Holocene acidification process recorded in three pollen profiles from Czech sandstone and river terrace environments

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Introduction

Late Quaternary climatic changes had dramatic effect on the terrestrial biosphere. In temperate mid-latitude regions of the Northern Hemisphere, vegetation belts migrated over several thousands of kilometers. These macroscale vegetational changes were accompanied (and were partly in response to) changes in soil properties. The ways in which soil-vegetation relationships have evolved, and particularly the response of vegetational and pedogenetic processes to climatic change, are of fundamental importance in understanding the dynamics of contemporary ecosystems. Viewed in this light, acidification is a long-term natural process that occurs especially during warm phases of Quaternary climatic cycle (Iversen 1958; Birks 1986). It is characterized by loss of cations (namely bivalent bases - Ca^{2+} and Mg^{2+}) that are normally bound to clay minerals in the soils. Under wet and warm conditions, bases are leached from these complexes, being dissolved in percolating water and transported out of the ecosystem (and finally through the rivers to the sea). This process results in change in species composition and productivity of the ecosystems. The dynamics of acidification is seriously modified by climatic changes, biotic influences, and, during the Holocene, also by human intervention (Bell & Walker 1992). Antropogenic activities contribute to the acidification through removal of biomass (grazing, mowing, woodcutting, harvesting without subsequent manuring) and through triggering the soil erosion. Positive backbound mechanisms may play an important role in case of biological control of acidification. To give a simple example from Central Europe: At the first stage of acidification, coniferous trees (namely *Pinus sylvestris*, *Picea abies*, and *Abies alba*) spread within broadleaf forests. During the decomposition of coniferous falloff, humic acids are produced in great quantities. Organic compounds in soils change from mull to mor humus. This efficiently speeds up further acidification and soils structure is changed in the process called podzolisation. Usually also upper layer of underlying bedrock is being leached and decalcified.

Due to its long long-term nature, acidification processes can be best studied in secular to millennial time scale. Pollen analysis is appropriate tool for this as it enables to record time scales long enough and because vegetation corresponds directly to local geochemical changes.

The pollen and sediment chemistry evidence

Soils developed on relatively acidic bedrock are often more sensitive to loss of nutrients than those on calcareous substrata. This is why best evidence for Holocene acidification in the Czech Republic comes from sandstone regions and from river environment with extensive cover of acidic sands and gravel. In the following, we will give three examples of profiles, where acidification process can be studied (location of profiles indicated in Fig. 1).

Anenské údolí, Broumovsko sandstone region

The site, a topogenic mire in the bottom of a valley at 645 m a.s.l. altitude, is surrounded by dramatic

