Solar and anthropogenic forcing of late-Holocene vegetation changes in the Czech Giant Mountains
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LATE-HOLOCENE HUMAN IMPACT AND PEAT DEVELOPMENT IN THE ČERNÁ HORA BOG (GIANT MOUNTAINS, CZECH REPUBLIC)

Abstract: Pollen analysis of a small peat bog at Černá Hora, Czech Republic, shows late-Holocene human impact on the vegetation. The palynological results are compared with historical documentation. Macrotom fossil analysis and changing pollen concentrations provide evidence that human impact on the regional vegetation determined changes in the hydrological conditions of the bog, and in the peat accumulation rate. From approximately 2100 BP (start of peat growth) to approximately 1400 BP no human impact has been identified from the pollen record and the decomposition of the peat deposit indicates moderately moist conditions within the catchment. Subsequent changes corresponded with two phases of inferred human impact on the vegetation. From approximately 1400 BP (seventh – eighth century AD) and especially after 900 BP (eleventh – twelfth century AD), human impact (deforestation) became evident and the less decomposed peat was formed under locally wet conditions.

5.1 Introduction

The Giant Mountains or Krkonoše (Figure 5.1), part of the Sudety mountains which form the northern fringe of the Bohemian Massif, are the highest mountain range of Central Europe to the North of the Alps.
The elevations range from 400 to 1600 m. The strong environmental gradients form the basis of a distinct altitudinal vegetation zonation. According to Rybníček and Rybníčková (1994), at around 2000 BP the natural vegetation of the lowland area was mixed broad-leaved forest composed of Carpinus and Quercus. In the submontane zone (500-1100 m), Fagus sylvatica dominated forest communities, in admixture with Abies alba and Picea abies. Beneath the forest line (1100 to 1300 / 1400 m), in the montane zone, a continuous belt of indigenous Picea abies forest was present, with Fagus sylvatica, Acer pseudoplatanus and Sorbus aucuparia in admixture (Rybníček, 1990; Rybníček and Rybníčková, 1994). Locally, Fagus could be present up to the forest line (Fanta, 1981). Since the Middle Ages, the vegetation characteristic of the submontane and montane vegetation belts has been replaced by plantations of Picea abies. In the subalpine zone, Pinus mugo forms extensive stands on both mires and mineral soils. Picea abies and Sorbus aucuparia are present sporadically. The highest elevations are covered with alpine grass and herbaceous vegetation (Jeník. 1961; Fanta, 1969; Rybníček and Rybníčková, 1994; Flousek, 1994; Emmer et al., 1998).
The regional archaeology of Roman artefacts and Baltic amber imports allow inference to be made on the existence of pre-historical trade routes connecting the southern and the northern headlands of the Giant Mountains (Řehák and Květ, 1993). Evidence of human presence at the southern and south-eastern headlands of the mountains in pre-historical times (from the Celtic until the Roman period) comes from the discovery of
coins and coin deposits at various places (Ježek, personal communication). Abundant archaeological documentation confirms the existence of Germanic settlements in the lowlands to the west of the Giant Mountains, along the river Jizera and in the area of Český ráj, in the second – sixth century AD (Waldhauser and Košnar, 1997). The Germanic colonisation was followed by the Slavic colonisation during the Migration Period, in the sixth – seventh century AD. Remains of Slavic settlements have been found at Chouštníkovo Hradiště near Dvůr Králové (Sigl and Vokolek, 1993) and at Vřesník (Zeman and Buchvaldek, 1967), in the direct vicinity of the Slavic fortress of Vala at Kal (Kaliferst, 1989; Kaliferst et al., 1986). Both Vřesník and Vala are situated near the town of Pecka, about 25 km south of the investigated site of Černá Hora.

According to Lokvenc (1978) and Bartoš and Nováková (1997), the mountainous area of the Giant Mountains was not, or was only scarcely inhabited before late Medieval time. The first historical records of human influence on the forest composition date from the thirteenth and the fourteenth century. In the fifteenth century ore mining, metal processing and glass manufacturing were operated locally; this industry used the nearby forest as source of fuel and timber. The beginning of human impact on the vegetation at the forest limit is recorded after this period for the central part of the mountains (Rybniček, 1990). Large-scale exploitation of forest developed in the sixteenth century (Rybniček, 1990), when the area had been appointed as a source of wood for the silver mines in Kutná Hora (Central Bohemia). The first colonists, who opened high altitude pastures to clear the forest by order of the Czech kings, were experienced wood cutters, mine workers and craftsmen from the Alps (Central Inn area, Schwaz, Tirol, Austria). At the beginning of the seventeenth century, the central and eastern part of the Giant Mountains area was largely deforested (Lokvenc, 1978; Bartoš and Nováková, 1997). Associated with forest clearance, the colonists introduced pastoralism; this resulted in a local lowering of the alpine timberline and in permanent deforestation of accessible slopes.

Organised forestry developed in the eighteenth century as a reaction to a lack of timber for continued industrial activities in the area. The focus of this forestry was on Picea abies, which can quickly regenerate naturally. Picea was predominantly planted within extensive forest clearings. Regeneration of indigenous broadleaved species was
neglected. At the end of the twentieth century, after 250 years of this practice, forest composition decreased from about 30% of broadleaved constituents (reconstructed natural composition) to some 5%, while that of *Picea* increased to 87%. The development of forestry in the area followed the principles of the soil-rent theory and the "Normalwald", typical for the Central European forestry school of the eighteenth and nineteenth century (Flousek, 1994; Fanta, 1999). This change in forest composition might be seen as the main cause of the borealisation of forest owing to the establishment of a dark, wet and cool microclimate and acid litter in dense planted *Picea abies* forests (Emmer et al., 1998; Fanta, 1999).

