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Climate Change: The Karst Record

Extended Abstracts of a Conference held at

The Department of Geology,
University of Bergen, Norway,
August 1- 4th 1996.

Edited by Stein-Erik Lauritzen

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Climate Change: The Karst Record

Introduction

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On the wide arena of the geoscientific community, karst topics have played a relatively modest, but stubborn role. The study of caves requires not only scientific skills and imagination, but also the skills of entering caves. This physically very demanding field technique is also somewhat excluding; without sufficient field experience, it may be difficult to fully appreciate the various processes in the cave environment. Therefore, an exaggerated myth is that karst scientists are either fanatic, underground mountaineers (who justify their obsession by writing papers), or being so specialized that their work has little general interest. Of course, we all know that these exaggerated statements are not true (taking the risk of being equally narrow-minded), but we also know that the challenge of convincing others lies on the shoulders of the karst scientists themselves. We have therefore seen, - among many other developments - the emergence of *The Karst Waters Institute* in the USA, the *UIS congresses*, Karst Commissions *in The International Geomorphological Union*, various *IGCP Projects*, the speleothem (SPEP-III) projects under PANASH[1], and quite recently, a proposal for an *European Science Foundation Scientific Network* of karst research groups[2], as well as many thematic issues in a variety of international journals. During the last few decades there has been a steady stream of ground-breaking papers in leading geoscientific journals, not least in the topics related to paleoclimatology.

Paleoclimatology is therefore the main idea of this symposium. Karst caves are unique repositories for various forms of paleoclimatic information, being well protected from destructive processes acting on the surface. The powerful dating methods available for speleothems combined with their highly resolvable stratigraphy make them unique among terrestrial deposits and a valuable complement to deep-sea sediments. The taphonomy of karst caves is favorable both as pit-fall traps and as habitats for various vertebrates and invertebrates that possess narrow climatic preferences. Also, the knowledge on the emergence of modern humans is derived from deposits in caves and karst sites. The challenge is therefore to link the so-called entrance facies together with the deep cave environment and with the surface Quaternary stratigraphy. Because karst is regionally wide-spread, the climatic data extracted from it can be used to test various space- and time-dependent climatic models. The purpose of this symposium was to gather together a wide international selection of researchers who work with paleoclimate- related aspects of karst, and to focus upon those

[1] See Gasse, F. (1995): PEP-III: The Afro-European Transect, pp. 65-88 in: *Paleoclimates of the Northern and Southern Hemispheres. The PANASH Project. The Pole-Equator-Pole Transects.*ISSN 1023-9421
[2] ESF «Karst GeoEcosystems» (KAGES), meeting in Postojna, Slovenia, June 1996.

topics where karst research can make significant contributions of wide interest. I think we have succeeded in doing so.

The driving force of paleoclimatic research is of course curiosity (as with any science), but also the need for prediction. Future climate changes are of great concern to all of us, not least those who are going to make political decisions for the future. Whether we like it or not, it is the politicians' desire to make reliable predictions about future climate that nowadays generate much of the research money. Paradoxically, it is easier (and much safer!) to predict the natural variability of average climate in 20 or 100 kyr from now than from year to year in the next 5 or 50 years. One reason, apart from uncertainties in the anthropogenic changes, may be that most paleoclimatic records are not sufficiently resolved to pick up such high frequencies. The recent results on annual, and even higher frequency banding in speleothems may contribute significantly to enhance the precision of such predictions. So, if future climate can be «predicted» at all from past climatic change, then speleothem research is perhaps the only activity that provide long-term input data of a resolution that is much higher than the timespan to the next political election!

It is also important to focus on the conservational aspects of karst. Having proven that speleothems are important targets for paleoclimatic deciphering, the sampling pressure on these beautiful and rare deposits has also increased markedly. For less than 10 years ago we were only a handful of seasoned cavers who kept up the faith in speleothems as paleoclimatic proxies, - and sampled them with great care. Today we are an order of magnitude larger population who run them through our cutting and polishing machines, digest them in acids and process them in mass spectrometers, electron microscopes and ICP instruments. The higher the curiosity for details in the paleoclimatic record, and the higher the scientific ambitions become, the higher is also the need for looking into ways of utilizing such a limited resource with care. One way is to establish an international database of specimens, so that duplicate sampling can be avoided. This and other possibilities will be discussed in the commission meetings.

Climatic change information in karst may be arranged in various categories, of which the following was chosen for the symposium:

1) Speleothems as high-resolution recorders of various paleoclimatic proxy data.
2) Cave sediments and stratigraphic information, including paleomagnetism.
3) Climatically influenced changes in karst processes and landforms.
4) Biostratigraphy and archaeology in caves.
5) The relation of recent speleofauna to environmental changes.

In spite of the coincidence of timing of the symposium with several other important events in the geoscientific community, the response to the organizers' announcements has been formidable. This Proceedings contains 71 extended abstracts, spanning all 5 topics listed above. Three of them are keynote topics: *Chemical Kinetics, Speleothem Growth and Climate* (Dreybrodt), *Dating Cave Deposits* (Ford), and *Paleoclimate Inferences From Stable Isotopic Studies of Speleothem* (Schwarcz). All 71 contributors (there are actually 131 authors!) share the honour of presenting this symposium to the scientific community.

Welcome to enlightened darkness!

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EFFECTS OF TECTONİC MOVEMENTS and CLIMATIC CHANGES ON KARSTIFICATION IN TURKEY

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Abstract

Turkey has several types of karstic land-forms containing karrens (lapiés), caves, dolines, uvalas and poljes and ground river valleys. Karstification is related to the thickness and purity of limestone, as well as climate, height and tectonic movements. Well-developed karstic features are widespread in/on the mesozoic comprehensive limestone in the Taurus mountains. Wide poljes are widespread in the tectonic corridors in the Taurus mountains.

Karstification has begun to develop towards the end of the Mesozoic cracked limestone in general. Large poljes were developed, some of them were occupied by the neogene lakes in which limely and clayey materials were accumulated. Some poljes contain lignite deposits. The fresh water lakes such as Lake Beyşehir and Eğirdir are found in the tectonic-karstic depressions in the western part of the Taurus mountains. Poljes also contain sinkholes. When sinkholes are obstructed, the shallow lakes are formed within the poljes and/or uvalas. For example, Lake Suğla which is the prominent poljes, middle west of Taurus, is dried up via the natural opening of the sinkholes.

Ground river systems are found between the Lake Region, which is located in the western part of the Taurus mountains, and Mediterranean coast. These river systems have been shifted towards the deeper parts of the limestone as the result of the progressing of karstification and the vertical uplifting of Taurus mountains during the upper Tertiary and early Quaternary time.

Old travertine formation named Antalya travertine deposits may have formed as the result of the sheet flood originating from the upper part of the Taurus Mountains towards the end of the last glacial period. The eolian materials which are found in the reddish soils in the karstic lands indicate the existence of the cold and dry climatic period. Some travertine layers covering the reddish soil also show the climatic changes.

Key words: Karstification, tectonizm, climatic changes

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Luminescence and Discharge Variations in Stalgmite Drip Waters, Bristol, England

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Introduction

The measurement of stalagmite drip discharge is important in a palaeoclimatological context. In order to determine the relationship between the drip discharge onto stalagmites and precipitation change, and its palaeoenvironmental applications to annually laminated stalagmites, data were collected from Lower Cave, Bristol, England. Discharge data were collected over two annual field cycles; the 1991-1992 field cycle occurred after five years of below average precipitation (1.3-15.8% below the twelve year mean), whereas the 1994-1995 cycle followed three years of above average precipitation (4.9-23.9% above the twelve year mean). Over the second annual cycle, samples were also collected for luminescence analysis, in order to determine the relationship between annual luminescence banding preserved in stalagmites and their hydrological characteristics.

Site Description

Lower Cave, Bristol (51° 27' N, 02° 36'W) is a 18 m long cave in Lower Carboniferous Limestone. The climate of the region is cool temperate oceanic, with a 30-year mean annual precipitation of 842 mm with a winter maximum, and a mean annual temperature of 10.0 °C with a winter minimum of 3.9 °C (January) and a summer maximum of 16.5 °C (July). In summer evaporation exceeds precipitation. Seven drip sites (LC-1 to LC-5, LC-6a, LC-6b) were analysed within the back 5 m of the cave, the sites chosen such that the drip water would have passed through > 15 m of limestone. The drip waters all originated from actively depositing straw stalagmite sources; the straws were within a 2 m^2 area but not visibly hydrologically connected.

Results and Interpretation

The response of the seven sites to the difference in long-term precipitation between 1991-1992 and 1994-1995 is presented in the table. Discharge at six of the seven sites increased with increasing precipitation, although this increase in discharge varied by between 119% and 278%. One site, LC-6b, went from being hydrologically inactive to having limited activity dependant on LC-6a. LC-6a went from being hydrologically inactive in summer in 1991-1992 to being active throughout the year in 1994-1995. One site (LC-1) decreased to 13.2% of its former discharge in 1994-1995. The variability of discharge also increased with increased annual precipitation. Differences in the lag time between precipitation and discharge are also noticeable; in 1991-1992 statistically significant lags occur at 24-30 days; in 1994-1995 these occur at between 1-6 and 1-20 days. The cross-correlations between the sites also vary between years; there are generally stronger correlations for annual data between sites in 1994-1995 compared to 1991-1992, and this persists for both summer and winter data. In 1991-1992, cross correlations break down for the lower discharge summer period.

The variability of response between sites is typical of the variability of flow in the unsaturated zone (Smart and Friedrich, 1987). Cross-correlations between the sites broke

Site	Discharge 1991-1992 ($l\ s^{-1} x10^{-7}$) mean	1σ	CV	n	Discharge 1994-1995 ($l\ s^{-1} x10^{-7}$) mean	1σ	CV	n	Change in discharge between 1991-2 and 1994-5
LC-1	6.07	2.21	36%	13	0.80	0.61	77%	16	x0.13
LC-2	7.84	4.66	59%	13	55.2	57.5	104%	18	x7.05
LC-3	8.18	2.14	26%	16	22.7	24.8	109%	18	x2.78
LC-4	14.2	2.94	21%	16	35.1	53.8	153%	18	x2.47
LC-5	5.24	0.61	12%	16	6.26	2.64	42%	18	x1.19
LC-6a	8.47	5.64	67%	16	30.6	24.0	79%	16	x3.61
LC-6b	dry		-	16	35.1	24.4	70%	18	

Table 1. Hydrological data for 1991-1992 and 1994-1995.

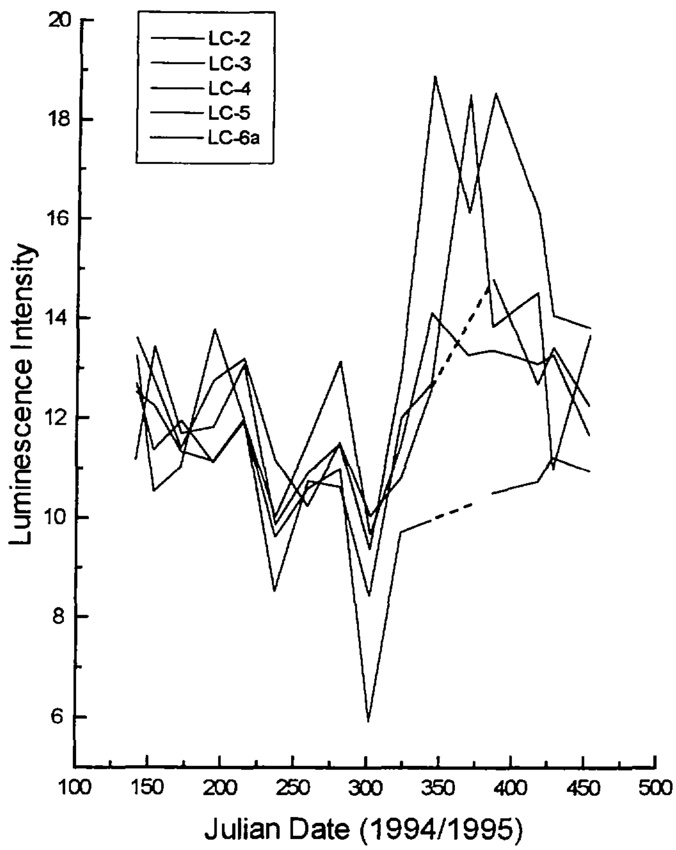

Figure 1. Variatons in drip water luminescence over the period 1994-1995.

down in the summer of 1992, demonstrating the importance of evaporative loss from the surface and the presence of a decoupling between the unsaturated zone and surface precipitation. Discontinuous soil cover at the site suggests this evaporative loss may occur from the groundwater system as well as from soil moisture. In 1994-1995, cross-correlations were maintained all year. It is suggested that the increased precipitation recharged the aquifer and filled a significant amount (if not all) of the available storage, leading to both rapid pulse flow in response to precipitation, which would explain the high winter discharges, as well as more water to sustain discharge into the summer when evapotranspiration exceeds precipitation, which would explain the maintained cross-correlations. In addition, LC-1 decreased in discharge whereas all other samples increased, suggesting blocking or diversion of the flow path. The nature of the transition from high to low discharge of LC-1 is not known; future studies of long term, high frequency time series data is needed to determine whether this occurred gradually or catastrophically.

Luminescence variations for sites LC-2 to LC-6 (samples were not obtained for LC-1 due to the low discharge) are presented in figure 1, and demonstrate that luminescence increases in general at all sites from November to March (Julian days 330 to 420). This correlates with the winter maximum of discharge. Hence it seems likely that (1) when precipitation exceeds evapotranspiration, organic matter which has decomposed over the summer and autumn is washed into and through the karst groundwater system and/or (2) surface organic matter production is continuous but the high molecular weight organic molecules are only transportable through the karst aquifer when there is increased discharge. Winter increases in organic matter have also been inferred from observations of deposition of visible laminae in speleothem (Genty et al, in press).

Conclusions

In this study, the importance of complexities of flow are highlighted. Drip discharges demonstrated both typical seepage flow characteristics, as well as overflow, underflow and seasonal dryness. The results presented here demonstrate that palaeoenvironmental reconstructions using speleothem samples should ideally use multiple samples. The complexities of flow at even low discharge stalagmite drip feeds suggest that caution must be exercised when interpreting individual samples

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Recent Stalagmite Growth Rates: Cave Measurements, Theoretical Predictions and the Environmental Record

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Background

In a recent papers, Dreybrodt (1980; 1981; 1988) has established a theoretical model for the kinetics of calcite dissolution and precipitation, based on the rate laws of Plummer et al (1978). This model takes into account the three processes which occur during the deposition of a stalagmite: (1) chemical reactions at the calcite-solution interface; (2) diffusional transport of species through the solution to the surface of the solid; and (3) slow conversion of carbon dioxide into protons and bicarbonate ions. It was shown that these processes could be combined into a rate equation of the form:

$$R = F\{[Ca^{2+}]_{eq}-[Ca^{2+}]\}\{1-\exp(-^{t}/_{Td})\}x1.174x10^{6} / t \qquad (mm\ yr^{-1}) \qquad (1)$$

where Td is a function of P_{CO_2}, temperature, and the thickness of water on the stalagmite cap (F); $[Ca^{2+}]_{eq}$ is the Ca^{2+} concentration at saturation, and t is the time between drips. The equation can also be extended to include splash effects.

No studies have undertaken a calibration of this relationship in the cave environment, although laboratory simulations by Dreybrodt (1988) demonstrated a good agreement within x2, and Baker and Smart (1995) have recently performed a calibration for drip-fed flowstones. Growth rate variability was demonstrated to be most sensitive to variations in calcium concentration (40%), followed by water film thickness (27%), temperature (19%), drip rate and cave air P_{CO_2} (each 7%). In a recent study, a doubling of growth rate was observed in a stalagmite deposited in Sutherland through measurement of annual laminae width (Baker et al, 1995). In a theoretical analysis of the growth rate predicted by equation (1), this growth rate doubling was predicted to have been generated by an increase in calcium concentrations from 2.1 to 3.5 mmol l^{-1}.

Recently, improved dating precision and annual laminae counting (Baker et al, 1993; Genty, 1993; Genty and Quinif, 1996) has allowed the determination of the growth rates of stalagmites deposited in the Quaternary time period. There is thus potential for the use of the growth rate model to interpret these Quaternary growth rate variation. In this study we compare predicted growth rates derived from the model of Dreybrodt (1988) with those measured for recently deposited stalagmite samples, in order to determine the adequacy of the model.

Method

Recent growth rates were determined for stalagmites from two cave or mine systems. The first was from Browns Folly Mine, Avon, England, which is situated in Jurassic limestone and in which copious speleothem deposition has occurred since abandonment in 1880's. The second was the Grottes de Villars, Dordogne, also within Jurassic limestone. Growth rates were determined by measuring the distance between annual visible or luminescence laminae (both sites), annularity was confirmed by measuring the thickness of the total sample if the time of growth commencement was known (e.g. from the date of opening of Browns Folly Mine) or by ^{14}C analyses (Villars). UV laser and/or visible microscope techniques, together with image analysis techniques, were used to obtain

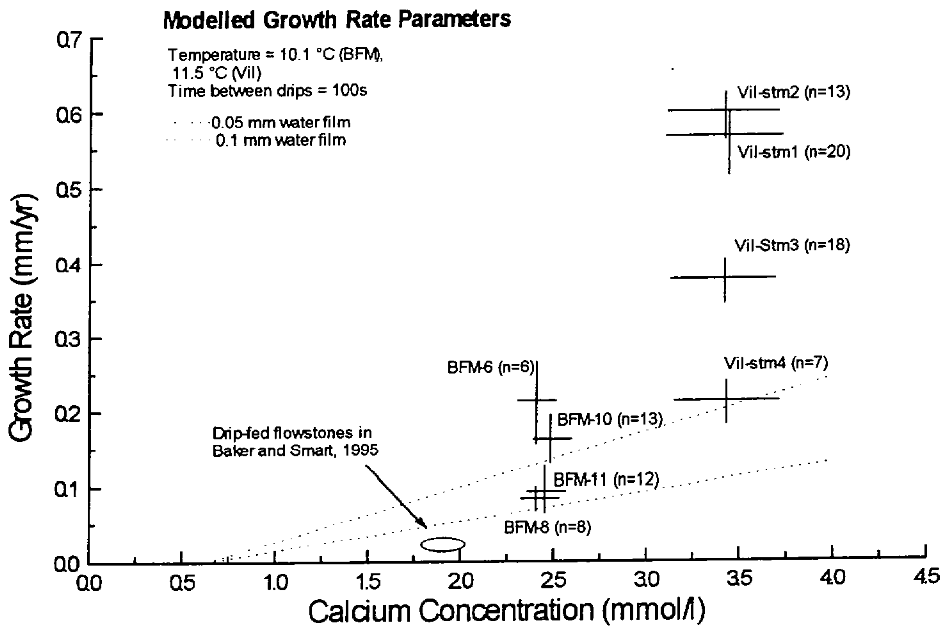

Figure 1. Relationship between theoretically predicted growth rates (from Dreybrodt, 1988) and observed growth rates from Browns Folly Mine and Grottes de Villars.

multiple estimates of growth rate; the mean and standard deviation for each site was then calculated.

To enable comparison to the growth rate theory, measurements of calcium concentration, temperature, and water flux (drip rate, water film thickness) were undertaken. Cave air PCO_2 was not measured, but assumed to be $3x10^{-4}$ atm. This approximation does not have a significant effect on growth rate, as shown by Dreybrodt (1988). Measurements were made over the course of the annual hydrological cycle within the period September 1995 to August 1996.

Results

For both sites, calcium concentrations were measured for 8-9 drip sources of varying discharge and spatial location and over the period of seasonal variations. In Browns Folly Mine, calcium concentrations are remarkably constant at 2.45 ± 0.22 mmol l^{-1} (n=18), for Villars the concentration is 3.45 ± 0.42 mmol l^{-1} (n=14). For both sites, T = 10.5 ± 1.0 °C, and drip rates onto the sampled stalagmites were in the range 1 drip s^{-1} to 1 drip 200 s^{-1}. By measuring annual visible and luminescent laminae thickness, growth rates for Villars were determined to be 0.21 - 0.58 mm yr^{-1}, and those for Brown's Folly were 0.08 - 0.23 mm yr^{-1} . The comparison to theoretical predictions is in figure 1. Theoretically modelled growth rate shows a reasonable agreement with that observed within x2-3, similar to the error associated with the Plummer et al (1978) equations. Sensitivity to calcium is shown to be most important, suggesting that changes in growth rate of Quaternary stalagmite samples are best interpreted as changes in dripwater calcium concentrations.

Conclusion

The importance of calcium as the key variable in determining growth rate, as predicted by Dreybrodt (1980; 1981; 1988) is confirmed, although the agreement with the theory is only within a factor of x 2-3. This error is the same as that observed by Dreybrodt (1988) in laboratory experiments and is the same as that associated with the Plummer equations. Further research is necessary into other causes of this variability. For example, the thickness and variability of the water film on stalagmites is poorly understood, as is the splash effect of dripping water which may cause turbulent flow. Finally, samples from Villars show a strong correlation between growth rate and luminescence intensity, suggesting that high concentrations of organic matter may lead to disruption of the crystal growth structure and hence higher growth rates (see Genty et al, this volume).

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Late Quaternary Paleoclimate in the Eastern Mediterranean - Stable Isotope Systematics of Soreq Cave Speleothems.

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Determining recent continental climatic changes in the Eastern Mediterranean region is one of the major challenges that faces scientists concerned with developing models for climatic evolution. The present-day Eastern Mediterranean region is semi-arid, located in a narrow transition zone between humid and arid climates. The area is located within a wider desert belt which extends from India to Morocco, but possesses a milder and less extreme climate because of the moderating influence of the Mediterranean Sea. Like other climatic transition zones, this region is very sensitive to environmental changes. In this study we show that a continuous stable isotopic record obtained from cave deposits (speleothems) dated from 25,000 to 1,000 yr. BP. allows a detailed insight into climatic evolution during the Holocene and late Pleistocene time and that the global events of glaciation, deglaciation, warming etc. are evident in the Eastern Mediterranean area. We particularly focus on determining the evolution of rainfall and vegetation pattern, using constraints provided by our understanding of the present-day system. The Soreq Cave is located in the Judea mountains, near Jerusalem, Israel. The present-day conditions are typical to semi-arid climate with most of the rain occurring from December to March with an average of 500 mm rain.

Cave waters in the Soreq Cave are ^{18}O fractionated relative to rain waters (usually 1 to 1.5‰ higher) and variations in $\delta^{18}O$ values reflect fluctuations in the annual amount of rainfall, wet/dry seasonal changes and evaporation processes in the epikarst zone. In a closed cave system, such as the Soreq cave, low magnesium calcite (LMC) is depositing in isotopic equilibrium from the cave waters, whose temperatures range from 18 to 22°C and $\delta^{18}O$ (SMOW) vary from -6.3 to -3.5‰. The $\delta^{13}C$ (PDB) values of dissolved CO_2 in waters vary from -15.6 to -5.4‰ and reflect the contribution of the dolomitic host rock, soil-derived CO_2 with C3 type vegetation, CO_2 degassing and carbonate precipitation. Thus, the $\delta^{18}O$ (PDB) values of most of the present-day LMC speleothems are between -6 to -5‰ and most $\delta^{13}C$ (PDB) values range from -12 to -8‰ (shaded rectangle in Fig. 1).

The $\delta^{18}O$ - $\delta^{13}C$ ranges of fossil speleothems dated from 25,000 to 7000 yr. BP differ from present-day range, and thus could not have deposited under present-day conditions. Only speleothems younger than 7,000 yr BP exhibit isotopic compositions similar to those of present-day speleothems. On the basis of the secular tends in isotopic compositions a division into six separate age-groups is possible (Fig. 1).

- 25,000 ± 2,500 to 17,000 ± 1,500 yr BP. The speleothems are markedly ^{18}O-enriched with $\delta^{18}O$ = -4.0 to -2.3‰ and $\delta^{13}C$ = -11.0 to -7.5‰.
- 17,000 to 15,000 ± 1,500 yr BP. Isotopic compositions show a decrease, with $\delta^{18}O$ = -5.0 to -3.6‰ and $\delta^{13}C$ = -12.5 to -10.0‰.
- 15,000 to 12,000 ± 1,500 yr BP with low values of $\delta^{18}O$ = -6.1 to -5.1‰ and $\delta^{13}C$ = -13.5 to -12.0‰.
- 12.000 to 10,000 ± 1,500 yr BP with low values of $\delta^{18}O$ = -6.5 to -5.8‰, but with $\delta^{13}C$ showing an increase relative to the previous group, $\delta^{13}C$ = -12 to -10.5‰.
- 10,000 to 7,000 ± 1,500 yr BP. Speleothems are markedly ^{13}C-enriched and ^{18}O-depleted with $\delta^{18}O$ = -6.8 to -5.8‰ and $\delta^{13}C$ =-9.5 to -4.0‰, thus defining a clear change in climatic conditions.
- 7,000 to 1000 ± 600 yr BP with $\delta^{18}O$ = -6.0 to -5.0‰ and $\delta^{13}C$ = -12.0 to -9.5‰ (i.e., mostly in the present-day range).

The $\delta^{18}O$ – $\delta^{13}C$ trends of the various age groups merge into one another (Fig. 1) and clearly demonstrate that the Soreq cave speleothems are an excellent tool for the reconstruction of the continental paleoclimate in the Eastern Mediterranean region.

