Chronozones
Pinus
Betula
AP
NAP
Cyperaceae
SA 2
SA 1
(300)
765±145 BP
1720±140 BP
(1800)
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Acer
Alnus
Picea
Fagus
Abies
Carpinus
Juglans

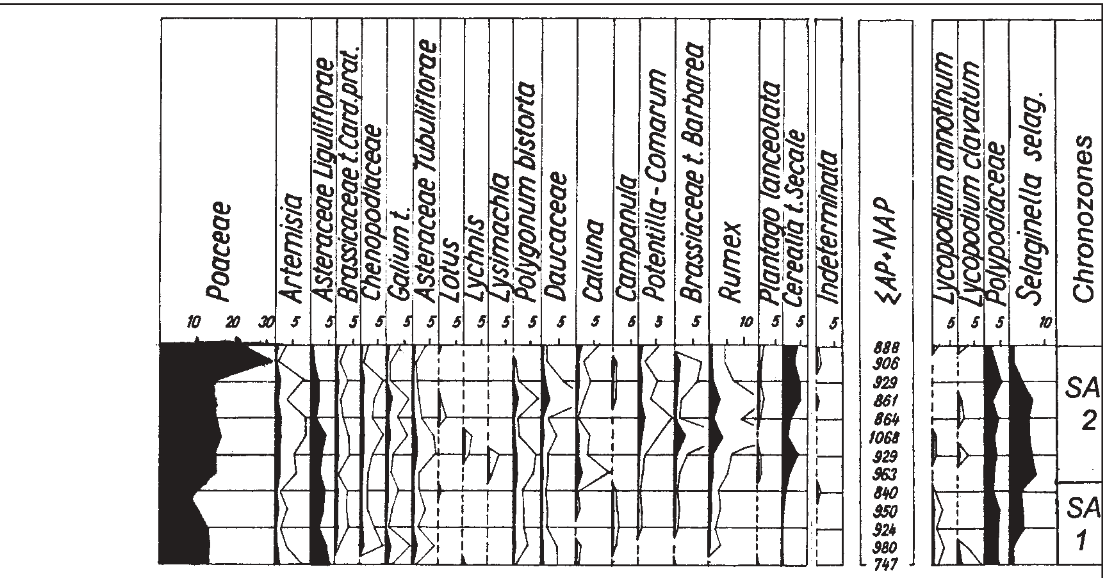


Fig. 2. – Pollen diagram for Velká Kotlina (HJ-1-A), 1400 m a.s.l. Scarce (less than 0.5%) pollen grains (depth cm: pollen type, percentage): 10: *Vaccinium* type 0.2, *Polygonum lapathifolium* 0.1; 25: *Centaurea cyanus* 0.3; 30**:** *Centaurea cyanus* 0.2; 40: *Botrychium* 0.1; 45: *Succisa* 0.3, *Botrychium* 0.1; 55: *Tilia* 0.1. Analysed by R. Rypl and E. Rybníčková.

