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Changes in vegetation of the Černé Lake area inferred from pollen analysis of lake sediment: period between 3400 BC and 1600 AD.

Změny vegetace v širším okolí Černého jezera v období mezi 3400 př. n. l. a 1600 n. l.

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Abstract

Pollen were analyzed along a 1.15 m long profile of lacustrine sediment of the Černé Lake in Bohemian Forest, Czech Republic. The oldest sediment layer (from about 3300 BC) contained the highest proportion of the *Ulmus* pollen and a large amount of the pollen of *Corylus*. A strong increase of *Picea* and *Abies* around 3100 BC was probably caused by abrupt short cooling of the climate. Between 3100 and 2200 BC the area of the Černé Lake was forested mostly by *Picea, Abies, Alnus, Betula* and *Fagus*. The population of *Fagus* and *Abies* gradually increased while *Picea, Ulmus, Corylus* and *Acer* retreated. An exogenous disturbance in the lake catchment affected the forest around 2600 BC and subsequently *Picea* with *Abies* retreated remarkably. The following period led to the invasion of deciduous trees (mostly *Fraxinus, Alnus, Tilia* and *Corylus*). A wetting of climate around 800 BC was accompanied by a retreat of *Quercus*. Repeated afforestation took place in the early AD centuries. The presence of *Gramineae* (*Poaceae*) increased from about 2400 BC to the end of the old era. Ruderal plants were observed in the whole investigated period, while *Cerealia* since about 2700 BC. Cultivation of rye (*Cerealia t. Secale*) became common earlier (from 10th century AD) than cultivation of wheat (*Cerealia t. Triticum*). The occurrence of herbs (NAP) systematically increased from the 12th century AD, but enhanced penetration of sunshine to the forest floor was already indicated around 200 BC and in the 10th century AD. Strong disturbance of forest by man after 1250 AD was accompanied by a remarkable and permanent decrease in *Fagus*, especially in the 14th and the 15th century. This was also connected with iron industry around the Černé Lake, mining being documented as early as in 1525 AD. Nutrients introduced into the lake during an erosion around 2600 BC caused a rapid growth of algae *Botryococcus sp.*, eutrophization and worsened the light conditions in the lake epilimnon. This probably hindered the growth of *Isoëtes lacustris*.

Key words: vegetation, pollen, sediment, palaeoecology, climate changes, ancient pollution, 800 BC, 3150 BC, Černé Lake, Bohemian Forest, Czech Republic.

Introduction

The Černé Lake in Bohemian Forest (N. Latitude 49°11'; E. Longitude 13°11') is situated at an altitude of 1008 m and is about 39. 5 m deep. The flora of the area was first described as early as in the 18th century (MAYER 1779). Quillwort (*Isoëtes lacustris)* discovered in the lake on September 24, 1816, by the Prague botanist TAUSCH (1819) belongs to the most interesting plants in the Czech Republic, as it only grows in the lake (TOMŠOVIC 1979). The state of the underwater colonies of *I. lacustris* were checked in the seventies and eighties of the

20th century and compared with a drawing from 1892 (ROTT & al. 1986; TOMŠOVIC 1979). The growths moved in SW part of lake, remarkably extended on SE side and disappeared in NW part of the lake (ROTT & al. 1986). The plants were somewhat smaller compared with the plants preserved in 19th century herbaria and grew in range of depth 2.5–6 m, primarily between 3 and 4 meters.