The time period between 25,000 to 17,000 yr. BP is known as the last glacial, and in the Soreq cave is characterized by constant growth of speleothems, with an average growth rate in the cross-sectional direction of more than 1mm/100 yr. Growth habits consist of light-colored concentric

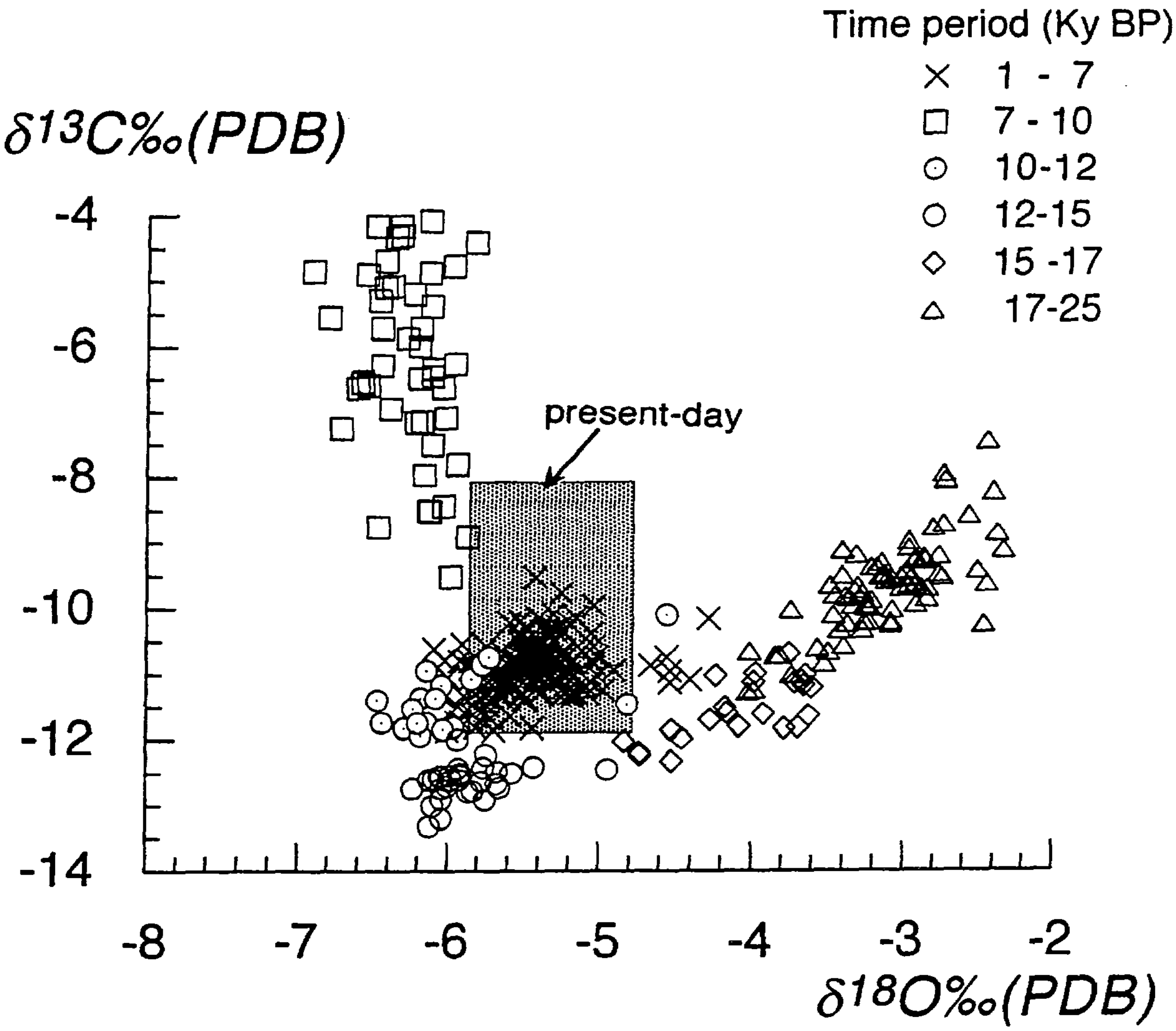

Figure 1. $\delta^{13}C$ vs. $\delta^{18}O$ plot of Soreq cave speleothems

laminae with large LMC crystals and low detrital components and are indicative of deposition from slow, constantly dripping water. $\delta^{18}O$ and $\delta^{13}C$ values are relatively high, and they are positively correlated (Fig. 1). Modeling of these ranges using using the carbonate paleotemperature scale and criteria based on the present-day variations of $\delta^{18}O$ of cave waters with rainfall, suggests that deposition temperatures were 12°C-16°C, cave water $\delta^{18}O$ (SMOW) values ranged from -4.5 to -3‰ and the mean annual rainfall was 300-450 mm. The $\delta^{13}C$ values are consistent with a soil cover containng both C3 and C4 type vegetation.

Speleothems from the three groups representing the time periods between: 17,000-15,000; 15,000-12,000; 12,000 to 10,000 yr BP. have similar petrographic characteristics and a distinct isotopic compositional trends that grade into one another. The average growth rate in the cross-sectional direction is 1mm/100 yr, slightly lower than the growth rate during the end of the last glacial period. During the time period of 17,000 - 15,000 yr BP there is a gradual decrease in both $\delta^{18}O$ and $\delta^{13}C$ values. Model calculations show that the drop in $\delta^{18}O$ is associated with warming to a temperature range of 14.5°C to 18.5°C and precipitation reaching 375-540 mm. The gradual decrease in $\delta^{13}C$ values indicates a transition towards a C3 type vegetation cover. Short periods with 'spikes' of higher $\delta^{18}O$ and $\delta^{13}C$ values indicate that climatic conditions were not stable. A continued, but more moderate decrease in isotopic compositions occurred between 15,000 to 12,000 yr BP, leading into an interval characterized by relatively constant, but low, $\delta^{18}O$ at around -6.1 to -5.1‰ and $\delta^{13}C$ at -13.5 to -12‰ (Fig. 1). These latter isotopic values indicate that the vegetation was totally of a C3 type. Temperatures appear to have been the same as in the previous period, but conditions were wetter with a mean annual rainfall of 550-725 mm. Between 12,000 to 10,000 yr BP, $\delta^{18}O$ values are the among the lowest observed throughout the whole studied period, but $\delta^{13}C$ values begin to show an increase. This period is viewed as transitional to the following one (10,000 to 7,000 yr) which is characterized by a sharp increase in $\delta^{13}C$. A notable 'spike' in $\delta^{18}O$ values, observed at around 11,500 yr BP, could be correlated with the Younger Dryas Event, which represented an abrupt global reversal toward colder glacial conditions.

The period from 10,000 to about 7,000 yr BP is represented by relatively small numbers of speleothems, and their petrography and isotopic compositions are very different from the rest of the Holocene speleothems. They are characterized by thin, irregular, brown-red laminae with the high concentrations of oxides and detritus. The growth rate in the cross-section direction is relatively slow at 0.5 to 0.6 mm per 100 years. The $\delta^{18}O$ values of -6.8‰ to -5.8‰ are the lowest observed and are coupled with increases to the highest $\delta^{13}C$ values of -9.5‰ to -4‰ (Fig. 1). The $\delta^{18}O$ values indicate that the annual average precipitation was almost twice that of the present-day. The $\delta^{13}C$ values of -9.5 to -4‰ indicate a lower dissolved CO_2 component in cave waters, relative to other periods. The combination of the highest $\delta^{13}C$ values with the lowest $\delta^{18}O$ values, the slow deposition rate, the rarity of speleothems, and the high concentrations of detritus indicate flooding events causing the removal of the soil.

The time period of 7,000 to 1,000 yr BP is the only one that partially overlaps with the present-day isotopic compositions. $\delta^{18}O$ values mainly range between -6 to -5‰, with some samples having values almost as high as -4‰. Thus, the temperatures estimated for this period are the same as for present-day. The $\delta^{18}O$ range is equivalent to 350-580 mm rainfall, a range similar to that of present-day. The $\delta^{13}C$ values range mainly between -12 to -10.5‰, which is smaller than the present-day (-11 to -8‰). The higher $\delta^{13}C$ values of the present-day range could be a result of human activity. Isotopic composition variablity in this time period indicates that short climatic variations occurred. For these we have independent evidence from archeological, geomorphological and climatological data.

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EVIDENCES FOR EFFECTS OF CLIMATIC CHANGES ON SAUDI ARABIAN CAVE DEVELOPMENT

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Speleological investigations were carried out in caves of Saudi Arabia. The primary objectives have been the exploration and development of hydrogeological features (e.g. groundwater renewal, structure controlled subsurface flow paths): Additionally a lot of observations brought interesting results of climatic effects on caves during the geological past.

The study area is located in the region of Ma'aqla, an area within the As Sulb Plateau, which itself belongs to the As Summan Plateau as part of the Eastern Arabian Shelf Platform. In this area the Paleocene Umm er Radhuma Formations is exposed as a sequence of light colored limestone and dolomites. This formation is overlain by Miocene clastic sediments. Both stratigraphic units offer good prerequisites for karstification. Generally the strata dip gently to NE and the caves investigated show a clear orientation to the same direction. Morphologically the area is characterized by different plain system with an old drainage pattern directed to NE or E.

The evaluation of the speleological investigations showed that the cave development started probably in the Eocene during a general lift-up of the Arabian Platform in the East.
This lead also to a lift-up of the Arabian Platform in the East. This leads also to a lift-up of the eastern part with its shelf-sediments and initiated the formation of a network of phreactic tubes. The phreatic tubes have been formed in most cases along bedding-planes. Only a small number of shafts interconnect different levels of such bedding-planes. The subsequent development is characterized by an alternating change between dry and wet climatic phases. Under increasing arid conditions former active channels became more and more dry, while the water table lowered down to 100-180 m below ground surface.

Emphasis is put on morphological details in the caves, and on sediment fillings at a more descriptive basis. Dating of speleothems are presented in a survey with critical comments on the reliability of data. At last an attempt is made to correlate the different findings to evolutional stages pronouncing the special influence of the climate.

As the main result it will be shown that different phases of strong erosion alternate with those of stagnation. Big speleothems formed between such erosional phases show periods of a relatively long-lasting humid climate under vadose conditions. Later on during periods of intense denudation of the landscape, caves have been opened to the surface and erosion took place, which can be shown by remnants of big columns of dripstone. the erosion of sediment filings occurred in such a way that the material was transported to deeper levels with passages open to sediment transport. The present-day status is mature one with respect to resent conditions in a semi- to partially hyperarid climate.

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Chemical Differences Between High Fluorescent and Low Fluorescent Speleothems.

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Few researchers have addressed the nature of fluorescence in speleothems. White (1984, 1986), White and Brennan (1989) and Lauritzen et al. (1986) demonstrated that much or all of the fluorescence is due to the presence of humic and fulvic acids in speleothems. Shopov (1987) investigated the paleoclimatic significance of the luminescence. It is logical to suppose that variability in this fluorescence is due to changing quantities of organic acids in the speleothems. However, this assumption has not been tested as yet. It is the objective of this paper, which is a review of work in progress.

1) There are two potential methods to characterize the quantity of fluorescence from the speleothems. The first photographs emitted light from a specimen when organics in it are excited by transmitted light from a flashgun (Shopov et al., 1994). Potential problems here are variable sample thickness and the brevity of the exposure: both will inhibit accurate quantitative comparison between samples. Varying thickness affects the amount of light passing through the specimen. While most speleothems fluoresce intensely for a short period following a flash, those with less organics fade more quickly, but this is not recorded due to the brevity of the photographic exposure (30th of a second).

The second method is spectroscopy, which measures the intensity of fluorescence from a sample when it is excited at certain wavelengths. This allows a more directed approach to the problem. It is possible to use the exact excitation spectra needed, instead of the broad spectrum of the flashgun. Peak intensities of the emissions in different samples are quantifiable and suggest what is causing the fluorescence. The wavelength spectrum to be used is predetermined by the wavelengths at which the organics emit. This is normally between 240-480nm; however, so as not to preclude other possible contributors of fluorescence, the wavelengths should be broadened to between 200-550nm if the spectrophotometer will allow it.

One advantage of photography is that it allows a finer determination of high and low fluorescent bands. The spectrophotometer can be used on larger bands of HFC or LFC if these are partitioned off from each other. It is planned to undertake detailed chemical analysis for differentiation of high and low fluorescence speleothems and also of high and low fluorescent bands within particular speleothems. To aid in later research, both methods will be applied.

The calcite samples in this study are taken from a variety of environments, but more importantly were selected for the amount of organics (related to colour) visible in each sample. The continuum begins with a pure (colourless) calcite crystal, which one can assume has little or no organics. At the other extreme, a sample from Crowsnest Pass, Alberta, is almost black, suggesting high concentrations of organics. In between these two end members are a gradation of coloured speleothems through white, yellow, red and brown. It is predicted that the pure calcite has no fluorescence while the darker specimens have the highest fluorescence.

2) To confirm the presence of the organics, and measure their variation in concentration, dissolved organic carbon (DOC) will be determined. DOC provides a

coarse bulk measure of the organic concentrations, but does not tell us what these organics are comprised of.
3) Characterization of Humic and Fulvic acids:
Using gel chromatography, it is possible to remove the organic acids from speleothems for separate analysis. Spectroscopy should also be able to demonstrate links between bulk sample fluorescence and the HA and FA fluorescence once the emission peak is determined.
A further important question is whether it is possible to quantify the amount of HA and FA within each sample, hopefully demonstrating that there are greater quantities of HA and FA in high fluorescent speleothems than in low fluorescent ones. Also of interest would be to quantify the relative contributions of each acid to the total amount of fluorescence within a sample.
Organics acids are complexing agents and consequently have the ability to incorporate trace elements into their molecular structures. These elements also influence fluorescence, thus their presence should be quantified, possibly using AAS, or an ion probe.
4) Other possible influences for fluorescence in speleothems:
If possible, the residual of the solution, once the HA and FA have been removed, should be analyzed. Its contribution to fluorescence has to be ascertained. Two analyses can be performed to achieve this. (1) fluorescence spectroscopy to measure the "leftovers" contribution (suggested by its intensity) to total fluorescence. (2) trace element analysis (using a probe or AAS) to identify the minerals in the calcite. Certain elements sensitize while others quench fluorescence. If quantities are high, then their contribution must be accounted for, as with the humic and fulvic acids.
5) Finally, from a holistic environmental approach, can the environments above the caves provide an explanation for measured differences in fluorescence in the speleothems?

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Isotopic composition of present-day alpine speleothems from Trentino (NW Italy): a key for palaeoclimatic interpretations in ancient speleothems

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The stable isotope composition of present-day carbonate speleothems have been analysed from 3 different caves in Trentino, NW Italy (Grotta Cesare Battisti: entrance elevation 1880 m a.s.l., mean annual temperature 3,5°C; Grotta di Ernesto: entrance elevation 1167 m a.s.l., mean annual temperature 6,4°C; Grotta del Calgeron: entrance elevation 467 m a.s.l., mean annual temperature = 7.5°C). All the speleothems come from poorly ventilated areas in the caves where humidity is almost at saturation, i.e.. no evaporation effect is to be expected. Consequently, the precipitation mechanism involved is only by CO_2 degassing.

Speleothem morphology and isotopic composition

We analysed active speleothems of different morphology in order to evaluate possible differences in isotopic composition. For the same morphology, and in the same place, differences in isotopic values of up to +/-0.5 ‰ in $\delta^{13}C$ and +/- 0.25‰ in $\delta^{18}O$ can be observed. These could be related to both kinetic effect and drip water provenance. Carbon and oxygen isotopic values display a trend towards increasing positive covariance from high drip-rate related morphology (microcrystalline cylindrical stalactites) to low drip-rate related morphology (soda straws). The following hierarchy in $\delta^{13}C$ and $\delta^{18}O$ enrichment has been observed: spray deposits ≡ soda straws > tip stalagmites ≡ cone stalactites > cylindrical microcrystalline stalactites.

For Grotta del Calgeron $\delta^{13}C$ and $\delta^{18}O$ covariance in different morphologies shows a good correlation (fig. 1), which is related to two different kinetic mechanisms acting together:

1) In low drip-rate related morphology the residence time of percolating water within the rock is longer, between one and several month (Borsato, 1995), consequentely the host rock contribution is enhanced, and the isotopic composition of both drip water and speleothems is enriched in ^{13}C. This interpretation is confirmed by the Mg/Ca ratio of the drip water percolating throught dolomitic limestone rocks, which is higher (i.e. higher host rock contribution) during periods of low drip rate.

2) At lower drip rate the longer "residence time" of the drop at the stalactite tip enhances CO_2 degassing that causes an enrichment in ^{13}C of up to 2‰ (Dever et al., 1983). This consideration can also explain the more positive isotopic composition in spray deposits, where each drop splashed twice and causes a higher CO_2 degassing. Although degassing may affect only $\delta^{13}C$ composition (Dever et al., 1983), the lack of evaporation suggests that the slight $\delta^{18}O$ enrichment ($\delta^{18}O$ enrichment is about 0,25 times that of $\delta^{13}C$) is also related to the degassing process.

Consequently, speleothem precipitation can occur in isotopic disequilibrium not only as a result of the evaporation effect (Gonzales & Lohmann, 1987), but also for different rates and velocities of CO_2 degassing: This has been documented for other calcite precipitation processes that involve rapid CO_2 degassing (Clark & Lauriol, 1992). For this reason, the interpretation of isotopic paleoclimatic series in speleothems are valid only if quantification and modelling of these kinetic effects are possible.

Carbon isotopic composition vs. altitude

The $\delta^{13}C$ composition of different speleothems with the same morphology (i.e. cone stalactite tips), displays a positive covariance with the altitude of the recharge area above the caves. This covariance is directly related to the pCO2 in the soil above the cave. At high altitude the thickness of the soil, as well as the density and activity of the vegetation, are reduced and, consequentely, there is a low CO_2 production. In these conditions the pH at which calcite saturation takes place in percolating water is slightly alkaline (between 7.5 and 8.5) producing a strong positive shift between dissolved CO_2 and $CaCO_3$ precipitates (Wigley et al., 1978). At low altitude, high soil pCO_2 enhances carbonate dissolution: water calcite saturation occurs at subacid pH (between 6.0 and 7.0), and the C-isotope fractionaction between dissolved CO_2 and $CaCO_3$ precipitates is smaller.

These considerations offer an alternative interpretation of $\delta^{13}C$ fluctuation vs. time for interglacial speleothems from alpine and temperate regions, where entirely C3 vegetational assemblages are to be expected, and C3-C4 fluctuaction are unrealistic.

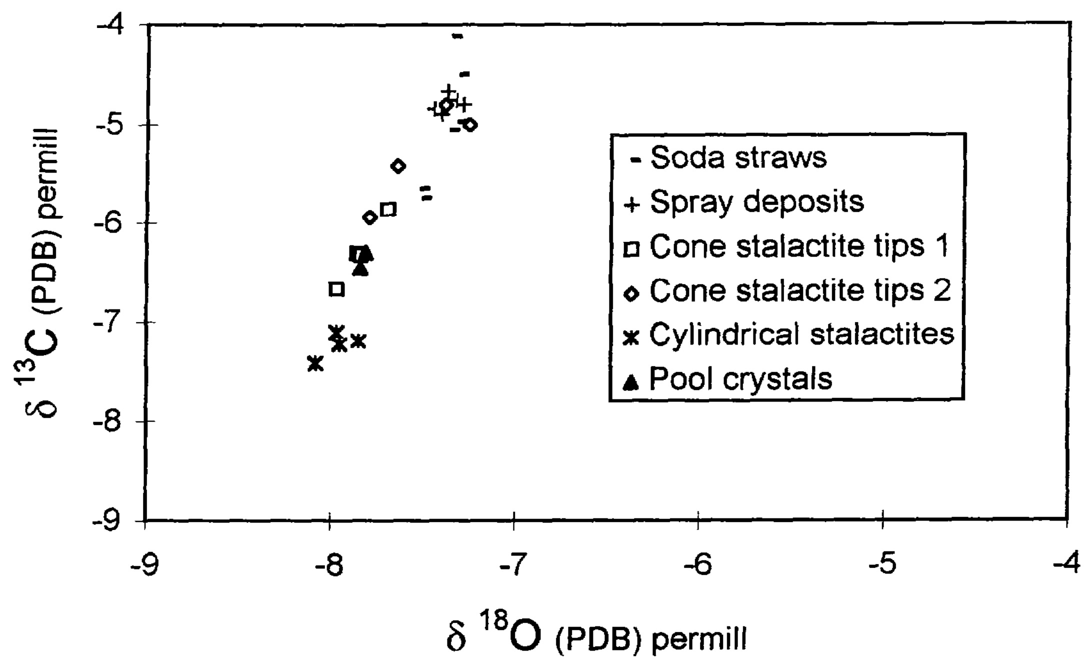

Figure 1. Isotopic composition of different speleothem morphologies in Grotta del Calgeron

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Paleoclimatic information in alteration assemblages of limestone-hosted base metal deposits

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Metal sulphide minerals in ore deposits in limestone terrains can undergo supergene alteration to produce relatively insoluble metal carbonates. In the case studied here, lead-zinc sulphide mineralization at Greenhow, North Yorkshire has undergone weathering by groundwater to produce an assemblage of smithsonite ($ZnCO_3$) and cerussite ($PbCO_3$) in addition to calcite. If this assemblage was precipitated in equilibrium then, since there is more than one carbonate mineral present, oxygen isotopic analysis of the carbonates can uniquely define both the temperature of deposition and the oxygen isotopic composition of the groundwater.

The alteration assemblage studied consists of late-stage "boxworks" of the three carbonate minerals with rarer anglesite ($PbSO_4$) and cinnabar (HgS) formed during supergene oxidation of a primary galena, sphalerite, calcite and barite assemblage. This occurs in the "Garnet Vein" in Coldstones Quarry where it is hosted by Carboniferous Limestone. The stable isotopic data on the carbonate minerals are given in Table 1.

Table 1. Stable isotopic data on carbonate minerals of the secondary alteration assemblage.

Mineral	No. of analyses	$\delta^{13}C_{VPDB}$ (‰)	$\delta^{18}O_{VSMOW}$ (‰)
Smithsonite	7	-3.01±0.47	26.99±0.09
Calcite	4	-5.64±0.10	24.63±0.17
Cerrussite	4	-14.17±2.20	15.80±0.19

This distribution of carbon and oxygen isotopes between these secondary carbonate phases is suggestive of isotopic equilibrium between the different phases. Indeed, calculation of the oxygen isotopic equilibrium temperature and equilibrium oxygen isotopic composition of water for each of the three possible mineral pairs gives consistent results, indicating that equilibrium was achieved amongst the minerals of the secondary carbonate assemblage (Table 2).

Table 2. Calculated equilibrium temperature and water isotopic compositions for carbonate pairs.

Mineral pair	$\delta^{18}O_{water}$ (V-SMOW)	Temperature (°C)
$ZnCO_3$ - $CaCO_3$	-3.4 ± 2.3	24 ± 10
$PbCO_3$ - $CaCO_3$	-2.0 ± 2.0	30 ± 11
$ZnCO_3$ - $PbCO_3$	-1.2 ± 1.0	35 ± 5
Averages	-2.2 ± 1.6	30 ± 9

All of the error ranges overlap, suggesting that full mutual equilibrium was attained and the best estimate of temperature and water isotopic composition during the alteration event is given by the combined average.

The slightly negative $\delta^{18}O$ of the water suggests that alteration was caused by a meteoric-derived groundwater. The temperature of the alteration event is a little too high to fit with a present-day meteoric waters of this composition. However, groundwater temperatures of 30°C in N. England would imply that there were no polar ice caps (the present-day groundwaters have temperatures of 7.5 to 8 °C) and thus ocean waters would have been depleted in ^{18}O by 0.5 to 1.0‰. The groundwaters were thus depleted in ^{18}O relative to contemporary sea-water by c. 1.5‰ which is similar to values at the present day for rainfall at c. 30°C. Such conditions probably last pertained in this area in the Tertiary and we are currently attempting to constrain the age of the alteration event.

Study of a carbonate alteration asssemblage associated with limestone-hosted lead-zinc mineralization has enabled paleotemperature and groundwater ^{18}O to be determined. Such mineralization is relatively common in limestones forming karst aquifers and similar alteration assemblages may provide useful paleoclimatic information to complement that in the speleothem record.

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Isotopic Composition of Palaeoprecipitation and Palaeogroundwaters from Speleothem Fluid Inclusions

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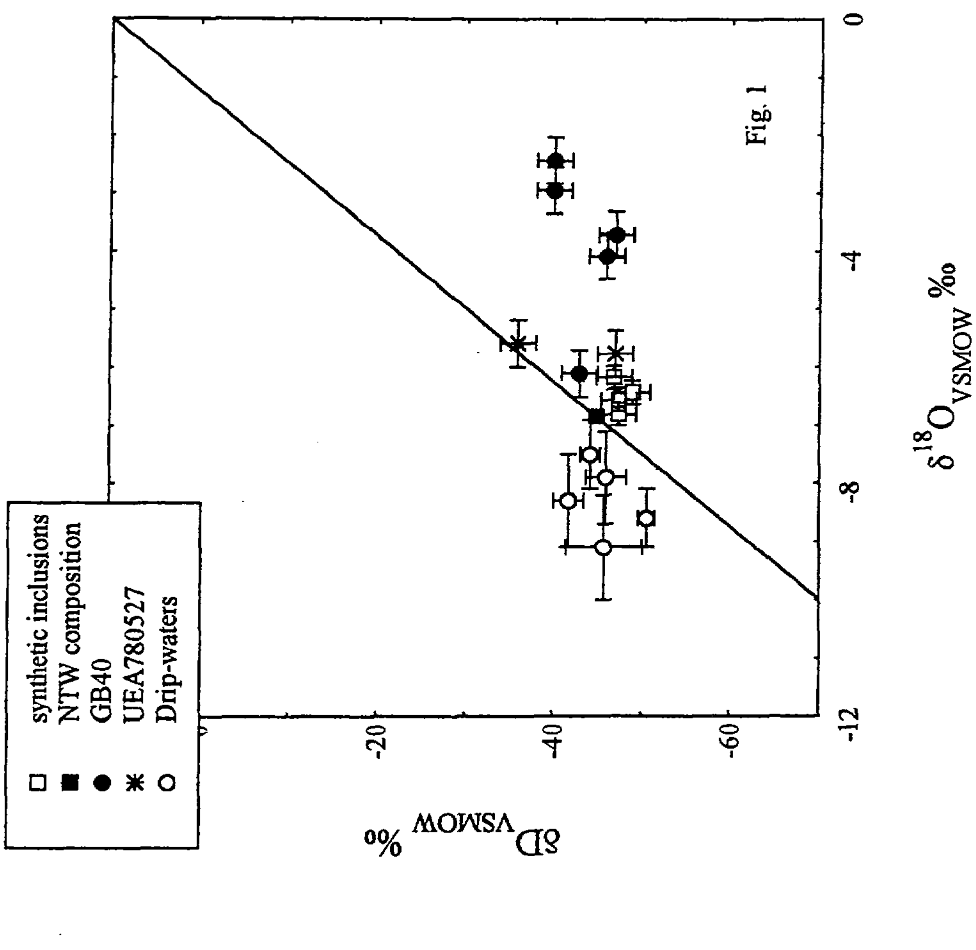
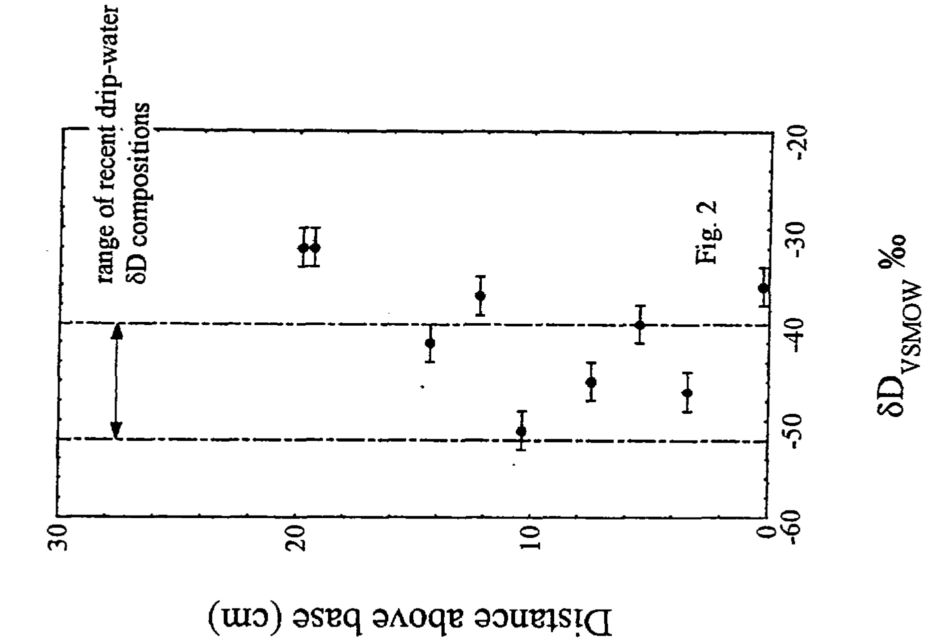
The stable isotope composition of ancient speleothems contains an important palaeoclimatic signal. Fluid inclusions, trapped in the speleothem calcite as it is precipitated, are a geologic archive of palaeoprecipitation and palaeorecharge. There are, however, few reliable measurements of the isotopic composition of fluid inclusion water from speleothems. This is largely due to the analytical problems associated with the extraction and separation of less than 1 μl volumes of water from the host calcite and its subsequent analysis for both $\delta^{18}O$ and δD. The main source of error is due to adsorption of the inclusion water onto fresh calcite fracture surfaces generated during crushing or decrepitation. Fractionation at this stage leads to depleted isotopic compositions in the recovered water. To overcome these problems we have developed an extraction system based on cold crushing of samples and thermal desorption of the released water. Tests with synthetic inclusions of known isotopic composition in Iceland spar show that water can be recovered quantitatively and without isotopic fractionation. Using the technique we have made several new analyses of the hydrogen and oxygen stable isotope composition of fluid inclusions from two Holocene speleothems from GB cave in the Mendip Hills. A brief synopsis of the data is given here.

