climate at 18 ka ago is also expressed in pollen diagrams from the Hula basin in northern Israel (Horowitz, 1979). Another example of such discordance is the Early Würm loess unit dated as 62–72 ka BP. During this period, erosion prevailed in the Central Negev. In addition to this indicated a good correlation between climatic curves for Israel and oxygen isotope curves obtained from the northern Atlantic Ocean (Horowitz, 1992). Although the major climatic fluctuations in the Negev are related to global climatic changes, appreciable disparities occur between the duration of a period with distinctive climatic conditions and the duration of corresponding geomorphic processes. The study of continuous sequences permitted the conclusion (Weinstein-Evron, 1983) that the main climatic phases, both glacial and interglacial, were interrupted by episodes of different duration, characterized by opposite climate. Thus, the strongly deterministic climatic model, which explains a change in erosion-accumulative processes, and which is based on direct correlation with the global climatic scale, does not work in a simple form.

Phases of alluvial accumulation (Fig. 2) coincide with arid (*terraces I, III*) as well as with semi-arid periods (*terraces II, IV*). However, analysis of pollen data shows that the degree of aridity during the periods of accumulation was not as severe as during periods of strong erosion. The present-day hyper-arid spectra are characterized by absolute prevalence of Chenopodiaceae, whereas the alluvium of *terrace III* contains spectra with an almost equal content of true desert Chenopodiaceae and dry steppe Compositae + *Artemisia* elements. Episodes of accumulation within arid periods could reflect the slightly more humid periods. Therefore, low-amplitude climatic fluctuations within climatic phases in a sensitive desert region can induce a major reaction of the fluvial systems and can lead to the changing in the regime of alluvial processes (erosion ↔ accumulation).

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Sedimentary Deposits of Bohemian Forest Lakes as an Archive of Pollution by Metals

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ABSTRACT. Chronology of metal pollution was studied in 0.3 to 1.3 m long sediment cores collected from lakes in Bohemian Forest (SW Bohemia). The ^{210}Pb and ^{14}C datings provide a reliable chronology of cores extending back to above 6500 BP. The sediments have recorded both regional and local atmospheric pollution caused by smelting of metals, for Pb since about 2810 BP. Concentrations of Pb, Cu, Bi, and As increased around 2000 BP, 1400 BP and 1050 BP. The pollution produced by smelting was much more pronounced in the 14th and 16th century AD, when concentrations of Pb exceeded natural by a factor of 7–8. The Middle Age maxima resulted from pollution by metal smelting in the wider surroundings of the lakes and are probably mostly Bohemian origin.

KEY WORDS: palaeolimnology, metal pollution, Bohemian Forest.

Introduction

The profiles of lake sediments (Norton, 1986; Renberg et al., 1994), peat (Lee et Tallis, 1973; Shotyk et al., 1998) and ice (Hong et al., 1994; Hong et al., 1996) contain records concerning not only the changes in the vegetation and climate but also the past local and regional variations in the atmospheric deposition of some trace elements. The changes can be studied by the trace element analysis of the sediments. The present work survey results of the first study of the sediment profiles from the Bohemian Forest lakes.

Methods

With the help of a home-made piston corer with a diameter of 0.06 m, three profiles were collected in the Černé Lake, two profiles in the Čertovo, Plešné and Prášilské lakes each and one profile in the Popradské Lake in the High Tatras, Slovakia. The total metal concentrations were determined in the Czech Geological Survey laboratories using flame atomic absorption spectroscopy (FAAS); Bi, Sb and As being determined by the hydride technique (HG AAS).

Results

Dating of the sediments

The sedimentary layers less than 150 years old were dated by P.A. Appleby of the Liverpool University using the ^{210}Pb method (Appleby et al., 1988). One to three samples of older parts of the profiles were date using the ^{14}C method with AMS in the Rafter Radiocarbon Laboratory, New Zealand (a total of 9 CRA data). Prior to the dating, components with differing isotopic composition (e.g. roots) were separated.

The age of the sediments between the layers dated by ^{14}C and ^{210}Pb was obtained by interpolation assuming a constant rate of mass deposition. We assess the error in determination of the sample age at ≤ 15 years for sediments about one hundred years old and ≤ 200 years for 4000 years old sediments.

Period prior to 2100 BP

More than 3700 to 4000 years ago, the concentrations of Cu and Cd and mostly also the concentrations of Zn and Ni (but not those of Co, Ag and Pb) were increased in the Plešné and Prášilské lakes. The natural concentrations of some elements,

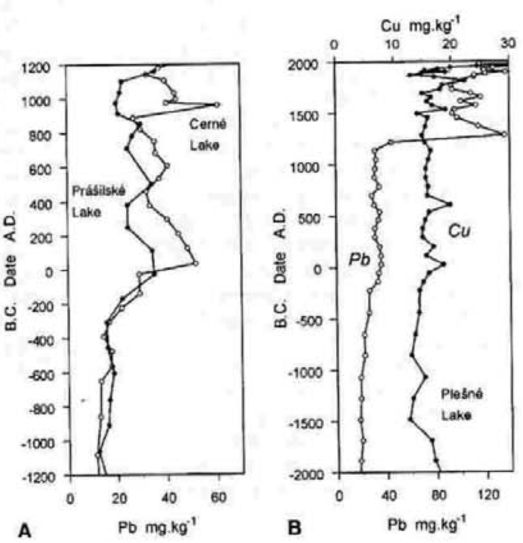

Fig.1. (A) Changes in concentrations of Pb in the Černé and Prášilské Lake profiles between 1200 BC and AD 1200.
Pollution by Pb in Roman times, around AD 600 and probably also around 500 BC and AD 900 are demonstrated.
(B) Concentrations of Cu and Pb in the Plešné Lake sediments. Seven or eight peaks of Pb concentrations were observed. Anthropogenic pollution by Cu in Roman Times is also demonstrated.

e.g. Cd or Be, probably decreased during the whole preceding Holocene period. These changes are attributed to changes in the climate and soil development (Taylor and Blum, 1995). The interpretation of the Černé and Čertovo lake profiles is complicated during this period by local erosion events (Veselý, 1998) that resulted from falls of large numbers of trees from the lake wall, high winds and mudflows in the lake.