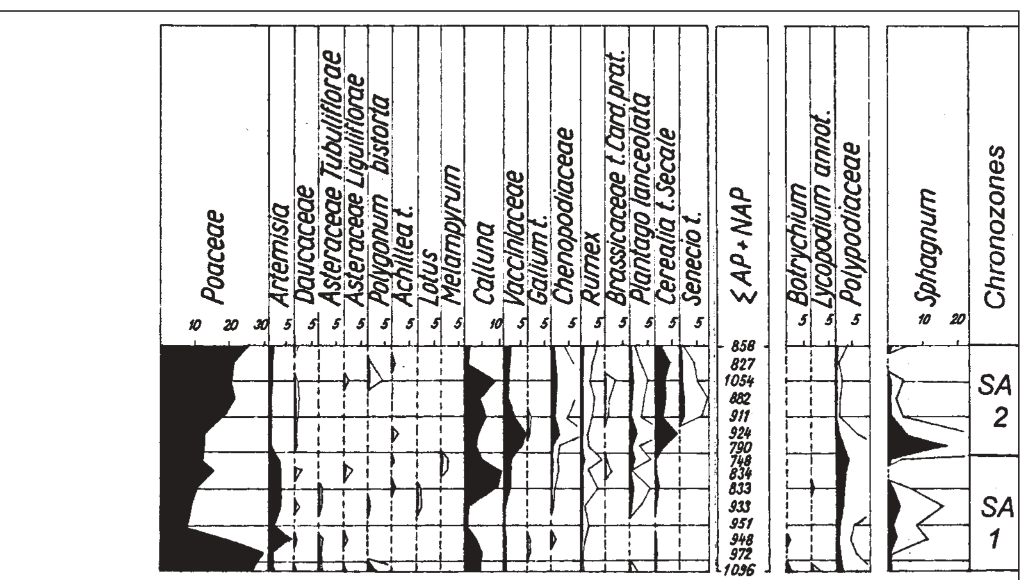
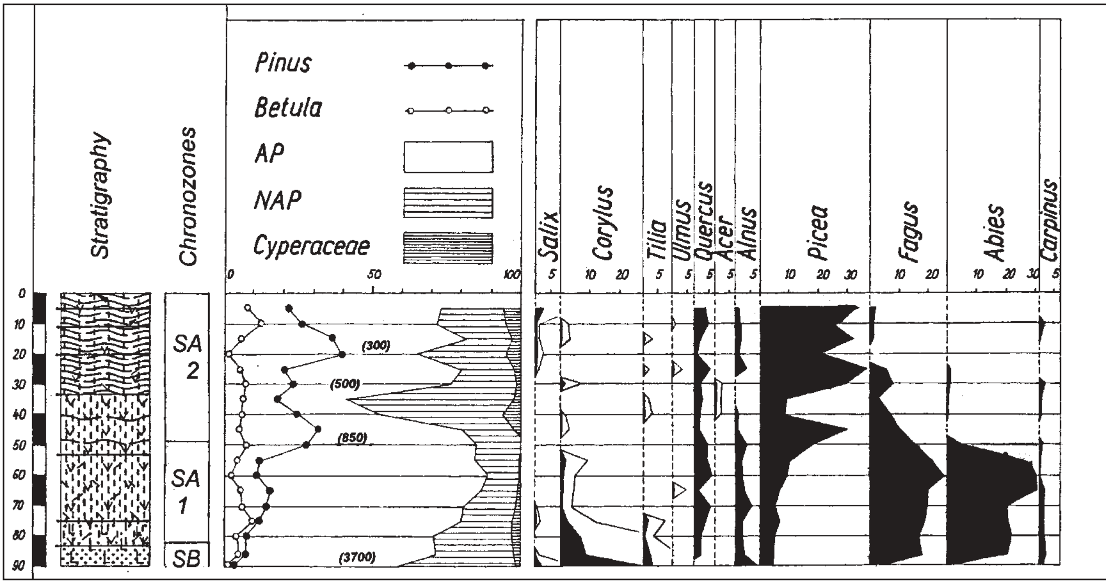
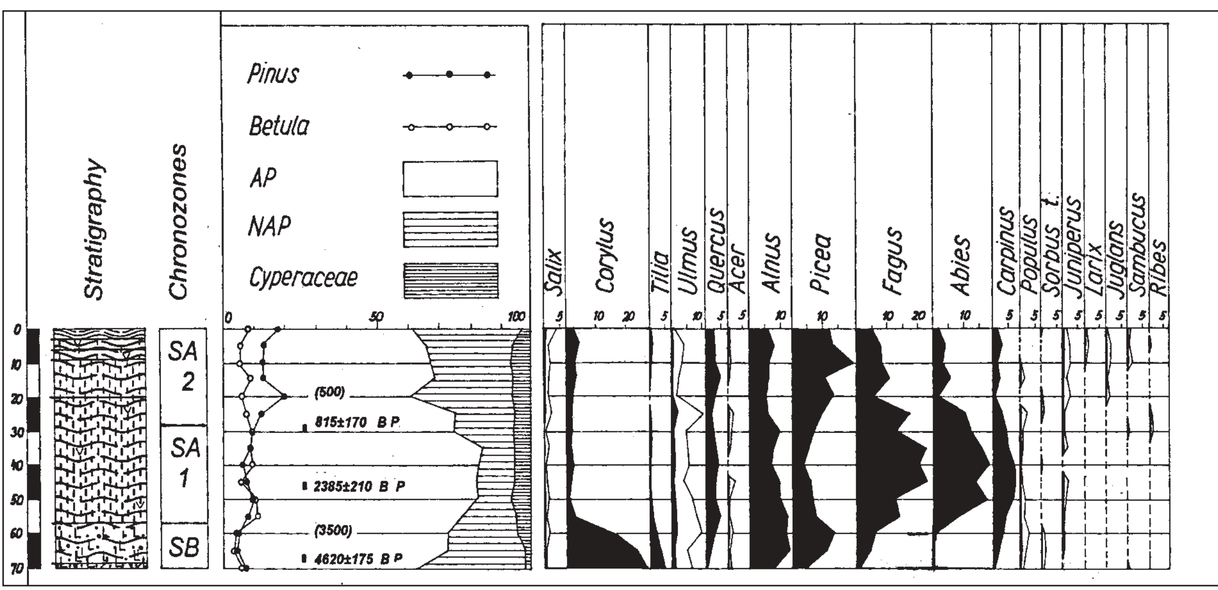


