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Late Glacial and Holocene Climatic Record in a Stalagmite from the Holštejnská Cave (Moravian Karst, Czech Republic)

Jaroslav KADLEC[1], Helena HERCMAN[2], Karel ŽÁK[3] and Tomasz NOWICKI[2]

[1] *Institute of Geology, Academy of Sciences of the Czech Republic, Rozvojová 135, 165 02 Praha 6, Czech Republic*
[2] *Institute of Geological Sciences of the Polish Academy of Sciences, Twarda 51/55, 00-818 Warszawa, Poland*
[3] *Czech Geological Survey, Klárov 3, 118 21 Praha 5, Czech Republic*

ABSTRACT. A stable isotope climatic record has been obtained from a 318 mm high stalagmite which grew up in the Holštejnská Cave located in the Moravian Karst, Czech Republic. The $^{230}Th/^{234}U$ age data from 7 segments separated from this stalagmite between its base and top document that its growth covers time span 13.6–4.3 ka BP. Variations of carbon and oxygen stable isotope ratios of calcite along a stalagmite vertical axis reflect climatic oscillations during the Late Glacial, a temperature increase and a vegetation development during the Pleistocene/Holocene transition as well as the Holocene Optimum.

KEY WORDS: cave carbonate, U-series dating, stable isotopes, climatic record.

Introduction

Cave carbonates are secondary mineral formations deposited in subsurface cavities from groundwater, which has percolated through the adjacent limestone rock. These carbonates, if precipitated in isotopic equilibrium with the seepage water, may provide paleoclimatic record and allow an estimation of mean annual paleotemperature changes.

The Moravian Karst formed by Devonian limestones is situated in eastern part of the Czech Republic 200 km SE of Prague (Fig. 1). Cave systems draining the Moravian Karst were formed by subsurface streams during the Cenozoic. The Holštejnská Cave located at the northern periphery of the Moravian Karst has a character of a horizontal, 40–50 m wide corridor, which represents the upper level of the ponor cave system. The lower level, called Cave No. 68, is situated 60 m below the Holštejnská Cave and was discovered by excavation of the sinkhole No. 68 in front of the entrance of the Holštejnská Cave (Fig. 1). Both levels are connected by vertical or subvertical karst shafts filled with fluvial deposits. The Holštejnská Cave is nearly completely filled with three sequences of fluvial sediments of different age divided by layers of cave carbonates. The sediments inside the Holštejnská Cave are exposed in extensive sections excavated by local cavers.

Methods and materials studied

The studied stalagmite was exposed in a section excavated in southern part of the cave corridor (Fig. 1). The oldest sediments exposed in this section are fluvial sandy gravels with strongly weathered greywacke pebbles. The middle fluvial sequence is missing in this section due to erosion by subsurface stream. The youngest fluvial sediments fill channels incised into older fluvial bodies. The youngest fluvial deposits are formed by clayey silts with horizontally lying, locally cross-bedded sands and are overlaid by a flowstone layer with stalagmites up to 318 mm high. Fine laminated infiltration sediments transported by meteoric water from the karst surface through a sinkhole No. 74

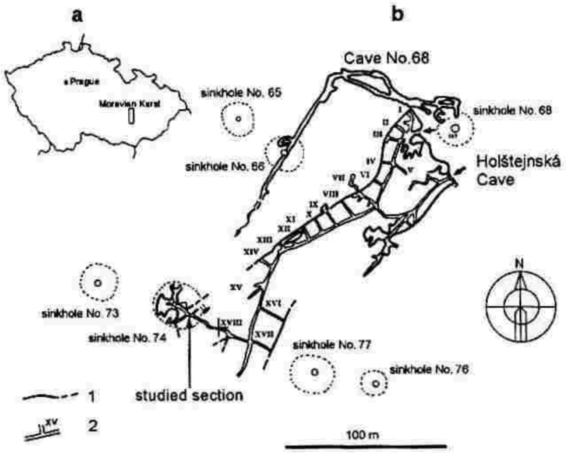

Fig. 1. Location of the Moravian Karst (a) and a map of the Holštejnská Cave and Cave No. 68 (b).
1 - cave walls, 2 - excavated corridors in the cave sediments, I–XVIII - numbers of excavated corridors

filled the cave corridor almost up to the ceiling during last sedimentation period (see Fig. 2).

Lithology of the stalagmite

The "root" of the stalagmite is formed by underlying fluvial clayey silt of the youngest fluvial sequence cemented by calcite precipitated from seepage water, which came through karst shaft connecting the cave corridor with a sinkhole No. 74 on the karst surface. The lower and central part of the stalagmite (0–210 mm from its base) has a character of whitish translucent calcite with reniform structure and no distinct lamination. The upper part (210–318 mm from the stalagmite base) is formed by laminated calcite with alternating darker and lighter laminae up to 1 mm thick.

