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New speleothem dates from caves in Germany and their importance for the Middle and Upper Pleistocene climate reconstruction

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ABSTRACT:

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Twenty speleothems from caves of different karst regions (mainly from the Franconian-Swabian Alb and the Bavarian Alps) in Germany were dated with the TIMS-U/Th-method The samples were taken from stalagmites of various sizes.
Beginning and end of the growth phases were determined by dating the base and the tip of each sample. The dates obtained fit into the general scheme of Pleistocene climate in Germany, where speloeothem growth is interrupted by cold periods. Some of the samples could not be dated because they suffered from secondary loss of uranium most probably due to leaching. Those samples belong to visibly older sinter generations. Leaching could have occurred under permafrost conditions when the caves were filled with ice or when groundwater was trapped in the caves below a permafrost cover.

Key words: Uranium-Thorium method, TIMS, Speleothems, Germany, Palaeoclimate.

INTRODUCTION

The Pleistocene climate history of Central Europe is characterized by a high variability, higher than in most other regions of Earth. This is due to the influence of the North Atlantic and its leading role in amplifying Glacial/Interglacial cycles and its interaction with the major transient continental ice masses. Some authors suggest that the glacially important Dansgaard/Oeschger Cycles are induced by internal periodic instabilities of the North Atlantic (e.g. PELTIER & *al*. 1999). Layers of coarse lithoclastics, which occur in North Atlantic sediments (so-called Heinrich layers) are witnesses of periodic wide-spread collapses of the Laurentian ice shield with severe climatic consequences for the climate in Europe (HEINRICH 1988). Also, the sudden terminations of the glacial periods can only be caused by short-term changes in the Earth System, such as the onset of the deep ocean circulation in the North Atlantic (e.g. KEIGWIN & *al*. 1994, ADKINS & *al*. 1997). The climatic record of the past several hundred thousand years has been recovered in high resolution from ice cores both from Greenland and Antarctica (e.g. GROOTES & *al*. 1993), showing that the Northern Hemisphere is imposing its climate variability onto that of the southern hemisphere, albeit with attenuated amplitudes.

Historically, geological records from continental Europe were therefore leading in identifying past climate changes, such as is documented in the names of the Interglacial and Post-Glacial climate periods of the last glaciation cycle (e.g. KLOSTERMANN 1999). Further back, however, this record is largely blank (perhaps with the exception of glacial loess covers and isolated paleolimnic records) and the paleoclimatologist needs to refer to the isotopic chronology established by continuous marine sediment records and ice cores (e.g. MARTINSON & *al*. 1987; DANSGAARD & *al*. 1993).

Caves, however, provide a protected environment, where continental high resolution records can be found. Specifically the growth of speleothems (MOORE 1952) provides a record which has largely been unread in Europe. This has many reasons. Some of them are methodological and others are inherent to the cave environment and the speleothems themselves. Also, not many geologists are familiar with the potential of cave speleothems and only few have first hand access to these resources.

Methodologically it was first necessary to develop a dating technique, which could look beyond the time range of the ^{14}C determination. After initially using U/Th α–spectrometry (e.g. DUPLESSY & *al*. 1972; ATKINSON & *al*. 1978; HENNIG 1979; GŁAZEK & HARMON 1981; HENNIG & *al*. 1983), the development of U/Th TIMS dating (e.g. EISENHAUER & HENNIG 1997) now allows to use smaller samples and to obtain more precise dates, even for those time ranges, which so far were the realm of the ^{14}C technique.

The environmental reasons for being so slow in uncovering the cave-based climate record are several. The first is accessibility of the record. Many caves are protected under natural preservation regulations. Others lack speleothems, or are only accessible to divers and even if they occur in quarries, where sampling could be conducted, this is often forbidden by the quarry owners or news of the resource reach the university teams too late. But the most discouraging fact is:

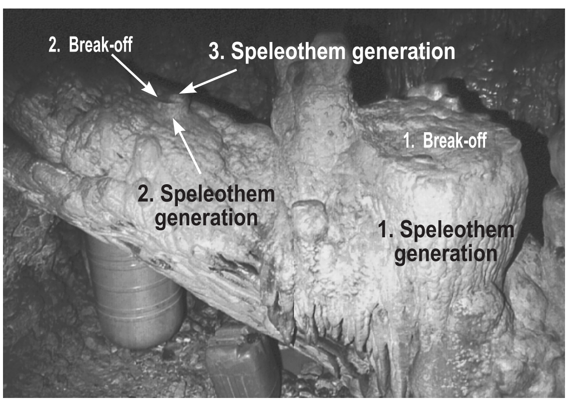

Fig. 1. Several generations of broken speleothems in the cave of Burggaillenreuth (Zoolithenhöhle) near Muggendorf, Frankonian Alb (Foto KEMPE)

the speleothems in Central European caves appears to be a large jumble of broken masses, all encased in an impenetrable layer of Postglacial and Holocene speleothems (Text-fig. 1). This situation is unlike the situation in caves from more southern latitudes, where the stalagmites have apparently grown throughout much longer time periods and appear to be larger and less damaged.