In the Giant Mountains, peat deposits are present on flat areas at altitudes from 800 to 1400 m. While at higher altitudes peat growth characterised almost all the Holocene after approximately 8000 BP (Hüttemann and Bortenschlager, 1987), at lower altitudes peat growth seems to be a rather "young" phenomenon, generally since about 3000 BP (Firbas, 1952; Paclova, 1957). A striking feature is the luxuriant bog vegetation resulting in fast peat growth and bog expansion in the areas occupied by forest, causing damage to the trees. The causes of the late-Holocene peat expansion are not exactly known, but climatic change to cooler and wetter conditions and even human impact (compare Moore, 1975 and Moore et al., 1986) may have played a role. A key for settling this issue is the reconstruction of palaeoenvironmental change. We analysed material from a core taken in a small peat bog located on the flat ridge between the mountains of Černá Hora and Světlá. The occurrence in the palaeobotanical record of indicators for changes in climate or for human impact could provide the answer to the issue of peat expansion in the mountain and submountain vegetation belts in the Giant Mountains and could possibly indicate a suitable management policy for these wet areas.

### 5.2 Materials and methods

The peat bog at Černá Hora (50°39'38.2571''N, 15°45'21.0822''E, geographical coordinates on the Krasovsky ellipsoid) is situated at about 1190 m (Figure 5.1); the bog is about 10 m long, 5 m wide and about 100 cm deep in the central part. It is situated in an opening of the forest, about 20 m long and 10 m wide. The terrain is mildly sloping with a south-western aspect. The surface of the mineral subsoil may form a pocket at the place where now the peat is growing. The present vegetation is mainly composed of *Sphagnum* and *Polytrichum* species, *Calamagrostis villosa*, *Juncus filiformis* and *Eriophorum vaginatum*. Individuals of *Pinus mugo* agg. are present in the transitional area between the bog and the *Picea* forest. *Vaccinium oxycoccos* and *V. uliginosum* are present in the bog vegetation. In the planted *Picea* forest, *Sorbus aucuparia* and *Vaccinium myrtillus* are frequent.

**Palaeoecological sampling**

The material was sampled in September 1996. A pit of about 2 x 1.5 x 1 m was dug to expose a peat section. The material was sampled by pushing two metal boxes (50 x 15 x 10 cm) into the peat profile. The peat column is 96 cm deep and the overlap between the two boxes is 2 cm. Our sampling strategy has two advantages over coring: a larger quantity of material becomes available, and the material is not compressed during sampling. Furthermore, in the pit the most suitable column of peat could be chosen and wood (thick coniferous roots) could be avoided.

In the laboratory the material was subsampled. Contiguous slices were cut, 1 cm thick for the upper 87 cm of depth, and 0.5 cm for the lower 9 cm of the core. From these slices, cylindrical subsamples for microfossil analysis (0.77 cm$^3$) and for macrofossil analysis (4.5 cm$^3$) were taken. The code CRH (Černá Hora) was chosen for the core.
Chapter 5

The analysis of pollen and macrofossils was done with a sample distance of 5 cm between 95 and 65 cm depth and between 45 and the top of the sequence; between 65 and 45 cm depth and for the samples at 96 and 95 cm depth, the analysis was carried out with a sample distance of 1 cm, to allow a more detailed palaeoenvironmental reconstruction for the intervals that had shown vegetation changes.

Microfossil samples were treated with KOH and acetylated according to the method of Fægri and Iversen (1989). Inorganic material in samples below 45 cm depth was separated by using a bromoform / alcohol mixture of specific gravity 2 (Fægri and Iversen, 1989; Moore et al., 1991). To estimate pollen concentrations, two tablets of Lycopodium spores (circa 12,542 spores per tablet) were added to each sample. The minimum pollen sum per sample was 500 grains. After having reached the pollen sum, the remaining part of each slide was scanned so as to detect sparsely occurring taxa, reported in the diagram as “+”. For the microfossil data, a concentration and a percentage diagram were plotted.

Macrofossil samples were boiled with KOH (5%) and sieved to obtain the fraction > 150 µm (Birks and Birks, 1980). The identifiable material was counted (fruit, seeds), or estimated as volume percentages (vegetative remains).

Loss on Ignition
Subsamples of peat with a wet weight of about 5 g were dried at 105°C for approximately 16 hours; 2 g of the dry peat were taken and combusted in an oven at 450°C for 12 hours. The loss-on-ignition (LOI) results are expressed as percentage of dry weight.

C/N analysis
About 1 mg of sample, previously dried at 65°C, was put in a Carlo Erba element analyser. There the material was combusted at 1040°C in an O2 saturated atmosphere. The reference material for the determination of C and N was acetyanilide (% C = 71.09, % N = 10.36).

5.3 Radiocarbon dating of the Černá Hora sequence

Procedure for selection and preparation of the samples for radiocarbon dating
Five levels (90.5, 63, 60, 55 and 48 cm) were AMS radiocarbon dated at the Centre for Isotope Research (CIRO) of the University of Groningen. In order to improve the accuracy for the uppermost sample, only selected above-ground plant material was collected. No macrofossils suitable for 14C dating were preserved within the samples from 90.5, 63, 60 and 55 cm. For these levels we concentrated and dated the pollen fraction present in the samples. For the same levels, a bulk peat sample was also dated to compare with the results from the dating carried out on the concentrated pollen samples. For the level at 48 cm, two samples were collected: CRH 48a consisted of Picea needles and CRH 48b was composed of pure Sphagnum leaves and branches. Both samples were treated with HCl 4%, KOH 1%, HCl 4% to eliminate eventual CO2 formed by bacterial activity, and dried at 80°C for about 24 hours. For the extraction of pollen for radiocarbon dating, the procedure was based on the method of Brown (1994).

