Acknowledgements

The project "Sinter and Palaeoclimate in Central Europe during the Pleistocene" is funded by the Deutsche Forschungsgemeinschaft (DFG). Special thanks go to the Sontheimer Caving Club for the permission to take samples in the Sontheimer Cave and in the Hintere Kohlhalden Cave and for their help in the field.

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Oxygen Isotope Climatic Record in a Carbonate Flowstone Layer from a Medieval Underground Mine in the Kutná Hora Ore District

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ABSTRACT. The 37 cm thick carbonate flowstone layer found in a gallery of abandoned medieval mine in the Kutná Hora ore district (65 km E of Prague) started to grow about 500 years ago. Re-opening of the gallery in the 1960s terminated its growth. The relationship of calcite $\delta^{18}O$ to climatic changes was studied in a vertical profile (42 samples), covering the whole thickness of the flowstone layer. Assuming constant growth rate, an arbitrary time scale was attributed to individual sampling points. The oxygen isotopic data of flowstone were compared with temperature data published by Brázdil (1994) and Mann et al. (1999), and with isotope temperature obtained from $\delta^{13}C$ values for tree-rings from the Black Forest (Lipp et al., 1991). These comparisons show that changes in the $\delta^{18}O$ values of flowstone were dominantly controlled by changes in $\delta^{18}O$ values of water feeding the gallery. A good agreement between the $\Delta\ \delta^{18}O$ curve and the curve for summer temperature indicates that summer precipitation was the main source of water penetrating into gallery.

KEY WORDS: carbonate flowstone, oxygen isotopes, climate, medieval mine.

Introduction

In 1967, a hydrological 22 m deep shaft located in the historical centre of the mining town Kutná Hora (65 km E from Prague) revealed partly flooded underground passages of a medieval mine in the Osel ore belt. One of the important phenomenons observed in the medieval gallery was the presence of rich calcite dripstone decoration including floor flowstones up to 37 cm thick. Samples of the flowstone were taken for a stable isotope investigation.

Medieval galleries of the Ag (± Zn, Pb, Cu) ore zone Osel discovered in 1967 were later partly drained by cleaning of a medieval adit about 250 m long, which today represents the only entrance into the mine (Pechoèová and Hoffmanová, 1991). This adit, 0.5–1.0 m wide and 1.5–2.5 m high, is nearly horizontal and follows a local first-order geological and hydrological boundary between the folded, high-grade metamorphosed and faulted gneissic basement and the overlying horizontally layered Cretaceous platform sediments. At the boundary a transgression horizon of Cretaceous conglomerates is typically developed. The total thickness of Cretaceous rocks above the studied mine level varies between 12 and 20 m. The Cretaceous rocks are represented mainly by sandstone with calcite cement, containing from 15 to 30 wt.% calcite. Dripping water penetrates into the gallery in many places, locally forming larger inflows of up to 0.3 l/sec. Today, the entire system is drained through the old draining adit; deeper levels are filled with water. The area above the studied mine belongs to the historical town centre.

Methods and material studied

The flowstone, which was precipitated on the gallery floor, is composed of several white-yellowish layers formed by hard, porous, dendritic calcite crystals with indistinct banding. Calcite crystals grew under water. Two block samples (A and B) were cut out from different places of the flowstone and used for stable isotope study. Block A was cut vertically and 42 point samples for isotopic analyses were taken. Block B, which was collected from another part of flowstone layer, was cut horizontally into 11 larger segments, which were homogenised and used for isotopic analyses. Isotopic analyses were done according to McCrea (1950); the released CO_2 was measured on a Finnigan MAT 251 mass spectrometer.

Age of the flowstone

The age of individual layers of the flowstone is a very important parameter for the interpretation of stable isotope data. Historical evidence, precipitation rate and ^{210}Pb dating were combined to estimate the age of flowstone:

Open pit mining in the region of Kutná Hora probably began in prehistoric times but widespread underground mining of Ag ores started in the late 13th century. There are no historic records on this particular mine, one of dozens of such mines operating at the same time in the region, but the general history of Kutná Hora is well known (Kořán, 1988). Two phases of mine abandonment must be considered. The first event is associated with the Hussite upheaval around AD 1420, the second event with flooding of the nearby Osel mine around AD 1515. An abandonment of the mine was a prerequisite for flowstone deposition because the sinter rests on decayed wooden floor now preserved as negative print of wooden textures on the flowstone base. The floor was used for the transport of ore by wheelbarrows. During the 16th century, the system of shafts was out of operation, forgotten and the collapse of the entrance sealed it off. The deep vertical mining excludes all dates older than approx. AD 1300, the position of the mine in the inner city excludes dates following the end of 15th century because at that time mining activities moved to surrounding areas. As the most probable date of the beginning of flowstone formation we take AD 1400.