We are convinced that this broken nature of the speleothem record is itself a climate record and that it is related to the large and frequent climatic changes in Europe itself, i.e. it has been caused by the wide-spread occurrence of ice in caves under glacial and permafrost conditions (KEMPE 1989; KEMPE & ROSENDAHL 1999). We therefore have essentially a punctuated record, consisting of continuous interglacial and interstadial sections separated by glacial hiatuses. The climate record in Central European caves will therefore need to be pieced together from many individual observations. This is a task which will take many years. We have now started a German Research Council (DFG) funded project entitled “Speleothem and Paleoclimate in Central Europe during the Pleistocene”. One group (A.E. and B.W.) will conduct the U/Th dating and measure isotopic composition of the speleothem, while the second group (S.K. and W.R.) will conduct the field research and collect the accompanying evidence such as sedimentological, mineralogical, paleontological and ecological data.

AIMS OF THE PROJECT

The project will address the following questions:

- What are the possibilities and shortcomings of the U/Th TIMS method and how do their results compare with ^{14}C ages?
- When and how long did the speleothems grow in Central European caves?
- Are certain Interglacials more speleothem-active than others?
- Are the stillstand periods correlated with the glacial maxima or do they also occur at other, intermediately cold periods?
- How soon after glacial maxima does speleothem formation resume?
- How do the isotopic records compare with the marine and ice core records?
- Does the composition of the acid-residual components of speleothems change with time and what sort of climate record does it contain?
- How does the speleothem-derived information correlate with the other data available for cave sediments and paleontological or archeological remains?

SAMPLE SELECTION AND ANALYTICAL METHODS

In order to obtain a larger regional overview from the beginning, speleothem samples from caves in the Bavarian Alps, the Swabian Alb, the Frankonian Alb, the Harz (Text-fig. 2) and the Eifel were selected. All in all, eight stalagmites cut into two halves longitudinally, one stalactite and three flowstone layers, a total of 20 samples, were chosen. In many cases the main problem was to obtain meaningful samples at all due to constraints imposed by the administration of the caves. The sample from the Eifel is from a cave which was destroyed by quarrying and the sample from the Einhornhöhle/Harz was collected from the rubbish left by *unicornu fossile* diggers in past centuries.

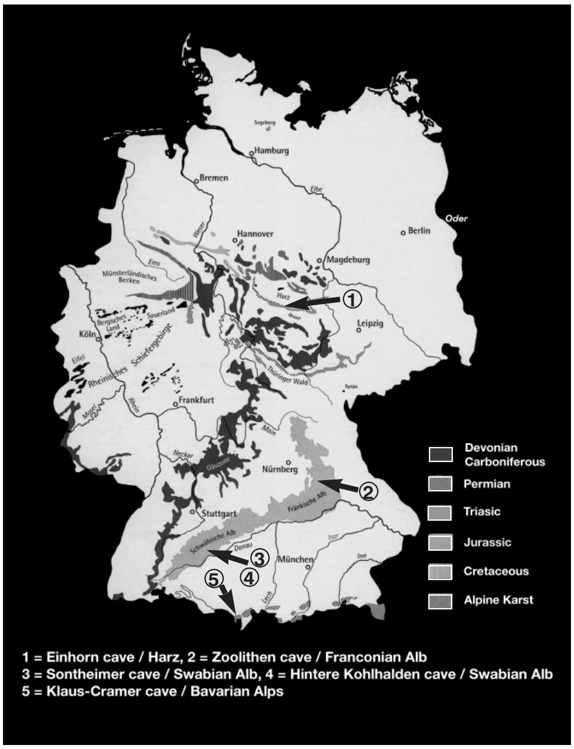

Fig. 2. Karst regions of Germany with marked sample localities quoted in the article

For twelve of these samples we have already U/Th TIMS measurements. These include two small stalagmites, 4 cm wide and 6-8 cm long, (KCH-A and KCH-B) fom the Bavarian Alps (Allgäu/Gottesacker-plateau), collected in the Klaus-Cramer Cave, 2000 m above sea level (ROSENDAHL 1997). From the same cave we have also dates from a larger part of a wall-flowstone (sample KCHSi1 a and b), which was dated during the preparatory phase of the project (ROSENDAHL & *al.* 1998). These results show that the Klaus-Cramer Cave contains at least three different speleothem generations.