Results
The 14C dates are given in Table 5.1. For the depths 90.5, 63, 60 and 55 cm, we assume that the dates given by the pollen concentrate samples are more reliable than those given by the bulk samples. As the bulk sample is composed mainly of rootletts coming from higher levels, it should be younger than the age of the sub-sample from the same level composed of pollen. The results confirm this (see Table 5.1). In the
following part of this article we refer, for the depths 90.5, 63, 60 and 55 cm, to the ages of the pollen-concentrate samples only. Two samples CRH 48a and CRH 48b, show a good correspondence inside their standard deviation and both dates can be considered reliable. As the age of depth 48 cm, we use the date of the *Sphagnum* sample CRH 48b (smaller standard deviation).

**Calibration and interpolation of the radiocarbon dates**

The dates were calibrated to the calendar time-scale with the Cal 20 program (van der Plicht, 1993). The results of the calibration are shown in Table 5.2. Hereafter (Table 5.3) we present the result of both a linear interpolation of dates and of the interpolation based on changing concentrations of pollen sum elements (Pollen Density Dating or PDD) (cf. Middeldorp, 1982). When indicating the age of a level where no radiocarbon date is available, we refer to the results of the linear interpolation. These interpolations have limitations and do not yield absolute age values. Nevertheless, the results provide indications of changing sedimentation rates and an indication of the age of each level. The main limitations are the number of $^{14}$C dates in the core and the choice of a single value for the calibrated date (middle point between the oldest and the youngest boundaries of the calendar age interval with 1σ confidence level; see Table 5.2).

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Lab. no.</th>
<th>Date</th>
<th>Material</th>
<th>Event</th>
<th>Age difference (a-b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48b</td>
<td>GrA-10107</td>
<td>170 ± 30 BP</td>
<td><em>Sphagnum</em></td>
<td>fast <em>Sphagnum</em> growth,</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><em>Abies-Fagus</em> forest eliminated</td>
<td></td>
</tr>
<tr>
<td>48a</td>
<td>GrA-10574</td>
<td>200 ± 70 BP</td>
<td>Conifer needles</td>
<td>maximum Cerealia,</td>
<td>310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>second phase of human</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>impact</td>
<td></td>
</tr>
<tr>
<td>55b</td>
<td>GrA-10088</td>
<td>590 ± 30 BP</td>
<td>bulk sample</td>
<td>decrease of human</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>impact, peak of <em>Pinus</em></td>
<td></td>
</tr>
<tr>
<td>55a</td>
<td>GrA-9828</td>
<td>900 ± 45 BP</td>
<td>pollen concentrate</td>
<td>maximum grasses</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>maximum, first phase of human</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>impact</td>
<td></td>
</tr>
<tr>
<td>60b</td>
<td>GrA-10108</td>
<td>1010 ± 35 BP</td>
<td>bulk sample</td>
<td>start of peat growth</td>
<td>45</td>
</tr>
<tr>
<td>60a</td>
<td>GrA-10531</td>
<td>1080 ± 60 BP</td>
<td>pollen concentrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63b</td>
<td>GrA-10085</td>
<td>1260 ± 35 BP</td>
<td>bulk sample</td>
<td></td>
<td></td>
</tr>
<tr>
<td>63a</td>
<td>GrA-9832</td>
<td>1380 ± 45 BP</td>
<td>pollen concentrate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.5b</td>
<td>GrA-10084</td>
<td>2035 ± 35 BP</td>
<td>bulk sample</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.5a</td>
<td>GrA-10534</td>
<td>2080 ± 60 BP</td>
<td>pollen concentrate</td>
<td></td>
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</tr>
</tbody>
</table>
Table 5.2 Calibration of the radiocarbon dates and choice of a single value as result of the calibration.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Date</th>
<th>Cal date 1σ</th>
<th>Cal date 2σ</th>
<th>Corresponding age in cal years BC / AD</th>
</tr>
</thead>
<tbody>
<tr>
<td>48b</td>
<td>170 ± 30 BP</td>
<td>&gt; 1928 cal AD</td>
<td>&gt; 1918 cal AD</td>
<td>1741 cal AD</td>
</tr>
<tr>
<td></td>
<td>1800 - 1810 cal AD</td>
<td>1840 - 1872 cal AD</td>
<td>1718 - 1818 cal AD</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1734 - 1776 cal AD</td>
<td>1672 - 1686 cal AD</td>
<td>1666 - 1698 cal AD</td>
<td></td>
</tr>
<tr>
<td>55a</td>
<td>900 ± 45 BP</td>
<td>1156 - 1212 cal AD</td>
<td>1028 - 1232 cal AD</td>
<td>1129 cal AD</td>
</tr>
<tr>
<td></td>
<td>1116 - 1140 cal AD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1046 - 1092 cal AD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60a</td>
<td>1080 ± 60 BP</td>
<td>942 - 1016 cal AD</td>
<td>1144 - 1154 cal AD</td>
<td>954 cal AD</td>
</tr>
<tr>
<td></td>
<td>892 - 922 cal AD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63a</td>
<td>1380 ± 45 BP</td>
<td>624 - 684 cal AD</td>
<td>736 - 770 cal AD</td>
<td>654 cal AD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90.5a</td>
<td>2080 ± 60 BP</td>
<td>22 - 6 cal BC</td>
<td>202 cal BC - 68 cal AD</td>
<td>86 cal BC</td>
</tr>
<tr>
<td></td>
<td>166 - 32 cal BC</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.4 Description of the pollen zones

The results of micro- and macrofossil analysis are presented in Figures 5.2 and 5.3. For Abies, Betula, Fagus, Picea and Pinus the pollen concentration curves are given in Figure 5.4. The pollen sum (calculation basis for percentages of microfossils) comprises arboreal pollen, non arboreal pollen and human impact indicators. Cyperaceae, Ericales and Melampyrum are considered as possibly local, and thus excluded from the pollen sum. Micro- and macrofossil diagrams are divided into local assemblage zones from A to E.