Fig. 3. – Pollen diagram Velký Máj (HJ-2-A), 1350 m a.s.l. Scarce (less than 0.5%) pollen grains (depth cm: pollen type, percentage): 0: *Plantago media* 0.1; 20: *Centaurea cyanus* 0.1; 25: *Centaurea cyanus* 0.1; 30: *Ranunculus arvensis* t. 0.1; 35: *Polygonum aviculare* 0.1, *Urtica* 0.1, *Lychnis* 0.1; 40: *Centaurea cyanus* 0.1, *Silene* 0.1. Analysed by R. Rypl and E. Rybníčková.


Stratigraphy
Chronozones
Pinus
Betula
AP
NAP
Cyperaceae
SA 2
SA 1
SB
(300)
(500)
(850)
(3700)
Salix
Corylus
Tilia
Ulmus
Quercus
Acer
Alnus
Picea
Fagus
Abies
Carpinus


Stratigraphy
Chronozones
Pinus
Betula
AP
NAP
Cyperaceae
SA 2
SA 1
SB
(500)
815±170 B P
2385±210 B P
(3500)
4620±175 B P
Salix
Corylus
Tilia
Ulmus
Quercus
Acer
Alnus
Picea
Fagus
Abies
Carpinus
Populus
Sorbus t.
Juniperus
Larix
Juglans
Sambucus
Ribes

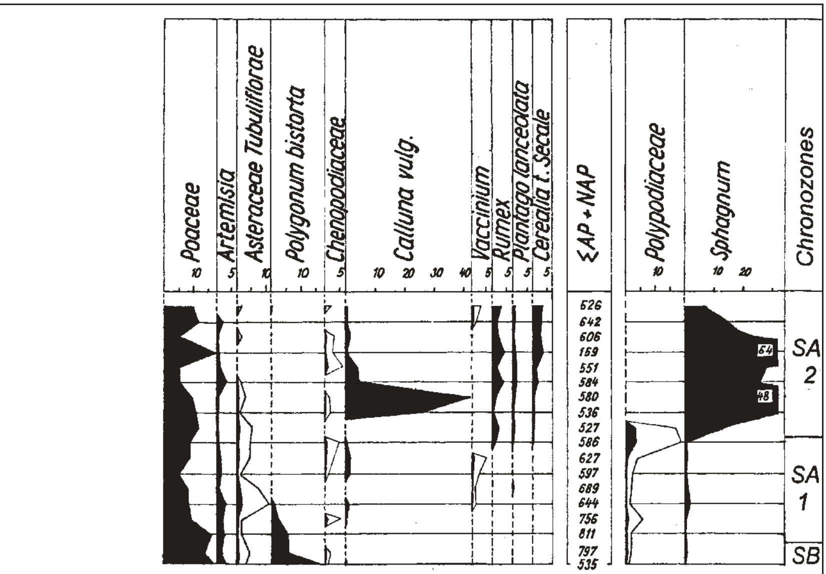


Fig. 4. – Pollen diagram Barborka (HJ-3-A), 1315 m a.s.l. Scarce (less than 0.5%) pollen grains: 5: *Lysimachia* 0.3, *Pteridium aquilinum* 3.8, *Lycopodium clavatum* 0.3; 10: *Juglans* 0.3; 25: *Centaurea cyanus* 0.4; 35: *Juglans* 0.3; 75: *Daucaceae* 0.3; 75: *Daucaceae* 0.2. Analyzed by R. Rypl and E. Rybníčková.