From caves in the Franconian Alb we took samples from the Zoolithen Cave (also known as Cave at Burggaillenreuth or Gaillenreuth Cave, type locality of the *Ursus spelaeus* ROSENMÜLLER 1794; e.g. ROSENDAHL 2001), from the Doktors Cave (FRANKE & *al.* 1959) and from the Sophien Cave (SCHABDACH 1999). Up to now only a 20 cm long stalagmite of the Zoolithen Cave (ZooHSi2) yielded dates.

In the Swabian Alb samples from two caves were dated. The first stalagmite, 30 cm long and 15 cm wide (SHSi1), was obtained from a pit in the Sontheimer Cave, which was primarily filled with breccia-like sediments (HÖHLENVEREIN SONTHEIM 1997). The second sample, a candle-like stalagmite (HKHSi1) with a total length of 150 cm, was collected from the Hintere Kohlhalden Cave, 100 m S of the Sontheimer Cave (HÖHLENVEREIN SONTHEIM 1997).

The sample from the Einhornhöhle/Harz (EHSi1) is a combination of a flowstone-curtains and a later stalagmite. The inner structure of the sample shows six growing phases (EHSi1 a to f) interrupted by two hiatuses, possibly caused by ice (Text-fig. 3).

Other measurements conducted include Fourier-Transform-Infrared-Spectrometry (FTIS), Laser Induced Plasma Spectroscopy (LIPS) and Atomic Absorption Spectroscopy (AAS).

DATING RESULTS

The oldest age (342.05 ± 71.40 ka) yielded the Zoolithen Cave stalagmite ZooHSi2. It belongs to one of the macroscopically oldest speleothem generations of the cave. The next younger dates derive from the Klaus-Cramer Cave. The samples KCHSi1 yielded ages of 201

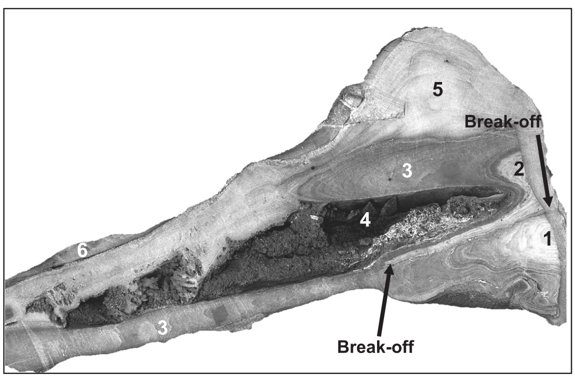

Fig. 3. Cross-section through a speleothem from the Einhornhöhle/Harz with six growth phases

± 10 ka for KCHSi1a and 194 ± 6 ka for KCHSi1b (ROSENDAHL & *al.* 1998, 2000).

The stalagmites KCH-A and KCH-B, also from the Klaus-Cramer Cave, yielded ages (calculation over isochrone diagramm) of 155.27 ± 0.46 ka and 126.54 ± 0.74 ka, respectively. KCH-A, however, has lost uranium secondarily, so that its age is probably too old and we can assume that KCH-A is of similar age as KCH-B.

The inner structure of sample SHSi1 (Sontheimer Cave) shows two growing phases. The older one (phase 1; SHSi1o) suffered secondary loss of uranium and cannot be dated (Tab. 1). The first layers of the second phase (SHSi1a) yielded an age of 125.75 ± 1 ka. Three more determinations in younger layers yielded ages of 109.48 ± 4.5 ka (SHSi1b) and 79.64 ± 2.7 ka (SHSi1c). The layer closest to the surface, however, gave an older age again, i.e. 139.72 ± 9 ka (SHSi1d). From the 150 cm long stalagmite HKHSi1 we have so far only ages for its base and tip. The base yielded an age of 21 ± 0.9 ka, and the tip an age of 2.77 ± 0.1 ka. The accompanying geochemical and mineralogical analyses are still being processed.

Only the outer, stalagmitic layer of sample EHSi1 (EHSi1e and EHSi1f) yielded correct ages. Both dates (8.5 ± 0.2 ka and 2.8 ± 0.2 ka) fit into the early and late Holocene. For the other growing phases (EHSi1a to d) we only can estimate that they are of Upper Pleistocene age and that they predate the Last Glacial Maximum.