Zone A (96 - 92.5 cm, before the first century BC)

The sediment is formed of indeterminate rootlets and sand. The concentrations of pollen sum elements vary between 65,000 and 124,000. Arboreal pollen reaches 92%. Corylus and Alnus have high percentages: about 20%, and 25% respectively. Betula and Fagus are also abundant. Abies is present at low percentages: around 3%. Among the herbs, Artemisia, Asteraceae Tubuliflorae, Poaceae, Ericales and Cyperaceae are present; Plantago lanceolata, P. major/media, Chenopodiaceae, Ranunculaceae, Urtica, Humulus/Cannabis type and Melampyrum occur. Monolete psilate fern spores are abundant. The following fungal spores are present: Ustulina deusta (Type 44), Type 17 and the newly distinguished Type 571 fungal spore (Figure 5.5).
Table 5.3  Interpolated age BC/AD by means of linear interpolation and Pollen Density Dating (PDD). The calibrated dates used for the interpolations are indicated in bold.

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Linear cal BC/AD</th>
<th>PDD cal BC/AD</th>
<th>Depth (cm)</th>
<th>Linear cal BC/AD</th>
<th>PDD cal BC/AD</th>
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<tbody>
<tr>
<td>0.0</td>
<td>1996.0 AD</td>
<td>1996.0 AD</td>
<td>55.0</td>
<td>1129.0 A D</td>
<td>1129.0 A D</td>
</tr>
<tr>
<td>1.0</td>
<td>1990.7 AD</td>
<td>1995.3 AD</td>
<td>56.0</td>
<td>1094.0 AD</td>
<td>1051.6 AD</td>
</tr>
<tr>
<td>5.0</td>
<td>1989.4 AD</td>
<td>1990.1 AD</td>
<td>57.0</td>
<td>1059.0 AD</td>
<td>1019.6 AD</td>
</tr>
<tr>
<td>10.0</td>
<td>1942.9 AD</td>
<td>1973.3 AD</td>
<td>58.0</td>
<td>1024.0 AD</td>
<td>984.9 AD</td>
</tr>
<tr>
<td>15.0</td>
<td>1916.3 AD</td>
<td>1959.6 AD</td>
<td>59.0</td>
<td>989.0 AD</td>
<td>966.7 AD</td>
</tr>
<tr>
<td>20.0</td>
<td>1889.8 AD</td>
<td>1952.3 AD</td>
<td>60.0</td>
<td>954.0 A D</td>
<td>954.0 A D</td>
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<tr>
<td>25.0</td>
<td>1863.2 AD</td>
<td>1941.1 AD</td>
<td>61.0</td>
<td>854.0 AD</td>
<td>861.1 AD</td>
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<tr>
<td>30.0</td>
<td>1836.6 AD</td>
<td>1932.5 AD</td>
<td>62.0</td>
<td>754.0 AD</td>
<td>804.6 AD</td>
</tr>
<tr>
<td>35.0</td>
<td>1810.1 AD</td>
<td>1887.5 AD</td>
<td>63.0</td>
<td>654.0 A D</td>
<td>654.0 A D</td>
</tr>
<tr>
<td>40.0</td>
<td>1783.5 AD</td>
<td>1843.2 AD</td>
<td>64.0</td>
<td>633.3 AD</td>
<td>622.6 AD</td>
</tr>
<tr>
<td>45.0</td>
<td>1756.9 AD</td>
<td>1798.3 AD</td>
<td>65.0</td>
<td>612.7 AD</td>
<td>591.6 AD</td>
</tr>
<tr>
<td>46.0</td>
<td>1751.6 AD</td>
<td>1789.0 AD</td>
<td>70.0</td>
<td>509.4 AD</td>
<td>546.2 AD</td>
</tr>
<tr>
<td>47.0</td>
<td>1746.3 AD</td>
<td>1776.7 AD</td>
<td>75.0</td>
<td>406.1 AD</td>
<td>461.6 AD</td>
</tr>
<tr>
<td>48.0</td>
<td>1741.0 A D</td>
<td>1741.0 A D</td>
<td>80.0</td>
<td>302.9 AD</td>
<td>408.2 AD</td>
</tr>
<tr>
<td>49.0</td>
<td>1653.6 AD</td>
<td>1654.9 AD</td>
<td>85.0</td>
<td>199.6 AD</td>
<td>267.7 AD</td>
</tr>
<tr>
<td>50.0</td>
<td>1596.1 AD</td>
<td>1613.0 AD</td>
<td>90.5</td>
<td>86.0 A D</td>
<td>86.0 A D</td>
</tr>
<tr>
<td>51.0</td>
<td>1478.7 AD</td>
<td>1491.0 AD</td>
<td>95.0</td>
<td>6.9 BC</td>
<td>302.3 BC</td>
</tr>
<tr>
<td>52.0</td>
<td>1391.3 AD</td>
<td>1408.0 AD</td>
<td>96.0</td>
<td>27.6 BC</td>
<td>465.3 BC</td>
</tr>
<tr>
<td>53.0</td>
<td>1303.9 AD</td>
<td>1337.1 AD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>54.0</td>
<td>1216.4 AD</td>
<td>1263.1 AD</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Zone B (92.5 - 64.5 cm, from before the first century BC to the end of the sixth century AD)
The peat is mainly composed of unidentified rootlets. Vegetative remains of *Eriophorum vaginatum* are present from 80 cm depth upwards. The decomposition rate is high. Total concentration of the pollen sum elements varies between approximately 21000 and 25000. Two levels are present where the concentration is around 7200 grains per cm$^3$, and one level where the concentration is ca 12,000 grains per cm$^3$. About 94 - 98% of the pollen sum is comprised of arboreal pollen: *Abies* increases at the beginning of this zone and subsequently remains stable. *Pinus* has a maximum at the beginning and end of zone B. *Artemisia*, other Asteraceae Tubuliflorae and Poaceae are present. *Melampyrum* is very abundant from 90 to 80 cm depth; its percentages vary between 7.6 and 26.2%. At 75 cm depth, *Melampyrum* decreases to less than 2%. *Urtica, Humulus/Cannabis* type and Chenopodiaceae occur. Also fungal spores of *Ustulina*, the coprophilous ascomycete *Sporormiella* (Figure 5.5), and Type 90 were found.