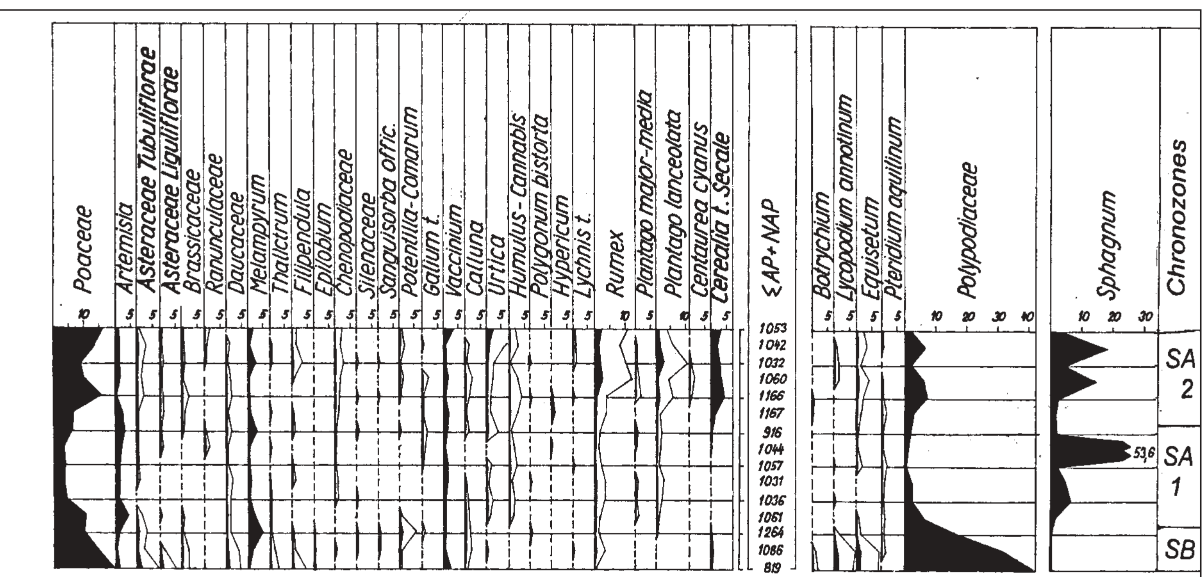


Fig. 5. – Pollen diagram Velký Děd (HJ-4-A), 1395 m a.s.l. Scarce (less than 0.5%) pollen grains: 0: *Frangula* 0.1; *Cerinthe* 0.1, *Rubus* 0.1, *Valeriana* 0.1, *Anthoceros laevis* 0.1, *A. punctatus* 0.1; 5: *Centaurea jacea* 0.1, *Gentiana* 0.1; 10: *Frangula* 0.1; 15: *Chelidonium* 0.1, *Lamium* t. 0.2, *Polygonum aviculare* 0.1, *Scrophularia* t. 0.1, *Veratrum* 0.1; 20: *Chelidonium* 0.1, *Chrysosplenium* 0.3, *Lysimachia* 0.2, *Echium* 0.1, *Euphorbia* 0.2, *Lotus* t. 0.1, *Mercurialis* 0.1; 25: *Lonicera* 0.1, *Fagopyrum* 0.1, *Vicia* t. 0.1; 30: *Lonicera* 0.1, *Campanula* 0.1, *Chrysosplenium* 0.1, *Mercurialis* 0.1, *Ophioglossum* 0.1; 35: *Convolvulus* 0.1; 40: *Vicia* t. 0.1; 55: *Campanula* 0.1; 65: *Valeriana* 0.1, *Viscum* 0.1; 70: *Geranium* 0.1, *Succisa* 0.1, *Viscum* 0.1, *Lycopodium clavatum* 0.1. Analyzed by E. Rybníčková.

Results of pollen analyses

The pollen diagrams presented in Figs 2–5 indicate the vegetation present in the Subatlantic (SA1, SA2), and in the case of the profile from the Barborka site (HJ-3-A, Fig.4) that at the very end of the Subboreal (SB) period. The entire Subboreal (SB) and possibly the transition to the Atlanticum (AT2), dated to ca 4700 B.P., was recorded in the Velký Děd profile (HJ-4-A, Fig. 5).

Corylus and *Tilia* dominate the SB assemblages, and *Picea* and *Alnus* are present. Grass pollen is most abundant in this period (15–20% of total). A characteristic feature of this period is the decrease in representation of *Corylus* and *Tilia*, increase and first peak in *Picea*, maximum of *Alnus* (at least in the HJ-4-A), and increasing presence of *Fagus* and *Abies* pollen.