INTERPRETATION

The age of the sample ZooHSi2 corresponds to the MIS 9 Interglacial (Text-fig. 4). This is in accordance with the stratigraphic information of the sediment profile at the collection site.

Sample	234U/238U ± 2 sigma	230Th/234U ± 2 sigma	230Th/232Th ± 2 sigma	Age ± 2 sigma [ka]
ZooSi2	1,04 ± 0,0148	0,9683 ± 0,0199	1268,510 ± 25,630	342,05 ± 71,40
SHSi1o	0,846 ± 0,00615	2,5634 ± 0,0656	20,419 ± 0,537	
SHSi1a	1,17 ± 0,0206	0,7013 ± 0,0283	58,994 ± 2,451	125,27 ± 1
SHSi1b	1,03 ± 0,0112	0,6368 ± 0,0159	3,358 ± 0,081	109,48 ± 4,5
SHSi1c	1,20 ± 0,0148	0,5267 ± 0,0116	6,1 ± 0,134	79,64 ± 2,7
SHSi1d	1,02 ± 0,0175	0,7262 ± 0,7262	6,137 ± 0,153	139,72 ± 9
HKHSi1a	0,950 ± 0,0133	0,1756 ± 0,0076	10,373 ± 0,442	21 ± 0,9
HKHSi1b	0,906 ± 0,0134	0,0244 ± 0,0027	3,77 ± 0,411	2,7 ± 0,29
EHSi1e	1,05 ± 0,0185	0,0754 ± 0,0019	189,384 ± 4,633	8,5 ± 0,27
EHSi1f	1,04 ± 0,0111	0,0256 ± 0,001	157,729 ± 6,374	2,8 ± 0,26
KCHSi1a	1,08 ± 0,0040	0,8707 ± 0,0135	108 ± 2	201 ± 10
KCHSi1b	1,06 ± 0,0090	0,8453 ± 0,0022	108 ± 1	194 ± 6
KCH-A	Age calculation over isochrone diagramm			155,27 ± 0,46
KCH-B	analytical values see Tab. 2			126,54 ± 0,74

Tab. 1. Table of analytical values

$^{230}Th/^{232}Th$ ± 2 sigma	$^{230}Th/^{234}U$ ± 2 sigma
2110 ± 75	0,0133 ± 0,000465
617 ± 66	0,00366 ± 0,000386
1547 ± 88	0,00712 ± 0,000390
11175 ± 106	0,335 ± 0,00255
86895 ± 369	1,40 ± 0,00798
392962 ± 3429	1,26 ± 0,00816
433666 ± 3281	1,26 ± 0,00586
163434 ± 935	1,30 ± 0,00595
27117 ± 919	1,01 ± 0,0243

Tab. 2. Analytical values of all analyzed samples of KCH-A and KCH-B

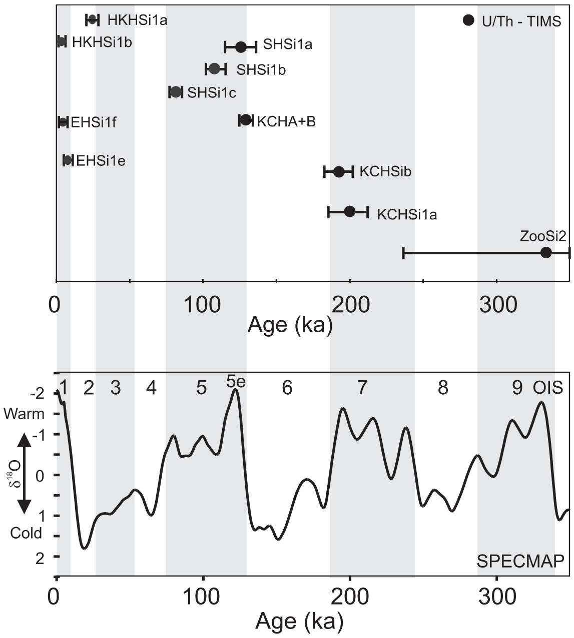

Fig. 4. Oxygen-isotope ($^{18}O/^{16}O$) record from the SPECMAP chronostratigraphy (after MARTINSON & *al.* 1987) with the positions of all reported speleothem dates

The older samples from the Klaus-Cramer Cave (KCHSi1) represent the early part of MIS 7, the Interglacial predating the Eemian (Text-fig. 4). Because this speleothem grew in the Bavarian Alps at around 2000 m about sea level we have to conclude, that during MIS 7 the climatic conditions (temperature and rainfall) were better for speleothem growth at Alpine altitude than today. Other cave deposits (e.g. paleontological) and travertines in Southern Germany indicate the importance of MIS 7 as compared with other interglacials as well.