The forest surroundings the lake during the second half of the 19th century was described in detail by KOMÁREK (1882) and flora of the surroundings of nearby town Železná Ruda by HOLUB (1965). The plants of the Černé Lake wall were especially studied by HILITZER (1930) and SOFRON & ŠTĚPÁN (1971). A review of geobotanic studies was published by SOFRON (1996) and a summary of natural investigations of the lakes in Bohemian Forest and their catchments by VESELÝ (1994). Spruce (*Picea*) has exceptionally well thrived there. Maple (*Acer*), ashtree (Fraxinus), linden (*Tilia platyphylla*), oak (*Quercus*) and elm (*Ulmus*) grew up to an altitude of 900 m. Beech (*Fagus*) grew on the lake shore forty years ago and willow (*Salix*) grew in the wall. There was a colony of fir (*Abies*) in a good health below the lake (SOFRON & ŠTĚPÁN 1971). According to a pollen research of the Jezerní mire in Bohemian Forest, mostly hazel (*Corylus*) and linden (*Tilia*) grew in the surroundings in the Atlantic period, but pine (*Pinus*) was already considerably substituted by spruce. Beech and fir began to expand in the late Atlantic, which were the most common trees of mountainous forests in Subboreal (after about 3100 BC) to early Subatlantic (KRIESL 1968). The pollen of Jezerní mire were recently studied by Břízová (VILE & al. 1995) and the effects of pasture on the forest at foothills of Bohemian Forest by MÁLEK (1979); a preliminary study on the history of forest in Bohemian Forest was published by SVOBODOVÁ (1995). The pollen of recent sediments of the neighbouring Čertovo Lake was analyzed by Almquist-Jacobson (VESELÝ & al. 1993). However, the pollen of trees were for the first time studied by REISSINGER (1931), who drilled from ice of the Černé Lake near the deepest site between December 28,1930 and January 4, 1931 and attained a depth of 15.35 m. Between 12 m and 5 m of the core, pollen of pine predominated, the sediment was without organic matter below of 13 m and consisted of a coarse-grained matter. A 2.3 m long core with a high organic matter content was observed by MICHLER (pers. comm.) in the Černé Lake at the begining of the nineties. A similarly thick layer of sediment is also present in the Prášilské and Rachel lakes, in Grosse Arbersee (MICHLER 1985) and the Plešné Lake, a layer of sediment that is rich in organic matter is somewhat thicker (about 3 m).

In this study we are dealing with the results of pollen analysis of the 1.15 m long core from Černé Lake. Pollen was analyzed by BŘÍZOVÁ (1991, 1996).

Methods

A core of 1.15 m long was taken by divers with a piston corer at a water depth of 26 m on August 15, 1987. The core was extruded vertically and sectioned at the lake shore into 0.01 m intervals to a depth of 0.2 m, at 0.02 m intervals from 0.2 m to 0.6 m, and at 0.05 m intervals to 1.15 m. The mineral particles were decomposed by leaching with HF, a modified acetylosis method was used for the decomposition of cellulose and organic remains (ERDTMAN 1954). A mixture of glycerol, ethanol and distilled water was added and a minimum of 500 grains was identified per sample. Identifications were aided by the reference-pollen collection, photos of the reference matter and an atlas (E. BŘÍZOVÁ, pers. comm.). The core and another core, taken in Černé Lake at a water depth of 16 m were also analyzed chemically. The lead concentrations were obtained by AAS after hot acid digestion of the sediment in a mixture of $HCl:HNO_3:H_2O$ 9:1:10.

Intervals of 0.30–0.32 m and 0.80–0.85 m were dated by the radiocarbon method with an aid of AMS in the Rafter Radiocarbon Laboratory, Lower Hutt, New Zealand (NZA 8103 a NZA 7755). Remains of plants and roots were removed and, after grinding, acid/alkali/acid washes were performed.

RESULTS

Dating

Fig. 1 shows the changes in the Pb concentrations in the two cores taken at a water depth of 26 and 16 m from the Černé Lake in 1987. It follows from Fig. 1 that between 0.16 and 0.18 m recent sediment was missing in core analyzed for pollen. An attempt to date the youngest core layers by ^{210}Pb method at the University of Liverpool (P. Appleby) was unsuccessful for the same reason. The samples analyzed were older than about 150 years and, therefore did not contain any unsupported ^{210}Pb, only the ^{210}Pb produced by natural decomposition of ^{226}Ra in the sediment. The core was obviously taken at a site where the natural stratification of sediment was anthropogenicaly disturbed in the last 130 years (VESELÝ 1994), e.g. by launching of a burden into the sediment during bathymetric measurements or during investigation of lake by divers.