Dating of the stalagmite

Seven segments (8 to 20 g) were separated from the central part of the stalagmite along its longitudinal axis. These samples were dated by $^{230}Th/^{234}U$ method (α-particle counting) in the Uranium-series Laboratory of the Institute of Geological Sciences of the Polish Academy of Sciences.

Stable isotope analyses

Point samples (68 sampling points, ~ 20 mg each sample) for the stable isotope analyses were separated from a longitudinal section along a stalagmite vertical axis using a dentist drilling machine. Obtained material from each sampling point was homogenised in an agate mortar and used for conventional C and O isotope determination (after McCrea, 1950). All measurements were done using a Finnigan MAT 251 mass spectrometer in Laboratories of the Czech Geological Survey.

Results and discussion

The results of stalagmite dating are summarised in Table 1.

The stalagmite started to grow at 13.3 ± 0.3 ka BP. Its growth was terminated at about 4.7 ± 1.1 ka BP. Based on the U-series data of other segments between the stalagmite base and top only minor variations in a stalagmite growth rate can be assumed.

Oxygen isotope data from the lower part of the stalagmite (13.6–10.4 ka BP) reveal several minor short-time oscillations in the range between -11.2 and -9.3‰. The $\delta^{18}O$ values started to increase more distinctively after 10.4 ka BP. Between 10.4 and 7.8 ka BP the $\delta^{18}O$ increased from -10.2 to -7.6‰, with minor negative excursion at 8.0 ka BP. After that, between 7.8 and 4.7 ka BP, the $\delta^{18}O$ values have oscillated between -7.6 and -8.8‰ with increase to -7.2‰ at the top of stalagmite. The increase in carbon isotope data reveals a short delay time after the oxygen isotope increase. The highest $\delta^{13}C$ values were detected in time interval 7.7–7.1 ka BP (Fig. 3).

The oxygen isotope composition of cave carbonate is controlled by two factors:

(1) temperature-dependent oxygen isotope fractionation calcite-water during the calcite precipitation in the cave, and
(2) temperature (climate)-dependent oxygen isotope variations of meteoric waters.

Both factors have opposite effect on the carbonate $\delta^{18}O$ values (see e.g. Gascoyne, 1992). In the studied case the tempera-

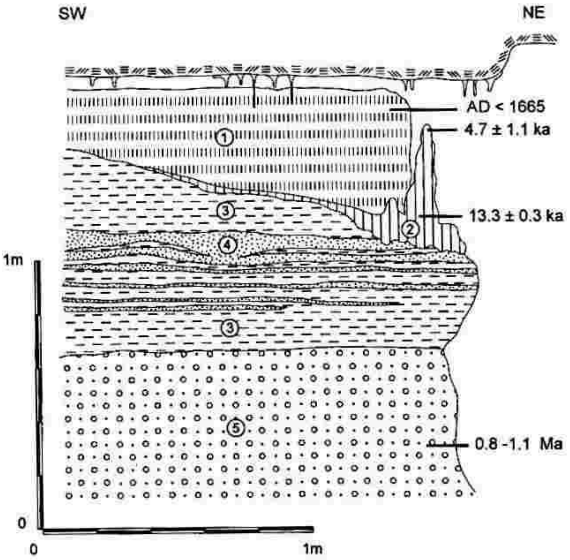

Fig. 2. Section in the cave sediments exposed in corridor No. XVIII.
1 - infiltration clayey silts with pottery fragments at the base and a charcoal younger than AD 1665 found in the upper portion of this sedimentary body; 2 - flowstone layer with dated stalagmite (see Table 1); fluvial sediments deposited during Last Glacial stage: 3 - clayey silt, 4 - sand; fluvial sediments deposited during late Early Pleistocene: 5 - sandy gravel; for more details concerning the age of the Holštejnská Cave deposits see Kadlec et al., 2000.

distance from stalagmite base (mm)	age (years BP)	1 σ error (years)
307–318	4700	± 1100
287–306	5830	± 710
217–228	7600	± 900
183–198	7800	± 700
160–170	10200	± 800
78–92	11300	± 750
5–16	13300	± 300

Tab. 1. The $^{230}Th/^{234}U$ ages of the stalagmite segments.