Synthetic inclusions were prepared by sealing μl quantities of water in glass capillary tubes and crushing these at room temperature under static vacuum with dry Iceland spar. Water released from the capillary was allowed to adsorb onto the freshly fractured calcite. Typical water:calcite weight ratios were in the range 0.1 to 0.2% and similar to that expected of many speleothems. Following adsorption, the water was cryogenically recovered into a trap whilst heating the crushing cell to 150°C. Measured yields showed a near 100% recovery. Isotopic analysis using micro-CO_2 equilibration for $\delta^{18}O$ and Zn reduction for δD gave mean compositions of $\delta^{18}O$ = -6.49 ± 0.29 ‰$_{VSMOW}$ and δD = -47.7 ± 0.9 ‰$_{VSMOW}$. These compositions, plotted on a δD versus $\delta^{18}O$ plot in Figure 1, are very close to starting water composition of $\delta^{18}O$ = -6.84 ‰$_{VSMOW}$ and δD = -44.9 ‰$_{VSMOW}$.

Two Holocene stalagmites from GB cave in the Mendip Hills were selected for analysis. GB40 is a milky white specimen displaying fine growth laminae. U-series dates indicate that the basal deposit of the speleothem has an age of 8,700 ± 500 years. There then followed a hiatus in deposition with a subsequent growth history resuming at 3,700 years and continuing until the immediate past. Microscopic analysis of this stalagmite shows that the fluid inclusion population is dominated by numerous small, sub-micron inclusions concentrated in bands parallel to the growth laminae. Specimen UEA780527 is composed of optically clear, silvery calcite, similar


synthetic inclusions
NTW composition
GB40
UEA780527
Drip-waters
δD VSMOW ‰
-20
-40
-60
-12
-8
-4
0
δ18O VSMOW ‰
Fig. 1


range of recent drip-water
δD compositions
Distance above base (cm)
30
20
10
0
-60
-50
-40
-30
-20
δD VSMOW ‰
Fig. 2

in appearance to Iceland spar. It is a good microstructural contrast to GB40 containing few large inclusions as opposed to many finely dispersed sub-micron inclusions. U-series and ^{14}C age determinations give conflicting results, but it is probable that the stalagmite growth spans the entire Holocene.

Results for $\delta^{18}O$ and δD analysis of both stalagmites are plotted in Figure 1. For specimen GB40 the data are averaged over the growth interval 3,700 to 800 years b.p, and for UEA780527 the results correspond to the early Holocene. The deuterium compositions of GB40 lie in the range -37 to -47 ‰$_{VSMOW}$ and are wholly consistent with modern drip waters from this cave (Figure 1). In contrast the oxygen isotope compositions lie in the range -2.4 to -6.4 ‰$_{VSMOW}$ and are clearly inconsistent with the modern drip waters. The displacement in oxygen isotope composition with respect to the drip waters and the World Meteoric Line suggests that the post depositional oxygen isotope exchange between the speleothem calcite and fluid inclusion water has occurred. There is no apparent relationship between either oxygen or hydrogen isotope composition and water content.

In contrast to specimen GB40, the inclusion waters from near the base of UEA780527 have compositions that are consistent and lie close to the WML. Moreover, using the inclusion and calcite oxygen isotope compositions, calculated cave palaeo temperatures are 9.7°C and 12°C. These are close to present day cave temperatures and within the range expected for the Holocene. A more complete study has been made of the hydrogen isotope composition of inclusions from this stalagmite. The δD composition is plotted as a function of distance (decreasing age) above the base in Figure 2. The data are in excellent agreement with the expected δD compositions of Holocene precipitation. It is worth noting that the isotope composition of recovered water is independent of the water content of this particular sample. Water contents range from less than 0.01 wt.% to 0.1 wt.%. This suggests that recovery is quantitative and that there is little or no isotopic fractionation.

The results obtained to date are very encouraging and suggest that we can reliably recover the δD, and in favourable circumstances the $\delta^{18}O$ composition of palaeo-precipitation from speleothem fluid inclusions. The results presented in this paper represent the first step in a major programme to characterise palaeoprecipitation isotopic compositions and cave palaeotemperatures in western Europe during the past 250,000 years.

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Chemical Kinetics, Speleothem Growth and Climate

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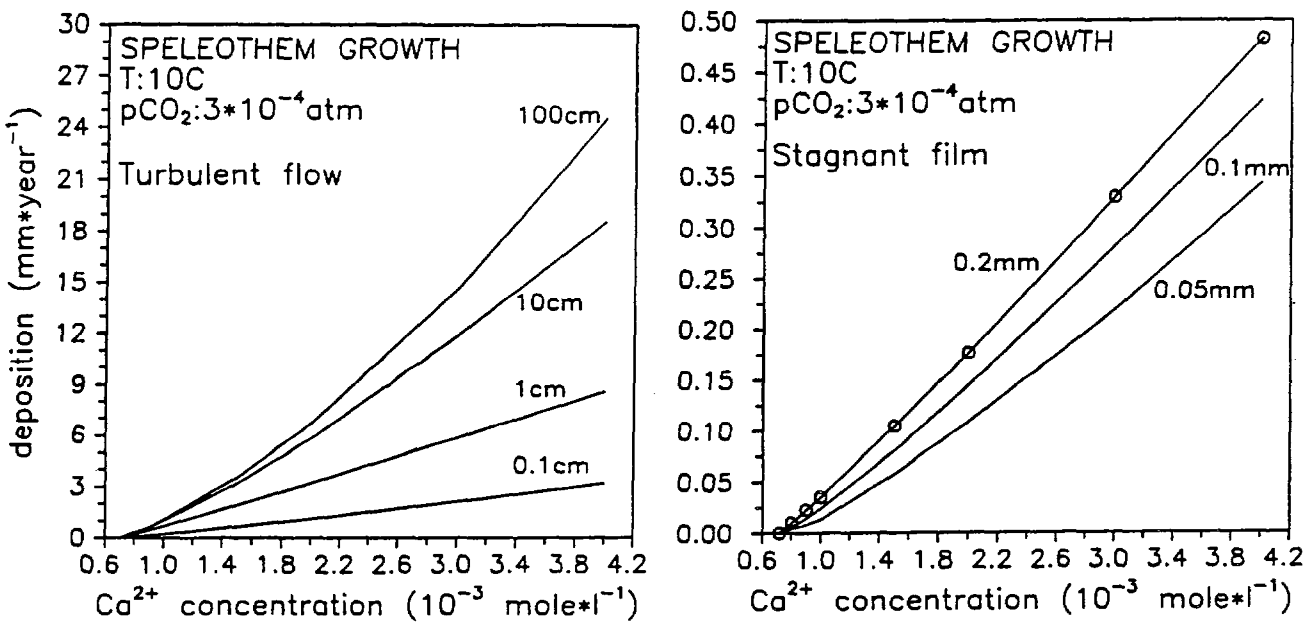
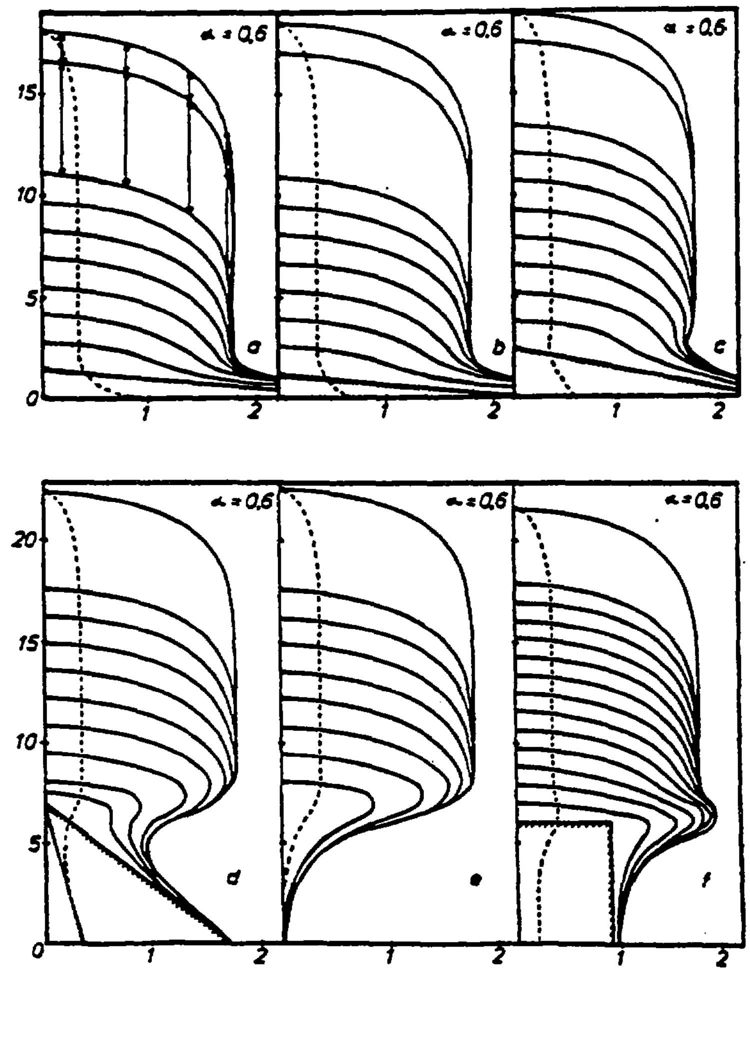
To interpret climatic records contained in speleothems, such as stalagmites or flowstone knowledge on the basic mechanisms of their growth is required. It is of utmost importance to understand which parameters determine the growth rates of speleothems and how these rates can be estimated. On the basis of a transport model by Buhmann and Dreybrodt (1985) (1) and our recent experimental work on calcite precipitation kinetics (2) it is shown that the rates of calcite deposition to speleothem surfaces covered by thin sheets of water do not only depend on the chemical composition of the supersaturated solution but also to a significant extent on the type of the flow of the water sheet. If the water sheet is stagnant or in laminar flow, the rates are much lower than for turbulent flow. Furthermore, owing to the slow reaction $H^+ + HCO_3^- \rightarrow CO_2 + H_2O$ by which CO_2 is released during calcite precipitation, the thickness of the water sheet is also of major importance in determining growth rates. Finally the growth rate of stalagmites fed by dripping water depends critically on the time interval between two drops, whereas stalagmites fed from a continuous source with the same chemical composition will exhibit quite different behaviour not only in growth rate but also in morphology.

Fig. 1 (right panel) illustrates maximal growth rates in mm/year for deposition from water sheets stagnant or in laminar flow with various thickness δ as a function of the Ca-concentration in the water. Temperature is 10°C and the partial pressure of carbon dioxide in the cave air is $3 \cdot 10^{-4}$ atm. These curves have been obtained from a modified transport model, taking into account that precipitation of calcite is inhibited for solutions with $\Omega = IAP / K_c < 2$. Therefore precipitation stops at an apparent equilibrium with 0.72 mmole/ℓ instead of the true chemical equilibrium at 0.63 mmole/ℓ (2). The left panel depicts the rates for water sheets in turbulent flow. Note that the scale is changed by more than one order of magnitude, showing the dramatic increase which can occur at turbulent flow. Recent experiments from our laboratory which support these data are presented.

One further has to consider that the rates are also dependent on temperature, and within the range of cave temperatures from 5°C to 25°C increase by more than a factor of 2. Variations of similar magnitude can be caused by changes of the partial pressure of carbon dioxide in the cave air. The rates decrease with increasing pressure, and deposition may even be inhibited completely if the supersaturated solutions have calcium concentrations below that of apparent equilibrium. As an example this apparent equilibrium is at 1.4 mmole/ℓ for 10°C and a carbon dioxide pressure of 10^{-3} atm. in the cave air. Taken this all together, we conclude that growth rates are determined by many parameters in a very conflicting way. Thus an increase of growth rates caused by a climatically induced increase in soil carbon dioxide might well be counter -balanced by decreasing temperatures which reduce the growth rates.



↑ Fig. 1: Growth rates of speleothems as a function of the calcium concentration for various thicknesses δ of the waterfilm in laminar (right panel) and turbulent (left panel) motion. The circles denote the rates for $\delta = 0.04$ cm, showing that for $\delta \geq 0.02$ cm ≥ 0.05 cm the rates become independent on film thickness δ.



← Fig. 2: Growth of an ideal stalagmite on different initial surfaces: a) flat plane; b) c) and d) inclined planes with increasing inclination, e) growth at a cave wall; f) growth on the edge of a rock. Note that the final equilibrium shapes are all identical

Not only the growth rates of speleothems but also their shapes depend on variables determined by climate. We present computer simulations for the shapes of stalagmites from the beginning of their growth until they have obtained their final stable equilibrium form (3). This shape follows from two simple principles: a) the growth is always perpendicular to the present surface, and b) the growth rates decrease with increasing distance x from the axis of the stalagmite. Fig. 2 shows the growth history of stalagmites which differ in their growth conditions only by differing initial surfaces upon which they started to grow. The lower curves represent the shapes of the stalagmite for time intervals ΔT in arbitrary units. The upper curves show the stable equilibrium shape, which is independent of the initial surface. Note that the diameter scale is magnified by a factor of 5. The real shape is given by the dotted curves. In all these calculations it was assumed that the growth rate perpendicular to the present surface is given by $f(x) = f(0)\exp(-\ell(x)/\lambda)$, where $\ell(x)$ is the length on the surface of the stalagmite from the drip point at $x = 0$ to x. It turns out that in this case the diameter of the stalagmite is $D = 2 \cdot \lambda$.
The diameter of a stalagmite growing under constant conditions is furthermore given by

$$D^2 = 4V / \cdot(\delta \cdot \pi[1 - \exp(-\alpha T / \delta)]) \tag{1}$$

where V is the volume of the feeding drop, T the time interval (in years) between two drops, δ is the depth (in cm) of the water sheet covering the speleothem, and α is the slope of the deposition rate curves, represented by Fig. 1. Note that the diameter does not depend on the Ca-concentration of the supersaturated solution. On the basis of the arguments above we will present simulations, which show how climatic variations can lead to various shapes. Decreasing water supply leads to conical shaped stalagmites, which often are encountered in caves. Increasing water supply gives club shaped stalagmites, whereas periodic changes in feed rates lead to periodic changes in the diameter. Thus studies of the stratigraphy of stalagmites might give supplementary information.
The growth rate of a regular stalagmite is shown to be

$$W = 1.17 \cdot 10^6 \cdot (c_{eq} - c)(1 - \exp(-\alpha T / \delta)) \cdot \delta / T \quad \text{[cm/year]} \tag{2}$$

where c is the calcium concentration of the feeding water and c_{eq} the apparent equilibrium concentration in mole/ℓ. This is valid for D>3.5 cm, the minimum diameter of a stalagmite. In combination with eqn. 1 we therefore can correlate growth rate and diameter, which can be a useful information when selecting samples in a cave.

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Low latitude speleothems and palaeoclimatic reconstruction

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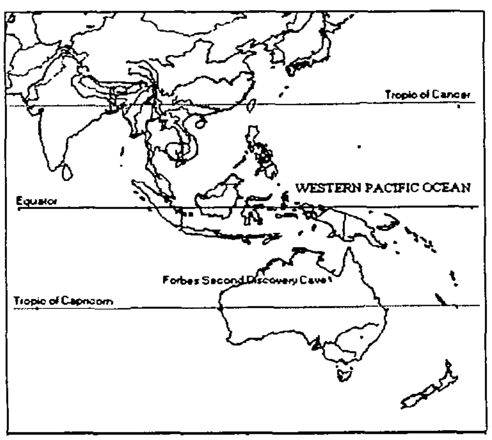
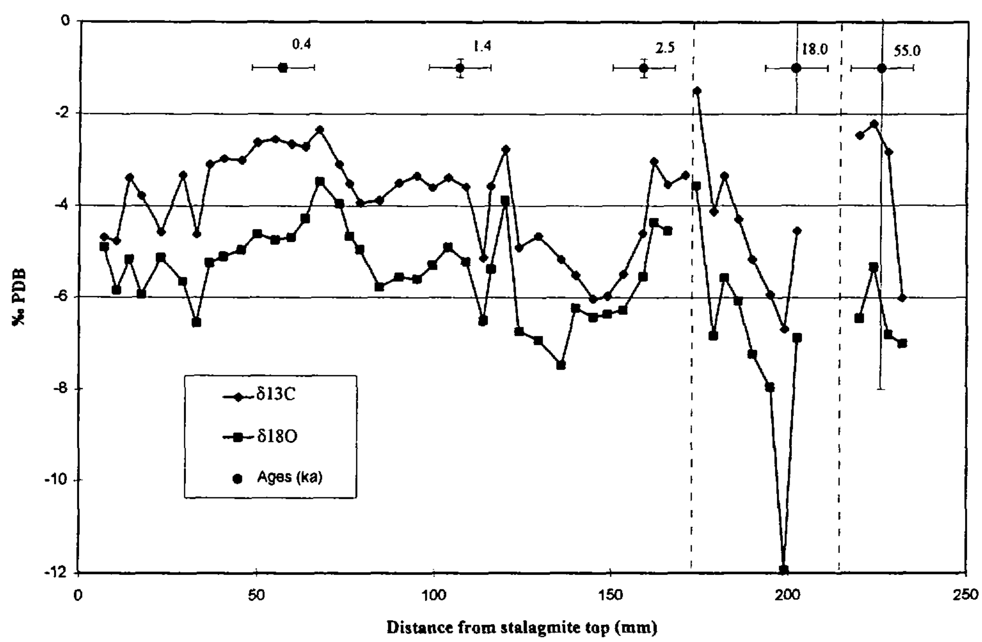
Environmental changes (such as the growth of ice sheets and the cooling of the oceans) cause the $\delta^{18}O$ content of precipitation to change over time. If this precipitation becomes supersaturated with $CaCO_3$ on the Earth's surface, and secondary $CaCO_3$ is deposited, then $\delta^{18}O$ in the secondary $CaCO_3$ may be precipitated in equilibrium with isotopes in the rainfall at the *temperature* of deposition. Hence records of the $\delta^{18}O$ content of continental carbonates may vary with temperature and the isotopic composition of rainfall. In coastal areas or on islands, especially in temperate areas, the isotopic content of precipitation is simply affected by changes in the isotopic content of the ocean water and the difference between the air temperature at the source of rainfall and that at the site of precipitation. $\delta^{18}O$ in 'coastal' carbonates may therefore be used to calculate absolute values of temperature change. In tropical carbonates, however, the effect that temperature has on $\delta^{18}O$ is minimal compared to the effect of a complexity of other factors, including air-mass stability, circulation patterns and the character of rainfall events (Grootes 1993, 39). Thus, the isotopic content of low latitude speleothems may respond to environmental change in a different fashion to that of temperate speleothems. There are three scenarios which might be expected in tropical stalagmites. First, the factors affecting $\delta^{18}O$ may cancel each other out causing no change in $\delta^{18}O$ with time (Talma and Vogel's (1992) results may be an example of this). Secondly, temperature may dominate the $\delta^{18}O$ signal if temperature has changed sufficiently in the past. Thirdly, other factors, particularly the amount effect, may control the $\delta^{18}O$ signal (see Burns and Matter 1995). A 230 mm tall stalagmite sampled from Forbes Second Discovery Cave (FSDC) in tropical northwest Queensland, Australia, provided the opportunity to consider these issues. The stalagmite was sectioned into two vertical slices, and individual growth laminae were sampled at close intervals for stable isotope analysis.



Before any consideration of the climatic signal preserved in tropical speleothems can be made, however, it must be shown that the isotopes in the calcite were deposited in equilibrium with the isotopes in the rainfall (and in the resultant percolation waters). The main cause of non-equilibrium deposition in carbonates is kinetic fractionation. The clearest indication that this has happened is normally thought to be the covariation of trends in $\delta^{13}C$ and $\delta^{18}O$. Any environmental signal in the isotopes in the rainfall is lost, and the two isotopes simply vary as a function of the fractionation process. For example, one consequence of kinetic fractionation is that within a single lamina, both isotopes will become heavier away from the centre of the band where the film of supersaturated waters was thickest. This is because as the water becomes thinner on the sides of the stalagmite $H_2{}^{16}O$ will be preferentially removed by evaporation. In turn, this evaporation causes CO_2 to be quickly removed from solution, depleting the waters of ^{12}C. The lighter isotopes (and the molecules they form) are more 'reactive' because they have weaker bonds than heavier isotopes.

Hendy and Wilson (1968) proposed that the pattern of $\delta^{13}C$ and $\delta^{18}O$ within single bands and along the growth axis of speleothems should be investigated to test whether or not kinetic fractionation has occurred. Parameters for the first of these tests have since been developed. Within single laminae, a range of $\delta^{18}O$ values >0.8‰ (Lauritzen 1995, and Fischer unpublished data compilation), together with a progressive enrichment of $\delta^{13}C$ that is approximately twice the enrichment of $\delta^{18}O$, is interpreted as diagnostic of kinetic fractionation. Preliminary results from the analysis of two bands of the FSDC stalagmite show that there is neither an increase nor a progressive enrichment in $\delta^{18}O$ and $\delta^{13}C$ with distance from the central axis, and the variation in $\delta^{18}O$ within individual laminae is <0.6‰.



The FSDC stalagmite shows a strong correlation between $\delta^{13}C$ and $\delta^{18}O$ along the growth axis (above), and therefore fails Hendy and Wilson's (1968) second test for equilibrium fractionation. Their second test, however, may not be appropriate for low latitude stalagmites because these isotopes can covary as a result of climatic changes in monsoonal precipitation (Geyh 1994, Burns and Matter 1995, Fontes *et al.* 1996). This relationship may arise because soil $\delta^{13}C$ is affected by plant abundance (Burns and Matter 1995) and type (Mazor 1991), which are influenced by moisture availability. In turn, in the tropics, the amount of precipitation strongly influences the $\delta^{18}O$ content of rainfall (Dansgaard 1964, Rozanski *et al.* 1993).

Hence, other evidence for assessing whether equilibrium deposition has occurred must be considered if low latitude speleothems are to be used as palaeoclimatic indicators. First, where relative humidity is close to 100%, kinetic fractionation should be limited. Although tropical caves can be large and open, they may also contain passages of extreme heat and humidity. In this context, it is notable that a stalagmite from Forbes Inferno Cave in northwest Queensland, a cave which experiences close to 100% relative humidity, displays a clear correlation between $\delta^{18}O$ and $\delta^{13}C$. This strongly suggests that the relationship is not the result of kinetic fractionation.

Secondly, if tropical speleothems have been affected by kinetic fractionation they should not display $\delta^{18}O$ and $\delta^{13}C$ trends similar to other isotope records known to be climatically controlled. Geyh's (1994) results maybe interpreted in this light. Geyh (1994) showed that, despite a strong isotopic correlation along the growth axes of several speleothems from Israel, the $\delta^{18}O$ in these speleothems matched coeval $\delta^{18}O$ records in marine carbonates and mollusc shells from the Mediterranean Sea Basin, while $\delta^{13}C$ showed similar fluctuations to $\delta^{13}C$ from wood. In these isotope records, $\delta^{18}O$ appeared to become lighter with increasing rainfall, perhaps as a result of the precipitation causing an increase in freshwater and humidity, about 25 ka, 20 ka and 10 ka ago. This compares with isotope records from alluvial carbonates in Oman, where $\delta^{18}O$ and $\delta^{13}C$ were strongly correlated, and low $\delta^{18}O$ values corresponded to sedimentary evidence for higher and more prolonged channel flows (Maizels and McBean 1990 in Burns and Matter 1995, 176).

Similarly, the FSDC stalagmite displays $\delta^{18}O$ lows (< -6.0‰ PDB) about 3 ka and 18 ka years ago which appear to correspond with $\delta^{18}O$ depressions in central Australian (latitude 23-25°S) groundwater in the late Holocene and late Pleistocene. (Note that present day rainfall in central Australia has a $\delta^{18}O$ value of -5.5‰ SMOW). The depression in groundwater $\delta^{18}O$ values was probably the result of recharging rainfall ($\delta^{18}O$ < -7.0‰ SMOW) higher than at present, because in the modern environment of northern Australia, lower values correspond to higher monthly rainfall (Calf *et al.* 1991). The $\delta^{13}C$ values from the FSDC stalagmite (-6.0 to -1.5‰ PDB) are to some extent heavier than those of central Australian groundwaters (< -6.0‰ PDB); but despite this, are not so different from other speleothems shown to have been deposited in isotopic equilibrium with an input of $\delta^{13}C$ from C4 vegetation, but under open system conditions of bedrock dissolution (that is, the percolation waters are in contact with soil CO_2 during the dissolution of the bedrock). For example, Holmgren *et al.* (1994, 177) found $\delta^{13}C$ values of -6.5 to +0.1‰ (PDB) in the Lobatse II stalagmite from Botswana.

The isotopic record from FSDC, therefore, supports the hypothesis that other palaeoclimatic controls, apart from temperature, may dominate the $\delta^{18}O$ signal in tropical speleothems. The established tests of isotopic equilibrium deposition in speleothems may not apply, particularly if the dominant control is the amount of precipitation. Tropical speleothems may provide valuable (but different) records of climatic history.

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Dating Cave Deposits.

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Caves may function as giant sediment traps, accumulating samples of the clastic, chemical and organic debris that are mobile in the natural environment about them. They are amongst the most richly varied deposits that form in continental environments and tend to be preserved for greater spans of time than most others do. Accurate dating will solve many problems in archeology, paleoclimatology, ecology, and geomorphology. This review presents its author's perspective on the current situation.

Cave deposits are divided broadly into **clastic, organic** and **precipitate** categories. They may be dated by **absolute** methods such as radiometry, by **relative** methods (deposit A is older/younger than deposit B) or by **marker** methods (deposit A is older/younger than some independent known event such as the Brunhes-Matuyama magnetic reversal at ~780 ka BP).

Studies of **clastic deposits** have focussed on allochthonous materials and the classical methods (chiefly, relative methods) of stratigraphy. Where dated by absolute methods, these have usually been applied to organic materials or calcite precipitates found within a given clastic sequence. There is good potential for ESR or TL dating of fluviatile or eolian sands carried into caves but this has seen little application as yet. The principal success with clastic deposits **per se** has been achieved by matching their magnetic declination and inclination signals to the major excursions and reversals of the Earth's magnetic field that have been determined (chiefly) by dating lavas. The work of the late V.A. Schmidt on fluviatile clays of the Mammoth Cave system, Kentucky, remains the outstanding example: applying "Occham's Razor", he attributed the earliest deposits to the Reunion magnetic excursion of about 2.13 ma BP.

Organic deposits include allochthonous floral detritus and decay products, plus the remains of exclusively cave-dwelling (troglobitic), cave-nesting (trogloxenic) and trapped animals. Two hundred years ago, recognition of warmer/colder sequences of faunal remains (including extinct species) in north European caves provided early evidence of the Quaternary ice ages. Much of prehistory has been reconstructed by applying stratigraphic and biostratigraphic methods to hominid occupation sites. There has been considerable success with the absolute methods applied to bone, teeth and wood, chiefly the ^{14}C, ^{230}Th:^{234}U, ESR and TL techniques: I am not aware of AAR being applied.