There is a conspicuous increase in the Pb concentrations in Fig. 1 around a depth of 0.2 m and further around 0. 6 m. Two increases around a 0.2 m depth are specific for the lakes in Bohemian Forest (VESELÝ 1997). We have found them neither in the Popradské Lake in the High Tatra Mts. (Slovakia), nor in the Lake Wełky Stav in Poland. These are relics of smelting activities in the Middle Ages, which were interrupted by the Hussite war in the 15th century and resumed in the 16th century, e. g. in the town Jáchymov or in the town Stříbro. The increase in the Pb concentration at a depth of about 0.6 m (in the incomplete core at about 0.45 m) was also observed in other European lakes (RENBERG & al. 1994), in a ice core from Greenland (HONG & al. 1994) and has probably a hemispheric range (HONG & al. 1994). It is connected to long-range atmospheric transport of Pb from metallurgical works in the Roman

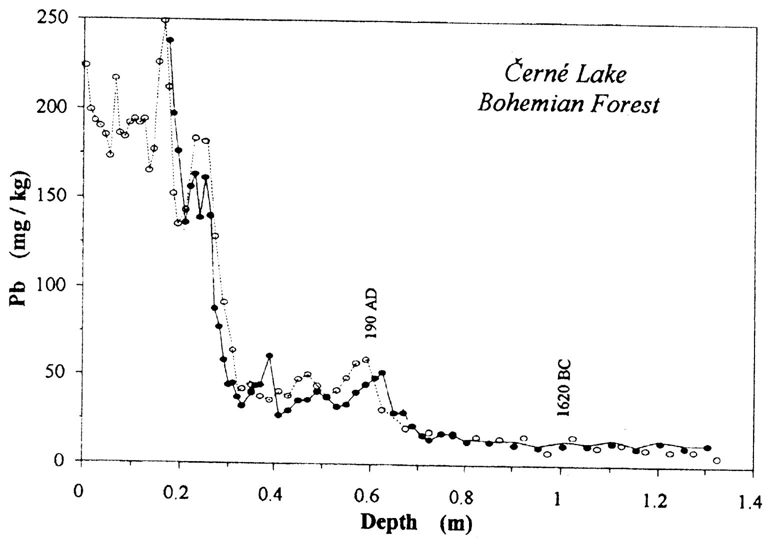

Fig. 1. – Concentrations of Pb in the sediment of the Černé Lake

times. These emissions of Pb were the highest just around the era change (BC/AD) (SETTLE & PATTERSON 1980).

The core can be dated under the condition constant accumulation rate between these two dates, 1430 AD for a small decrease of Pb concentrations in a depth of 0.23 m and 0 AD for a depth 0.62 m, corresponding to the oldest perceptible Pb maxima. Between the dates and depths mentioned a mean mass accumulation rate was 17 mg. m^{-2}. y^{-1}. By extrapolation we have obtained a year around 1640 AD for the top of core and 3400 BC for its end, the core covering a time span of about 5 millenia. We estimate the possible error below 100 years between 1640 AD and 500 BC; in the 2nd and the 3rd millenium BC there is a higher uncertainty.

For a younger layer the Conventional Radiocarbon Age (CRA) 1711 +/–77 BP ($\delta^{13}C$ –28.4) was found (NZA 8103) and CRA = 3278 +/- 73 BP ($\delta^{13}C$ –28.8) for the 0.80 to 0.85 m layer (NZA 7755). The CRA of the lake mud is often difficult relate to calendar date (HEDGES 1991, OLSSON 1996). This transfer (by calibration for CRA as a function of the calendar years) can be carried out using a software (e. g. by OxCal – STUIVER & al. 1993), however, the transfer could only be accomplished after a correction for the 'reservoir effect' or possible contamination. The 'reservoir effect' occurs when the $^{14}C/^{12}C$ ratio in the lake water is lower than that in the atmosphere. The sediment can also be polluted by C of a different age (OLSSON 1986) or the CH_4 produced by bacteria in the lower, permanently anaerobic sediment layer may ascend higher. Some of these processes, which caused troubles with ^{14}C dating are not explained in detail (KILLIAN & al. 1995), their extent is unclear and they lead often to errors of several hundred years occurred in the literature. The organic fractions of sediment that include aquatic components usualy give older dates than expected (OLDFIELD & al. 1997).

The apparent age (the difference between the CRA found and radiocarbon age corresponding to the actual age) of Swedish lake sediments are usually between 300–400 years (OLSSON 1986). An apparent age of 240 years was found for the 0.3–0.32 m core interval, for which 1711 (CRA)–240 = 1471 BP ('reservoir corrected age'). For the interval of 0.8–0.85 m, the OxCal programme yielded an interval of 1680 to 1510 cal. BC and an extrapolation assuming an accumulation rate of 17 mg. m^{-2}. y^{-1}, an age of 1628 BC was obtained, well in the range calculated.