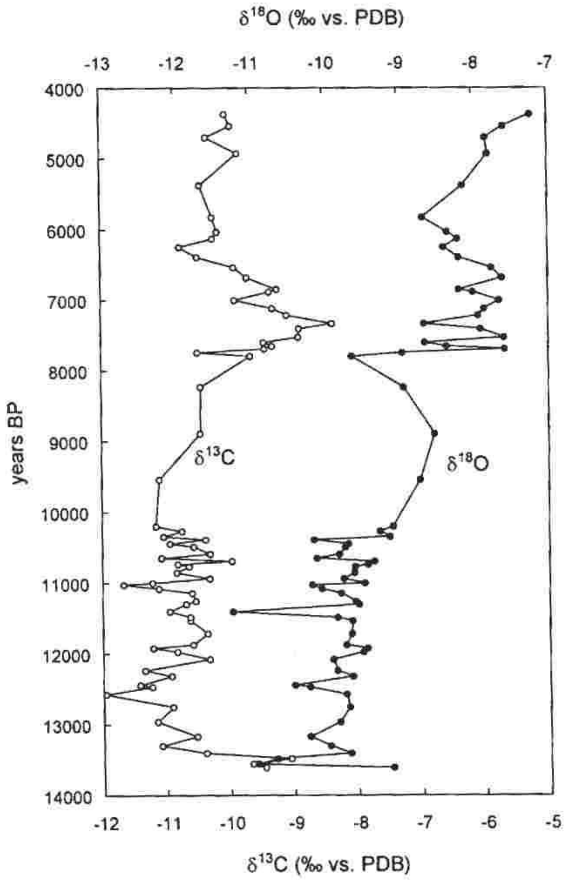

Fig. 3. The $\delta^{13}C$ and $\delta^{18}O$ variations between the stalagmite base and top.

ture increase resulted in increase of the carbonate $\delta^{18}O$ values. The temperature dependent oxygen isotope variations of meteoric waters had thus larger effect than temperature controlled oxygen isotope fractionation during the precipitation itself.

The higher $\delta^{13}C$ and $\delta^{18}O$ values near the stalagmite base document that the stalagmite started to grow in warm interstadial conditions at around 13.6 ka BP. Following climatic deterioration (between 13.5 and 12.4 ka BP) is evidenced by decrease of both $\delta^{13}C$ and $\delta^{18}O$ values. This rapid deterioration of climatic conditions can be correlated with the start the Younger Dryas Stadial. During this cold stage the $\delta^{18}O$ variations reveal several short temperature oscillations (see Fig. 3). The increasing trend in $\delta^{18}O$ values starting at about 10.4 ka BP represents a temperature increase connected with the Pleistocene/Holocene boundary. The Holocene Optimum, which was preceded by distinct cold oscillation, is detected both by $\delta^{18}O$ increase and $\delta^{13}C$ maximum between 7.7 and 6.5 ka BP. It is not clear if these high $\delta^{13}C$ values reflect a global change in $\delta^{13}C$ values of atmospheric CO_2 or local factors related to a boom of vegetation on the karst surface and changes in soil processes.

The lithology of the precipitated calcite in the studied stalagmite has changed since the Holocene Optimum beginning. Due to increased content of organic matter produced by vegetation on the surface the upper part of the stalagmite get a character of laminated carbonate with alternating dark and light laminae.

Temperature dependence of $\delta^{18}O$ values of recent meteoric waters in central Europe was studied by Rozanski et al. (1993), who concluded that 1 °C mean annual temperature increase results in +0.65‰ increase of $\delta^{18}O$ of water. The temperature controlled oxygen isotope fractionation calcite-water during the cave carbonate precipitation produces an opposite effect of about -0.25‰ per 1 °C. Assuming similar factors controlled the oxygen isotope composition of meteoric waters in the past, a net effect of +0.4‰ per 1 °C can be estimated. The isotopic shift observed in the studied stalagmite between the range of Late Glacial calcite $\delta^{18}O$ data (-11 to -9‰) and the Holocene range (-9 to -7‰) of about 2‰ can be therefore recalculated to a mean annual temperature increase of 5 °C.

Conclusions

The stable isotope data from the stalagmite grown in the Holštejnská Cave have yield climatic record covering the time span between 13.6 and 4.3 ka BP. The $\delta^{18}O$ values document several short-time temperature oscillations in the Younger Dryas Stadial. The $\delta^{18}O$ increase which started after 10.4 ka BP is linked with warming connected with the Pleistocene/Holocene transition. The 5 °C mean annual temperature increase can be estimated for the time period Late Glacial - Early Holocene. The Holocene Optimum was preceded by distinct colder oscillation in the late Boreal period. A similar temperature decrease was detected by Frisia et al. (1997) in a stalagmite from the Grotta di Ernesto located in Pre-Alps of Trentino (northeastern Italy). Based on isotopic record preserved in the Holštejnská Cave stalagmite the Holocene Optimum started rapidly at 7.7 ka BP as documented by steep $\delta^{13}C$ and $\delta^{18}O$ increase and took about 1200 years. This climatic optimum was followed by deterioration of climate in the Subboreal period after 6.5 ka BP.

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