The **palynology** of cave deposits is generally disappointing. In clastic sequences pollen grains are often destroyed by oxidation. In calcite speleothems they tend to be in very low abundance, requiring dissolution of large samples in order to obtain statistically significant counts: nevertheless, the Belgian pioneer group of B. Bastin has made significant discoveries in Holocene and some older specimens. In both clastic and calcite sediments there are problems of re-working of older pollen deposits to be addressed; presence of a few exotic grains must be interpreted with caution.

A new area of study that will receive substantial attention at this Symposium is that of **organic acids** incorporated into calcite precipitates. S-E. Lauritzen and colleagues have pioneered investigations of **amino acid racemization** within them to begin to build an "aminozone" chronology for arctic regions.

Calcite, aragonite and gypsum are the principal precipitates of interest. **Calcite** is the most abundant and the main focus of radiometric absolute dating applications in caves today. The **^{14}C method** continues to be applied, despite the "dead carbon" problem (published proportions of dead carbon range from 0.1 to 0.65): in future, its use may be restricted to dating intervals in very young deposits to confirm that they contain annual growth bands. The **^{230}Th:^{234}U method** using the thermal ionisation mass spectrometric technique (TIMS) is now the principal method; in principle it may yield ages back to ~500 ka BP with ±1% error. Where the ratio, ^{234}U ^{238}U, at the time of deposition can be shown by ^{230}Th:^{234}U results to be constant in a cave, age estimates can be extended back to ~1.25 ma BP. This gives a convenient time overlap across the Brunhes-Matuyama magnetic reversal and the Jaramillo magnetic excursion (0.90 - 0.97 ma BP) which can be detected by **SQUID magnetometry** if present in calcites: this permits a composite chronology to be constructed.

The U-Pb isochron method will permit dating back to the origin of the Earth. Its applications to speleothems are being investigated. With current technology, large variations in initial U concentration are desirable in a sample and are rarely found. In addition, loss of ^{222}Rn will be difficult to evaluate in ancient deposits. Nevertheless, this is a most interesting new development.

There have been many estimates of ages of materials by measuring their accumulated radiation with the **TL, ESR or optical luminescence techniques**. In calcites good correspondence with U series ages is obtained back to ~100 ka BP, and investigation of older deposits continues with mixed results. Error margins are likely to be large.

It is now recognised that many speleothems display **annual banding** that can be detected by light microscopy, laser confocal microscopy or by exciting the luminescence. This offers the potential for a tree ring scale of paleoenvironmental reconstructions.

In conclusion, absolute dating of cave deposits has advanced significantly in the last 20 years. Two major findings I would emphasise are (1) **deposits/events are often much older than was supposed** previously: Occham's Razor (assuming most economical time sequence for a sedimentary section) is a dangerous weapon, to be handled with care. (2) **Changes in accumulation rates and hiatuses in deposition are common in all categories of cave deposits**. They may be difficult to detect. In calcite speleothems a depositional hiatus of ~100,000 years may be marked by only 0.5 mm bleaching, for example. Caves are important preservation sites but in the Quaternary very few offer the environmental stability that is found in the deep sea cores.

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The Last Two Interglacials in the Mid-Continent from Vadose and Phreatic Speleothem Records, Jewel Cave and Wind Cave, South Dakota, U.S..

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Jewel Cave and Wind Cave are in the Black Hills, S.D., at the centre of the continent. In Wind Cave sample WC MAJ is a thermal water calcite precipitate similar to sample DH11 at Devil's Hole, Nevada, but only 2.4 cm thick. Eight TIMS U series dates show that it grew from 330 to 160 ka BP, when the water table fell below its position. $\delta^{18}O$ and ^{13}C profiles display two distinct halves: (i) 160-225 ka, where O and C are negatively correlated (as at Devil's Hole) and there is 3‰ variation in ^{18}O. (ii) between 225 and 325 ka BP both isotope signals are heavier and uniform. This "plateau" of ~100 ka duration may signify homogenising geothermal effects.

In Jewel Cave sample JC11 is a vadose calcite flowstone 12 cm thick, displaying strong color banding. From twelve TIMS U series dates, it grew at intervals between 92±1 and 470±50 ka BP. Eight 10-point growth layer analyses of O and C ratios were made to check for isotope kinetic fractionation effects. Four different profiles have been measured between 92 and 240 ka, with a highest resolution of 300-500 years. Marine isotope Termination II is signalled by ^{18}O increase of 3.0‰ between 131 and 129 ka. Isotope stage 5e lasted from 129 to 119 ka. At our scale of resolution, it contains four or more excursions of 0.5‰. Growth in the previous interglacial (equivalent to marine isotope Stage 7) displays abrupt shifts of up to 4‰ in the ^{18}O signal; peaks occur at ~210, ~192 and ~178 ka BP.

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TEM and SEM investigation of speleothem carbonates: another key to the interpretation of environmental parameters.

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Electron microscopy investigation of speleothem calcite, both in scanning (SEM) and transmission (TEM) modes, allow for the recognition of growth and replacement mechanisms as a function of the precipitating fluid. SEM and TEM observations were carried out on chips and foils taken from slabs of still active, Holocene stalagmites which were removed from the following three caves: (1) Crag Cave, which is located in SW Ireland, near the Atlantic shore, 60 m a.s.l., (2) Clamouse, which is in Southern France (N of Montpellier), 75 m a.s.l. and (3) Grotta d'Ernesto, which is an Alpine cave, located near the Dolomites (N Italy), at 1165 m a.s.l..

Stalagmites from Crag and Ernesto exhibit similar textures. Layers of microcrystalline (equant crystals with diameter ranging from 5 to 30μm) and skeletal calcite (a network of elongated crystals from 10μm up to 200μm long which resemble a scaffold) alternate with more uncommon layers of columnar calcite (single crystals up to 30 mm long and 1 mm wide with elongation perpendicular to the substrate). Microcrystalline and skeletal calcites are arranged in large "extinction domains", i.e. areas with the same unit extinction and elongation perpendicular to the substrate, which possess rugged "interdomain" boundaries as a consequence to their composite nature. TEM observations on microcrystallyne and skeletal calcites revealed the following microstructures:

i) dislocation-ridden crystallites, less than 1/10 of a μm in size, which are slightly mismatched one with respect to the other, but exhibit a preferred orientation in the diffraction pattern. This explains why the crystallites form unit extinction domains. The mechanism by which large speleothem crystals are "manufactured" by the addition of small units with the same orientation inferred by Kendall and Broughton (1978) is demonstrated by transmission electron microscopy;

ii) variable grain sizes, from less than 1/10 of μm to over 3μm. Small grains are dislocation ridden. Larger grains exhibit few dislocations. Few defects for larger grains indicate a different growth rate as a probable consequence to changes in the chemical composition of the fluid at growth sites (see discussion below). Actually, microcrystalline, skeletal and dendritic calcite possess a morphological instability that increases from microcrystalline to dendritic forms. Consequently, slight changes in the chemistry of dripwater causes dissolution and subsequent reprecipitation of "secondary" calcite in pores. The almost defect-free calcites may be indeed these "secondary" cements after dissolution-reprecipitation phenomena;

iii) pervasive microtwinning. Twin planes exhibit a direction almost perpendicular to the elongation of the skeletal individuals. Twinning, therefore, explains the "sawtooth" morphology observed by SEM and, possibly, the elongation of skeletal crystals;

iv) chess-board microstructures and lamellae in microcrystalline calcite, which indicate the skeletal nature of some microcrystalline calcite;

v) pervasive microporosity. Commonly pores exhibit a rhombohedral shape, indicative of "negative crystals" filled by fluid inclusions of submicron size.

The microstructures observed, with the exception of the large crystals characterized by few defects, are indicative of rapid growth in conditions far from equilibrium (cf. Sunagawa, 1984). In the case of twinning, deviation from equilibrium is most probably represented by high supersaturation at growth surfaces. The higher the supersaturation, the higher the probability to form growth twins in calcite.

Skeletal and dendritic crystal fabrics with high dislocation density should be related to a high degree of supersaturation at the surface of the growing crystals and to the presence of impurity components. In general, when the number of molecules hitting the forming nuclei is very high, the solute itself prevents the impurities from blocking growth sites. But when the amount of impurities is large, supersaturation must be enhanced to keep nucleation and growth rate at suitable values.

The observed skeletal and microcrystalline textures in Crag Cave and Ernesto stalagmites may indicate that for most of the Holocene, precipitation was controlled by the interplay of high supersaturation at crystal surfaces and presence of impurities (organic molecules, cations other than Ca^{2+}, clay etc.).

The topmost 2 to 5 mm in both Crag and Ernesto active stalagmites are composed of columnar calcite. SEM observations revealed that crystal termination exhibit flat faces with a few macrosteps. TEM allowed for the recognition of few dislocations and subgrain boundaries that limit crystals larger than 50 µm. The combination of SEM and TEM observations indicates for these crystals a relatively slow growth rate at low supersaturation. Crystal growth occurs (and occurred) by means of spiral mechanism, which is almost self-perpetuating and, as a consequence, may be active even at saturation (i.e. at equilibrium). This type of calcite is less porous and morphologically more stable with respect to microcrystalline and skeletal calcites. Consequently, it is less prone to be affected by dissolution-reprecipitation phenomena. In addition, it should have grown more "in equilibrium" with respect to dendritic and skeletal calcite.

The stalagmite from Clamouse is different. It consists of columnar calcite and subordinate fans of acicular crystals with square ends, which resemble aragonite needles. In the fan-shaped regions, the microstructures observed are as follows: i) dislocation loops, which are commonly aligned along growth fronts (10.4); ii) large number of subgrain boundaries; iii) pervasive porosity.

Diffraction patterns indicate the sole presence of calcite. What appeared to be "aragonite remnants" under optical microscope are in reality calcite crystals and holes. During replacement dislocation loops most probably isolated extra disks of atoms, one unit cell thick, with different composition . In other words, dislocation loops "sequestered" ions so that the region within the loop may have more Sr (or Mg) with respect to the area outside (Reeder pers. comm.). The inability of the crystal to get rid of all the impurities may be indicative of relatively rapid replacement.

In columnar calcite from Clamouse another striking feature is the presence of curved faces and sweeping extinction in some individuals. Similar features have been sometimes related to precipitation from hydrothermal fluids (Kostecka, 1993). TEM observations reveal fringes, stacking faults, coarse modulated patterns and many subgrain boundaries. Electron microprobe analysis indicate the presence of Mg in these calcites. This cation may be responsible for the presence, within the same crystal, of areas characterized by different chemical composition (stacking faults and coarse modulation). Consequently, lattice distortion is probably caused by the accomodation of this foreign ion and the mismatch of adjacent grains accounts for the strong sweeping extinction..All the observed features can be related to growth from dripwater containing Mg derived from dolomite dissolution as a consequence to long residence time, and are not indicative of high temperatures.

In conclusion, TEM and SEM observations of Holocene stalagmites from different caves give clues to the understanding of growth mechanisms and rates and reveal possible different chemical compositions within the same crystals, which, in turn, can be related to the chemical properties of the precipitating fluid. These facts may have implications for geochemical studies of speleothem calcites.

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PALEOCLIMATIC RECORD FROM THE MEDITERRANEAN-DESERT BORDER KARST, ISRAEL

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The Jerusalem region, being adjacent to the present arid zone, is very sensitive to environmental change.

Stalagmite AF12 from Jerusalem West Cave was analyzed for $\delta^{18}O$ and $\delta^{13}C$. Being truncated by a road-cut, the cave has no natural opening, favoring conditions for equilibrium deposition in the past. The cave is located on a slope where the possible catchment for drip water includes the nearby karst surface as well as possible allogenic input from the topographically higher outcrops of a non-karstic formation. Uranium series TIMS dates of the stalagmite indicate growing during most of the last glacial cycle.

The largest amplitude of climatic change occurred between isotopic stages 6-5e. Smaller amplitude changes occurred during the last 20,000 y. Apart from temperature and meteoric water changes, indicated by $\delta^{18}O$, large shifts seems to have taken place in local vegetation, indicated by the $\delta^{13}C$ curve. A good correlation with the oceanic oxygen isotopic curve was found.

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Growth rate, grey level and luminescence of stalagmite laminae

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Description and Terminology

Two main kinds of calcite growth laminae fabrics have been defined (Genty, 1992; Genty et al., in press): 1) white porous laminae (WPL) which are white and porous when observed under reflective light, and sometimes show a brown layer of organic matter under transmissive light; 2) dark compact laminae (DCL), which are much more dense and absorb incident light which makes them darker. WP and DC calcite fabrics are different from the speleothem color (which is, generally, more or less brown); WPL and DCL can be found in both dark brownish or colourless stalagmites.

Background

Many speleothems are composed of millimetre scale growth laminae; these are particularly visible on polished vertical sections of stalagmites. Recently it has been demonstrated that, in several cases, luminescent and visible laminae are annually deposited: an alternation of WPL and DCL is deposited in one year (Shopov and Dermendjiev, 1990; Genty, 1992, 1993; Baker et al, 1993;). The physical and chemical study of the growth laminae is just at its beginning and is of great interest for paleoclimatic reconstruction , principally because of its high resolution chronology. A correlation has been observed between growth laminae thickness of a tunnel stalagmite and water excess, which demonstrates that, besides the calcium concentration (see Baker et al., this volume), the drip rate and/or duration of dripping is an important factor in growth rate (Genty and Quinif, 1996). Under UV light some laminae luminesce due to organic matter trapped in the calcite lattice; this organic matter comes from microbial breakdown of soil organic matter. Comparison of the luminescent and visible laminae in one stalagmite from the Godarville tunnel (Belgium) has shown that the white porous laminae (WPL) are the most luminescent (Genty et al., in press). Since high organic matter concentrations have has been observed in winter drip waters in a British cave (Baker et al, unpub. data) and because a green chalk mark put on a stalagmite of the Godarville tunnel in Autumn 1992 was found two years later under a WPL, it is highly probable that at least in this tunnel WPL develop in Winter. Other comparisons on Holocene and historical stalagmites of the Villars cave (Dordogne, France) have confirmed the link between luminescence and WPL. Thus, it seems that organic matter is the primary cause of both white porous calcite and luminescence. We show here that grey level and luminescence are strongly linked to the vertical growth rates of stalagmites, which provides further insight into the paleoclimatic significance of calcite fabrics and/or growth rate variations

Methods

The intensity of the visible light reflected on WPL and DCL (the grey level) is measured by digital image processing. A video camera, linked to a video computer board, digitalizes an image of a polished section (512x512 pixels); then, several numerical filters enhance the image and, finally, laminae thickness and grey level are measured by a specific software. Luminescence intensity is obtained by a laser UV excitation at 325nm; a photomultiplier selects a 480nm wavelength. Growth rates have been calculated with annual laminae thickness, which gives a high precision value, and by AMS radiocarbon ages. The latter have been made by microdrilling 10 and 30 mg of carbonate across very few growth laminae (between 1 and 7 annual laminae). When possible, comparison between laminae counting and ^{14}C duration have been made and have confirmed the annuality of the growth laminae studied. Grey level and

Figure 1 - Grey levels and growth rates of a stalagmite (PNst4, Père Noël cave, Belgium). Grey levels, measured by digital image processing, are correlated with the vertical growth rates calculated with laminae thicknesses.

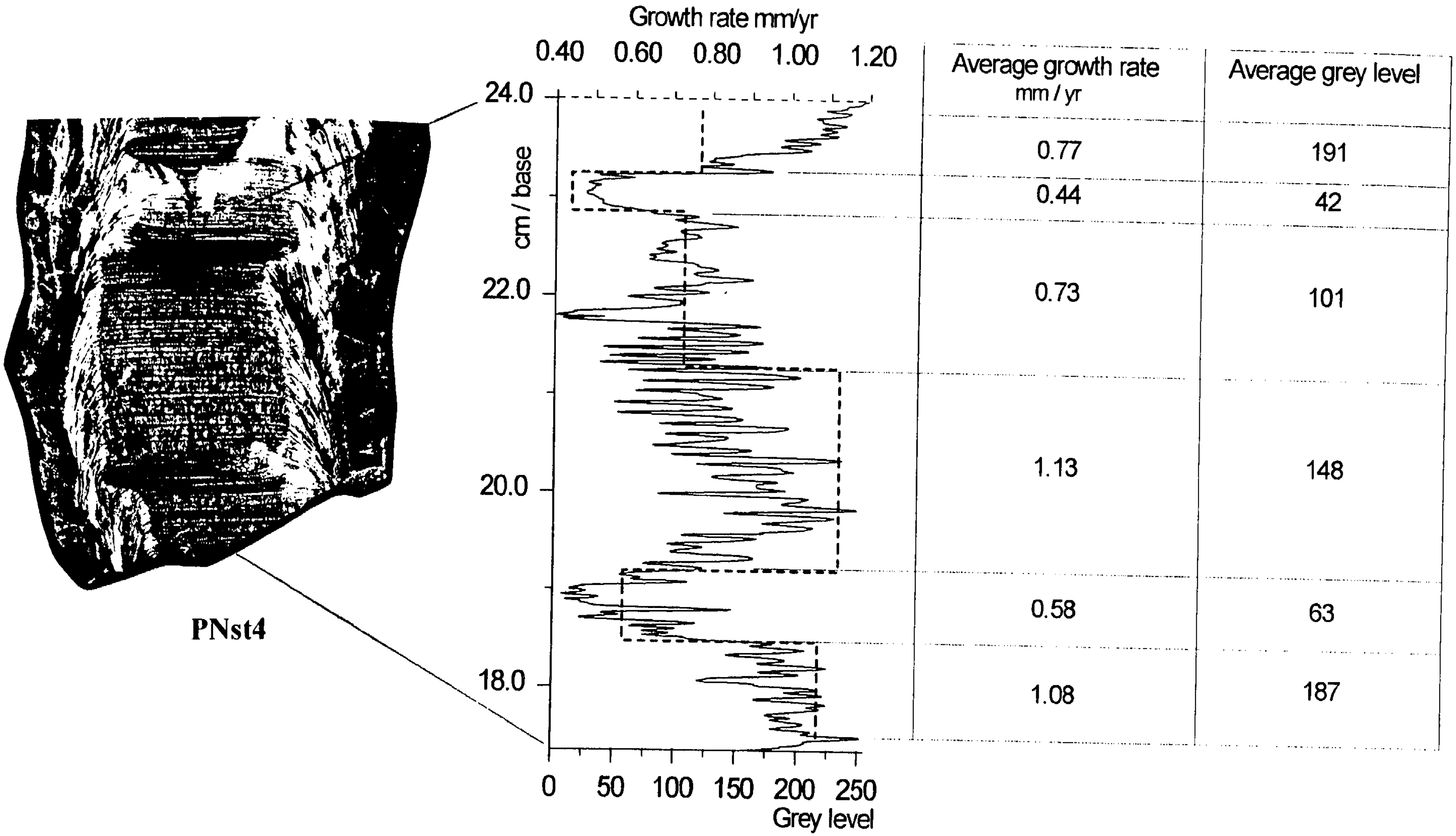

TABLE 1 - Growth rates from laminae measurements and ^{14}C dating and grey level calculated by digital image processing.

Stalagmite name and cm/base	Average growth rate mm/yr	Average grey level	Stalagmite name and cm/base	Average growth rate mm/yr	Average grey level
PNst4 above D19	1.13	148	**PNst4 above D23**	0.77	191
PNst4 D19	0.58	63	**PNst4 D23**	0.44	42
PNst4 below D19	1.08	187	**PNst4 below D23**	0.73	101
PNst4 above D58	0.50	227	**PNst4 above D75**	0.83	107
PNst4 D58	0.24	70	**PNst4 D75**	0.35	43
PNst4 below D58	0.77	203	**PNst4 below D75**	0.89	187
PN-stm1 above D42.5	0.65	204	**PN-stm1 above D47**	0.56	146
PN-stm1 D42.5	0.45	59	**PN-stm1 D47**	0.31	38
PN-stm1 below D42.5	0.54	136	**PN-stm1 under D47**	0.53	208
Vil-stm1 1230AD/1600AD	0.76	153	**Vil-stm1 30AD/740AD**	0.36	124
Vil-stm1 740AD/1230AD	0.26	113	**Vil-stm1 150BC/30AD**	0.75	166

luminescent profiles have been made on vertical polished sections of stalagmites. Areas where visible changes in the calcite laminae fabrics are observed were preferentially analysed; i.e. discontinuities or hiatuses composed of a few millimeters thick band of dark compact calcite (which is in fact composed of several very thin DCL).

Results

Seven discontinuities from two tall columnar stalagmites (Père Noël cave, Belgium) have been studied. At each discontinuity, grey level and luminescence decrease as the WPL disappear progressively. When grey level and luminescence decrease towards the discontinuity, it appears that the vertical growth rate, measured by laminae counting, decreases by a factor of two or three: i.e. below the D19 discontinuity of PNst4, the vertical growth rate is 1.08mm/yr, at the discontinuity, it is 0.58mm/yr and just above, growth rate increases again to 1.13mm/yr (Fig 1). For all the discontinuities studied, the average vertical growth rate variation is linearly correlated to the grey level change; this is true for average measured values but also for each growth laminae measurements ($r=0.73$, $n=33$, for the D75 discontinuity of PNst4) (Fig.2). A similar situation occurs between the grey level and the ^{14}C growth rate of a stalagmite from a SW France cave (Vil-stm1, Grotte de Villars). On this sample, no hiatus are observable, which suggests that average vertical growth rates calculated with ^{14}C ages are true and similar to growth rates calculated with laminae (comparisons of corrected - dead carbon - callibrated 14C ages and laminae counting agree well). The base of this stalagmite, between 150BC and 30AD, is composed of white porous calcite (thick WPL) and the growth rate is very high: 0.75mm/yr; then, abruptly, in a few years around 30AD, calcite fabrics becomes dark and compact, with very few visible laminae, and the growth rate decreases : 0.36mm/yr between 30AD and 740AD, 0.26mm/yr between 740AD and 1230AD. Then, WPL appear progressively, the grey level increases and the growth rate reaches 0.76mm/yr between 1230AD and 1600AD.

Interpretation

The two main calcite fabrics found in stalagmites are linked to vertical growth rate: white and porous calcite, composed of thick more or less clear WPL, is linked to high growth rate; while dark compact calcite, mainly composed of DCL, is linked to low growth rate. Because high grey level corresponds to a high luminescence, and because luminescence is principally due to organic matter, it appears that high growth rates occurs when calcite organic matter content is higher. Several hypotheses can be suggested to explain this relationship: 1) high growth rate is due to a higher calcium concentration because of a more intense plant activity in the soil; the latter produces more organic matter, which explains why high growth rate sections have a higher luminescence and grey level intensity; 2) high growth rate is due to a higher flow rate, which brings into the cave all the organic matter content of the soil; however, this could explain short variations of calcite fabrics, but unlikely in those whose duration is several centuries, as observed in Vil-stm1 stalagmite; 3) high growth rate is due to the organic matter interaction with calcite during precipitation: it may disrupt crystals and lead to higher growth rate (?).

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SIGNIFICANCE OF STRONTIUM VARIATIONS IN A TASMANIAN SPELEOTHEM

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ABSTRACT

Secular variations in the content of strontium in a Tasmanian speleothemexhibit a striking bimodal distribution pattern. Strontium isotope analyses are used to demonstratederivation from two distinct sources, the first a persistent one from the overlying limestone,the second an intermittent one believed to be derived from terrestrial dust. If an aeolian origin ofsome of the strontium contained in speleothems at other inland cave sites can be confirmed, theyshould provide sensitive records of how terrestrial dust flux has varied during the Quaternary. Innear-coastal sites significant amounts of strontium may be derived from seasalt and in thoseareas temporal variation of the element in speleothems may reflect changing distance from the coastdue to changes in sealevel.

KEYWORDS: speleothem, strontium, strontium isotope analysis, uranium seriesdating, Quaternary studies, Tasmania.

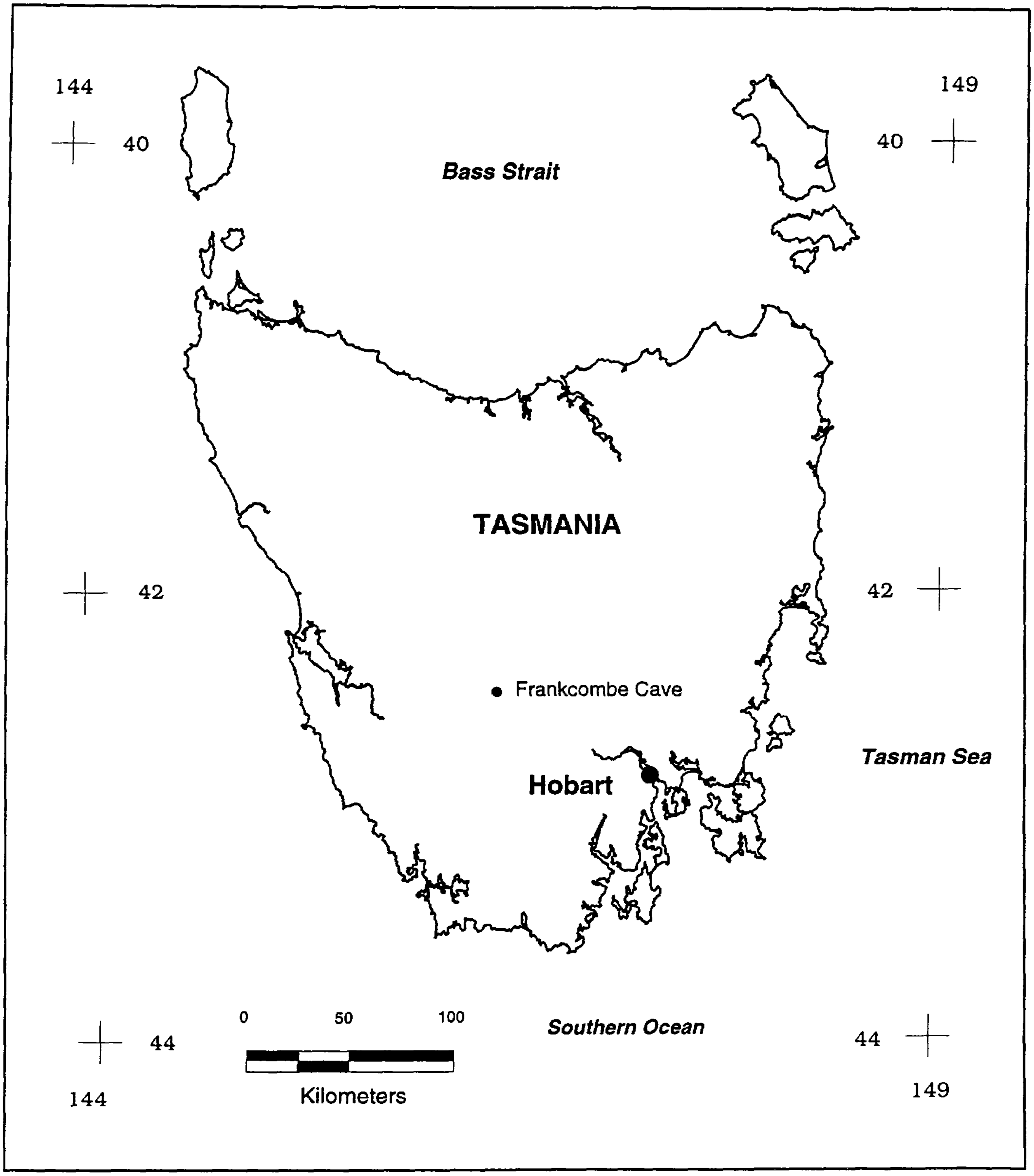

Figure 1 - Locality map showing location of cave site within Tasmania.