The concrete pavement and vertical reinforcements of the tourist route from 1963–67 are locally covered by an up to 2 cm thick flowstone layer indicating recent formation rate of about 6 cm per century. Such rate is in good agreement with the thickness of 37 cm formed since approx. AD 1400. Since dating attempt using ^{210}Pb was not successful, a linear arbitrary scale (AD 1400–1960) was attributed to the profile.

Results and discussion

There was a good agreement between the two oxygen isotope profiles, one consisting of point data (A) and the other one consisting of homogenised intervals. Regarding sample A and B were cut at different locations of the flowstone layer, we concluded that calcite of the both profiles were deposited under similar conditions and under oxygen isotopic equilibrium with water. Profile A studied in detail was used for the interpretation and comparison with other paleoclimatic records.

The measurements of air temperature have been recorded in Prague since 1771. Written chronicles and other records on climate exist for older periods. Oxygen isotope data obtained for the flowstone from Osel mine were compared with climatological records for the Czech Lands published by Brázdil (1994) and with $\delta^{13}C$ values in tree-rings from the Black Forest (Lipp et al., 1991) and with data published by Mann et al. (1999).

While the temperature curves of Mann et al. (1999) and our curve from Kutná Hora are different, agreement between the Kutná Hora record and curves of Brázdil (1994) and Lipp et al. (1991) is much better.

Data of Brázdil (1994) are given as fluctuation of 10-years averaged air temperature (ΔT summer, winter and yearly averages) plotted as anomalies with respect to the 1851–1950 mean. The differences of $\delta^{18}O$ values from mean $\delta^{18}O$ ($\Delta\delta^{18}O$) were