Pollen assemblages in the SA1 are the most important for reconstructing the summit vegetation in the Hrubý Jeseník Mts before the advent of man. *Fagus sylvatica* and *Abies alba* clearly dominate, *Picea abies* and *Alnus* are important components, and *Ulmus, Tilia, Acer* and *Lonicera* are present. Pollen of *Quercus, Carpinus, Pinus* and some of that of *Betula* is likely to have come from the foothills.

Radical changes occurred between 500 and 700 years B.P., during the early Subatlanticum (SA2), when *Fagus* and *Abies* retreated and were replaced by *Picea abies*. This event is synchronized with the appearance of indicators of agricultural activities connected with settlement of the neighbouring foothills and uplands (see the curves of cereal, *Centaurea cyanus, Plantago lanceolata* and *Brassicaceae* pollen, and the slight decrease in the total AP sum). Human impact on the vegetation in summit areas, namely the deforestation connected with summer grazing and/or hay making, dated back to about the middle of the 17th century (Nožička 1956, Hošek 1973, Jeník & Hampl 1992) is indicated by the growing representation of grasses and a higher occurrence of *Urtica, Rumex* and partly also of *Calluna* in pollen assemblages.

Discussion

The most striking feature of the pollen assemblages is the dominance of *Corylus avellana* and *Tilia*, dated by 14C back to between ca 5000 and 3500 B.P. This is typical of middle Holocene spectra of the Atlanticum at these altitudes. *Corylus avellana*, especially, was the dominant woody species at, over and around 1000 m at that time in Central European mountains, e.g. Krušné hory (Erzgebirge), Harz, Schwarzwald, Šumava (Böhmerwald). For a survey of records of hazel nuts in the "mittleren Wärmezeit" (AT2) peat layers, see Firbas (1949: 155); they correspond with the high pollen representation of this species in many pollen diagrams. However, we found a high representation of hazel pollen in the Subboreal layers from the summit of the Jeseníky Mts, which is not common in Central Europe. A similar higher pollen representation is recorded for the neighbouring mountain chains of the Sudetes, the Pančická louka mire in the Krkonoše Mts (Hüttemann & Bortenschlager 1987), the Zielenec bog in the Orlické hory Mts (Madeyska 1989) and possibly in undated pollen diagrams from the Jizerské hory Mts (Krauseová 1987 and unpublished diagram, 1997). In our pollen diagrams from the Beskydy Mts, which belong to the Western Carpathians (Rybníček & Rybníčková 1995) there are high percentages of *Corylus* pollen in the Subboreal layers, too. Thus, it is likely that *Corylus avellana* locally formed the shrub cover

Table 1. – Stratigraphy and description of sediments (see Troels-Smith 1955 for a detailed explanation) in the profiles Velká Kotlina (HJ-1-A) and Velký Máj (HJ-2-A). Physical properties: Lim – upper boundary, Nig – degree of darkness, Strf – degree of stratification, Elas – degree of elasticity, Sicc – degree of dryness. The classification of colours follows the Munsell Soil Color Chart (Munsell Color Company, Baltimore 1954). Components: Tb (Hyp) – moss peat, Th – herbaceous peat, Dh – herbaceous detritus, Dg – granular detritus, Ag – coarse clay, Ga – fine sand particles, Gg – coarse sand and/or little stones, [A] – charcoals.

Profile	Velká Kotlina				Velký Máj				
Depth (cm)	0–10	10–40	40–60	> 60	0–10	10–28	28–54	54–58	> 60
Physical properties:									
Lim	–	0	1	1	–	3	2	1	1
Nig	4	4	2	1	3	2	2	3	2
Strf	1	1	1	0	3	2	2	0	0
Elas	0	1	0	0	2	2	2	0	0
Sicc	1	2	1	1	1	2	3	3	3
Colour	5YR 2/1	5YR 2/1	10YR 3/1	2,5 YR 5/0	5YR 2/2	2,5YR 3/2	5YR 3/2	5YR 2/2	2,5YR 5/0
Components:									
Tb (Hyp)	++	+							
Th	2^2	1^2			3^2	2^2	2^2		
Dh	1				++	++	1^2	1^2	
Dg	1	3	0.5		1^2	2^2	1^2	2^2	+
Ag			2	0.5					2
Ga			1.5	1.5					2
Gg				2					
[A]							[2]	[1]	

Table 2. – Stratigraphy and description of sediments (see Troels-Smith 1955 for a detailed explanation) in the profiles Barborka (HJ-3-A) and Velký Děd (HJ-4-A). Tb (Sph) – sphagnum peat, Tl – wood peat; for other abbreviations see Table 1.