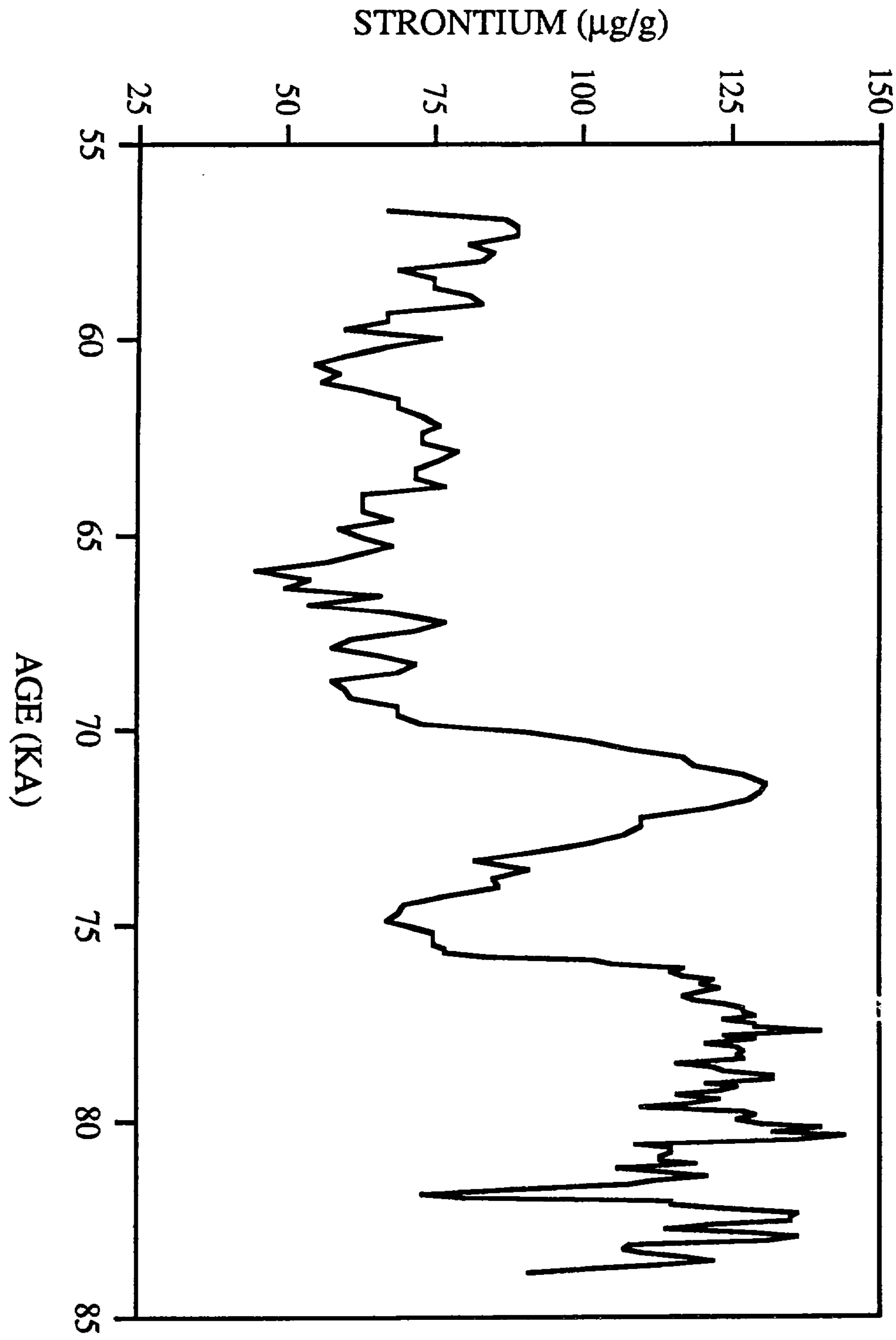

Figure 2 - Histogram showing bimodal distribution of strontiumconcentrations in 170 samples each representing a 5 mm slice of the core of the FT stalagmite.

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Fossil Bat Fauna (*Mammalia: Chiroptera*) from Pliocene/Pleistocene Localities in Southern Poland.

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The Kraków - Wieluń Upland is known from accumulation of fossil deposits. The majority part of fossil-bearing localities were found south from Częstochowa, near Olsztyn (Figure 1).

The quarry in Przymiłowice is situated in the Upper Jurassic (Oxfordian) limestone hill. The oldest fauna A (Upper Villanyian; Late Pliocene) was in unit 4 of the Przymilowice 3 locality. It consists of *Plecotus abeli, Myotis helleri* and *Rhinolophus cf.macrorhinus.* Fauna B (Lower Biharian, Early Pleistocene) was found in unit 5 of the localities 1, 2 and 3 and consists *Myotis steiningeri, Myotis helleri and Rhinolophus sp.* The biostratigraphic position of bat assemblages (fauna C) discovered in unit 6 in localities 4, 5 and 6 is difficult to determine because of lack of index species. Thermophilum bat fauna (*Myotis emarginatus*, *Myotis bechsteini* and *Rhinolophus ferrumequinum*) suggests an interglacial character of the fauna. Fauna D of unit 9 in the 9th locality consists Holocene species which are the present-day inhabitants.

Locality Kielniki 1 lies within Kielniki quarry. Age of fauna is a Upper Biharian, Early Pleistocene. Bat fauna consists *Myotis cf.steiningeri* and *Rhinolophus cf.macrorhinus.*

Fauna of bats from Kielniki 3B is dating on Upper Villanian, Late Pliocene (Biozone MN 17) and include following species: *Myotis exilis*, *Myotis cf.bechsteini*, *Myotis steiningeri.*

The bat fauna described here consists new species for Poland, *Myotis steiningeri*, which is common in Late Pliocene/Early Pleistocene fauna. This species is similar to *Myotis bechsteini* which was reported from many Late Pliocene and Early Pleistocene localities.

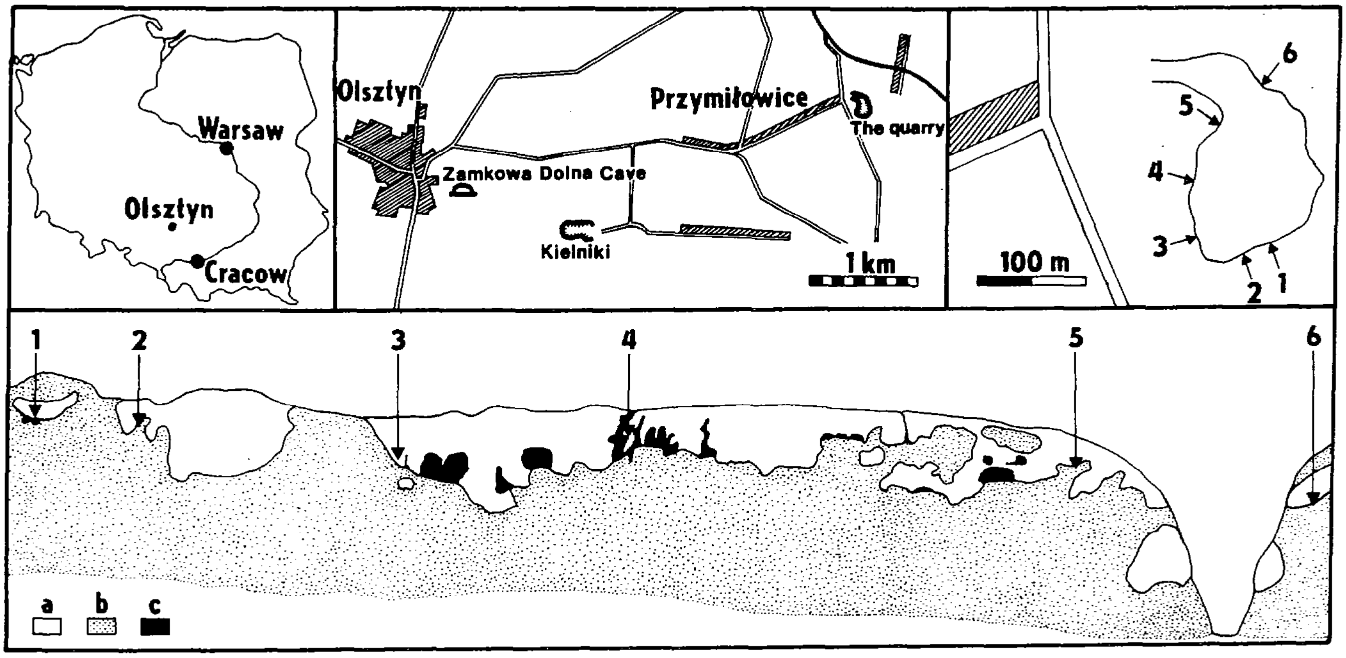

Figure 1:

Location of thePrzymilowice and Kielniki 1, 3B. The lower part of figure shows faunas assemblages found in Przymilowice quarry.

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Microfacies types of calcite speleothem: hydrodynamical and chemical controls of their origin

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Carbonate speleothems are very common freshwater authigenic sediments formed in karst areas. Owing to specific subterrestrial sedimentary environment the speleothems commonly contain a number of paleoenvironmental records which are impoverished or even completely lost in the surficial deposits (e.g. fluvial, eolian or lacustrine).The so far done studies concentrated mostly on descriptive analyses of the speleothem growth forms, morphology, mineralogy or crystal habit. On the other hand, cave calcite has been widely applied in advanced methods of radiometric dating of the Quaternary deposits and in paleoclimatic reconstructions based on their stable isotopes contents.

In contrast to the above mentioned studies we know a very few about the processes of sedimentation of the speleothems and their physicochemical and biological controls.This paper presents preliminary results of our study on reconstruction of the environmental controls of the speleothems formation from Poland and Slovakia in terms of their microfacies variability. We assume that each type of microfacies could be attributed to a specific environmental characteristic (water energy, temperature, chemical composition, content of clastic impurities, microbial activity, etc.).

Several types of microfacies (**mf.**) have been found and defined.

Moonmilk mf. - originally soft, massive or faintly laminated, clotty agglomerates of tiny calcite needles, crystallised within microbial mat. The mat, composed of filamentous fungi and bacteria displays very high porosity. The mature, indurate moonmilk becomes denser owing to aggrading recrystallisation.

Botryoidal mf. is built up by radially arranged bunches of calcite needles embedded in siliciclastic lamina. This microfacies is closely related to depositional breaks and accompanies corrosion surfaces and residual clastic drapes.

Columnar mf. dominates in the most of the speleothems and is represented by large calcite crystals, visible even with naked eye. Colour of the sparry calcite ranges between white (or transparent) to dark brownish, depending on the clastic or organic impurities. Size of the monocrystals (up to several cm) suggests that they grew under stable hydrodynamic regime and were precipitated unconstrainedly from relatively thick water layer. This type of microfacies could be attributed to warm and humid climate. The columnar habit of crystals characterises also another type of microfacies called **rhythmically laminated mf.** In contrast the columnar flowstones this mf. comprises perfectly seasonally laminated ("varved") sets composed of coupled calcite-allophane laminae arranged in flat laying bands or in small domal forms. The calcite lamina represents a dry season increment while the dark lamina might be attributed to wet seasons involving more intense percolation of the soil-derived allophane material or (and) organic chemical compounds. The seasonal couples are grouped in bands reflecting likely longer-term climatic fluctuation. Generally the rhythmically laminated flowstones are attributed to relatively dry and warm climate.

The last kind of microfacies called **blocky mf.** is exclusively limited to basinal layers commencing every flowstone cover. The clastic material (up to grain fraction) hindered unconstrained growth of euhedral crystals. The blocky mf. develops in relatively turbulent water flow regime.

Careful analysis of vertical (chronological) succession of the microfacies along with geochemical and paleontological studies allow precisely reconstruction of environmental changes within the cave system as well as within the surficial karst catchment area.

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Origin of black coloured laminae in speleothems from Cracow-Wieluń Upland

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During study of speleothems from caves in the Cracow Wieluń - Upland black coloured laminae were found inside some of them. These laminae occur in stalagmites and flowstones from 9 caves.

All these caves were developed in Upper Jurassic limestone. The caves are of Late Tertiary and or Early Pleistocene age. Examined speleothems occurred on the surface of Pleistocene clastic deposits or on the walls of caves.

We have examined 13 specimens of speleothems. The main results were obtained by means of detailed microscopic observation (both SEM and under petrographic microscopy cpoupled with UV radiator) and of radiocarbon dating of samples.

Almost all of them are Holocene in age; only the lowest part of one stalagmite from Jaskinia Ciemna Cave is late Pleistocene.

Components of the black laminae have been recognized as charcoal particles. These particles are black, opaque in transmitted light and angular in shape. The size of them ranges from several micrometers to 1.5 mm. Exceptional largest fragments display well preserved internal structure while the structures of the smaller ones are completely obliterated. SEM investigation reveales various mode of xylem preservation. In some samples the xylem ultrastructure are good preserved, the cell wall fibrous texture can be seen. The textures of other fragments are homogenized completely up to cracking of the homogenized xylem.

The charcoal particles built clumpy aggregates. These aggregates occur: (1) on the corrosional surfaces, where they fill irregular pits, (2) on the surface of calcite crystals, and (3) are dispersed within the crystals. On the corrosional surfaces the microballs composed of charcoal and allophane minerals were visible. The agglomeration of charcoal is owing to high cohesive forces among particuls.

Besides the concentration of charcoal particles the dark coloured of the calcite could be related to absorbed hydrogen-rich organic, probably aromatic chemical compounds as evidenced by yellow brown UV fluorescence.

The character of black coloured laminae shows that their origin is related to prehistoric human activity. The archeological material dating from Paleolithic to the Middle Ages which was previously found in these caves strongly supports the interpretation.

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Comparison of Speleothem Dating by the TL, ESR, ^{14}C and $^{230}Th/^{234}U$ methods.

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Speleothems undoubtedly contain much geological information. Isotope dating of the speleothems can be used to establishing a time scale for the geological record in the cave sediments. They are used as a time marker for paleoclimatic changes reconstruction, dating of the archaeological materials, tectonoc processes etc.

In the literature we can see the results of the speleothems dating by diffrent methods. The results obtained with different methods often are significantly different (Tab 1).

Table I
Speleothems dating results with different methods

Cave	Sample	$^{230}Th/^{234}U$	TL	ESR	^{14}C
Temnata	G 1	93±10		575±65	
Temnata	G 4	140^{+11}_{-10}		275±85	
Magurska	MZ	76±4	100±35 125±35	125±55 145±55	
Kasprowa N.	KD 1	97±9	65±15		
Kasprowa N.	KD 2	82±7	175±90		
Goryczkowa	G - 1	95±11	235±90 165±50		
Dziewicza	JD 1/5	67±11			47.8±1.5
Bez Nazwy	JBN 1/1	40±5			30.4±1.9
Bez Nazwy	JBN 1/2	58±4			44.5±2.2
Krasnohorska	KZSA	55±4			36^{+5}_{-3}
Krasnohorska	KZ 1	34±8		280^{+40}_{-55}	
Diviaca	D	26±5		130±60	
Salanka	S 1	64^{+11}_{-10}		210 - 330	
Miętusia	Mt II/2		40±12	35±15	25.6±0.5
Miętusia	Mt II/1		50±10		$36.6^{+3.2}_{-2.3}$

* Present adress: Institute of Geological Sciences, Polish Academy of Sciences, al.Żwirki i Wigury 93, 02-089 Warszawa, Poland

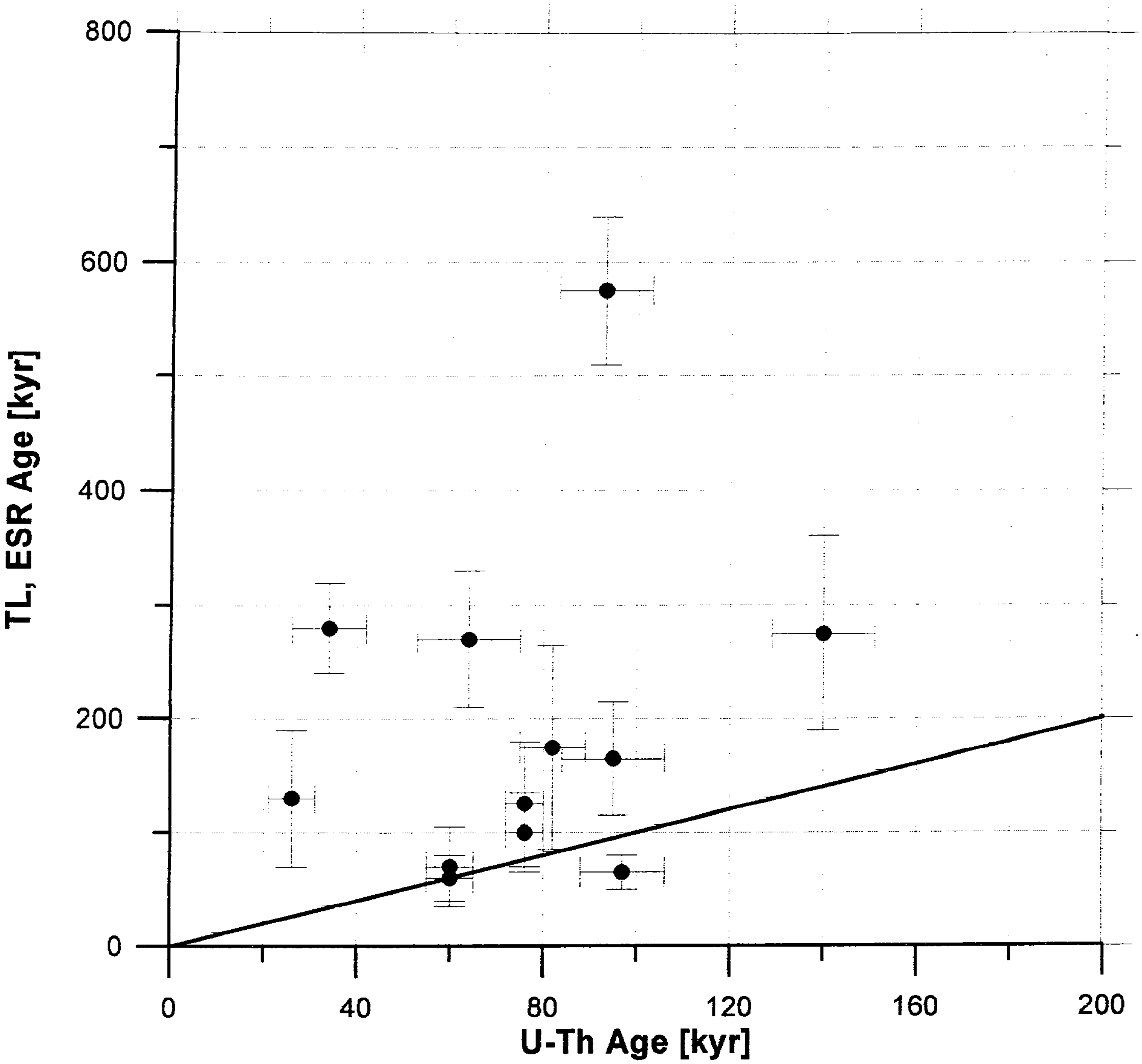

Fig. 1
Comparison of the TL and ESR dating results with The U-Series dating results.

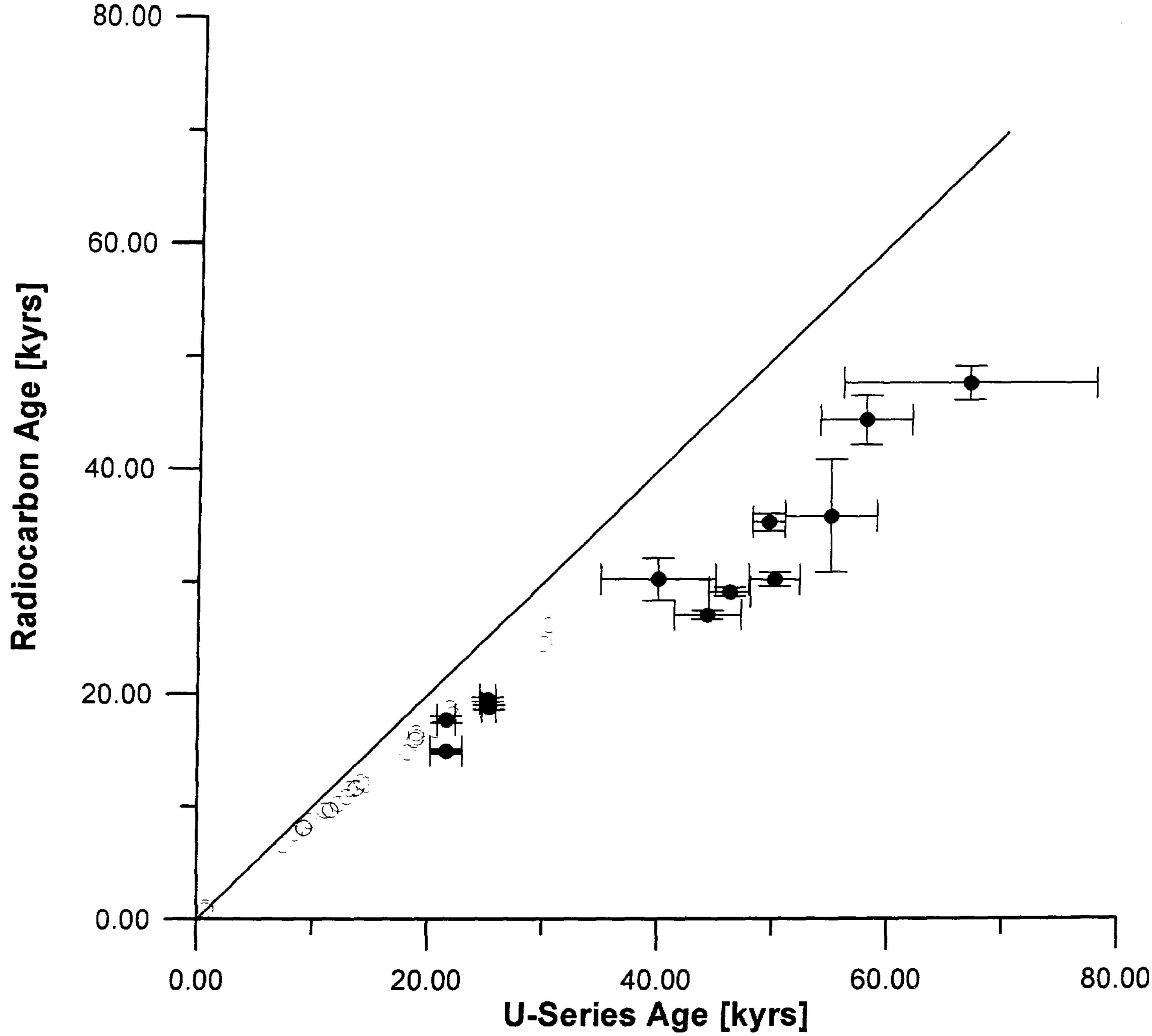

Fig. 2
Comparison of the ^{14}C dating results with the U-Series results. Black circles: speleothems, white circles: corals.

Miętusia	Mt I/2	60±5 [2]	70±35	60±20	
Lobaste[1]	L II 4 6A	21.6±0.8			17.8±0.3
Lobaste[1]	L II 4 5	21.6±1.4			15±0.2
Lobaste[1]	L II 4 4	25.2±0.7			19.6±0.2
Lobaste[1]	L II 4 5A	25.3±0.6			18.9±0.2
Lobaste[1]	L II 4 4A	26.8±0.4			13.2±0.2
Lobaste[1]	L II 4 2	44.3±2.9			27.2±0.4
Lobaste[1]	L II 4 2B	46.2±1.8			29.3±0.4
Lobaste[1]	L II 4 1A	49.6±1.4			35.5±0.8
Lobaste[1]	L II 4 1	50.1±2.2			30.4±0.6

1) Holmgren et all. (1994)
2) J. Głazek (1985)

It is very important to show the possible reasons for this discrepancy.

In this work the results obtained by TL, ESR and ^{14}C methods are compared with the results of $^{230}Th/^{234}U$ method.

If we compare the results of TL and ESR methods with $^{230}Th/^{234}U$ results, we found that no correlation is visible (Fig. 1). The most important reason of this discrepancy are changes of the dose rate in the past. For the age calculation we use the dose rate measured in the cave or in the laboratory. We do not know if the dose rate was constant in the past as we assume. The dose rate changes effect is the reflection of the individual history of the sample.

The comparison of the results of ^{14}C dating with $^{230}Th/^{234}U$ give us completly different picture. We can see significant correlation beetween these results (Fig. 2). For the samples younger then 20 kyrs (U-Series age) the correlation is similar to the results obtained for corals (Bard et all., 1993). The plateau is visible for the samples c.a. 30-45 kyrs old. Similar effect was reported earlier by Vogel (1983). Radiocarbon age is c.a. 10-15 kyrs too low for the samples older then 40 kyrs.

As strong shifting of radiocarbon ages is surprising and its explanation needs mor measurements (work in progress).

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Detritic contamination as a indicator of the breaks in the speleothems deposition

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The Pleistocene calcite flowstones of two caves systems from the Tatra Mountains and Kraków-Wieluń Upland have been studied in terms of theirs growth breaks. Microscopic analyses of the microfacies were done using Olympus MB 6. Major and trace elements have been determined on thin slides by electron microprobe JXA 840 A (Jeol - Japan) combined with LINK analytical system.

Materials

Miętusia Cave is one of the largest caves in Poland. It is located in the Western Tatra Mountains (Southern Poland) - in Miętusia Valley. Two samples were collected for the analyses: M 1 B and M 2 B (Fig 1).

Bez Nazwy Cave is a small cave in the Kraków-Wieluń Upland (Southern Poland). We have collected one sample for our study: JBN 1 (Fig 1).

All samples have been dated with Uranium - Thorium methods in U-Series Laboratory in Bergen (Fig. 1).

The most visible in macroscopic feature of the flowstones is their banding. Thickness of particular layers oscilates from decimal fraction of a milimeters to 2 centimeters. Their colour gets stronger from white by cream to the various shades of light brown and grey-brown. In the samples M 1 B and M 2 B the xenomorphic calcite crystals can be seen. They are alonged, perpendicular to the lamination and parallel to the flowstone growth direction.

Microscope observations allowed to separate repeated forms of calcite as well as groups of both carbonate minerals and detrital material (facies).

Palisade calcite (sample M 2 B: Fig. 1, fot. b) possesses characteristic alonged crystals (wide $\leq$ 10 µm) put parallel to each other.Crystalls show close inner formation and no inclusion or enclaves of detrital materials. The upper ends are usually automorphic piramids (rare rectangular) and covered with detrital materials (sample M 1 B: Fig. 1, fot. b). Palisade calcite growth on a „tooth-shaped" calcite.The palisade calcite crystals are nearly parallel, sometimes with a slight radiating or converging tendency. The c axis is oriented parallel with the crystalls and perpendicular to the growth surface.