Zone C (64.5 - 60.5 cm, from the beginning of the seventh to the end of the ninth century AD)
The peat of this zone is characterised by the first occurrence of recognisable *Sphagnum* leaves and branches in the macrofossil samples and by the increase of *Eriophorum vaginatum* remains. The concentration of pollen sum elements oscillates from values around 10,000 to approximately 26,000. The arboreal pollen percentages decrease from 96% of zone B to 83%. *Picea, Pinus Abies* and *Quercus* show a decrease relative to zone B. The increase of other trees such as *Carpinus, Ulmus, Tilia, Fraxinus* and
Corylus might be an artefact as a consequence of percentage calculations. The percentage of human impact indicators increases to about 1%. The first Cerealia and Secale pollen occurs. The Poaceae strongly increase. Artemisia and Asteraceae Tubuliflora increase slightly and taxa such as Plantago lanceolata, P. major/media, Rumex acetosella type and Chenopodiaceae occur. Monolette psilate fern spores increase and Pteridium occurs. Ustulina deusta and Type 83 occur.

Zone D (60.5 - 55.5 cm, from the beginning of the tenth to the end of the eleventh century AD)

Sphagnum is not preserved in the macrofossils, and peat is mainly formed of unidentified rootlets and Eriophorum vaginatum. Charcoal is present. The concentration of pollen sum elements increases in comparison to the previous zone, and it reaches values between 32,000 and 79,000 at the top of this zone. The percentage of the arboreal pollen slightly increases to about 89%, mainly because of an increase in representation of Abies and Pinus. The percentages of Poaceae decrease. The curve of Melampyrum reaches its maximum value and Ericales show an increase.

Zone E (55.5 - 0 cm, from the beginning of the twelfth century AD to the present)

Sphagnum becomes important as peat forming element: after having disappeared from the macrofossils in zone D, it occurs again at 57 cm depth and at 56 cm it reaches approximately 60% in volume of the peat and it remains a main peat constituent up to the top of the sequence. A shift is observed from Sphagnum cf. magellanicum to Sphagnum section Acutifolia, Sphagnum papillosum and Sphagnum section Cuspidata. In the upper 10 cm of the sequence Polytrichum is present. The concentration of the pollen sum elements decreases to about 12,000-14,000 at the base of the zone, it oscillates between 51.5 and 47.5 cm depth, and from 47.5 cm to the top it remains stable to values lower than 5000. The percentages of arboreal pollen decrease to values between 60% and 80% and reach a minimum of ca 47% at 49 cm depth. Mainly Abies and Fagus are affected: Abies decreases to values of less than 3% at 45 cm depth and remains low; Fagus nearly disappears at 47 cm depth and subsequently oscillates between 1 and 3%. Carpinus, Ulmus and Tilia pollen curves are also affected and they either disappear or their presence becomes discontinuous. The increase of Pinus and Picea from 45 cm depth is mainly an effect of percentage calculations, due to the disappearance of Abies and Fagus (compare the concentration curves in Figure 5.4). Human impact indicators constitute from 6% to 23% of the pollen sum. Cerealia type and Secale increase and their curves become continuous. Other human impact indicators increase and their presence becomes stable. The first grains of Centaurea cyanus appear at the beginning of this zone. Fagopyrum and Linum usitatissimum are present. The curve of Artemisia shows a maximum at the beginning of this zone. At the start of the second phase of human impact, between 54 and 45 cm depth, monolette psilate fern spores increase. Fungal spores of cf. Entophylyctis lobata (Type 13), Type 8E, the coprophilous Sporormiella, Type 83 and Type 3A occur. A newly distinguished fungal spore, Type 572 (Figure 5.5), appears and reaches 91% at 50 cm depth. Charcoal particles, observed in the microfossil slides, gradually increase in zone E.

5.5 Regional and local vegetation development and human impact

The base of the section, corresponding to the start of organic accumulation at the sampling site, dates back to before the first century BC (zone A). The very high pollen concentration is indicative of a low sedimentation rate.
Figure 5.2. Microfossil diagram of the site of Černá Hora. The pollen sum is constituted of arboreal pollen, non arboreal pollen and human impact indicators (upper diagram). In the lower diagram are reported the taxa not included in the pollen sum. The hollow line indicates that the curve is exaggerated by a factor 6 for easing readability. The AMS $^{14}$C dates are BP.
Figure 5.3   Macrofossil diagram of the site of Černá Hora.
Figure 5.4  Concentration curves of the pollen sum and of Abies, Betula, Fagus, Picea, and Pinus (Černá Hora site).

The relative abundance of Corylus, Alnus, Fraxinus, Tilia and Carpinus in the pollen assemblage may point to relatively warm and humid climatic conditions in the lowlands. Covering the period from before the first century BC to the end of the sixth century AD, zone B represents the situation existing before human impact. High arboreal pollen percentages, the abundance of Abies, Fagus, Picea, Quercus and the presence of Acer, Carpinus, Tilia, Ulmus, point to the existence of natural, undisturbed vegetation in the valleys and the mountains. Close to the site a forest formed by Abies and Fagus with some Picea was present; the presence of needles of Picea as macrofossils indicates that Picea was also growing in the immediate vicinity. In this interval are relatively high percentages of Pinus subgenus Pinus pollen grains. This type of pollen belongs most likely to Pinus mugo agg. as, in the mountain area of the Giant Mountains, Pinus sylvestris is absent. The presence of Pinus mugo agg. may indicate local occurrence of this species. The low representation of grasses and herbs points to the low level, or even absence of human impact in the area. At the beginning of the seventh century AD (zone C) changes in the vegetation occurred. The curves of Abies, Fagus, Picea and Pinus decrease. The Poaceae and weeds (Artemisia, Chenopodiaceae, Plantago lanceolata and Rumex acetosella type) spread. Plantago major/media occurs and ferns spores (Monolete psilate fern spores and Pteridium) increase.
Figure 5.5  Spores of the coprophilous fungus Sporormiella (1 - 6) and of two new Types: Type 571 (7 - 10) and Type 572 (11 - 14). Type 571 is a spindle-shaped spore 19.1 - 26.6 x 6.6 - 9.1 µm. At both ends the walls are thickened, showing appendages of about 1.5 µm in diameter. Type 572 is a fungal spore, one-septate, 20.8 - 35.7 x 9.1 - 12.5 µm. The septum shows an approximately 1 µm wide pore. The distal cell ends bluntly, longer and wider than the proximal cell. An approximately 2 µm wide pore is present on the proximal cell. The wall near the pore is thickened. All magnifications x1000.