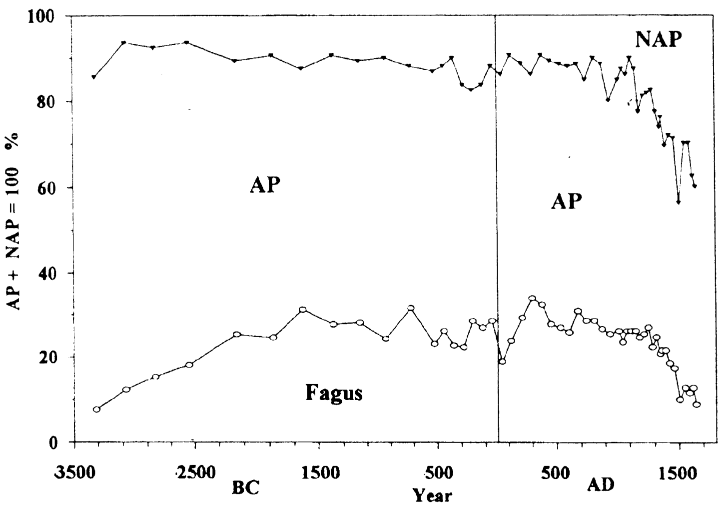

Fig. 2. – Total pollen diagram. AP = arboreal pollen; NAP = non – arboreal pollen; *Fagus* = beech

Pollen analysis

A total pollen diagram (Fig. 2) depicts the predominance of trees (AP) over herbs (NAP), almost over the whole time span of 5 000 years. The wider surroundings of the lake was heavily forested in the oldest period (to about 2400 BC) when the most frequent species were spruce (*Picea*), hazel (*Corylus*), alder (*Alnus*) and birch (*Betula*). Oak (*Quercus*), ironwood (*Carpinus*), hazel, birch, elm (*Ulmus*), maple (*Acer*), linden (*Tilia*) were usually restricted to the foothills. The higher extent of oak, hazel and elm in the oldest layer analyzed (from around 3 300 BC) is in a good agreement with a higher temperature of Atlantic. An abrupt and short-time increase of spruce grains from 15 to 28 % and fir from 5 to 15 %, in time when elm, hazel and oak retreated was observed between 3 100 and 3 200 BC. Spruce, together with fir and beech, predominated in the forest also later, however spruce was retreating and beech, on the contrary, increasing (Fig. 3).

The organic matter content in the sediment decreased to a half around 2600 BC, probably as a consequence a higher input of mineral particles to the lake – an erosion event. Spruce-fir-beech pristine forest in the lake catchment was probably strongly disturbed by a gale in 26th or 27th century BC and water washed mineral particles from under the unrooted trees. A decrease elm in the occurrence ended, and the number of spruce, beech, ash and willow trees decreased, on the contrary, the number of fir grains in the sediment was largest (around 18 %). Spruce retreated abruptly to 1/8 over a time span of 900 years. Conifers were partly substituted by deciduous trees during several of the following centuries and same of them (ash, linden and alder) were maximally extended around 2200 BC of the whole core time span. While the number of ash and linden trees was low, occurrence of alder was important (19 %). The number of hazel grains in the sediment increased at the end of the 3rd millenium BC, the gradual expansion of beech ended (around 25 % of pollen), while oak remained between 4 and 6 % (Fig. 3). Oak grew mainly at sunny sites in lower altitudes and therefore was not disturbed by the erosion event.

The content of mineral particles increased also in the 17th century BC, and in the 2nd and 16th century AD. Abrupt increases of mineral particles were observed in the sediment of the Černé Lake also in the early Holocene (MICHLER, pers. comm.). However, such a variation of organic and mineral matter has not been observed in the sediments of the other two lakes in Bohemian Forest (Plešné and Prášilské) and the variations observed in the Černé Lake are thus local. The sheer lake wall of the Černé Lake is situated quite near of the lake and grown-up trees must have repeatly fallen into lake during gales. Some trunks were fixed in the sediment in the opposite position (by tip into the sediment) below the lake wall and several substantial decreases of organic matter are evidences of this.