The „tooth-shaped" calcite always growth as a first one on a ground as well as on some levels of deposited detrital material (sample M 1B:Fig. 1, fot. b; sample M 2 B, fot. a). The „tooth" are not well developed, sharp ended pyramids of calcite wich growth on the angle of 60 - 90 degrees to the surface. The c axis is parallel to the elongation of the crystals.

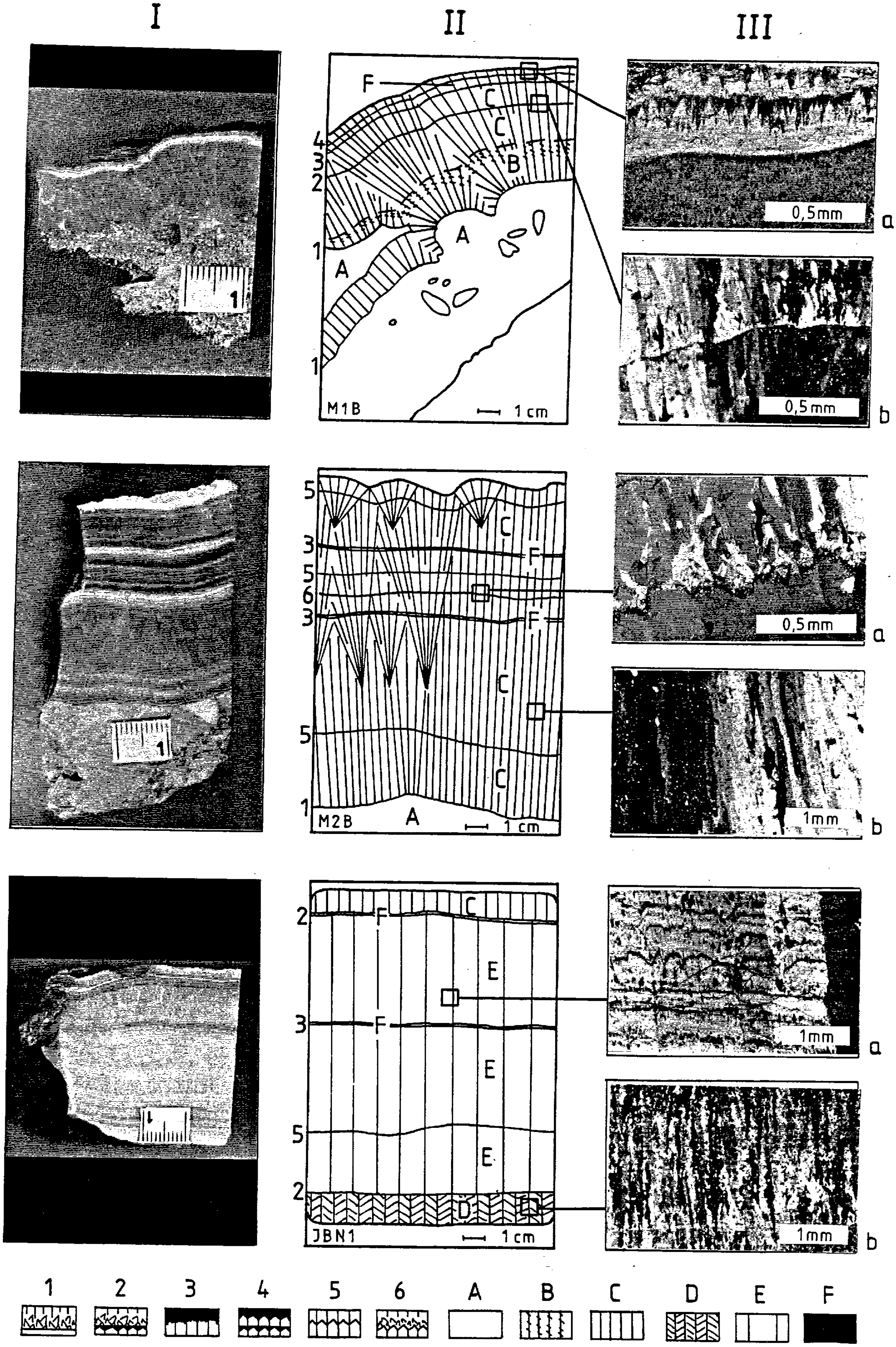
The columnar calcite's crystals are $\leq$ 100 µm wide. They may appear along the whole section of the flowstone. Sometimes the crystals includ enclaves of fine calcite or laminas of detrital material. The laminas cross the crystals of columnar calcite but do not disturb their growth (sample JBN 1: Fig 1, fot a). The c axis is oriented parallel with the crystalls and perpendicular to the growth surface.

Fig. 1

Studied materials. I: macroscopic view of the samples; II - microscopic view of the samples (scetch); III - established microfacies. 1 - 6: types of the boundaries: 1: „tooth shaped" calcite-ground, 2:"tooth shaped" calcite-detrital material covering sharp ends of crystals, 3: calcite - calcite with growth-in detrital material, 4: palisade calcite-detrital material on the sharp ends of crystal, 5: detrital layer within calcite crystals, 6: „tooth shaped" calcite on the detrital material's layer; A-F: Kinds of calcite layers: A: the sediment, B: palisade calcite with inclusions, C: palisade calcite, D: botroidal facies, E: columnar calcite, F: calcite with growth-in detrital material.

Fig. 2

Example of geochemical studies of the sample M 2 B. A, B, C: the maps of the elements distribution within the layers consisting of detrital contamination.


I
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III
F
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C
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4
3
2
1
1
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5
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1
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C
C
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M2B
1 cm
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a
1mm
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Figure 1

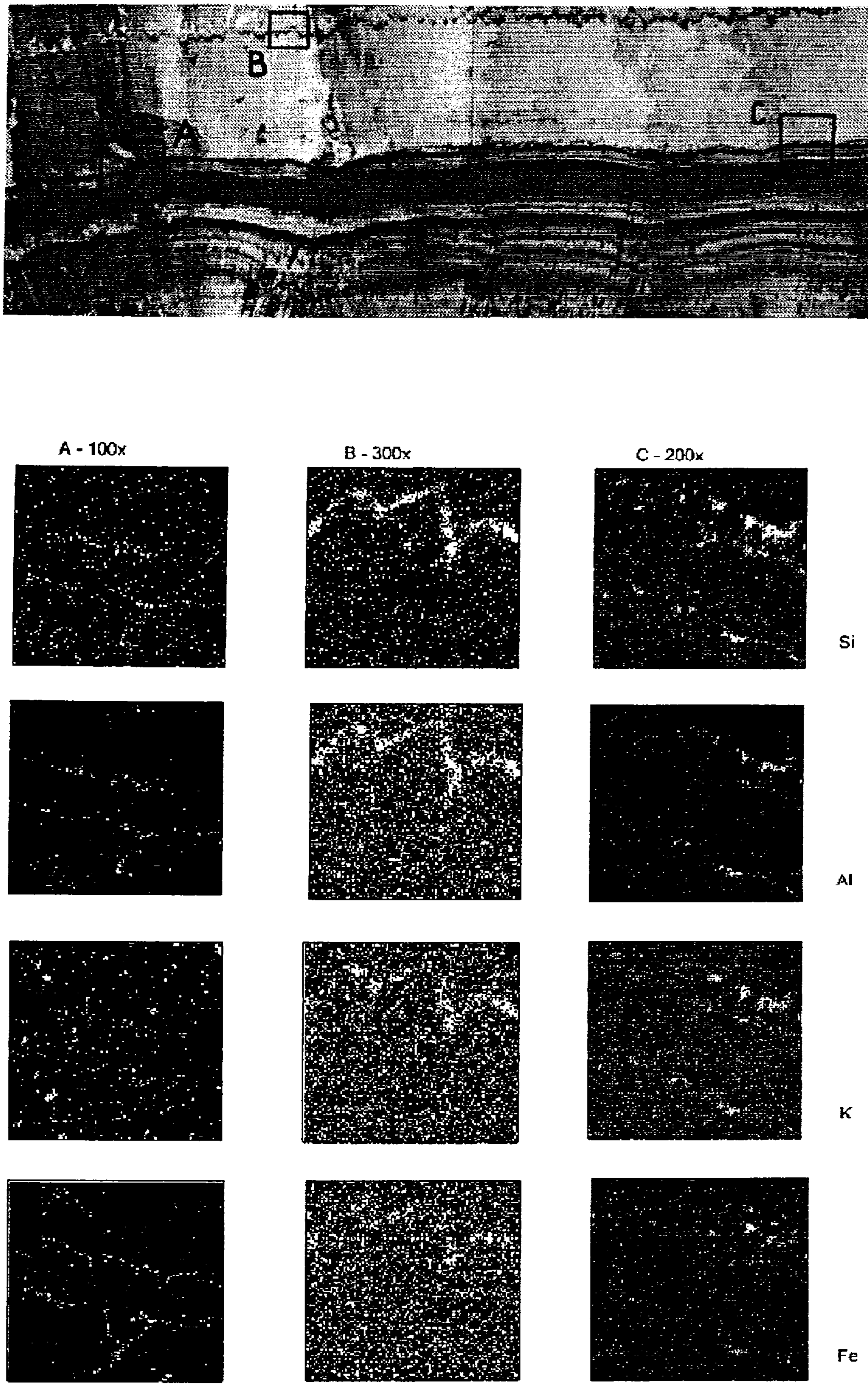

Figure 2

The botroidal facies develops within clay matrix (sample JBN 1: Fig. 1, fot. b). There are strongly alongated calcite crystals „bush-like" shaped. The boundaries between them are unclear becouse of a presence of detrital material and very fine crystals. In addition little pores may appear.

Geochemical analysies

Major and accompanied elements have been determined in the selected parts of all samples. Analysis of palisade and tooth shaped calcite, both from Miętusia Cave, have shown low Mg contents. Only cluster calcite from the bottom part of flowstones (dropstones) has no Mg at all.

In opposite to the Miętusia Cave the whole investigated profile of the flowstone, from the Jaskinia Bez Nazwy Cave are pure calcite, no matter of their shape.

Fine and coarse laminae and layers present in the flowstones of the both caves were carefully examined. Several analysis and maps element's distribution were taken from the part of the samples with the layers of detrital material or corrosional breaks (example: Fig. 2).

Quantitative analysis some of the layers and laminae contaminated by detrital material in the flowstone of Miętusia Cave has shown slightly increasing of Mg, Al, K and Fe, and sometimes significant increasing of Si. Their chemical composition indicates of micas and feldspars presence in this layers. Which is due to the aboundance of dust of magmatic rocks present in the neighbour area. Small grains of these rocks as well as individual minerals observed as biotite and muscovite, feldspars, plagioclases and quarz are present at the bottom of the deposite. That is also possible that the dark colour of some laminae is probably due to the presence of some amount of organic matter, because there were no significant contents of the mentioned elements in them (Fig. 2 A).

In the flowstone taken from Bez Nazwy Cave laminae are enriched in Si because of the smashed quartz grains. Other minerals like rutile, biotite or iron-oxides are very few. Probably in these laminaes organic matter also exists.

Some wide pale layers in the flowstones of both caves demonstrate very interesting structure.

As were shown on the maps of the elements distribution (Fig. 2) there are some characteristic mariginal zones enriched in Al, Mg, Fe, K and Si or Si respctively. Sometimes these zones are also underlined by microscopic determined grains of quarz and micas, but the inner part of this layers consist of calcite silt. Here organic matter probably also exists.

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Randomisation as a methods of frequency histogram construction

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The speleothems provide a sensitive tools for paleoclimatic reconstructions. Correlation between humid, warm climates and intensive speleothems growth is known since 1970 when the first histogram based on ^{14}C dates was published (Geyh, 1970). For 26 years intensive works in this subject was done.

The first works based on frequency histograms disregarded the uncertainties of the dating results. Next step was the method proposed by Hennig et al. (1983). They used simply method of error weighting. This method was discussed by Gordon and Smart (1984). They proposed a method „cumulative distributed error frequency curve constructed from the known normal distribution of the age around the quoted value".

This method is usually used for the analyses of radiometric dating results at the present time.

In fact the result of $^{230}Th/^{234}U$ dating can not be describe by normal distribution. The $^{230}Th/^{234}U$ ratio in a nonlinear manner cousing the assymetry in quoted errors observed especially for older dates. As a solution of this problem we use conversion of the quoted ages and their limits to $^{230}Th/^{234}U$ ratios. We must known $^{234}U/^{238}U$ ratio too.

We propose, as a solution of this problem, different methods of the frequency histogram construction by „randomisation method" (Fig. 1).

As a result of the measurement we obtained $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ ratios with their uncertainties $d(^{230}Th/^{234}U)$ and $d(^{234}U/^{238}U)$. For each data we generate a set of value of $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ described by normal distribution with means $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ and standard deviations $d(^{230}Th/^{234}U)$ and $d(^{234}U/^{238}U)$. For eachof the pair: $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ we calculate the age. As a results we obtained histogram which approximate real distribution of the age. We repeat this procedure for each data and we can construct final „frequency histogram". If the number of „randomisation" is big enough we can obtain the picture similar to the smooth probability distribution function (PDF) (Fig. 2).

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Gordon D., Smart P., 1984, Comments on „Speleothems, Travertines and Paleoclimates" by G.J. Hennig, R. Grun, and K. Brunnacer, Quat. Res., 22, 144-147.

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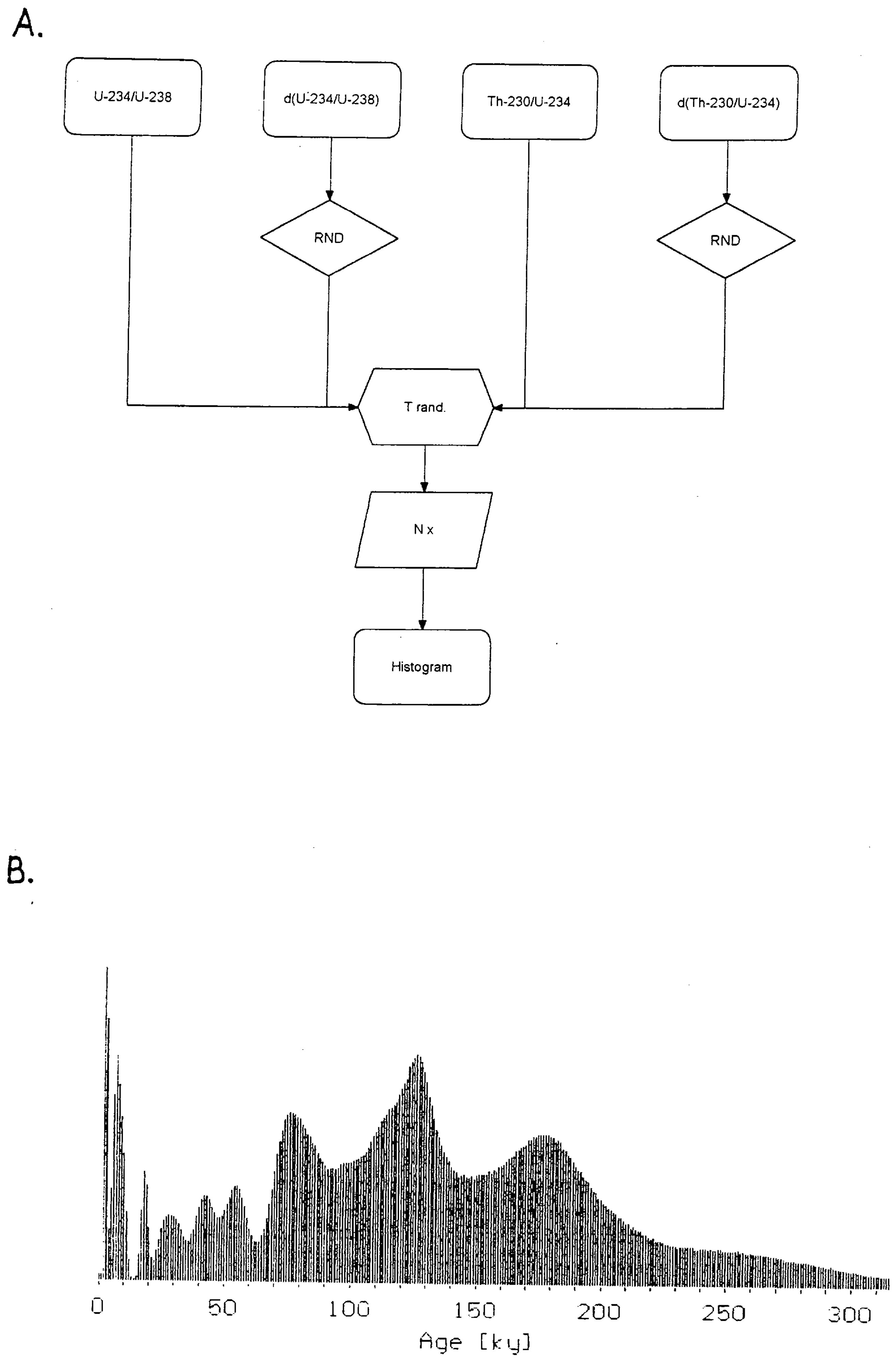

Fig. 1.
„Randomisation method" of the frequency histogram construction.
A.- schematic diagram of the methods, B- final histogram for 30 000 randomisatin of 75 dating results of Tatra Mts. speleothems.

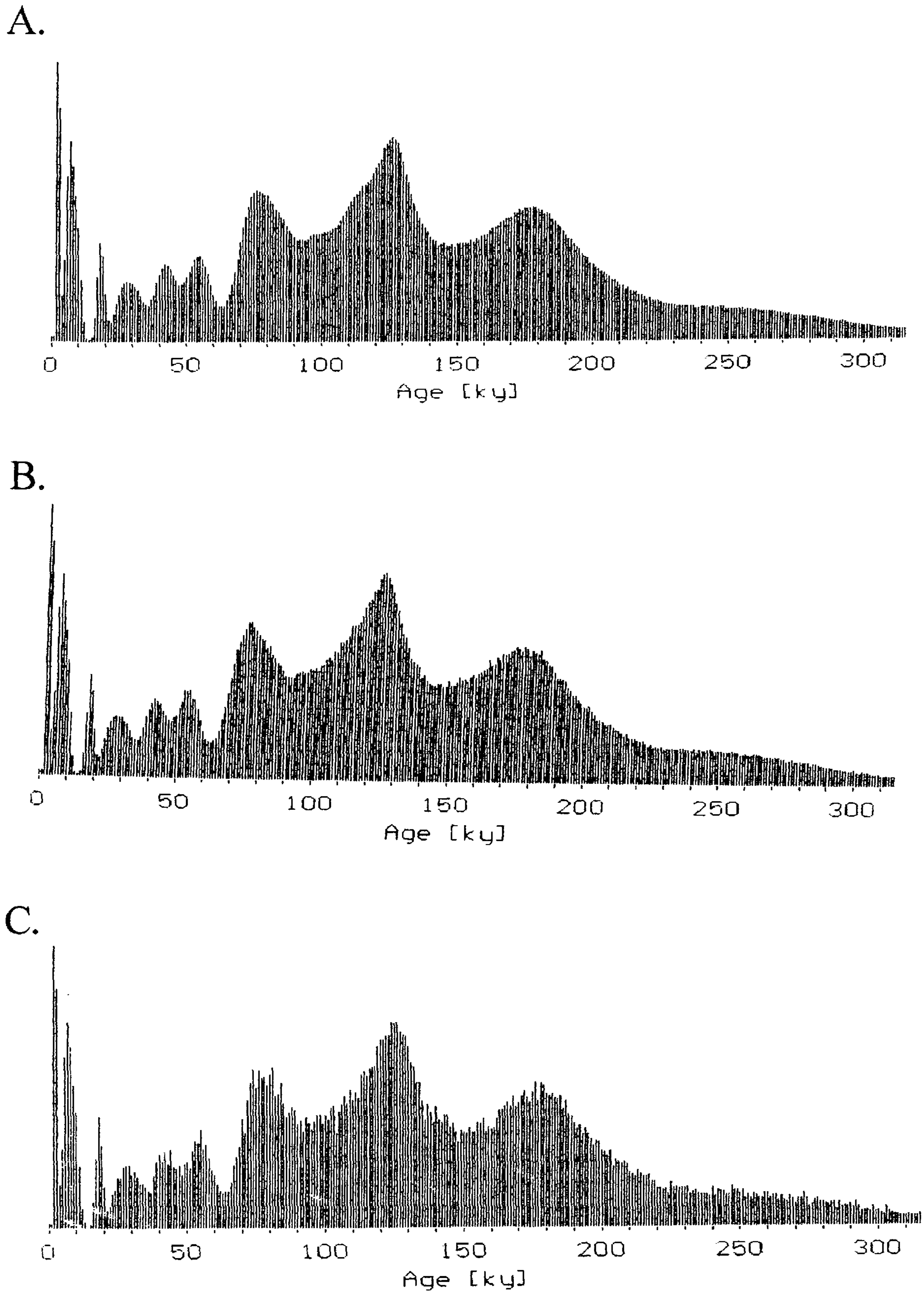

Fig. 2.
Frequency histograms constructed by „randomisation method" for 75 dating results of Tatra Mts. speleothems. A- 30 000 randomisation, B- 10 000 randomisation, C- 1000 randomisation.

Holocene Climatic Record in the Calcareous Tufa Mound in Svatý Jan pod Skalou, Bohemian Karst (Czech Republic)

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Dry climatic oscillations in the Epiatlantic and Subboreal represent important climatic events in the Holocene. Climatic changes are well recorded in accumulations of calcareous tufa deposited by some karstic springs. During dryer periods horizons of humic soils were formed instead of tufa. A calcareous tufa mound of the size of about 40,000 m^3 was deposited in Svatý Jan pod Skalou (30 km SW of Prague) during the Holocene by the largest Bohemian Karst spring which now discharges at its base. The spring is characterised by a discharge close to 20 l/s, and virtually constant temperature (11.3 to 11.6 °C), which is slightly higher than the mean annual temperature in this area and indicates deeper circulation of karstic water. The middle part of the Holocene is developed as an approximately 13 m thick complex formed by various types of calcareous tufa with interbedded fossil soils and debris layers.

Four independent methods were applied to date individual layers. Five carbonate samples covering the whole stratigraphic extent known were dated by ^{14}C and by U-series methods. In addition, 3 samples of charcoal from the upper part of the profile were dated by AMS. The upper part of the profile was dated also archaeologically. As of today, radiocarbon data of carbonates and charcoal and the archaeological dating of pottery are available.

All ^{14}C dates of carbonates were corrected for their lower initial radiocarbon content using a value of 83 % activity of modern carbon measured in dissolved bicarbonate of the spring water. Tree-ring calibration was introduced to both carbonate and charcoal ^{14}C dates. The agreement of both sets of radiocarbon dates from the upper part of the profile and of archaeological dating was good. In the middle part of the profile the radiocarbon age of charcoal is about 800 years higher compared to the radiocarbon age of carbonate. The charcoal was either produced by combustion of older wood (alternatively, charcoal pieces could have been redeposited by water or human activity), or the initial radiocarbon content of carbonate varied with time. Regardless of these uncertainties it is clear that the carbonate deposition in Svatý Jan pod Skalou covers the range from about 8000 to 2500 BP.

The study of molluscan assemblages shows analogous results. The lower part of tufa accumulation was deposited during the Late Atlantic climatic optimum. The climatic conditions changed in the Epiatlantic[1]. The upper part of tufa mound originated under wetland and aquatic (small pools) conditions alternating with short dry periods.

$d^{18}O$ values of carbonate are from -7.3 to -8.3 ‰ PDB, $d^{13}C$ values vary from -7.9 to -10.5 ‰. Small variability of both $d^{13}C$ and $d^{18}O$ values, the character of tufa accumulation and high spring discharge indicate that carbonate may have been deposited under near-equilibrium conditions and isotopic composition of carbonate may thus reflect climatic changes. The constant spring temperature suggests that changes in oxygen isotope composition of carbonate were controlled mainly by changes in isotopic composition of water. Assuming a long-term

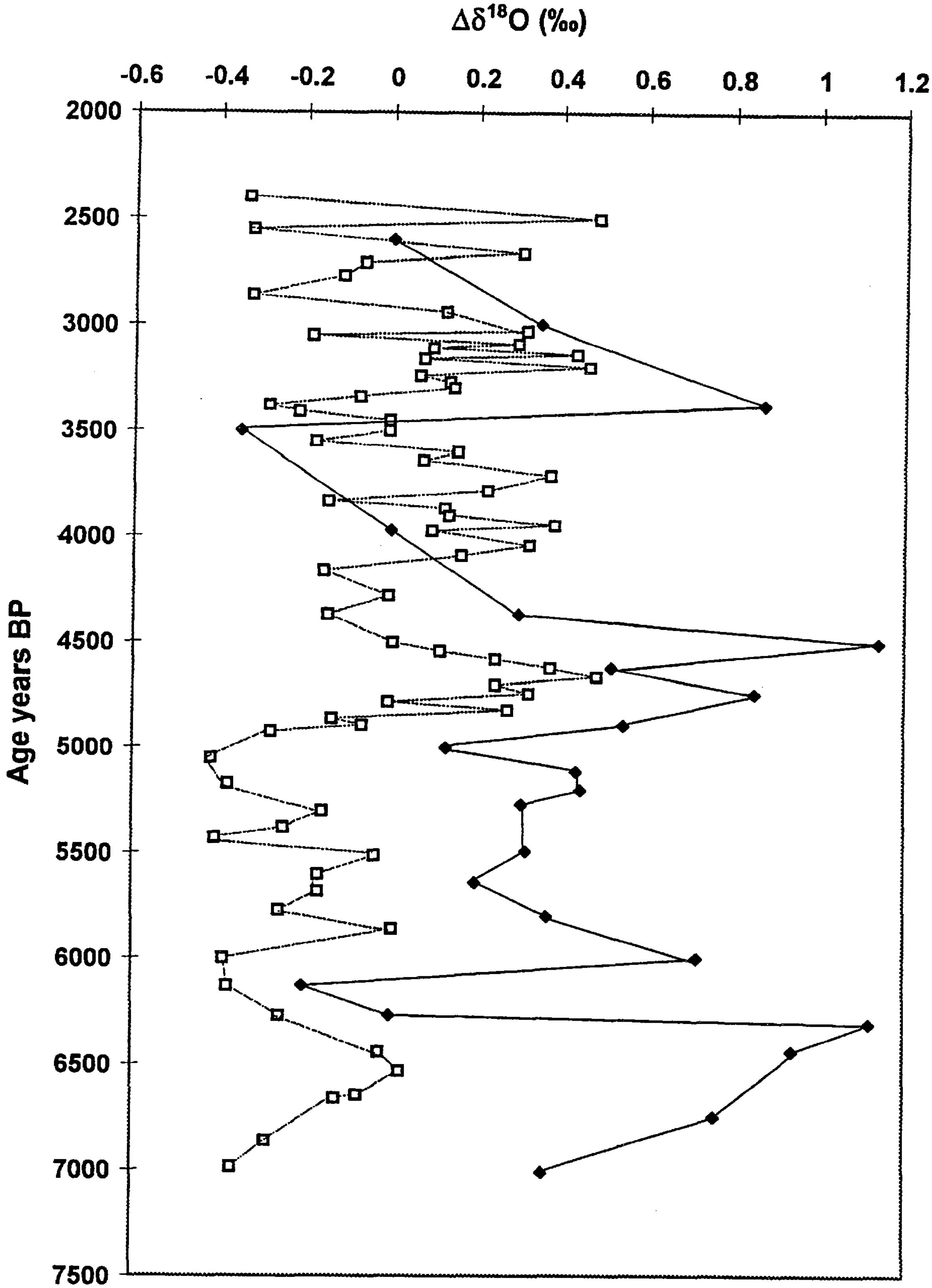

Fig.1: The correlation of the $\delta^{18}O$ values from calcareous tufa in Svatý Jan pod Skalou, Bohemian Karst (interrupted line) and $\delta^{18}O$ record from ice core from Camp Century, Greenland[4] (solid line).

temperature gradient of $d^{18}O$ in meteoric water of 0.6 ‰/°C[2], the measured differences in $d^{18}O$ values of tufa correspond to a temperature change of about 1.5 °C.