Profile	Barborka							Velký Děd						
Depth (cm)	0–5	5–20	20–33	33–53	53–75	75–83	> 83	0–3	3–6	6–9	9–20	20–57	57–69	> 69
Physical properties:														
Lim	–	2	1	2	2	1	1	–	2	2	1	1	1	0
Nig	2	2	2	1	3	3	2	1	2	3	2	3	3	2
Strf	2	2	2	2	1	1	0	0	3	1	1	1	0	0
Elas	3	3	3	2	2	1	0	2	2	2	2	1	1	0
Sicc	2	1	1	1	2	3	3	2	2	2	2	3	1	1
Colour	10YR 4/3	2,5YR 3/2	10YR 5/6	2,5YR 5/4	2,5YR 5/4	10YR 2/2	5Y 5/2	10YR 4/3	10YR 3/2	2,5YR 2/2	2,5YR 3/2	10YR 2/2	10YR 2/1	5Y 5/2
Components:														
Tb (Sph)	4^1	3^1	3^2	1^2	1^2			4^1	3^2	3^2	2^2	1^3	1^3	
Tl	+	+	0.5^1	1^2	1^2	1^2			++	0.5^2	+	+	+	
Th	+	1	0.5^1	2^2	2^2	1^2	+	+	1^2	0.5^1	2^2	1^2	1^3	+
Dg	+	+	+	+	+	+	+			++	++	++	++	+
Ag					+	1	1					1	1	2
Ga						1	3					1	1	2

at the uppermost altitude of the eastern Sudetes and the extreme NW Carpathians, not only during the Atlanticum, but also in the Subboreal between ca 5000 and 3000 years B.P. Especially in the Jeseníky Mts, hazel shrub with *Picea abies* could have served the same role as *Pinus mugo* in the formation of the subalpine belt in the summit areas of the Sudetes and Carpathians.

Currently most *Corylus avellana* occurs at 1300 m in the Velká Kotlina in our region and at 1100 m in the Labská jáma cirque of the Krkonoše Mts. *Tilia platyphyllos* grows at 1260 m at Velká Kotlina in the Jeseníky Mts and at 1130 m in the Krkonoše Mts (Šourek 1969, Kovanda 1990, Koblížek 1992).

The results of the pollen analyses of Opravil (1956, 1957, 1959) are relevant to our study. He used the dominant pollen as an indicator of the time scale of his pollen diagrams for the western part of the Jeseníky Mts. We believe that his *Corylus* pollen rich assemblages from the lowest depth are not of boreal but of subboreal age, as indicated by our results.

Fagus sylvatica, Abies alba and a little *Picea abies* pollen dominate the pollen assemblages of the Older Subatlanticum (SA1) between ca 3000 and 700 (600) B.P. Our results support the earlier suggestions of an abundance of beech and silver fir at even the highest altitudes in the Sudetes (Firbas & Losert 1949, Firbas 1952, Heynert 1964, Rybníčková 1966). Pollen of both these trees does not disperse very far (Andersen 1970, Huntley & Birks 1993) which means that quantities of about 15–20% of TS in the case of *Fagus,* and 10–15% in the case of *Abies,* must indicate that most of this pollen came from the surrounding forest. An abundance of both trees in forests at altitudes between 1300 and 1400 (1450m) was favoured by the climatic conditions that prevailed there during the so-called "little climatic optimum" in the Medieval period (Lamb et al. 1966). This is further supported by the fact that pollen from these trees occurs less frequently in diagrams from naturally treeless sites of Velká Kotlina and the Máj saddle (Figs. 2, 3) than from the "forested" areas of Barborka and Velký Děd (Figs. 4, 5).

Hošek (1983, 1984) records *Fagus* and *Abies* trees recently growing in spruce forests in the Divoký důl and Bílá Opava nature reserves at about 1200–1250 m and 1100–1300 m respectively. Koblížek (1990) records *Fagus sylvatica* growing in the Velká Kotlina nature reserve at about 1250 m (see also Neuhäusl & Neuhäuslová 1966).