Three increases in the mineral part of the sediment resulted in an increased grow of algae *Botryococcus sp.* in the lake water (Fig. 4) due to a higher input of nutrients or change in the N/P ratio. An expansion of the algae in the middle of the 3rd millenium BC, together with the contribution of an next input of nutrients in the 17th century BC, caused algae to grow intensely for about 1300 years. There was less spores of *Isoëtes lacustris* in the layers originating during this time of probable eutrophization of the lake water (Fig. 4). Quillwort depends on the light conditions in the lake epilimnon (LEE & BELKNAP 1971) and this became worse due to a higher abundance of algae in the surface water. A negative correlation between the occurrence of *Botryococcus sp.* and number of quillwort spores was probably connected to a change in light intensity in a depth of 3 to 4 m, where quillwort uses to grow. On the contrary, an occurrence of quillwort spores positively correlates with the occurrence of grains of spruce and *Sphagnum*, i.e. with a wetter and colder climate.

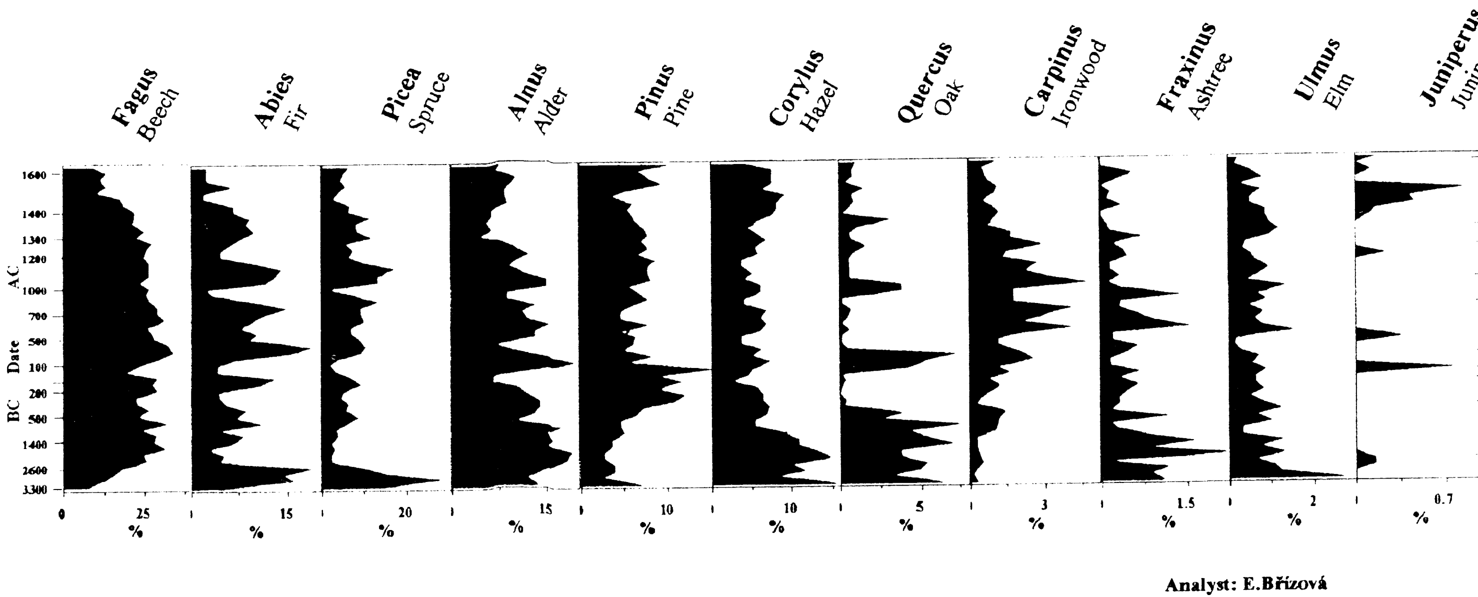

Fig. 3. – Changes of pollen values of trees

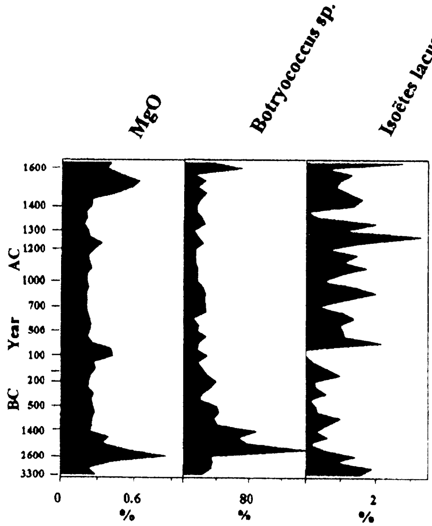

Fig. 4. – Correlation among contents of MgO, abundance of algae *Botryococcus sp.* and *Isoëtes lacustris.*