Isotope data obtained for calcareous tufa from Svatý Jan pod Skalou, Czech Republic, were compared with data for calcareous tufa deposits from southern Poland[3]. The $d^{18}O$ values of carbonate from the Czech profile are about 1 ‰ higher than those from the Polish profiles but the variability of about 1 ‰ in $d^{18}O$ values of carbonates is similar in all profiles. In southern Poland, lower $d^{18}O$ values (lower mean annual temperature) were found for 2200 ys BP, 5500 ys BP and 6300 ys BP; higher $d^{18}O$ values (higher temperature) were found for 6000 ys BP and 6500 ys BP. Considering the uncertainty in radiocarbon data in the carbonate material, it is possible to view the trends in $d^{18}O$ values from the calcareous tufa deposit at Svatý Jan pod Skalou and in southern Poland as consistent. Fig.1 shows the correlation of ^{18}O values from the tufa in Svatý Jan pod Skalou (interrupted line) with ^{18}O record from ice core from Camp Century, Greenland (solid line).

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The potential of speleothems in the reconstruction of southern African palaeoclimates - an example from Lobatse II Cave, Botswana

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High-resolution, precisely dated proxy data, spanning long periods are needed for understanding regional and temporal patterns of climate change and possible forcing factors. Such data are increasingly available for the Northern Hemisphere and high latitudes, but there is a need for high-quality records from the Southern Hemisphere to determine to what extent climatic changes are global or local. Continuous terrestrial high-resolution climate records from southern Africa are scarce, mainly because the region has few suitable palaeoenvironmental sites. The potential of tropical and sub-tropical cave speleothems is promising, although not yet fully explored (Brook *et al.* 1990, Railsback *et al.* 1994, Holmgren *et al.* 1995).

This on-going project aims at reconstructing southern African Holocene and Pleistocene climatic changes through studies of speleothems from caves in Tanzania (5-10°S), Botswana and South Africa (20-27°S) (Fig. 1). The sites in Tanzania are largely influenced by the Inter Tropical Convergence, while the sites further south experience the interaction between tropical and temperate circulation systems. Palaeoenvironmental records from these sites are expected to increase the knowledge about past patterns in the atmospheric circulation.

Research in the Lobatse II Cave, Botswana, using stable isotope analysis, radiocarbon and uranium-series dating, was initiated in 1991. One problem in semi-arid areas is evaporative cave environments, making the speleothems unsuitable for stable isotopic studies. However, the Lobatse II Cave is a closed cave with only a narrow entrance shaft and high relative humidity in the cave interior. Petrologic and stable isotopic investigation of one stalagmite, LII4, suggests that isotopic equilibrium conditions did exist in the past, although the speleothems today suffer from surface corrosion (Holmgren *et al.* 1995).

The stable oxygen isotopic content ($\delta^{18}O_c$) in speleothems is determined by cave temperature and by the stable oxygen isotopic content in meteoric water, which in turn is determined by the composition of the sea-water source and the geographic position of the cave. Both positive and negative relationships between the $\delta^{18}O_c$ value and temperature are possible. By analysing recent seepage water and speleothems, the relative temperature variations back in time can be obtained. This was a primary aim of this study, but since no recent formations were found, comparison was sought from other sites. The nearest comparable sites are Wolkberg Cave in Transvaal (Talma *et al.* 1974) and Cango Cave along the south coast, South Africa (Talma and Vogel 1992). At both localities a negative relationship between the $\delta^{18}O_c$ value and the temperature was inferred, i.e. the speleothems are enriched in ^{18}O during colder periods and depleted in ^{18}O during warmer periods. It is proposed that this relationship is also valid at Lobatse.

The stable carbon isotopic content in speleothems, $\delta^{13}C_c$, reflects changes in vegetation, provided that bedrock conditions can be assumed to have been constant for the period of speleothem growth. A $\delta^{13}C_c$ value of around -13 ‰ reflects an environment dominated by C_3 vegetation, while $\delta^{13}C_c$ values of around +1.2 ‰ reflect a pure C_4 biomass (Talma and Vogel 1992). C_4 plants grow preferentially in low latitude areas where high temperatures and summer rainfall dominate, whilst C_3 plants are common at higher latitudes, where night temperatures are low, winter precipitation high and water stress is limited (Vogel *et al.* 1978, Hattersley 1983).

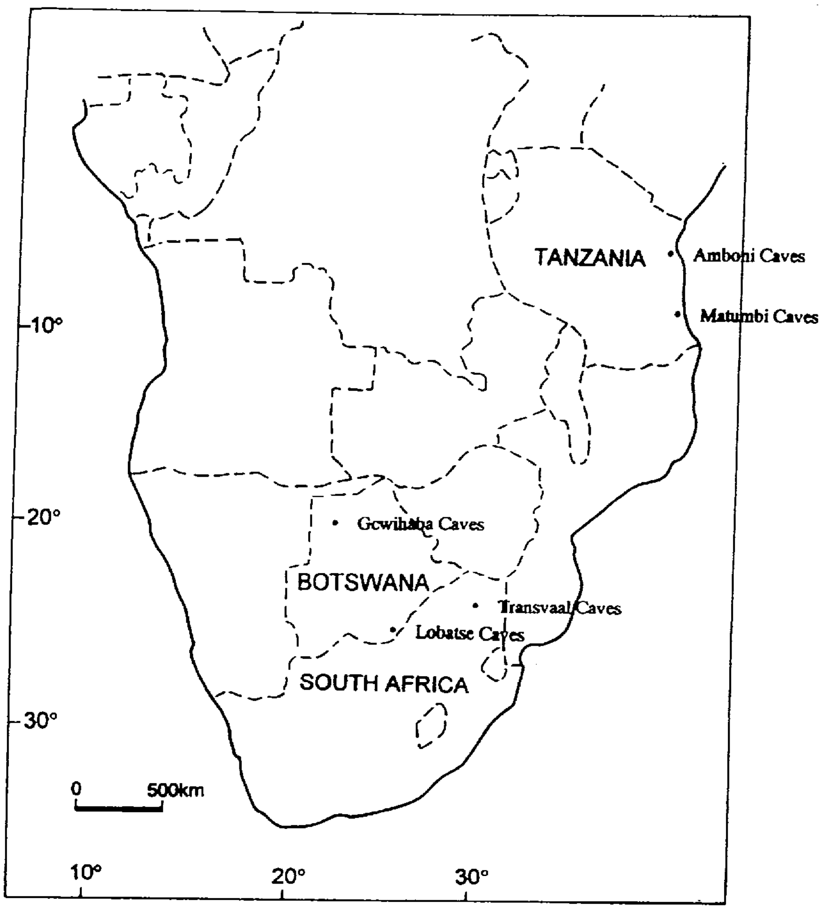

Figure 1. Map of southern Africa showing the location of caves mentioned in the text

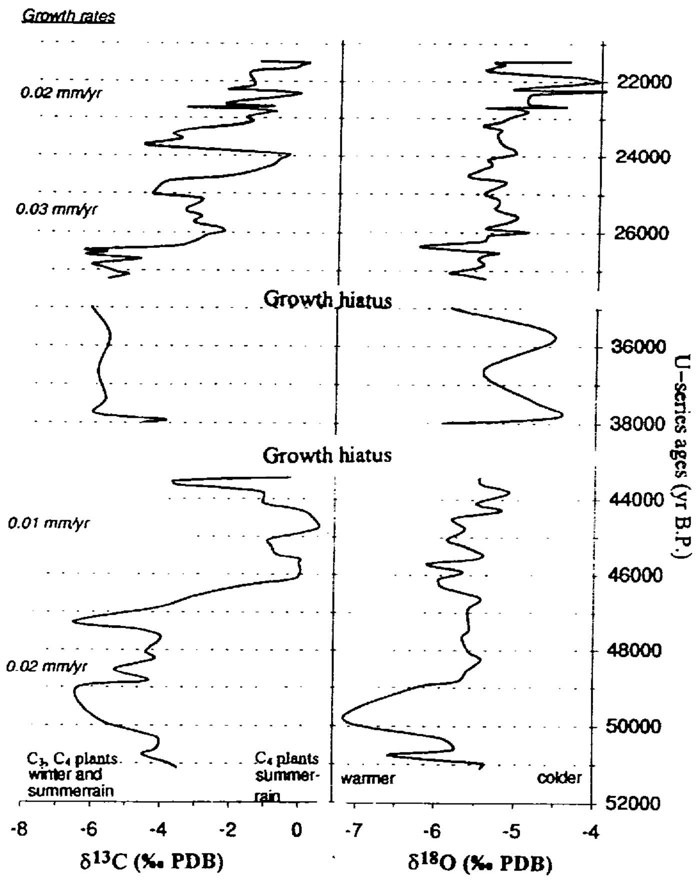

Figure 2. Growth rate and stable isotopic variations versus age of stalagmite LII4, Lobatse II Cave, Botswana, and inferred palaeoclimatic changes

Stalagmite LII4 has been U-series dated to 51,000 yr B.P. at the base, and to 21,000 yr B.P. at the top. Two long growth hiatuses, probably due to drier conditions, began at about 43,000 and 35,000 yr B.P., the latter period ended prior to 27,000 yr B.P (Fig. 2). The $\delta^{18}O_c$ record indicates a gradual temperature decrease of about 2°C from 50,000 yr B.P. towards the Last Glacial Maximum at 21,000 yr B.P. (Holmgren *et al.* 1995), which for southern Africa has been estimated to be about 5-6°C lower than the present (Heaton *et al.* 1986). The $\delta^{13}C_c$ record suggests periods of increased precipitation due to contribution of winter rainfall at 51-47,000, 27,000, 25,000 and 23,500 yr B.P. The calcite between the two hiatuses is recrystallised, thus the stable isotopic record for that period was not used for palaeoclimatic interpretation. Average growth rates calculated between absolute dated sections indicate that decreasing growth rates coincide with decreasing humidity, suggesting that the amount of precipitation is the major limiting factor for speleothem growth in semi-arid areas.

It is problematic to compare the Lobatse record with other palaeoclimatic records in the region because detailed records from this period of time are few and are mostly based upon uncalibrated radiocarbon age estimations of calcretes, speleothems and organic remains. In a preliminary comparison with ^{14}C-dated sites younger than 30,000 yr B.P., the wetter episodes documented in the Lobatse record at 27,000, 25,000 and 23,500 yr B.P., coincide with drier conditions further north. This pattern supports a palaeoclimatic model proposed by Cockroft *et al.* (1987), where an equatorwards migration of the westerlies increases the winter rainfall over the southern summer rainfall regime, but leads to drier conditions north of the boundary. Further strengthening of the westerlies and lowering of temperatures during the LGM led to dry and cold conditions over the whole region around 20,000 yr B.P.

Preliminary radiocarbon dating of a second stalagmite from Lobatse II Cave, indicate that this speleothem extends the climate record from Lobatse to include the period after the LGM. While it has been inferred from studies in north and east Africa that this period was one of globally drier conditions in presently semi-arid regions (Petit-Maire 1994), geomorphological studies from the Middle Kalahari document a wetter episode between 16-13,000 ^{14}C yr B.P. (Shaw and Thomas 1996). The ^{14}C age estimations of LII2 suggest that the growth rate decreased rapidly during the LGM but recovered shortly afterwards, hence supporting the idea of moister conditions after the LGM over large regions in semi-arid southern Africa.

Multiple sampling of fossil speleothems in semi-arid regions is necessary for palaeoclimatic purposes. However, the validity of these initial results from the project is encouraging. Of specific interest is the potential of southern African speleothems to provide high-resolution records documenting regional climatic variability, the relative influence of winter and summer rainfall regimes, and thus contributing to palaeoclimatic modelling.

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CLIMATIC SIGNAL OF THE KARST FILLING FROM SUBPIATRA, ROMANIA

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The most interesting deposits from the Lower and Middle Pleistocene of western Romania are located in the Bihor district.

Except the occurrences represented by karst fillings from Betfia, the typical place of the already described Biharian, a similar deposit has been recently mentioned at Subpiatra, in the vicinity of Alesd. This deposit was identified in the course of some dynamiting operations carried out in a quarry for Cretaceous limestone exploitation serving for the fabrication of cement.The dynamiting operations have completely destroyed the karst cavity where the clay filling was located. Thus we managed to retrieve from a level of the quarry covered by scattered material a significant quantity of blocks including fossil remains of reptiles and mainly of large and small mammals. The existing context raised the issue concerning the age of the filling material as well as the existence or non-existence of several faunistic and sediment levels. Among the pieces retrieved until the present moment some are most remarkable, such as some forest-dwellers including *Capreolus capreolus sussenbornensis* (Kahlke), *Cervus* sp., (*elaphus* size), *Sus scrofa* Linne, *Meles* sp., and some steppe forms like *Bison* cf. *priscus* Bojanus or remains of an elephant with trogontheroid features. This assemblage makes evident either the presence of varied landscapes exhibiting alternances of forested zones and open spaces or a filling material accumulated in a longer time interval. The age of fauna was assigned to the **MmQ-3b** unit, as defined by Agusti & alii (1987). The existence of numerous herbivores as well as the dominance of some immature specimens or young adults support our supposition that we have to deal with a small aven at Subpiatra, which functioned as a "natural trap".

The blocks yelded by the unrocking operations from Subpiatra were sampled for clay minerals assemblage analysis. XRD investigations were performed on the clay fraction below 2μ by decarbonatation of detrital matrix, associated to the fragments including the fossil remains. From the viewpoint of their quantitative and qualitative participation, the clay minerals exhibit a wide variation spectrum. The following two tendencies could be detected:

(a) the assemblage smectite (50-60%), kaolinite (10-15%) mixed layers 10/14(5%) and 14/14(5-10%) ± illite and chlorite (5-10%), quartz(5-10%) and goethite(<5%);

(b) the assemblage illite(35-40%), chlorite(20-25%), smectite(15-20%), quartz and feldspar(10-15%) ± kaolinite(5-10%).

These two assemblages indicate the presence of some considerable modifications produced at the level of climate and/or tectonics in the source area of the sediment which includes fossil remains.

In the case of the first mentioned assemblage, the dominance of smectite indicates a source area represented by slightly drained zones of low topography which evolved in a warm and moist climate, most probably a seasonal one. The presence of kaolinite admits the supposition concerning the existence of some hilly zones, with sufficient draining regime.

Under these circumstances we may estimate that the weathering processes were of a relatively long duration, being materialised in mature soils.

The second assemblage which is dominated by illite and chlorite and associated with quartz and feldspar indicates a source area which evolved in a significantly colder climate and/or with strongly diminished hydrolysis processes. Smectite and kaolinite which are still present might represent under these circumstances products of old reworked crusts.

The climatic signal is well individualised in the case of the first assemblage. In the second one it is blurred being covered by the clastic signal. Considering the long time interval during which the sediments accumulated, we are enabled to assign the two assemblages as a reflex to an interglacial - glacial climatic transition.

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Isotopic Study of Cave Carbonates from Moravian Karst, Czech Republic

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Cave carbonates termed speleothems are mineral formations precipitated in limestone caves from groundwater which has percolated through the adjacent carbonate host rock. Speleothems may provide paleoclimatic record for terrestrial environments (e.g., Bradley 1985, Gascoyne 1992).

The Moravian Karst is a famous karst area in Central Europe. Exploration and scientific research started here more than one century ago. In 1938 Professor Absolon conducted a demanding project with the aim to discover a large cave system with an active subsurface stream. A tunnel was dug in cave clastic sediments of the Zazdìná jeskyni Cave, which is located near the Punkevní jeskyni show-cave and the famous Macocha Chasm. Unfortunately, the project was interrupted in 1940 and never finished. The largest profile in cave sediments of the Moravian Karst more than 330 m long was exposed.

The Zazdìná jeskyni Cave consists of two parts. The vertical part is filled by rhythmically bedded sands and silts. This sedimentary accumulation is 33 m thick and in its upper part sediments with a reverse paleomagnetic polarity were found (Šroubek and Diehl, 1995). Consequently, the age of deposition is older than the paleomagnetic boundary Brunhes/Matuyama (780,000 years). In horizontal part of the Zazdìná jeskyni Cave, fluvial sandy gravels, sands and silts were deposited by a subsurface stream. The break in clastic sedimentation followed and a flowstone layer originated on the surface of fluvial sediments in some parts of the cave. During the last sedimentation period the laminated and thin-bedded silts filled most of the cave corridor up to the ceiling. These fine sediments were transported by meteoric waters vertically from the surface through cracks and karst chimneys.

The $d^{13}C$ and $d^{18}O$ values of layers and separate relics of flowstone document that in the horizontal corridor of the Zazdìná jeskyni Cave cave carbonates originated in two periods with different climatic conditions. The re-deposited blocks of flowstone preserved inside fluvial sediments in the frontal part of the cave probably originated in caverns above the main corridor and fell from the chimneys into the sediments deposited in the horizontal part of the cave.

The age of the flowstone layer deposited on the surface of fluvial sediments (200 m far from the cave entrance) was determined by U/Th method in the U-Series Dating Laboratory of Bergen University, Norway. The basal part of the flowstone layer was deposited 114.37 (+5.05/-4.85) kyr ago. Carbonate precipitation continued approximately 2,000 years and was interrupted for the following 10,000 years long hiatus as documented also by a 6 mm thick layer of silt. The upper part and the top of the flowstone layer is 99.85 (+3.30/-3.21) kyr old. The carbonate layer was formed at the beginning of the last glacial period, i.e., in isotope substages 5c-d.

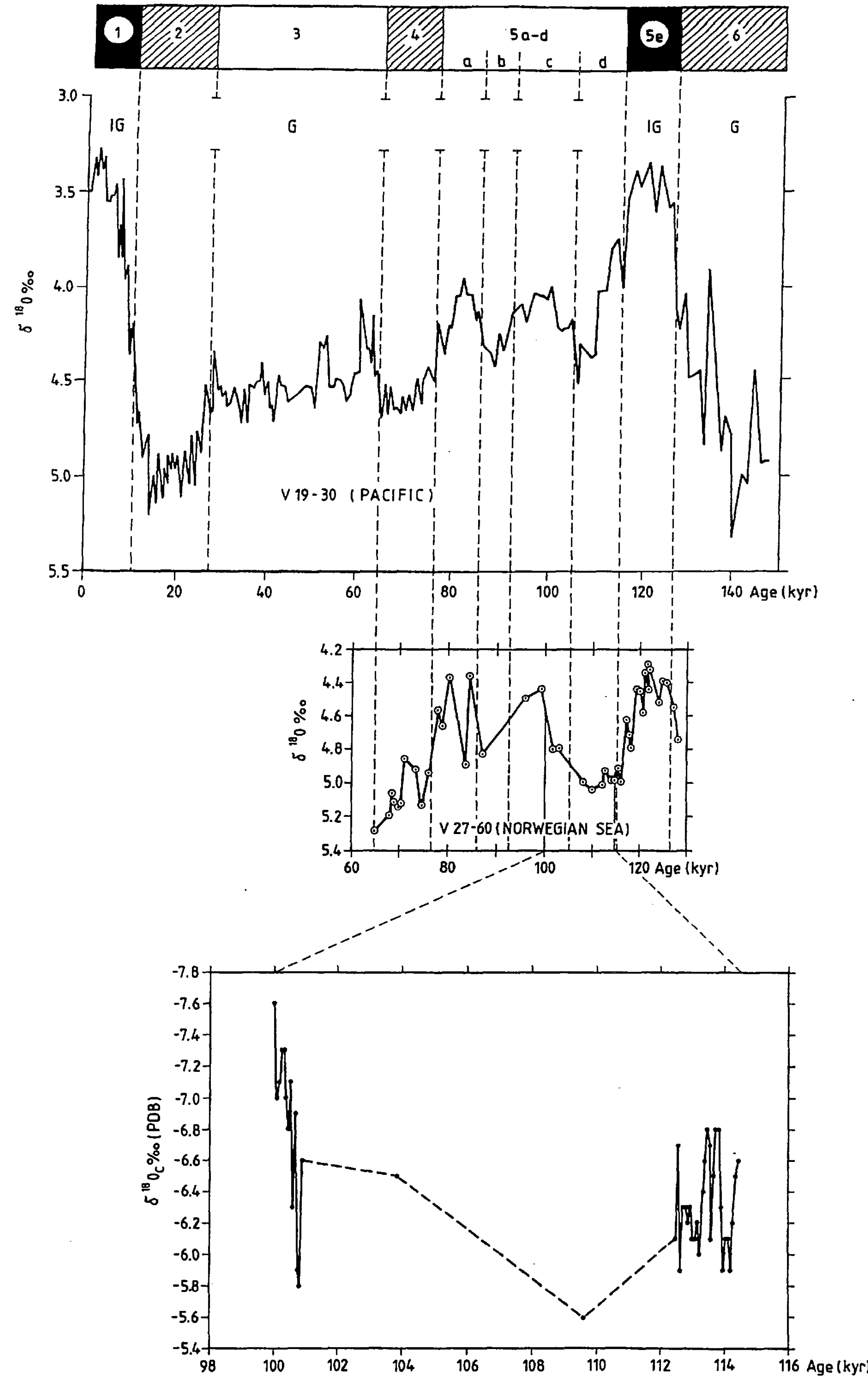

Fig. 1
Oxygen isotope record of benthic Foraminifera from core V19-30, East Pacific (according to Shackleton et al., 1983; division follows Labeyrie, 1984) - top; benthic Foraminifera from core V27-60, Norwegian Sea (Duplessy and Labeyrie, 1992) - middle; cave carbonate from the Zazděná jeskyně Cave, Moravian Karst - bottom.

The same flowstone layer was used for carbon and oxygen isotope studies. A detailed profile (42 samples in total) from base to top of this 10 cm thick layer was sampled and analysed. Small variability in $d^{13}C$ and $d^{18}O$ values which don't correlate with each other and the location of the sampling point deep in a narrow cave with limited ventilation suggest that the calcite was deposited in isotopic equilibrium with the seepage water.

The oxygen isotopic composition of cave carbonates is controlled by numerous factors. The most important factors are (i) temperature-dependent fractionation between calcite and water at the site of precipitation and (ii) oxygen isotopic composition of the meteoric water penetrating into the cave. The changes in oxygen isotopic composition of meteoric water of the past are influenced by numerous temperature and climate-related factorors, which are difficult to evaluate. Empirical evidence shows that in most caverns the cooler climate periods are accompanied by higher $d^{18}O$ values of the cave carbonates and vice versa (Gascoyne, 1992).

The studied flowstone layer from the Zazdìná jeskynì Cave records climatic changes during a ca. 15 kyr long period at the beginning of the last Glacial. A comparison of the $d^{18}O$ obtained record with the published oscillations of $d^{18}O$ values of marine benthic Foraminifera from V19-30 core (East Pacific, Shackleton et al., 1983) and V27-60 core (Norwegian Sea, Duplessy and Labeyrie, 1992) shows good correlation (see Fig. 1).
The laminated and thin-bedded silts deposited above the flowstone layer also provide some climatic information. These sediments were transported by meteoric water during a very rainy period. Poor vegetation cover on karst surface probably caused instantaneous penetration of meteoric waters to the limestones. The low amount of vegetation may have resulted from deterioration of climatic conditions. The laminated silts were deposited in the Zazdìná jeskynì Cave probably during the Early Weichselian/Early Pleniglacial or Middle/Late Pleniglacial.

Near the northern rim of the Moravian Karst a large profile in cave sediments is exposed in the Holštejnská jeskynì Cave. Three fluvial accumulations of different age are preserved in this cave. The oldest strongly weathered sandy gravels are covered by relics of a flowstone layer with inverse paleomagnetic orientation (Šroubek and Diehl, 1995). Consequently, the ages of the flowstone and the underlying fluvial sandy gravels are older than paleomagnetic boundary Brunhes/Matuyama (780,000 years). The middle fluvial accumulation is younger than 250,000 years (the age of the stalagmite below these sediments - Glazek et al., 1995). On the surface of the middle accumulation, relics of flowtone are preserved. The youngest sandy and silty fluvial accumulation was deposited probably during the last glacial period. On its surface relics of flowstone layer are also preserved.

Approximately 60 analyses of $d^{13}C$ and $d^{18}O$ were made from flowstones exposed in the Holštejnská jeskynì Cave. The resuts show that cave carbonates precipitated under different climatic conditions. The flowstone layer covering the middle accumulation of fluvial sediments consists of two parts - the basal part with a stalagmite (isotopic samples 1-5 in Fig.2) and the upper part of the carbonate layer (samples 6-10). Both parts show different $d^{13}C$ and $d^{18}O$ values (see Fig.2) and were deposited under different climatic conditions.

Because of the uncertainty in $d^{18}O$ of meteoric waters at the time of deposition a more precise calculation of the deposition temperature is impossible. The determination of dD values of the water trapped in fluid inclusions within the flowstone will allow the calculation of oxygen isotopic composition of meteoric waters and thus an estimation of mean annual surface temperature in the study area.