For the interpretation of these events, different explanations could be given, for instance wind damage causing an opening of forest vegetation and local waterlogging (Rybníček and Rybníčková, pers. com.). However, we consider that the observed changes point to the occurrence of a phase of disturbance (human impact) at approximately 1380 ± 45 BP (seventh – eighth century AD). We suppose that openings in the submountain and mountain forest were created, possibly either for forest pastures or for a first exploitation of ores. Cerealia, also present in this pollen zone, could not be cultivated at the altitude of the site; this pollen more likely originated from the lowlands. An interruption of human impact took place from the beginning of the tenth to the end of the eleventh century AD (zone D), where pollen of forest elements - Abies, Pinus and subsequently Fagus - increases, and that of herbaceous taxa decreases. Pinus increased its competitiveness with the availability of light in the openings and rapidly settled in the clearances. The presence of Salix and the slight increase in the curve of
Betula also point to the existence of open areas in the forest. Artemisia, Plantago lanceolata and Rumex acetosella type remained constant, possibly due either to some continuing human interference on the vegetation, or to a too short recovery time before the start of the following exploitation phase.

A second, more intense phase of human impact started around 900 ± 45 BP (eleventh – twelfth century AD; Table 5.2; zone E). This impact phase has conditioned the vegetation composition until the present time. Valleys and lowlands became permanently cultivated, as indicated, among others, by the curves of Cerealia type and Secale cereale and by the occurrence of Fagopyrum and Linum usitatissimum grains. The first occurrence of Fagopyrum is recorded in the fifteenth century AD; this finding corresponds well with the period of cultivation of this plant, native of Central Asia and introduced in Europe by the Mongolian population in the thirteenth and fourteenth century AD (cf. Hegi, 1948 ex Rybničková, 1974). The first occurrence of Centaurea cyanus pollen grains is recorded approximately in the twelfth century. The curves of weeds, of the nitrophilous Urtica, of grasses and of charcoal also point to a period of intense human impact. The occurrence of sporadic grains of Juniperus and the increase of Betula and Salix, and the maximum of Artemisia, all light-demanding taxa, confirm that an extensive opening of the vegetation took place.

A reduction or disappearance of the main tree taxa becomes evident; Abies and Fagus were nearly eliminated from the submontane and montane forest. In the lowlands, the presence of Carpinus, Quercus, Tilia and Ulmus was reduced. The increase of Picea and Pinus is thought to be mainly an artefact of percentage calculations, due to the reduction of Abies and Fagus, the other strong pollen-producers. Nevertheless, slight increases in the pollen concentration curves of Picea and Pinus only, may indicate that these two taxa remained longer than Abies and Fagus. Picea has a better capacity to recover from disturbance than Abies and Fagus (Lokvenc, 1978; 1992). Since the end of the eighteenth century, planting of Picea stands was introduced, so the increase of the Picea pollen curve may be attributed to the existence of plantations. Also the onset of colder conditions during the Little Ice Age might have played a role in increasing the competitiveness of Picea (Rybniček, 1990). The increased values of Pinus could be explained both by the presence of clearances in the forest and by an increased input of pollen coming from the Pinus mugo stands near the forest line. After deforestation, pollen derived from the forest line – just about 150 m higher than Černá Hora - could more easily reach small bogs that were not surrounded by a close forest.

5.6 Loss on ignition and C/N ratio

Loss on ignition (LOI) gives indications of the ratio between organic and inorganic matter. LOI fluctuations are caused by changes in the input of inorganic material in the system or by changes in net organic production.

The carbon/nitrogen ratio in a peat bog depends on the C/N ratio in the peat forming vegetation (Kuhry et al., 1992) and in differential loss of either carbon or nitrogen in the decomposition process (Kuhry and Vitt, 1996). During decomposition, carbon is released both under aerobic and under anaerobic conditions. Nitrogen is released only under aerobic conditions; its loss under anaerobic condition is negligible. Changes in degree of anaerobic decomposition can explain changing C/N ratios (Kuhry and Vitt, 1996). The results are reported in Table 5.4 and in Figure 5.6.

The very low values of LOI at the base of the section (zone A) indicate strong decomposition when organic accumulation started. In the curve of the LOI, minimum values are found at the limit between zones D and E (samples 54 and 55).
This suggests the occurrence of soil erosion after deforestation in the surroundings of the bog and maybe also the occurrence of superficial water runoff coming from the deforested surroundings of the bog. Low LOI values can, for a minor part, also be explained by a low peat accumulation rate.

The values of the C/N ratio are rather low from the base of the section up to 40 cm: very low values occur between 55 and 51 cm, with a minimum at 54 cm. A higher C/N ratio characterises the upper 35 cm. The rather low C/N values between 96 and 40 cm indicate persistence of decomposition under anaerobic conditions in the catotelm, which led to a loss of carbon and to a differential enrichment in nitrogen.
The high C/N ratio of the upper part of the zone E, from 35 cm to the top, indicate that no differential release of C or N occurred and thus the decomposition processes took place during a relatively short period mainly in aerobic conditions. Because the minimum in the C/N ratio between 55 and 51 cm coincides with the minimum in LOI, we can hypothesise a common cause. LOI may point to the occurrence of superficial runoff in this interval, as a consequence of deforestation. The presence of a surplus of superficial water might have determined anaerobic conditions in the acrotelm, suppressing the release of nitrogen, but permitting still that of carbon, thus finally lowering the C/N ratio. The excess of water would subsequently have favoured the growth of Sphagnum.