Period between 2100 and 1000 BP

The measured Pb concentrations begin to constantly exceed the background values in the 9th century BC (on average at 860 BC for 5 profiles), at a depth of 0.45 to 0.75 m.

The period is primarily marked by an increase in the Pb concentration around the turn of the eras in all the studied profiles (Fig. 1, Veselý, 1997, 1998). Two millennia ago, the Pb concentrations increased 2 to 4 times of the background values amounting to 11.2 ± 1.2 to 23.5 ± 4.6 mg/kg. One profile from Černé Lake, the only one divided into 0.02 m slices in this section, exhibited yet an older, mild increase in the Pb concentration around the year 500 BC, i.e. at the time of flourishing Greek civilization (Fig. 1). The anthropogenic flux of Pb into the lake sediments was only about 0.1 $mg.m^{-2}.yr^{-1}$ that time, i.e. 5 to 10 times lower than around AD 0 and about 150 times lower than around 1970. All the studied profiles further exhibited a smaller increase in the Pb concentrations around AD 550 and in most of the lakes also around AD 900 (Fig. 1). In the Černé Lake, the relative increase in the Bi and As concentrations around AD 550 was even higher than that around the turn of the calendar.

The Plešné Lake sediments contain, for natural causes, substantially less Cu than the other test sediments. Increases in the Cu concentrations have been observed for the time of the Roman empire, around AD 600, in the 16th century and repeatedly in the industrial period (Fig. 2).

Period between 1000 and 250 BP

All the studied profiles contained two or three pronounced Pb concentration peaks in the period from 300 to 800 years ago (Fig. 2). The Pb concentrations increased to 7 to 8 times the background value. The medieval accumulation of Pb possibly peaked somewhat earlier in the Plešné Lake than in the watersheds of the other lakes. This time shift might be connected with the production of silver at Jihlava or with production outside the Bohemian Kingdom. This increase in the Pb (and also Sb, Bi and As) concentrations has not been observed in the sediments of the Popradské Lake (Slovakia), at a distance of 500 km to the east. The Pb concentration in the Popradské Lake sediments increased smoothly for about 700 years, up to the 20th century.

Discussion

The beginning of the discernible production of Pb and Cu was caused by the discovery of a new technology of Pb-Ag smelting from galenite and Ag cupellation, about 5000 years ago and by the beginning of sulphidic ore smelting about 4500 years ago (Hong et al., 1996). The long-range atmospheric transport of Pb induced by people was so weak before 3000 BP in the Bohemian Forest that it cannot be distinguished from the natural variations and the changes caused by anthropogenic utilization of the landscape. Further research should clarify the cause of the irregularly observed increases in the Cu and Zn concentrations more than 3100 years ago which cannot be unambiguously attributed to anthropogenic effects at present.

During the Hallstadt period the intensity of anthropogenic Pb immissions was already unambiguously differentiable from the natural flux of Pb into the sediments amounting to 0.25 to 0.40 $mg.m^{-2}.yr^{-1}$. During the following period, the Greek production of Pb and Ag increased, being stimulated by the beginning of mintage (ca. 650 BC) and was assessed to be about one tenth of the later "Roman" production (Hong et al., 1994). During the peak of the Roman power, the contamination of the Bohemian Forest with Pb was quite perceptible. The Pb/Ag was produced in open-air furnaces with no control on emission rates. In our estimation, about 20 metric tones of anthropogenic Pb could deposit annually on the Bohemian territory around AD 0, i.e. about 0.5% of the Pb emitted (Hong et al., 1994). Approximately at the same time, about 2200 metric tones of Cu were also emitted annually into the atmosphere which definitely was reflected in the increase of the Cu concentration in the Plešné Lake. Such an increase is probably reported for the first time, because the Cu/Al ratio was used for the contamination of the Greenland ice (Hong et al., 1996).

The increase in the Pb, Cu, Bi and As concentrations was also observed during the 6th and during the 8th to 10th centuries AD. Contributions of emissions from Harz in lower Saxony are probable (Klauppauf et al., 1992). Among the Czech localities, Manin, now part of Kutná Hora, can be one of the sources.

The long-term, exceptionally large production of about 1/3 of the European silver in the Bohemian Kingdom at the end of the Middle Ages definitely strongly participated in the relatively strong pollution of the Bohemian Forest with Pb, Bi, Sb and As 700 years ago. The silver was first produced at Jihlava and its surroundings, later at Kutná Hora and in the 16th century at Jáchymov, Příbram and at a number of other places. Considerable amounts of Pb were used during the Ag production. At Kutná Hora alone, up to 20 tones of Ag were produced annually just around the year 1300 which respond to emission of 200 to 250 tons of Pb. The local Pb immissions in the Bohemian Forest were complemented to an unknown extent from sources outside the Bohemian Kingdom. An increase in the Pb concentration was also observed at the end of the Middle Ages in the Greenland ice (after AD 1200 - Rosman et al., 1997) and a weak increase around AD 1290 in Swiss peatbogs (Shotyk et al., 1998). However, these increases were much less pronounced than those in the Bohemian Forest lake sediments and the Pb pollution of that time is probably mainly Bohemian origin.

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