Beech was relatively early present in Bohemian Forest (MÜLLER 1927). Together with fir, it belongs to trees which spread slowly, exhibit a long period of sterility and have similar ecological requirements (SLAVÍKOVÁ-VESELÁ 1950). The number of beech grains in the sediment increased relatively from the oldest sediment of core to approximately the 17th century BC. With the exception of a short period around the BC/AD change, there was more than 20 % of beech grains in pollen spectrum during the period from 2500 BC to 1400 AD, in spite of beech already retreating from about 1250 AD (Fig. 2). The highest extension of spruce around 3100 BC was mentioned above. The number of spruce trees slowly increased in complex way after abruptly retreating in the first half of the 3rd millenium BC until a peak around 1100 AD; however, the former extention from the Atlantic/Subboreal turning point (28 %) was not attained. An increase in the number grains of pine was observed in samples from the time period of 400 BC to 100 AD, however, pine did not predominate in forest at that time. Number of oak grains rapidly dropped around 850 BC, oak nearly disappeared from the forest during the last five centuries of the old era, but was present again in the 1st and 2nd century of the new era (Fig. 3). Alder also retreated during the several last centuries of the old area, when decline of oak, alder and corylus was probably caused by woodland clearence. Number of ironwood trees (*Carpinus*) increased in a complex way until the 11th century AD. Ironwood took probably an advantage from the selective harvesting customary at that time as it easy rejuvenates by sprouts from stumps (SLAVÍKOVÁ-VESELÁ 1950).

New peaks in the numbers of several trees and a minimum of wild grass (*Poaceae*) (Figs. 1 and 5) signify aforestation of formerly exploited territories and areas without forest at the beginning of the new era (see also MÁLEK 1979). Number of oak, alder, pine and birch trees increased first, followed by fir and beech. Beech reached a peak abundance of about 33 % grains at that time. In the forest with beech and fir predominating there also grew higher number of fir, alder, birch and spruce trees. When analyzing diatoms from the core sediment ŘEHÁKOVÁ (1991) found the highest number of acidophilic *Aulacoseira lacustris* in sample from that time (from around 460 AD). A lower pH of the circulating water could be connected with a higher abundance of conifers (firs and partly also spruce in the catchment), or with a culmination of the extent of podzolisation forest soil (RYBNÍČEK & RYBNÍČKOVÁ 1968). However, spruce growing in the Černé Lake catchment is protected by magnesium rich mica-schists in