The above indicates that the precultural natural vegetation at the forest limit at that time was dominated by *Fagus sylvatica* (probably in polycormone shrub-like form), *Abies alba* and *Picea abies*. The presence of pollen of *Acer* (*pseudoplatanus*?), *Ulmus* (*glabra*?), *Sorbus aucuparia* and maybe even *Tilia* cf. *platyphyllos* (all of which have poor power of dispersal) indicates that these trees were present in the mixed beech forests. *Alnus glutinosa* and/or *A. incana*, which produce great quantities of wind-transported pollen, were certainly growing along the streams in lower parts of the mountains up to 800–900 m. *Fraxinus excelsior*, whose pollen does not preserve well, probably grew in similar habitats and reached higher altitudes.

The change from mixed beech-fir-spruce forest to the spruce forest stands started at the beginning of the Younger Subatlanticum (SA2) due to the climatic deterioration (so-called "little ice age") that occurred between the 16th and 18th centuries (Lamb 1964, Lamb et al. 1966, Svoboda 1995). A decrease in summer and winter mean temperatures, early and late frosts, favoured the reproduction of spruce, while that of *Fagus* and *Abies* was retarded, or even ceased at the upper forest limit. Later on the selective use of beech wood for fuel and charcoal production finalized the transformation.

Similar changes are documented by several pollen-analytical studies for the eastern parts of the Sudetes (Stark 1936, Firbas & Losert 1949, Opravil 1956, 1957, 1959, Rybníčková 1966, Madeyska 1989) and other Central European mountains (Firbas 1952, Heynert 1964, Hüttemann & Bortenschlager 1987, Hahne 1992, Speranza 2000, Svobodová et al. 2001).

Human impact was the major factor determining the present state of the vegetation in the summits of the Jeseníky Mts, including the present alpine forest limit. Jeník & Hampl (1992) give a very instructive historical account of the settlement of the open area below the mountains and of human activities in the mountains. We also used cartographic data published by Doskočil et al. (1965a, b, c).

The foothills of the Jeseníky Mts were settled by German colonists between the 13th and 14th centuries (e.g. towns of Bruntál, Rýmařov, Zlaté Hory, Jeseník, Velké Losiny and Šumperk, and neighbouring villages). Mining was the first human activity to affect the nature of the mountain vegetation especially in the neighbourhood of the towns of Jeseník (Au, Fe), Zlaté Hory (Au, Cu) and Rýmařov (Fe), where there were several smelting works and hammer mills. However, mining was restricted to altitudes below ca 850 m. Arable agriculture was limited to altitudes below approx. 600 m. In pollen diagrams this is reflected in the beginning of a continuous increase in cereal pollen (*Secale* type prevails), that of some weeds and synanthropic plants and a slight decrease in total AP percentages. This AP decrease is linked not only with the transformation of woodland into agricultural land in the foothills, but also with the cutting of wood for mining and the smelting of ore.

Exploitation of the mountain summits began later, at the beginning of the 17th century. Hay making and summer grazing at and above the forest limit also brought local deforestation and further erosion of the natural forest line. In the pollen diagrams this phase of mountain use is indicated by a further decrease in total AP percentages and a great increase in grass pollen (*Poaceae*). The beginning of spruce planting dates back to the turn of the 18th and 19th centuries in this region.

The extensive summer grazing and hay making on the summits of the Jeseníky Mts ceased during the 19th century, as it became uneconomical. The abandoned mountain pastures were taken over by foresters, who tried to re-establish the forest line to its previous (?) natural (?) level. Around the turn of the 19th and 20th centuries, *Pinus mugo, Pinus cembra* and *Larix decidua*, all alien to the Jeseníky Mts, were introduced for this purpose. Except for two pollen grains of *Larix* not a one of *Pinus cembra* type was found and the percentages of pollen of *Pinus sylvestris/mugo* type in the uppermost pollen spectra were not affected even at sites with extensive dwarf pine plantations close by (see Velká Kotlina and Máj diagrams, Figs 2 and 3).

In terms of pollen analyses it is difficult to comment on the many papers and different opinions concerning the present and past natural forest limits in the Sudetes in general and the Jeseníky Mts, in particular (Firbas & Losert 1949, Jeník 1961, 1972, 1973, Jeník & Lokvenc 1962, Bednář et al. 1966, Neuhäusl & Neuhäuslová 1966, Alblová 1970, Plesník 1972, 1984, Hošek 1972, 1973, Horák 1977, Deylová-Skočdopolová 1984, Rypl 1980, Jeník & Hampl 1992, Treml & Banáš 2000, Banáš et al. 2001a, b). Nevertheless, combining pollen analyses and field investigations of the summit areas we can contribute the following:

(i) It is indisputable that subalpine forest-free areas existed in the Jeseníky Mts during the entire Holocene. This is supported by the presence there of several boreal and subarctic plants and animals, which must be of a glacial origin. The existence of patterned subarctic soils in the highest parts of the mountains also indicates they have not been colonized by trees. However, the pollen analyses provide no or quite inconclusive evidence of subalpine (alpine) treeless vegetation.