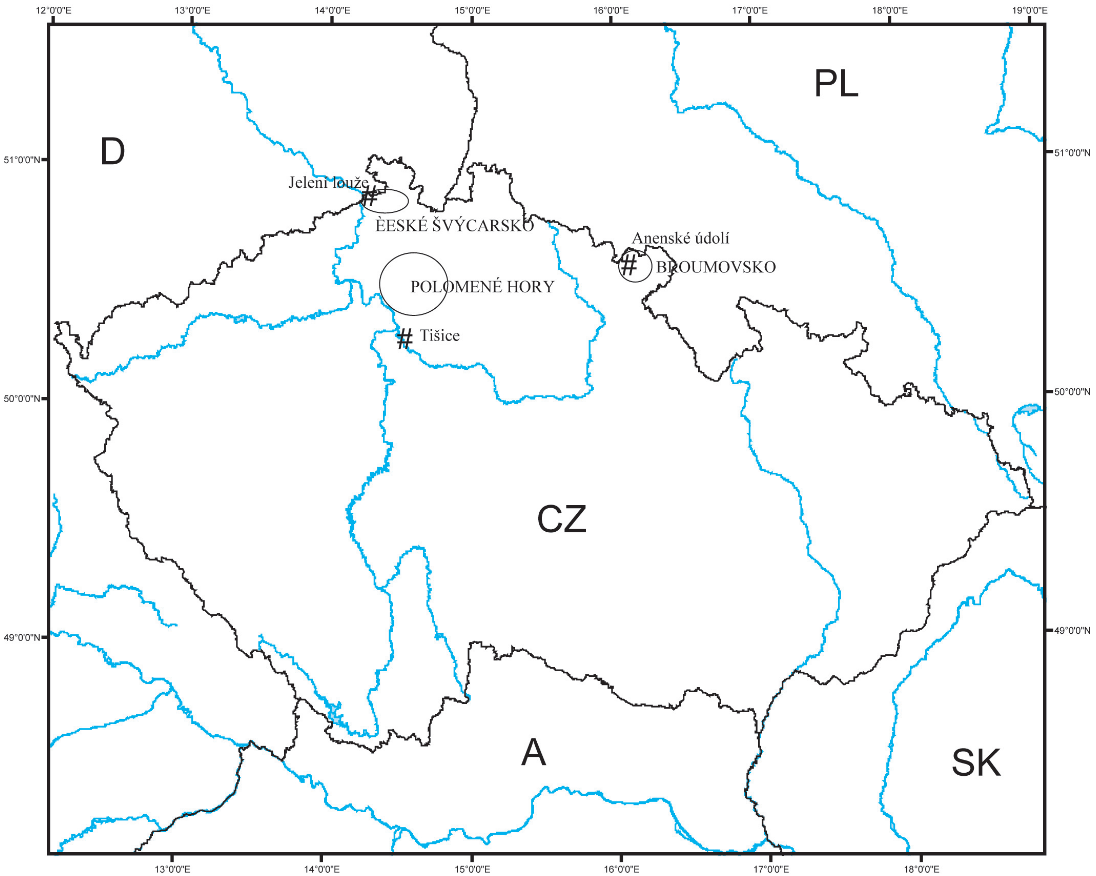

Fig. 1: Territory of the Czech Republic and the location of sites and regions mentioned in the text.

relief with sandstone rocks and gorges. Present vegetation is dominated by acidic pine woodland in relatively dryer situations and by spruce plantations in the bottoms of the valleys. Climate of the region is oceanic and relatively cold (mean annual temperature around 7°C and rainfall around 800 mm).

In the pollen diagram (Fig. 2) we see gradual vegetation change from mixed oak woodlands to communities dominated by spruce (*Picea abies*), beech (*Fagus sylvatica*), and silver fir (*Abies alba*). This change can be observed between 150 and 85 cm – i.e. between ca 4 100 and 3 400 B.P. according to radiocarbon chronology. While the decrease in demanding tree species is gradual, expansion of constituents of oligotrophic woodland communities is stepwise: In the first step this is the expansion of *Picea abies*, followed by strong increase in *Fagus sylvatica* and *Abies alba*. Also hornbeam (*Carpinus betulus*) appears in this stage. As human impact indicators virtually lacking in the pollen record we may assume that above-described process of acidification was controlled entirely by natural influences in this case.

To get more insight to process of acidification, samples for chemical analysis of Ca^{2+} and Mg^{2+} cations (Fig. 5) were taken directly from above-described peat profile. At first, concentration of both elements steadily rises (from about 190 to 95 cm). This must be the result of increased leaching from the soils in the catchment after invasion of beech (*Fagus sylvatica*). Leached cations were than bound into peat organic matter (Digerfeldt 1972). Maximum concentrations are found at the level of 95 cm – this is probably the result of silver fir invasion (see *Abies alba* curve in pollen diagram). As already described above, the decomposition of coniferous falloff may speed up acidification process. Spread of coniferous forest in the catchment caused more Ca^{2+} and Mg^{2+} to be released from the soils. After the maximum at 95 cm, the concentrations of both Ca^{2+} and Mg^{2+} started to decline as their availability slowly decreased in the catchment. At this time finally, acidification process was completed.