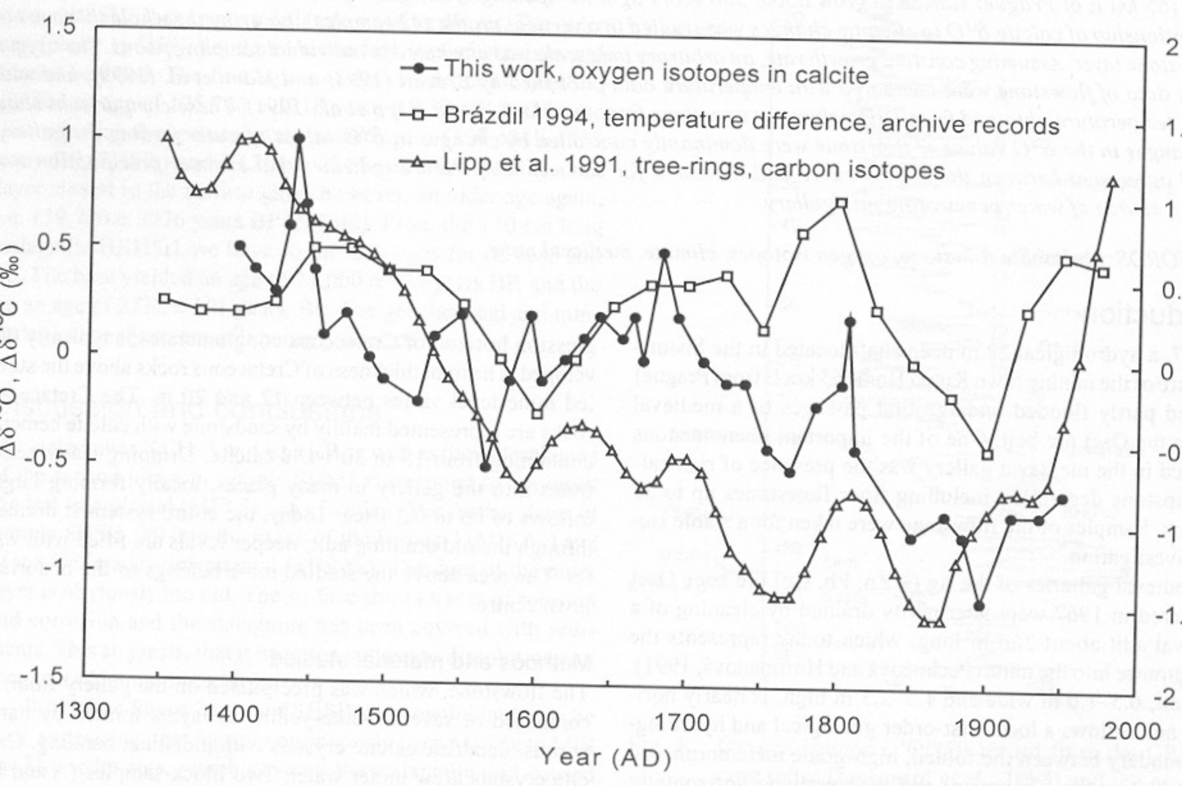

Fig. 1. The comparison of summer air temperatures (Brázdil, 1994), $\Delta\delta^{13}C$ of tree-rings (Lipp et al., 1991) with $\Delta\delta^{18}O$ of flowstone from the Kutná Hora.

compared with differences in summer, winter and year air temperatures and it was evident that the curve of $\Delta\delta^{18}O$ fits the curve of ΔT_{summer}. Time shifts of some peaks (Fig. 1) could be the result of irregularities in the precipitation rate of flowstone. Generally, it is obvious that the decreasing temperature is accompanied by decreasing $\delta^{18}O$ values of flowstone. Consequently, oxygen isotopic composition of the flowstone carbonate was controlled predominantly by the changes in oxygen isotopic composition of groundwater feeding the gallery and not by changes in temperature of calcite deposition.

The best agreement between $\Delta\delta^{18}O$ and ΔT_{summer} indicates that summer precipitation in the studied area was the main source of water penetrating into the gallery. This is supported by hydrological studies which found that 2/3 of today's annual precipitation in the Czech Lands occur from 1st April to 30th September (Hazdrová et al., 1983). The dependence of $\delta^{18}O$ values of precipitation on temperature is well known. Rozanski et al. (1993) published the value of 0.65‰ per one °C for long-term $\Delta\delta^{18}O/\Delta T$ of precipitation in Vienna. We used the same coefficient (the altitude of Kutná Hora is 270 m. a.s.l.; the altitude of Vienna is 203 m. a.s.l.) and calculated that the lowest $\Delta\delta^{18}O$ value (-1.1‰) found for flowstone from Kutná Hora, corresponds to ΔT of -1.7 °C and the highest $\Delta\delta^{18}O$ (1.0‰) to ΔT of +1.5 °C. These calculated differences in "isotope" temperatures are higher than those given in Fig. 1 by Brázdil (1994). Brázdil (1994) concluded that climate in the Czech Lands during the greater part of the last millennium had more continental character; colder and wetter years from the mid-15th century to the beginning and/or the latter half of the 17th century were probably related to so-called Little Ice Age (LIA). However, the last manifestations of LIA were recorded in mid-19th century. It is evident from Figures 1 that the lowest $\delta^{18}O$ values of flowstone were found for the period of second half of 19th century.

Oxygen isotopic data of calcite from flowstone were also compared with isotope temperature obtained from $\delta^{13}C$ values for tree-rings of firs from the Black Forest (Lipp et al., 1991). The comparison is given in Fig. 1. Although the climate at both sites could differ, the coincidence of both curves is rather good. It is very interesting that calculated differences in isotope temperatures for both flowstone and tree-rings are practically the same, but both are higher than the differences in temperatures given by Brázdil (1994).

Conclusions

Oxygen isotopic data indicate that a climatic record exists in calcite flowstone from the medieval mine in Kutná Hora. Its interpretation is complicated by uncertainty in the age of individual layers of the flowstone.

Changes in $\delta^{18}O$ values of flowstone probably reflect changes in $\delta^{18}O$ values of water feeding the gallery.

Agreement between $\Delta\delta^{18}O$ values and ΔT_{summer} indicates that summer precipitation was the main source of water penetrating into the gallery.

The period with the lowest recorded temperatures in Prague (65 km W of Kutná Hora) in the second half of the 19th century coincides with the lowest $\delta^{18}O$ values of flowstone of the same model age.

A good agreement exists between the time position and amplitude of temperature oscillations calculated from $\delta^{18}O$ of the flowstone and those based on tree-rings in the area of the Black Forest in Germany.

Acknowledgements

This work was supported by IAEA in Vienna research programme Use of nuclear techniques in paleoclimatology - Continental indicators of paleoclimate. The authors would like to thank the Regional Museum at Kutná Hora for permission to collect samples.

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