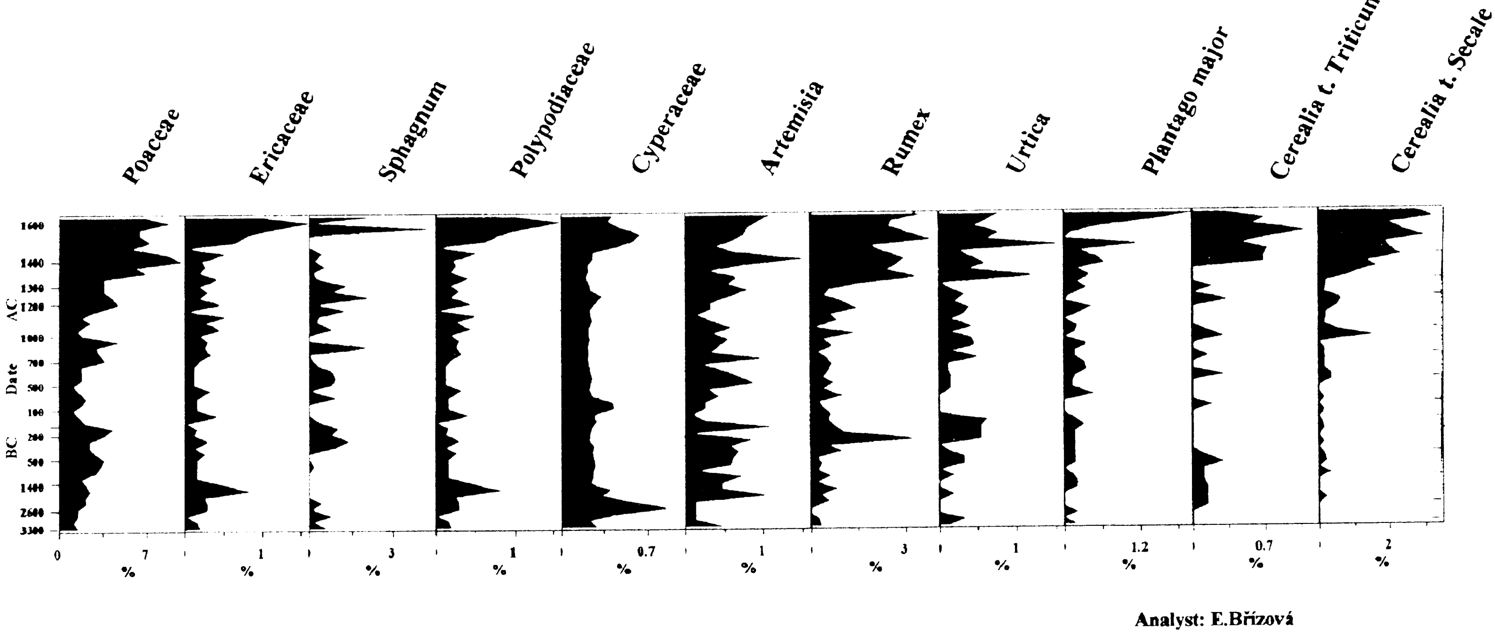

Fig. 5. – Changes of pollen values of herbs.

the bedrock (HÜTTL & SCHAAF 1997) from a more serious damage by atmospherically transported acids in the present time.

The abundance of herbs (NAP) increased and the wooded area evidently diminished around 300 BC, once more in the 10th century AD and permanently since about a half of the 12th century AD (Fig. 1). Wild grass (*Poaceae*) slowly extended since 24th century BC (approximately until 100 BC), during the time period of the 8th to 10th century AD and permanently also since the 12th century (Fig. 5). Slowly increasing presence of grass might have be a consequence of an increase in small deforested enclaves in the middle of the forest, above all along long-distance communications (BENEŠ 1996; PRACH & al. 1996).

The highest abundance of *Sparganium sp.* was observed in the oldest sediment layer, it decreased before 3000 BC, together with warmlike woods. The rare *S. affine* was first observed in the Černé Lake in 1885 and for the last time in 1959 (HOLUB 1965), and is now considered to be extinct. *Sphagnum* which can be considered as an indicator of wetlands and wet grass fields was missing for a long time between 2000 and 900 BC; around 1600 BC there was a higher number of *Ericaceae.* This can be explained by dehydration of the landscape in the drier and more continental climate. The abundance of *Ascomycetes* sharply increased around 850 BC. A peak of *Sphagnum* abundance (around 300 BC) is approximately contemporary with a peak of *Rumex* (Fig. 5), which prefers sites rich in nitrogen. Abundance of *Urtica* and *Ranunculaceae* also increased at that time, however both the herbs (together with *Sphagnum*) retreated at around 0 AD. Abundance of another pasture indicator – *Juniperus* – increased for a short time only in the 1st and 15th century AD and was mostly connected with larger changes in the landscape.

The ruderal herbs *Brassicaceae* a *Chenopodiaceae* were observed in the whole core. Wheat (*Cerealia t. Triticum*) was present permanently from 2700 BC to 500 BC, later only since a half of the 14th century AD. Presence of rye (*Cerealia t. Secale*) in the pollen spectrum was important in the 10th century AD and permanent after 1300 AD (Fig. 4). Abundance of cereals already in the first half of the 3rd millenium BC shows that the sources of the pollen analyzed come not only from the lake catchment, nor only from the nearest surroundings of the lake. It is necessary to look for the sources at longer distances and not only in the foothills of Bohemian Forest but also in the valley of the river Danube.