5.7 Comparison between palaeobotanical evidences of human impact and historical records

As discussed previously, two main phases of human impact on the vegetation are evident from the Černá Hora pollen record. The first human impact phase dates back to 1380 ± 45 BP (seventh - eighth century AD). The pollen diagram may provide an indication that during this period farming communities were present in the adjacent lowlands. This early human impact on the forest, already in the seventh - eighth century, (without supporting historical records) is controversial, and therefore we emphasise the careful selection of the $^{14}$C samples and the interpretation of these dates: for the sample at 63 cm, the $^{14}$C date on pollen concentrate (1380 ± 45 BP) and that on a bulk sample (1260 ± 35 BP) are in fairly good agreement with each other. Furthermore, the dates at 63 cm also fit well with the
dates of the depths below (90.5 cm, 2080 ± 60 BP) and above it (60 cm, 1080 ± 60 BP).
The onset of the Slavic settlement in the lowlands south of Černá Hora is in the sixth century AD. The nearest settled sites found until now are the early Slavic fortress Vala-Kal and the agricultural settlement of Vřesník, both at the town of Pecka (Zeman and Buchvalde, 1967; Kalfert et al., 1986), and Choustníkovo Hradiště at Dvůr Králové (Sigl and Vokolek, 1993) at some 25 km distance from Černá Hora. The founding of these settlements falls into the seventh century. They ceased to exist two centuries later. For the tenth and eleventh century the archaeological evidence displays a hiatus in the settlement continuity. The next wave of colonisation which has been archaeologically fully documented (the Pfemyslid colonisation) took place in the twelfth century. The settlement structure of the broader area, including the Giant Mountains, stabilised during the thirteenth century (Ježek, personal communication).

The beginning of the second human impact phase is recorded around 900 ± 45 BP (eleventh - twelfth century AD) and goes on until the present. It has maxima in the seventeenth century (49 cm, approximately 1653 cal AD; Table 5.3) and in the eighteenth century (47 cm, approximately 1746 cal AD; Table 5.3). This second phase corresponds well with the historical data reporting the continuous exploitation of the forest in the last ten centuries: the presence of a castle near Vrchlabí in the eleventh century, deforestation in the thirteenth century, extensive deforestation in the sixteenth century, the disappearance of a considerable part of the forest in the central and eastern part of the Giant Mountains area at the beginning of the seventeenth century and the application of modern forestry techniques since the eighteenth century.

5.8 Effect of deforestation on local hydrological conditions and peat development

Changes in pollen concentrations, peat composition and radiocarbon data indicate that some abrupt accumulation rate changes occurred between pollen zone B and zone E. Zones C and D represent the transition interval between the more decomposed lower part (zone B) and the less decomposed upper part (zone E). Zone C first records local conditions suitable for the formation of less decomposed peat; in zone D, formation of decomposed peat recurred. Changes in peat growth were synchronous with the major changes in regional vegetation (Figure 5.7).

We interpret the recorded disturbance and opening of the forest by human activity as the factor influencing local hydrology and thus influencing the decomposition process and the accumulation rate of the peat at Černá Hora.

We presume that forest exploitation in the vicinity of the bog led to a decrease in evapotranspiration and to local wetter conditions. Different mechanisms may have played a role in decreasing evapotranspiration, viz., changes in heat balance and a decline of the leaf area index (LAI) (Křeček, 1996), in combination with a change in water retention capacity of the soils (Bormann and Likens, 1994). In the case of recent deforestation studied by Křeček, in the upper plain of the neighbouring Jizera Mountains, after forest cutting the increase in albedo by 100% and in sensible heat flux by 40%, and the decrease in net radiation by 15%, determined a decrease in annual evapotranspiration by about 150 mm. The LAI declined from 16-20 to values lower than 3 after deforestation, determining a decrease in the interception and evapotranspiration of ground water by trees. This resulted in a decrease of the soil infiltration capacity from 150 to 40 mm h⁻¹.

The soil infiltration capacity may be further reduced after deforestation due to the disappearance of forest litter on the soil: the presence of dead biomass intercepts and disperses the energy of falling drops of water, increases water retention and facilitates percolation in the soil (Bormann and Likens, 1994).
The combination of a change in heat balance, a reduced leaf area index and a decrease in infiltration capacity, causes a surplus of water remaining in the soils.

Although the small bog of Černá Hora is ombrotrophic, and thus resembles a raised bog, its hydrological balance is not completely independent from the surroundings. We suppose that the above described processes occurred in the immediate surroundings of the bog and that, as a consequence, also the hydrological balance of the bog itself was influenced. As the site of Černá Hora is on a flat part of a gently degrading slope, the water did not flow away, but some stagnation may have occurred. The effect was...
enhanced peat growth and a decrease of the decomposition process, resulting in the preservation of Sphagnum in zone C. on top of the highly decomposed peat of zone B. Furthermore, as an effect of the decrease of decomposition a decrease of available nutrients was favourable for the growth of Sphagnum, further increasing the accumulation rate. The active acidification by Sphagnum (Clymo, 1984) will also have contributed to the decrease of the decomposition.

In zone D (from the beginning of the tenth to the end of the eleventh century AD), a temporarily increased tree density following a temporary decrease of human impact, led to drier soil conditions again (higher evapotranspiration). This led to a decrease of moisture in the bog. This hydrological change is also reflected in the temporary rise of Melampyrum (Moore et al., 1986; Turner et al., 1993) and in the local occurrence of sclerotia of Cenococcum geophilum. Owing to drier conditions, the decomposition rate increased, preventing the preservation of Sphagna. The high pollen concentrations indicate a slow peat accumulation, in agreement with the establishment of drier conditions and a high degree of decomposition of the peat forming plants.