The stalagmite samples KCH-A and KCH-B as well as the oldest layers of the second phase in sample SHSi1 correspond to the onset the Eemian (Text-figs 4-5), i.e. the last Interglacial (MIS 5e). The further dates of sample SHSi1 fall into the range of the Brörup- (MIS 5c) and of the Odderade-Interstadial (MIS 5a). The date of the outer layer obviously is too old. Its surface is visibly corroded and the stalagmite has been covered with sediments. This suggests, that it has been subject to dissolution and to secondary leaching of uranium.

Within the Phase 2 layer of SHSi1 no growth hiatus can be seen, suggesting that it grew continuously from MIS 5e to MIS 5a. This correlates also with the growth frequency levels J3 till J1 of secondary calcite deposits after BAKER & *al.* (1993). The sediments, which covered the stalagmite and caused leaching and corrosion in its outer layer, could have entered the cave by solifluction during the colder climate of MIS 4 or 3. The stalagmite HKHSi1 from the nearby Hintere Kohlhalden Cave stood on the same kind of sediments caused by solifluction. Its date of 21 ka BP for the onset of its growth came as a surprise since it is close to the Last Glacial Maximum (IS 2 of the Dansgaard-Oeschger cycles, Text-fig. 5). We would have expected that the Upper Pleistocene climate 25 to 15 ka ago would have sustained deep-seated permafrost in the region of the Swabian Alb. Under such conditions, speleothem formation should have ceased. If our date proves to be correct, then either the period of permafrost was shorter than so far assumed or permafrost coverage may have been discontinuous. Meanwhile a similar date has been obtained from a stalagmite of the Arbeitslosen Cave / Swabian Alb (ABEL 2002), which supports our conclusion of an early

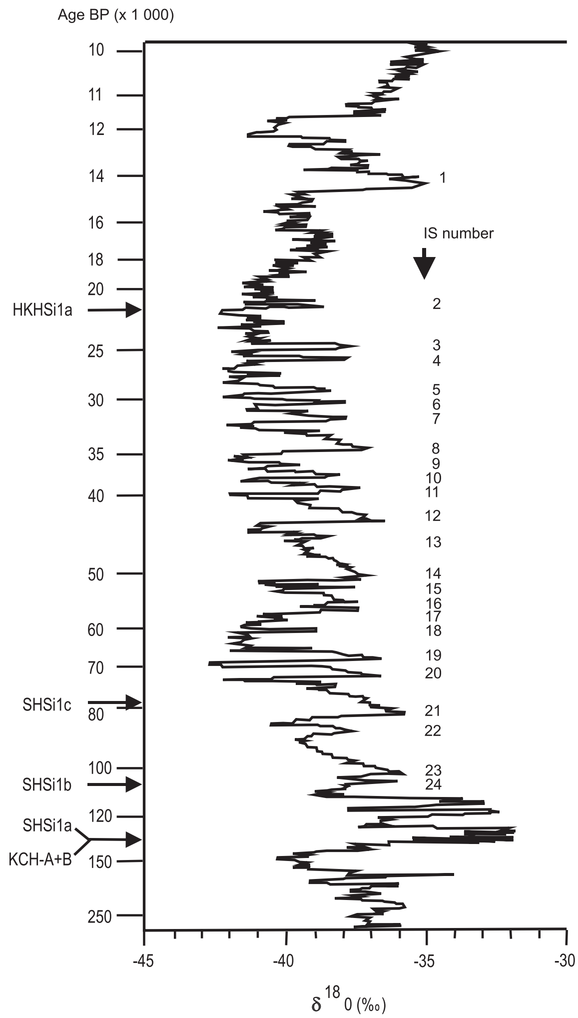

Fig. 5. Oxygen-isotope ($^{18}O/^{16}O$) record from the GRIP ice core (after DANSGAARD & *al.* 1993) with the positions of the reported Upper Pleistocene speleothem dates

demise of the continuous permafrost coverage. Onset and fading of permafrost presumably is responsible for the termination and beginning of speleothem formation periods in Central Europe. Furthermore, ice formation caused wide-spread damage to cave speleothem, effectively removing all pre-Holocene stalactites from the cave ceilings and breaking and overthrowing even large stalagmites (KEMPE 1989).

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