Discussion

The best results are obtained in lake sediment studies when taking multidisciplinary approach and when dating supported by accurately dated event is possible. The probability that dating of the core studied is correct is substantially enhanced by the response of vegetation to abrupt and important climate shifts around 3150 BC (Atlantic/Subboreal turning point) and 800 BC (Subboreal / Subatlantic turning point) in the pollen stratigraphy. The first climate shift probably belongs to the mostly important climate changes in the past approximately 9500 years. The millennial-scale warming terminates with a period of climatic disturbance called 'Piora oscillation'. An exceptional interest in these change follows from the fact that it brought serious floods to the Middle East described probably in the Old Testament (Genesis 7:6). In the time period of 3100 and 3200 BC, heavy flooding on the Jordan river transported twigs and leaves of *Quercus calliprinus* to a site near Dead Sea (Mt. Seldom or Sodom). During the flood level of the Dead Sea must have been about 91 m higher (Frumkin 1991). An abrupt cooling was a contemporary effect at higher latitudes. Tree rings of oak from Irish bog were narrow (BAILLIE & MUNRO 1988), elms declined in western Europe and the oak and hazel in the northern Europe. Bog development and the increase in peat-accumulation rates were observed in Norway and Poland. Chemical changes were identified in Greenland ice about 5150 years old (ZIELINSKI & al. 1994; BLUINER & al. 1995). There are indications that the reason for this might have be meteoric impact which could cause dense fog to envelop the world, lowering the temperature by several degrees or change in sea water circulation lessening of the heat flux from low latitudes. An abrupt cooling of that time expressed in Bohemian Forest above all by a relatively short substantial increase of conifers, by a decrease of deciduous trees (*hazel, elm, oak, willow, birch*) and herb *Sparganium sp.* to a half or even more. However, this period was relatively short, continuing less than 300 years.

The second climate shift happened around 800 BC, this time from continental (warm and dry) to a more oceanic climate regime (wetter and cooler) (GEEL & al. 1996). There is also not a clear explanation for this climate change and for contemporary increase in the ^{14}C in the atmosphere but wetting of the bog surfaces coinciding with the advent of solar (Homeric) minimum 830 +/–10 BC. A retreat of bog oak due to wetter and cooler conditions was observed in Ostfriesland (NW Germany) (LEUSCHNER 1992), together with a rise of the underground water level. This change caused an abrupt retreat of oak (from 7.5 % to 2.5 %) in the pollen spectrum and an increase in *Ascomycetes* pollen in Bohemian Forest.

While two previous climate changes around 3150 and 800 BC might have had considerable effects on prehistoric populations, the other changes were caused by people. The retreat of beech in the Middle Ages, extending of areas without forest, cultivation of cerealia and an increase of pasture on deforested enclaves in the 14th and 15th century were the main attributes of one such change. Only birch, linden and acer increased, the rest of beech suffered from moisture insufficiency and from pasturing (MÁLEK 1979). Retreat of beech began after 1250 AD, a little later than the increase in herbs. In the nearby surroundings of the Černé Lake, iron ores were mined at least since 1525, according to written documents (BLAU 1935). Iron ore mining was also important on Silberberg near the Bavarian Bodenmais (TROLL & al 1987) and it the second half of the 16th century below the Čertovo Lake (VESELÝ 1994). The effect of iron production on forest in the 16th and 15th centuries is unquestionable, however, limonite could also be mined substantially earlier. Beech was cut for producing charcoal, which was required for iron smelting. The decline in pollen values of beech in the 1st century AD is therefore suspicious.

Distinct anthropogenic effects on vegetation are indicated by results obtained also for the early Middle Ages (10th century) and from the time of Celtic settlement in Bohemia, when the forest temporarily retreated (Fig. 2). Abundance of *Poceae*, *Rumex*, *Sphagnum*, *Urtica, Rununculaceae, Pinus*, *Tilia* and *Salix* was higher and that of *Corylus, Quercus, Alnus* and *Artemisia* lower in the Celtic Bohemia around 200 BC. Deforestation was connected with many castle sites in the region at that time (BENEŠ 1996). Number of spruce and fir grains dropped to low level in the 10th century while several deciduous trees increased (*Betula*, *Acer* a *Salix*), as did herbs (NAP). Except for wheat and rye, *Poceae* and *Cyperaceae* increased. Higher contents of lead (Pb) were observed in the sediment of one core from the Černé Lake (Fig. 1) and one core from the Čertovo Lake (not shown). This may be connected with the not sufficiently investigated production of coins (Czech denars) in the 10th century AD (NOHEJLOVÁ–PRÁTOVÁ 1955).

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