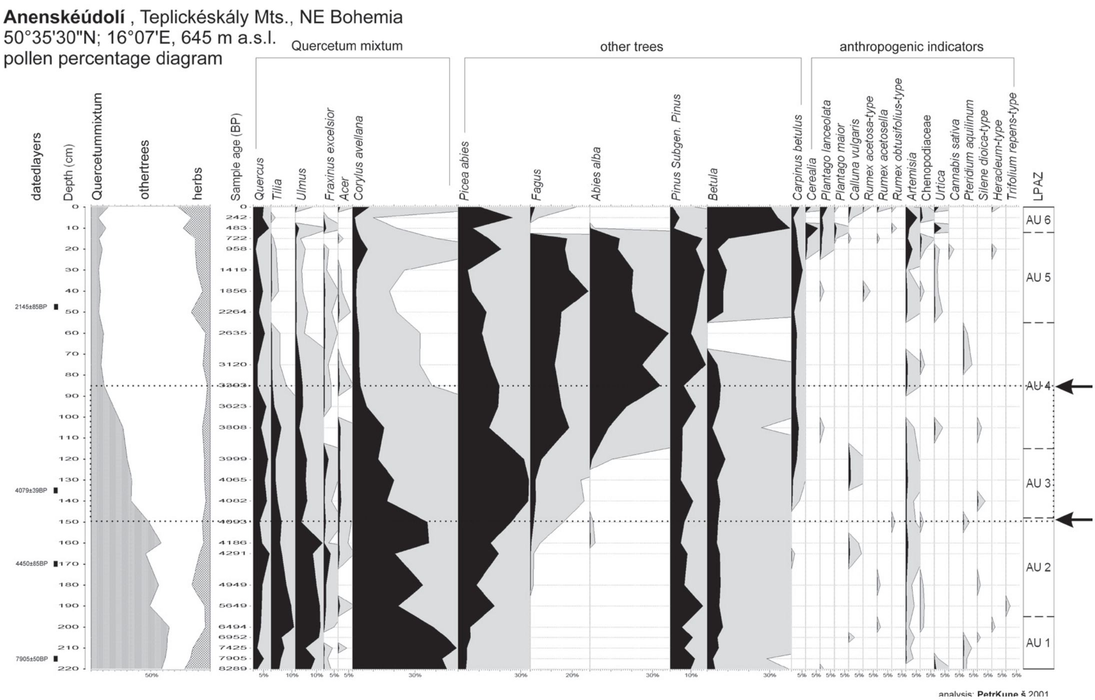

Fig. 2: Simplified percentage pollen diagram from Anenské údolí site. The period of acidification indicated at right.

Jelení louže, České Švýcarsko sandstone region

This pollen profile comes from a topogenic mire that is situated in relatively shallow sandstone gorge, about 400 m a.s.l. The site is surrounded by large sandstone plateau bordered by well-developed rock formations. Today, this area is extremely acidic with species-poor vegetation dominated by pine and birch. Surface pollen spectrum (0 cm in the pollen profile) reflects the present vegetation conditions. Local climate is rather oceanic with relatively high annual rainfall (nearby station at Chřipská: 934 mm).

Acidification process is seen in the pollen diagram between the depth of 210 and 120 cm (Fig. 3). This corresponds to the time period between about 4700 B.P. and 2900 B.P. according to radiocarbon dating. As in the case of Anenské údolí site, although final consequences of acidifications are very deep, the process itself is rather gradual. Vegetation response to acidification has a stepwise character. The starting point is the vegetation of rich mixed oak woodlands with significant admixture of hazel (*Corylus avelana*). In the first step, the curves of demanding trees (*Quercus*, *Tilia*, *Ulmus*, *Acer*, *Fraxinus*, and *Corylus*) decline in favor to expanding beech (*Fagus sylvatica*). During the second step we may observe another decrease in demanding broadleaf trees, but also the decline in *Fagus* that is replaced by silver fir (*Abies alba*). In the same period, anthropogenic indicators are very low in the pollen diagram, excluding again the possibility of anthropogenic control of acidification process.

Tišice, middle Labe region

Unlike the previous two cases, this site is situated at low elevation (165 m a.s.l.) and in very different geomorphologic situation - in a flat landscape within a broad valley of Labe River, adjacent to Polomené hory sandstone area. The valley is filed with sandy and gravel substrata of Pleistocene river terraces. We may trace the history of human impact in the region deep into Neolithic period from the pollen-analytical investigations and according to archaeological excavations (Dreslerová & Pokorný 2004). Today, this is an agricultural landscape with some little remains of acidic pine woodlands. Local climate is warm, dry, and relatively continental (mean annual climatic characteristics of nearby city of Mělník: 8.7 °C, 527 mm).