As a consequence of the deforestation at the start of the second phase of human impact (from the beginning of the twelfth century AD to the present) sudden changes in hydrology and peat accumulation, similar to those of zone C, were induced. We interpret the reappearance of Sphagnum peat and a low degree of decomposition as due to a raised water table. The hypothesis of the occurrence of a water surplus at this level is supported by the results of LOI and C/N ratio.

Up to the present, the level of the water table may have fluctuated but remained relatively high. At the surface Sphagnum is an important peat constituent, but that is most likely an effect of not-yet-occurred decomposition in the acrotelm; the occurrence of Polytrichum at 10 cm depth indicates that the local conditions became drier. If the changes in peat composition are compared with the results of pollen analysis, the tendency to drier conditions took place alongside the increase of Picea between 20 and 15 cm depth. This increase is most likely due to the plantation of Picea in the area. The increased tree-density after planting apparently also determined an increased evapotranspiration and lowering of the water table; this situation would favour drier conditions on the bog surface and stimulated the growth of Polytrichum.

Important for the present forestry activities is the question whether the patterns of peat extension and accumulation could return to pre-anthropogenic (i.e. reduced) conditions. Most likely this will not happen: the impact of human activities triggered the shift from moderately drained soils with the formation, at places like the Černá Hora site, of a highly decomposed, “dry” peat, to more waterlogged conditions which enhanced the expansion of Sphagnum peat growth. The present vegetation type, thanks to the abundance of Sphagnum, has a good buffer capacity for water: it can take up the surplus of water and use it during dry periods. It can, thus, not only successfully oppose the effects of the evapotranspiration of trees, but it also creates unfavourable conditions for trees that get waterlogged in their root zone. The decomposition rate of needles and other organic material is slowed down by the presence of water that reduces the microfaunal and microbial activity. Water also reduces the quantity of available oxygen and lowers the soil temperature (Moore et al., 1984). The soil acidification resulting from this process acts as a weakening factor for the trees; only plants resisting acid conditions, like Eriophorum and Ericales, can survive, while Sphagnum increases its dominance. Although macroclimatic and environmental conditions are different, the mechanisms behind the enhanced peat growth we observe for the Černá Hora bog seems to have much in common with those causing the development of blanket mires under influence of human impact on the British Isles (Moore, 1975; Moore et al., 1984). Deforestation and, even more important, the repeated alternation of deforestation and artificial afforestation during the historical period has had a positive effect on peat growth:
- during deforestation the water table rises, supporting *Sphagnum* growth,
- after afforestation, the accumulation of dead organic matter and the relatively low decomposition enhance soil acidification and absorption of water.

The described phenomenon supports the borealization hypothesis as formulated by Emmer *et al.* (1998). The indirect effect of former deforestation (peat growth, hampering drainage of the area and creating unfavourable conditions for trees) has led to worsened conditions for forest growth in the flat and semi-flat areas of the middle altitudes in the Giant Mountains. This situation, initially caused by deforestation, cannot be compensated for with the planting of *Picea* trees in close canopy. Dense stands of trees result in cold and dark conditions on the forest soils, which are unfavourable for decomposition. While the presence of trees can help to achieve drier conditions (higher evapotranspiration), it also determines fast accumulation of organic material that absorbs water and stimulates peat expansion. The alternation of deforestation and afforestation since the sixteenth century until the present time, will have contributed to the extension of the *Sphagno-Piceetum* forest community.

The role of climate has not been mentioned in our interpretation because in the data we did not find clear evidence for effects of climatic change. No climatic change is known to have occurred in correspondence with the first phase of human impact (zone C, from the beginning of the seventh to the end of the ninth century AD). After the Medieval climatic optimum, the first evidence of a climatic deterioration in historical time occurred in the Czech Republic around the fourteenth century (Firbas and Losert, 1949), thus after the change in peat accumulation at the beginning of the second phase of human impact (zone E, beginning of the twelfth century AD to the present time). This climatic deterioration might have enhanced the change, but could not have caused it.

The correspondence of the two phases of increased peat accumulation and of *Sphagnum* preservation (zones C and E) with the increase of indicators of human impact in the pollen record supports our hypothesis that human impact on the vegetation caused the changes in decomposition and peat accumulation rate. We suppose that the observed changes in humidity were limited to the bog and to its hydrological basin. In case climate change also played a role in determining the vegetation development, the effects were outstripped by the considerable hydrological changes as a consequence of human impact.

The main motivation of forestry in the Krkonoše National Park is restoration of self-sustaining forest communities and ecosystems as the main indigenous components of mountain landscape as well as for carbon storage. The reconstruction of the natural forest is promoted because of the role of trees as a store of carbon. We emphasise here that peat-forming vegetation may - on the long term - be a more effective store for carbon (Kobak *et al.*, 1998; Kuhry and Vitt, 1996) than a moribund forest.

### 5.9 Conclusions

The pollen and macrofossil record of a small bog in the area of Černá Hora shows that peat accumulation at the site started before the first century BC; until the end of the sixth century AD the natural vegetation was undisturbed. Human impact on the environment apparently started in the seventh – eighth century, it decreased from the beginning of the tenth to the end of the eleventh century AD and it increased again in the twelfth century. Since then it remained permanent. Human impact apparently had considerable effects: directly in the form of deforestation and indirectly - as interpreted by us - through hydrological effects and a related increase of peat growth which was most likely irreversible.
5.10 References

Bartoš M. and Nováková Z. 1997. The oldest pictorial map of the Krkonoše Mountains by the chronicler Simon Huttel. Trutnov: Vydal SokA.


Chapter 5