(ii) Our field investigations limit the subalpine ecosystems to the climatically extreme habitats above ca 1400 and 1450 m and edaphically conditioned forest-free habitats at several sites below this altitude, e.g. block screes.

(iii) Tree- and forest-free vegetation is found on windward sides of ridges and/or saddles with little snow cover during winter. On the leeward slopes, where snow accumulates and avalanches occur, forests are mechanically depressed down to below even 1200–1100 m.

(iv) An earlier natural forest on present treeless sites on the leeward slopes of Praděd and Petrovy kameny Mt up to above ca 1400–1450 m is indicated by the dominance there of spruce forest plants such as *Calamagrostis villosa, Luzula sylvatica, Homogyne alpina, Vaccinium myrtillus, Trientalis europaea, Athyrium alpestre* and *Plagiothecium undulatum*. Subalpine species are absent or, those like e.g. *Selaginella selaginoides, Swertia perennis*, grow just around the spring outflows.

Conclusions

1. Our pollen analyses indicate that *Corylus avellana-Picea abies-Tilia platyphyllos* stands with rich grass cover in a herb layer existed in the upper summit areas below the natural forest line on the Jeseníky Mts during the Suboreal (ca 5000–3000 B.P.), and probably since the Atlanticum.

2. A long-term vegetation succession of *Fagus sylvatica-Abies alba-Picea abies* stands with an admixture of *Acer* (*pseudoplatanus*?) and *Ulmus* (*glabra*?) ran on the upermost elevations in the Older Subatlanticum between ca 3000 and 600 B.P.

3. The sudden change in pollen spectra at ca 600 B.P. indicates a transformation from mixed beech-spruce-fir stands to open spruce forest associated with the general climatic deterioration of the "little ice age", which favoured spruce but not beech and silver fir. Human influences also have been a factor.

4. The pollen analyses and field investigations reported here support those botanists and foresters who suggest that the tree line was very variable and discontinuous. It is and was formed not only by climate but also edaphic influences and avalanches. Its altitude varies between approx. 1100 m in the Velká Kotlina cirque, an area prone to avalanches, and approx. 1300 m on block screes and wind-affected habitats, up to ca 1450m on the leeward slopes of the highest points.

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Souhrn

Pylové diagramy (obr. 2–5) ze 4 maloplošných rašelinišť ve vrcholové pradědské části Hrubého Jeseníku informují o vývoji vegetace kolem současné alpinské hranice lesa v době od asi 5000 let před současností (B.P.). V subboreálu v nadmořských výškách 1300–1400 m dominovaly porosty s *Corylus avellana, Picea abies* a příměsí *Tilia* cf. *platyphyllos*. Tyto porosty přetrvaly do asi 3000 B.P. Líska v Jesenících v těchto vrcholových polohách zřejmě zastupovala *Pinus mugo*, typickou pro tyto nadmořské výšky v jiných západnějších masivech Sudet. Mezi asi 3000 a 500–400 B.P. (ve starším subatlantiku, SA1) převládly porosty s nejspíše keřovitými formami *Fagus sylvatica, Picea abies* a *Abies alba* se zastoupením javoru (*Acer* cf. *pseudoplatanus*) a jilmu (*Ulmus* cf. *glabra*). Tyto porosty byly ovlivněny a měněny lidskými zásahy v průběhu mladšího subatlantika (SA2), zejména mýcením původní lesní vegetace, selektivním výběrem dřevin, pastvou a senařením od počátku 17. století. Tyto aktivity snížily na mnoha místech přirozenou alpinskou hranici lesa a přispěly spolu s klimatickým výkyvem tzv. „malé doby ledové“ k přeměně původních smíšených porostů v dnešní pseudoklimaxové horské smrčiny. Umělé výsadby smrku začaly i dle archivních záznamů na počátku 19. století. Přirozený výskyt *Pinus mugo* nebyl v Jesenících našimi výzkumy zaznamenán.

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