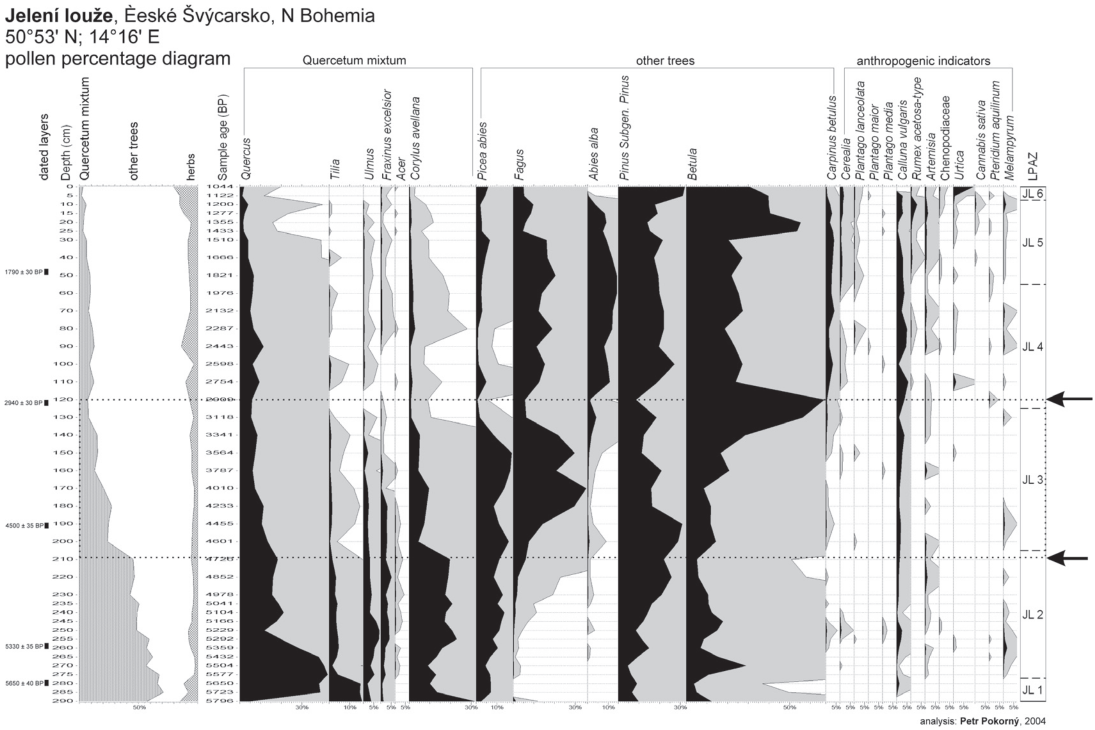

Fig. 3: Simplified percentage pollen diagram from the Jelení louže site. The period of acidification is indicated on the right side.

Older part of the pollen diagram (Fig. 4) is characterized by high pollen curves of *Quercus*, *Tilia*, *Ulmus*, *Fraxinus*, and *Corylus*. Acidification is much more dramatic process than in previous two examples. It is seen in pollen diagram as sudden vegetation change between 185 and 175 cm depth. This period corresponds roughly to 3 000 B.P. according to radiocarbon chronology. Demanding trees of mixed oak woodlands decline in this point and curves of *Pinus* and *Abies alba* increase significantly. This event is synchronous with sudden rise in antropogenic indicators – both arable and grazing indicators. Close correlation of both phenomena suggests an anthropogenic control of acidification process. This was probably the reason why vegetation change is so sharp in this case.

Discussion and conclusions

Sandstone and river terrace landscapes in the Czech Republic experienced considerable changes in their productivity, species richness and composition during the Late Holocene. These areas, today extremely acidic and oligotrophic, were much more nutrient rich during most of their Holocene history. In the example of three pollen profiles we could see how process of acidification may differ in the timing and in its dynamics. These differences are due to different local climatic setting and, more important, due to different human impact histories.

First evidence for Late Holocene acidification of Czech sandstone landscapes was given by V. Ložek (1998). His arguments are based on palaeomalacological finds from sedimentary fills of rock shelters at Polomené hory sandstone area. Middle Holocene snail communities were surprisingly rich in species, whereas at present the areas in question are characterized by only very poor communities consisting of few most resistant species. Strong decrease in snail species richness – from 41 species to only 6 in case of a single site - coincides with the Final Bronze Age period (about 3 000 B.P.). This suggests a dramatic transformation of ecosystem during respective time. For the explanation of this phenomenon, Ložek proposes model of environmental collapse induced by climatic change associated with human activity - woodland clearance and grazing. This model corresponds very well to our present

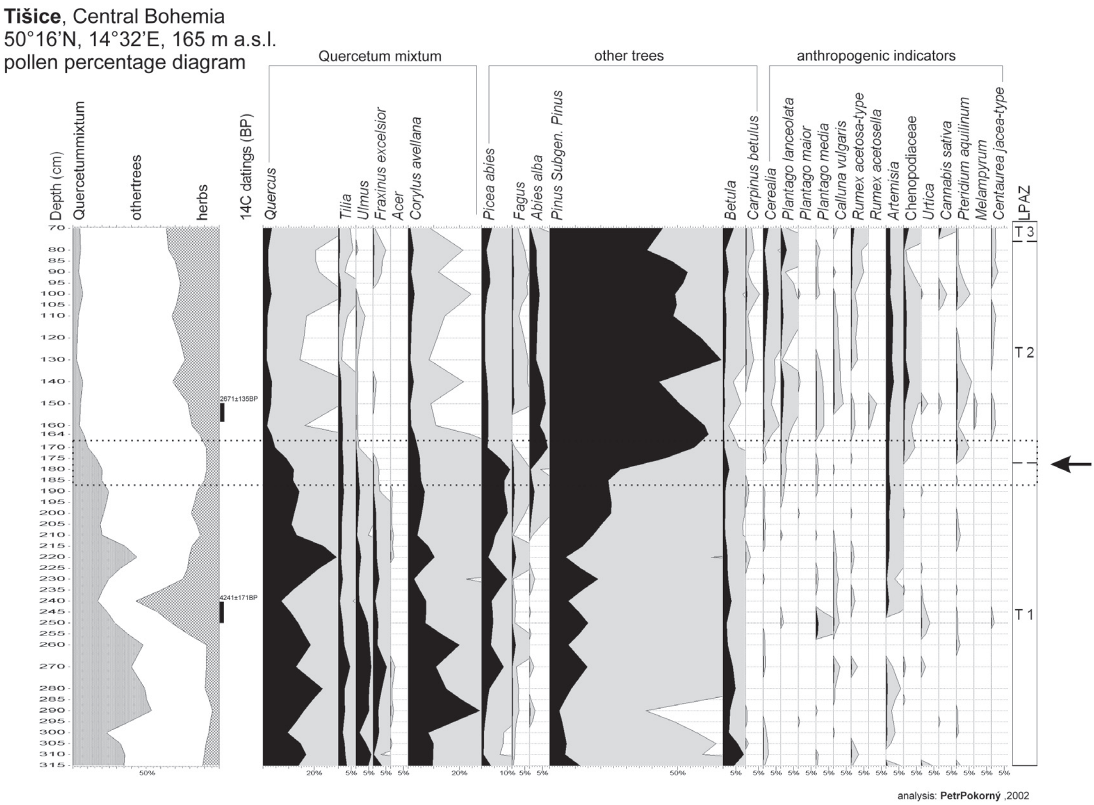

Fig. 4: Simplified percentage pollen diagram from the Tišice site. The moment of acidification is indicated on the right side.

data from Tišice site, where vegetation change to more acidic conditions is synchronous with significant increase in human impact. Also the timing of both acidification events is about the same (Late to Final Bronze Age). In contrast to this, pollen evidence from Broumovsko and České Švýcarsko sandstone regions suggests more gradual acidification that took place between ca 4 700 and 3 000 B.P. (Late Neolithic to Final Bronze Age according to archaeological chronology). This difference is probably due to the lack of prehistoric human influence which was negligible in two later mentioned regions.

According to arguments presented in this paper, soil acidification and ecosystem depauperization is a process that is natural under climatic conditions of Central Europe. Sandstone substrata are especially sensitive to loss of basic nutrients. Around 3 000 B.P., natural process of acidification culminated in both sandstone regions under study. This happened obviously without influence of man. Nevertheless, human impact may have been an important factor that speeded up this process. This happened during Late and Final

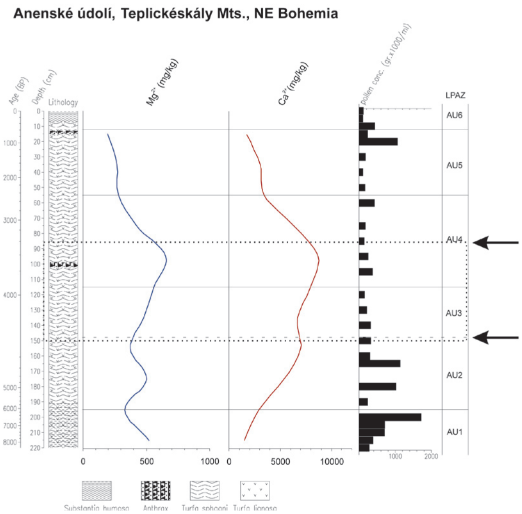

Fig. 5: Ca^{2+} and Mg^{2+} total concentrations diagram from Anenské the údolí site. The period of acidification (derived from pollen diagram; Fig. 2) is indicated on the right side.

Bronze Age (i.e. at about 3 000 B.P. again) in case of Polomené hory sandstone area and in nearby-situated terraces of Middle Labe River. Woodland clearance, grazing and subsequent soil erosion were probably most important control mechanisms that played a role.

Acknowledgements

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Résumé de la présentation

Histoire de la végétation des paysages de grès tchèques dérivée du profil de tourbières

<u>**Mots-clés:**</u> paléoécologie; palynologie; analyse de pollen; développement de la végétation; changement environnemental; holocène; acidification

En République Tchèque, les paysages de grès représentent un phénomène important. En dépit de ce fait, on ne sait que peu de choses au sujet de quelques aspects importants de leur histoire environnementale. Les régions gréseuses České Švýcarsko et Broumovsko ont été récemment soumises à des analyses polliniques qui ont apporté des informations significatives sur le développement de leur végétation au cours de l'holocène. De ce point de vue, l'histoire de ces paysages de grès se révèle étonnamment dramatique.

D'une part documentées par des recherches paléomalacologiques, leurs conditions nutritives dans le passé pourraient avoir été sensiblement différentes de celles que nous connaissons aujourd'hui. De nouveaux résultats palynologiques de České Švýcarsko confirment cette trouvaille. Dans l'holocène moyen, les forêts mixtes de chêne à grande abondance de noisettier, de tilleul et d'orme formaient l'essentiel des espaces boisés. Plus tard, des substrats riches en éléments nutritifs ont été soumis à un appauvrissement provoqué très probablement par des changements climatiques. L'expansion du hêtre et du sapin argenté en fut le résultat. Le rôle de l'impact humain dans ce processus fut négligeable. L'influence humaine s'accélère seulement à partir de la période moderne.

D'autre part, l'existence dans le passé d'une végétation contrastante à échelle spatiale très réduite a été également largement soutenue par les analyses polliniques. Les données de la région de Broumovsko démontrent l'expansion et l'établissement de forêts d'épicéas dans des stations à inversion climatique. En revanche, on trouvait des chênaies mélangées au noisettier quelques centaines de mètres au-dessus dans des stations plus lumineuses et plus chaudes. L'hypothèse de stations rélictuelles de grandes pinèdes dans tous les paysages de grès a été également rejetée du au très faible contenu de pollen de pin. En conclusion le transport de pollen et le processus de sédimentation dans des profils de tourbe ont apparemment eu lieu à échelle locale. C'est pourquoi on peut y retracer surtout l'historique de la végétation des alentours immédiats, moins celui de l'espace régional ou global.

Les résultats font ressortir clairement que les régions de grès diffèrent significativement dans leur histoire environnementale. Les différences climatiques et géologiques ainsi que les historiques de migration distinctes en sont la cause.