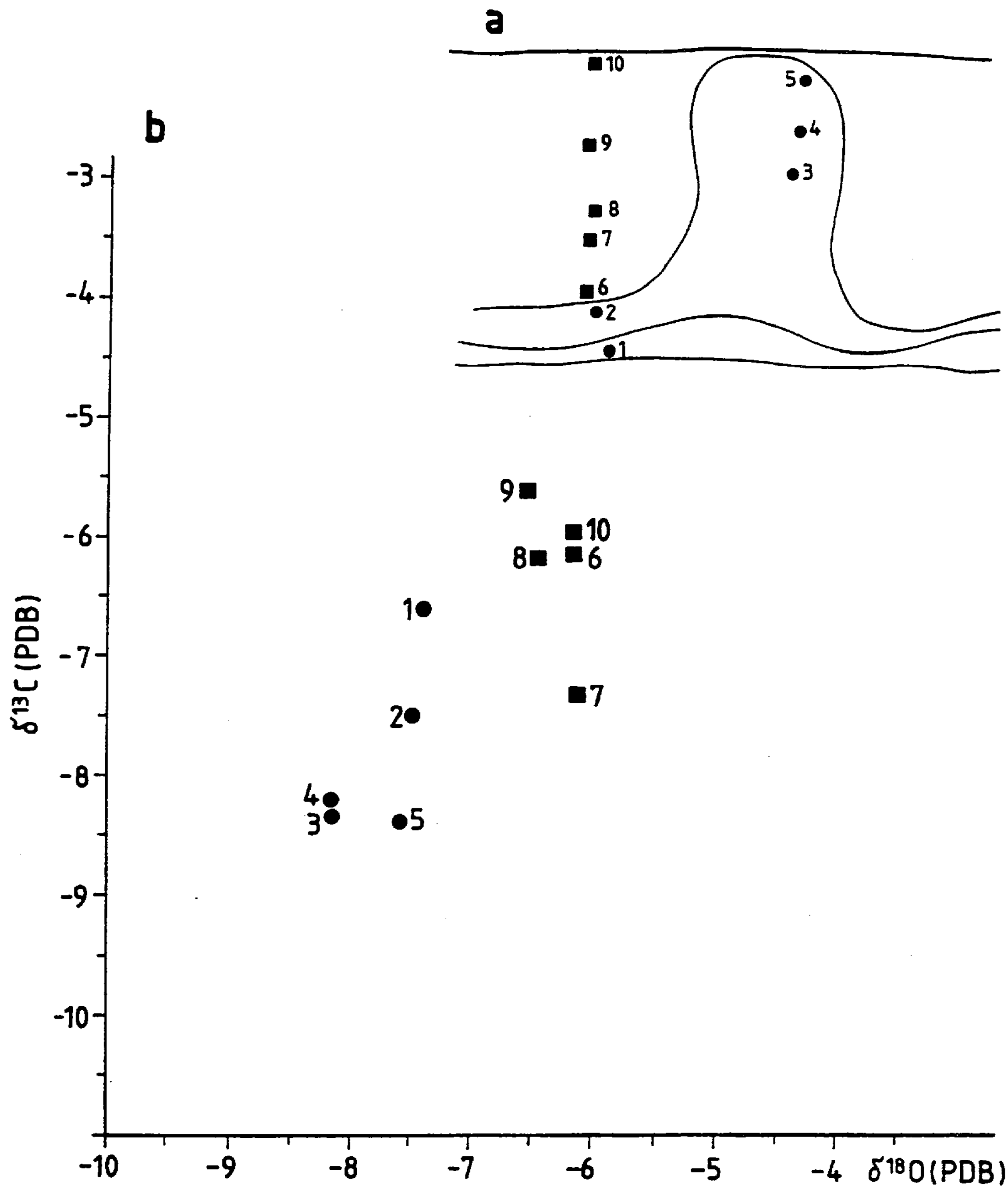

Fig. 2
Isotopic composition of the flowstone layer covering the middle fluvial accumulation in the Holštejnská jaskyně Cave, Moravian Karst: a) sampling points in the profile through 25 cm thick layer, b) $\delta^{13}C$ and $\delta^{18}O$ values from the lower part of flowstone layer with stalagmite and the upper part of the carbonate layer

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Stromatolitic stalagmites in Škocjanske Jame (Škocjanske Jame Caves, Slovenia)

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Very rare litearture about freshwater stromatolites was found. In Škocjanske Jame Caves, Slovenia), stromatolite stalagmites were discovered in one of the entrance halls mnamed Schmidl' Hall. In the pilot study, the sample location, orientation, morphology and internal structures were studied, both on polished surfaces and in thin sections. Cave stromatolitic stalagmites could be a source of past climatic conditions.

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Quaternary Cave and Landform Development in the Tysfjord Region, north Norway.

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Introduction

General cave levels and transitional morphology betveen vadose and phreatic phases can be used to interpret the evolution of the cave in relation to the surface geomorphology. Fossil, phreatic conduits, hanging above the present base-level in a formerly glaciated region, can only have existed when the limestone was not freely drained as it is now. Generally, cave levels are controlled by the local erosional base-level or by structural/stratigraphic factors that may perch passages above the base-level. Three different external conditions may explain vadose/phreatic transition in formerly glaciated terrain: bedrock control, ice-contact damming, or periods of high sea level stand. The aim of this study is to identify former watertables in the Storsteinshola cave system in Kjøpsvik, and try to relate them to the external conditions (Lauritsen 1996).

The Storsteinshola cave system in Kjøpsvik, north Norway

The master cave system in the Kjøpsvik karst area (Figure 1), Storsteinshola, display the largest paragenetic gallery known in the country (Lauritzen and Lauritsen 1995). The main corridor forms an inverted canyon, ~ 5 m wide and ~ 10 m high. The paragenetic roof have risen up towards a now defunct, sediment-choked paleospring (Nygrotta) at about 60 m a.s.l. In total, the passages display a complex morphology, which reveals several phases of development that can be associated with corresponding changes in the local base-level. The prominent paragenetic features were followed by erosion and outwash of the sediment fill and local wall collapse. After this, the cave was totally refilled with glacigenic gravel, sand and clay through one or several phases.

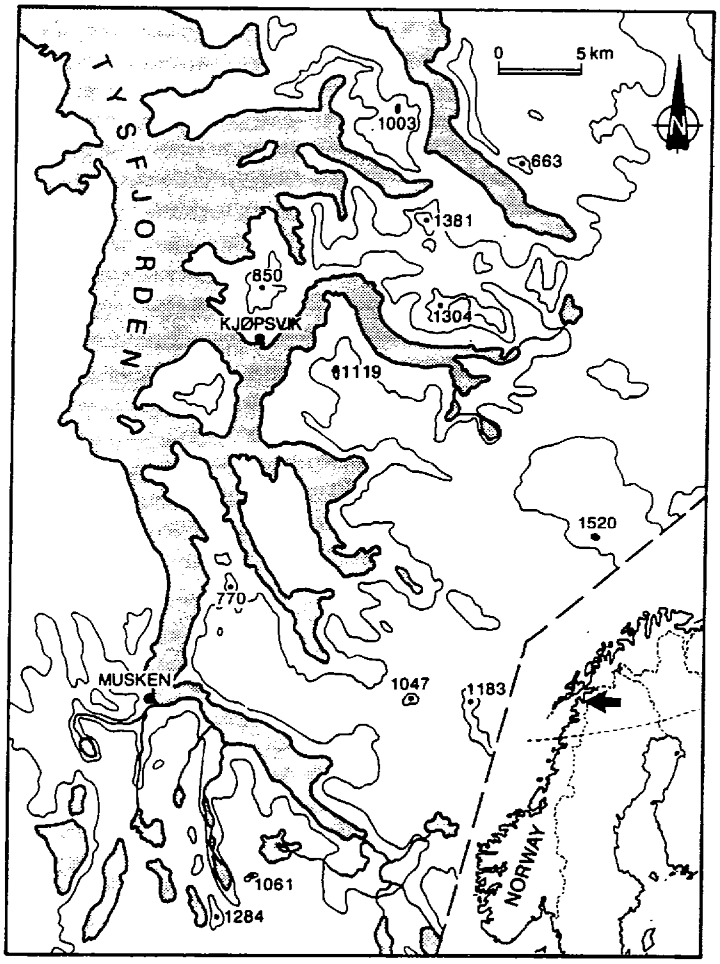

Figure 1: Location map.

Relation to surface morphology

Most of the present sediments in Storsteinshola where deposited during the last glaciation (Weichselian) or earlier (Nese 1996). Consequently, the younger vadose entrenchments in Storsteinshola, which in part intersects these sediments, may then be related to the last deglaciation in the area. This is supported by the high paleodischarge regime (2 - 5 m^3sec^{-1}) associated with the vadose entrenchments (based on passage and scallops morphometry). This flow regime demands a drainage area about ten times greater than the present catchment which is about 4 km^2 - or a regime with correspondingly higher specific runoff. A valley glacier filling the inner parts of Tysfjorden would increase the runoff sufficiently to account for the discharge associated with the vadose features in the cave. The most pronounced vadose downcutting in Storsteinshola corresponds in altitude with a marine shore line about 49 m a.s.l. in Kjøpsvik. This suggests that at least the last stages of the erosion of the sediment fill in Storsteinshola was controlled by sea level when the ice-contact damming no longer could sustain a high spring level for the cave system.

The largest collapse in Storsteinshola, which in part have destructed the pre-existing paragenetic gallery, are covered by the sediment infilling from the last glacial. The paragenesis, which must have operated against a stable base level over a longer time span, thus pre-dates this sediment fill. During the paragenesis the local base-level must have been at least 60 m a.s.l., which corresponds neatly with the altitude of the paleospring. Both ice-contact damming and sea-level can, in principe, satisfy these conditions, but they will not be sufficiently stable over the time-spans we think are needed for development of a paragenetic gallery with ~ 10 m vertical amplitude. Using present-day P_{CO2} conditions, an interglacial climate could produce a corrosion rate of roughly 10^{-2} - 10^{-1} cm/y (Lauritzen 1990). This converts to a total timespan of 10^4 - 10^5 years for the total paragenetic amplitude, during which a stable base-level is required. The most plausible explanation for base-level control during the paragenesis is therefore bedrock control.

Geomorphic analysis of the Tysfjord region displays several morphological levels, which can be remnants of former land surfaces. Some of them may be regarded as raised strandflats (Nansen 1922). The analysis are based on identification of distinct levels and knick-points on topographic maps, together with field observations. Distinct fjord shoulders, at an elevation of about 100 m a.s.l., are evident in the outher parts of the Tysfjorden. The observed paleospring level in Kjøpsvik, together with two paleo-springs in Hellemofjorden (Figure 1), falls slightly underneath the lowest morphological level in bedrock (Figure 2). This correspondence suggests that the rock shoulders, which are of regional extent, are remnants of a formerly more extensive land surface which then can explain the base-level control of the paragenesis in Storsteinshola.

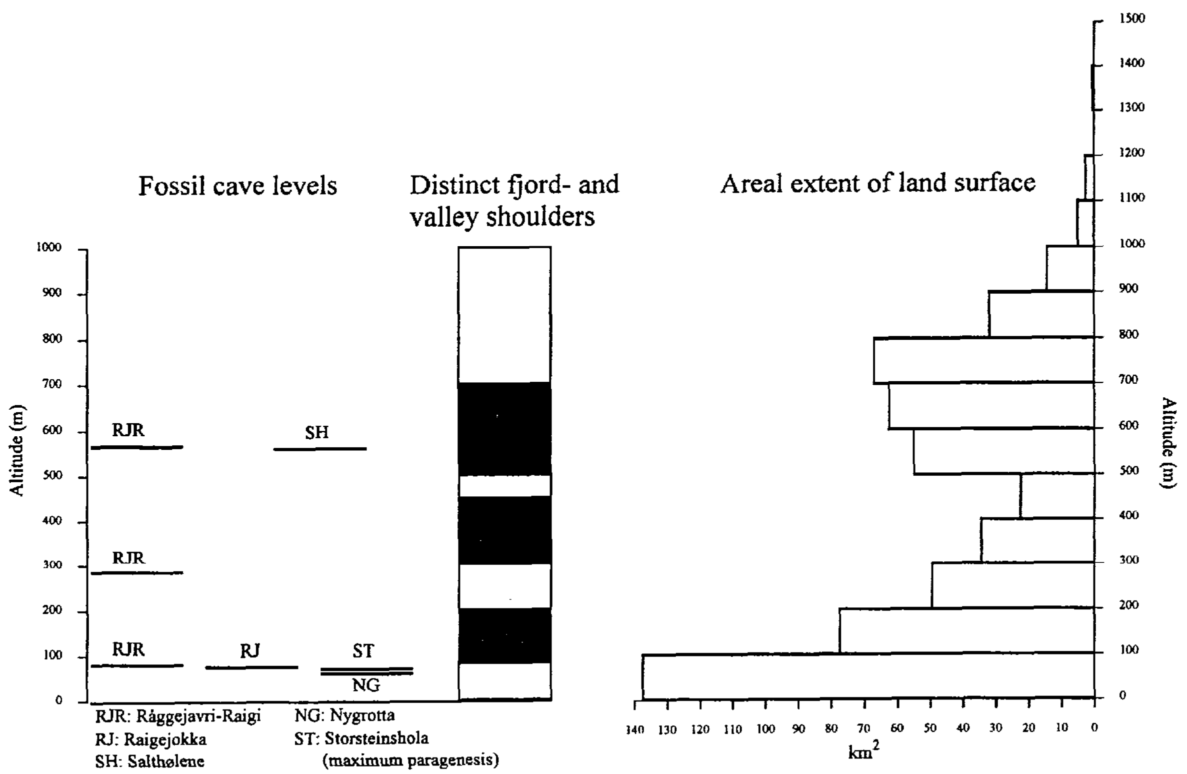

Figure 2: Altitude of cave levels in the Tysfjord region (left) combined with the distinct topographic knick-points in the same region (middle), group in three different levels. The histogram (right) shows the areal distribution of the land surface at different altitudes in the same region as the caves. Only topographic levels extending ≥ 0.5 km² are considered.

The probable age for the cave system

Our correlation between the palospring and remnants of former valleys imply a considerable age for the speleogenesis, and the time required for the total speleogenetic history may then be discussed in the same terms as other, relict (phreatic) caves in Norway (Lauritzen 1990). The highest mountains and their enveloping surface in Norway are thought to be remnants of a paléic surface formed prior to or during the Tertiary (Gjessing 1967; Klemsdal and Sjulsen 1988; Doré 1992; Riis 1992). Subsequent uplift and erosion have modified this surface to its present state. Remnants of these surfaces may be illustrated by the longitudinal section through the highest mountain summits from Vestfjorden in north-west in to the highest mountain massifs east of the Swedish border (Figure 3). Analysis of the surface morphology revealed a series of former valley systems. The paléic valley, which drained into the Baltic, can be traced quite far westward from distinct surface remnants dipping eastward. Headward erosion, by fluvial and glacial processes during the Tertiary and Quaternary, have gradually lowered and dissected the paléic surface, forming valleys and fjords, and moved the regional waterdivide eastward to its present location (Figure 3). All the presumably Tertiary erosional surfaces lie far above the paleospring level in Kjøpsvik (Figure 3). Commencement of karstification was also dictated by erosional uncovering of the overlying rocks, corresponding to erosion of more than 1000 m in the distal parts of Tysfjord. This suggests that the caves in Kjøpsvik are relatively young, compared to the paléic landscape, but they are certainly much older than the Weichselian.

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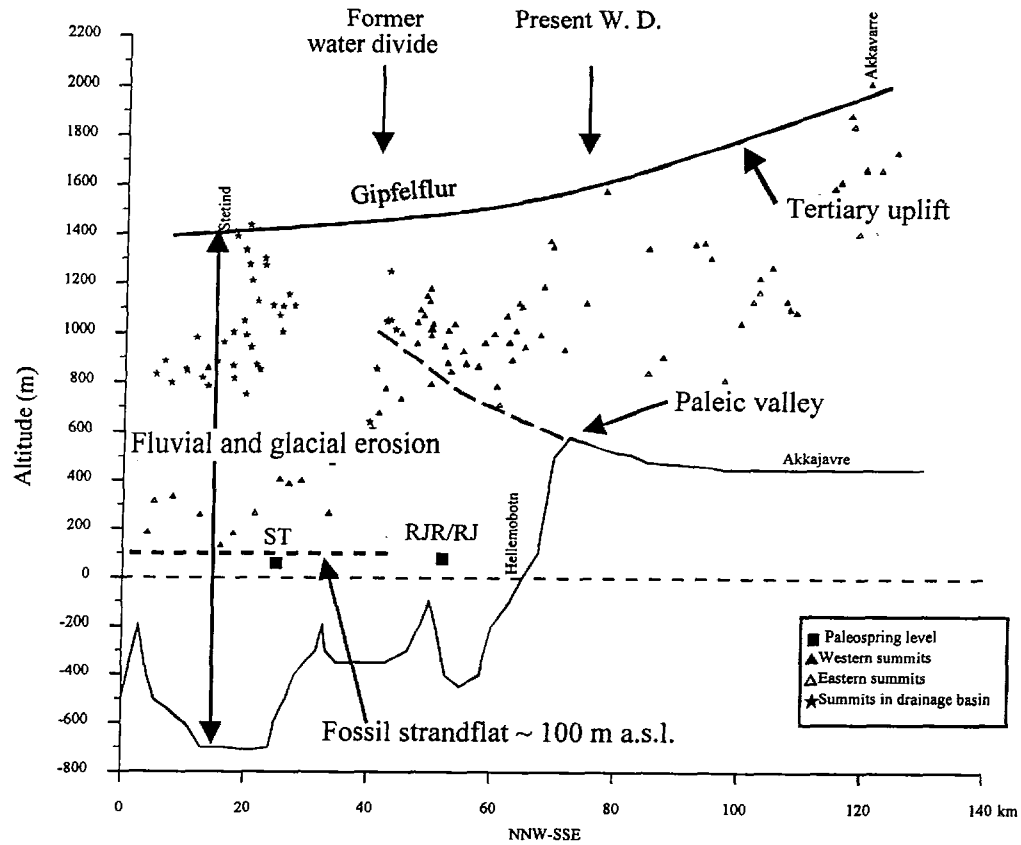

Figure 3: Longitudinale profile of Tysfjord and Hellemofjord with mountain summits in the Tysfjord drainage basin, which are remnants of former land surfaces. The accordant summits (Gipfelflur) define a surface which is dipping westwards is shown, together with an extrapolation of the paléic valley system draining the opposite direction. The ~ 100 m level (platform) in bedrock corresponds to the paleospring level in Kjøpsvik and Hellemobotn (ST: Storsteinshola. RJR: Råggejavri-Raigi. RJ: Raigejokka).

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Calibration of speleothem stable isotopes against historical records: a Holocene temperature curve for north Norway?

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Introduction.

The stable isotope signal in speleothems have been considered as «promising» for paleotemperature estimates for more than two decades. However, the remaining problem has been to find a unique functionality between temperature and the $\delta^{18}O$ signal. Provided that the calcite is precipitated in isotopic equilibrium, according to the Hendy (1971) criteria, the T (temperature)-dependence of the oxygen-isotope composition of calcite ($\delta^{18}O_C$) is dictated by the thermodynamic constants in the O'Neill equation (O'Neil *et al.* 1969) and by the isotopic composition of the dripwater [$\delta^{18}O_W = F(T,g,t)$], which in combination (Dorale *et al.* 1992) yields:

$$\delta O^{18}{}_C = e^{(\frac{a}{T^2}-b)}[F(T,g,t)+10^3]-10^3 \qquad (1)$$

where a and b are constants of the O'Neill equation, and F(T,g,t) is a function of temperature (T), geographic position (g) and time (t). The t- and g- dependence is intended to describe time- and site- dependent changes in stormtrack patterns (rainout) and changes in the source (seawater, $\Delta\delta^{18}O_{SW}$) due to the ice-volume effect (Lauritzen 1995). F(T,g,t) also include any averaging or biasing taking place when rainwater (or snow meltwater) passes down through the vadose zone before it enters the cave. Therefore, the problem of paleotemperature deduction is to find an approximation to F(T,g,t) that is valid for past climates and longer timespans. In its simplest form, the Dansgaard (1964) relationship may serve as an approximation of F(T,g,t):

$$F(T,g,t) \approx c(T-273.15)+d+\Delta\delta^{18}O_{SW}(t) \qquad (2)$$

c and d are site-dependent constants. The term $\Delta\delta^{18}O_{SW}(t)$ is added to model the time-dependent ice-volume effect. Provided that the constants c and d can be calibrated, equations (1) and (2) can be solved uniquely for T. This was attempted on a Holocene stalagmite from Mo i Rana, north Norway (66° 20' N).

Sample analysis and data processing.

The 32 cm tall stalagmite (a very large specimen at this latitude) grew directly on stream gravel and displayed some growth disturbance at the tip. TIMS dating revealed a basal age of 8 500 ± 200 yr, and a top age of 180 ± 15 yr. It was therefore inferred that the stalagmite ceased to grow during the Little Ice Age (LIA), around 1750 AC. The whole sequence was first sampled at every 5 mm for stable isotopes, later for every 1 mm, corresponding to 25- 30 years' resolution. Present- day stalactite tips (immediately above the sample) and dripwater matched the present-day cave temperature (+ 3.5 °C, Einevoll and Lauritzen, 1994). Based on historical and botanical records, it is generally accepted that the LIA climatic deterioration

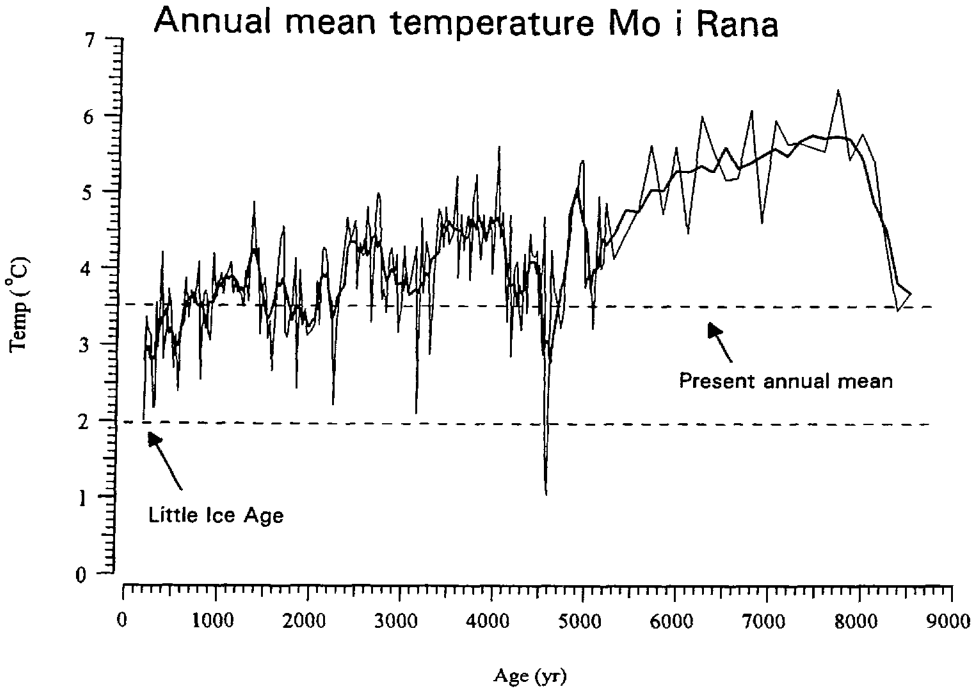

Figure 1. Time-series of isotope-derived temperatures for stalagmite SG-3. Thin line: single data points; thick line: 5 point running mean. Please note that before 5 500 yr, sampling is much less dense than later.

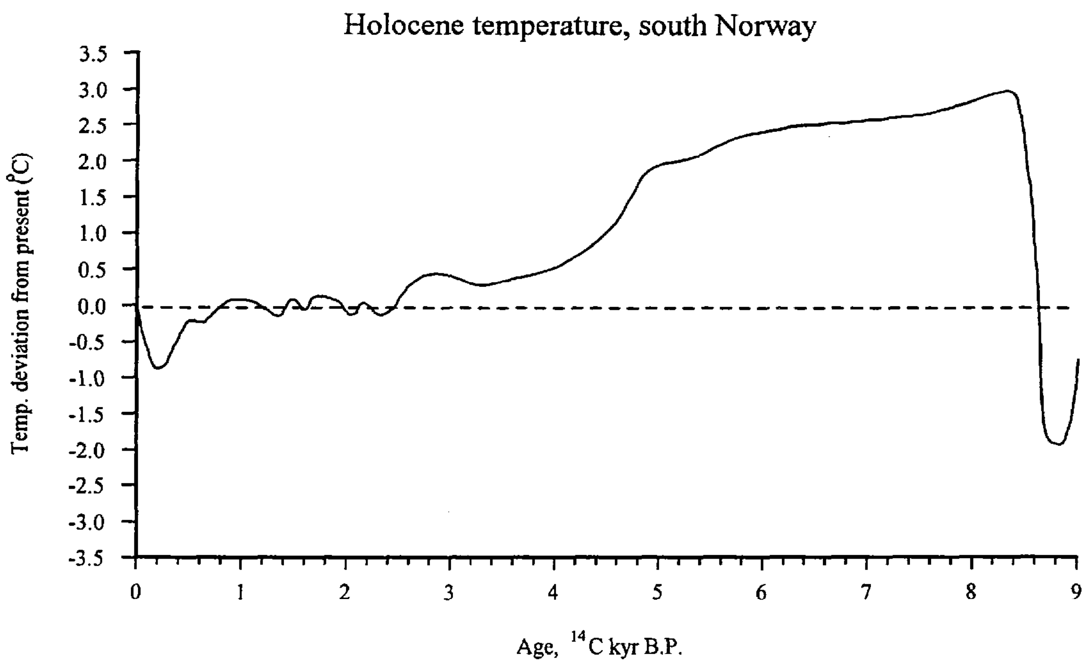

Figure 2. Temperature curve for south Norway during Holocene, derived from palynological (Moe, 1995) and combined botanical and glaciological data (Nesje and Kvamme, 1991).

in this region was accompanied by a drop of 1.5 °C in mean annual temperature. Using T and $\delta^{18}O_C$ for the present-day conditions and for LIA, respectively, is sufficient to calibrate the constants c and d in equation (2), [$\Delta\delta^{18}O_{SW}(t) = 0$]. This yielded c = -0.096 and d = -15.09, which contrasts the positive coefficient (c) of the Dansgaard relationship on modern precipitation. The time-dependent variation of «SMOW» ($\Delta\delta^{18}O_{SW}(t)$) was modeled from a standard, global stable isotope curve (i.e. Imbrie *et al.* 1984). The equation set (1 & 2) was then solved numerically for each stable isotope measurement. This resulted in the temperature curve in Figure 1.

Discussion.

The resulting temperature curve range over 5 °C, with a maximum some 3 °C higher than present, and with a cold spike at about 1 °C. The spiky nature of the curve is enigmatic, as it may suggest that the mean annual temperature varied rapidly by up to 3 or 4 °C over periods of 25-50 years, which is well comparable with the recorded «anthropogenic» temperature rise since the industrial revolution. This variation is induced by variations in the stable isotope measurements, and cannot easily be explained by post-depositional effects. For instance, the sample spacing is at least an order of magnitude smaller than the size of individual crystallites in the specimen, and structures like visible growth bands and luminescent bands are much finer.

A 5 point running mean of the data set compares favorably with totally independent temperature data from south Norway, based on botanical and glaciological evidence (Nesje and Kvamme 1991, Moe 1995). This suggests that the «average» temperatures derived from the stalagmite may be an adequate estimate of Holocene temperatures, but closer comparison with historical measurements during the last 200 years (which is lacking in the present record) is needed before confidence can be put on the «noisy» nature of the data.

It is also interesting to note that the «climatic optimum» in the speleothem temperature series is basically introduced through the $\Delta\delta^{18}O_{SW}(t)$-term.

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a Conference held at The Department of Geology, University of Bergen, Norway, August 1-4th 1996.

Preliminary comparison between Norwegian and Polish speleothem growth frequencies

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Speleothem deposition is controlled by climatic factors. The deposition of subaerial speleothems (stalactites, stalagmites and flowstones) occur only if supersaturated percolation water can enter cave galleries. Surpersaturation is generally achieved through CO_2 degassing due to elevated soil P_{CO2} realtive to P_{CO2}. Due to higher drip rates and higher production of soil CO_2, speleothem deposition is enhanced under warm, humid conditions. Conversely, due to the freezing of water and to reduced CO_2 production, speleothem deposition is inhibited during periods with permafrost . In a subglacial situation, caves may become an integrated part of the glacier aquifer and flooded. Cosequently, speleothem deposition is halted, and corrosion of existing speleothems may occur (Ford, Williams 1989).

This effect would expectedly be more pronounced at higher latitudes where thicker ice-sheets existed for a longer period of time. Therefore, the occurence of narrower and fewer time-windows for speleothem deposition at higher latitudes may then reflect paleoclimatic gradients during various intergalcials and interstadials through Europe (Lauritzen 1993).

From this point of view, the growth intervals for speleothems in karst areas in southern Poland may provide a very interesting test for this hypothesis. In this paper we present new U-series dates on speleothems from the Sudety Mountains, Holy Cross Mountains, Jura and Tatra Mountains, areas which were either nunataks or were situated south of the limits of the Scandinavian ice sheets.

The data sets consist of about 150 $^{230}Th/^{234}U$ dates of norwegian speleothems, all of them taken approximately at the arctic circle (i.e. at 65-68^{o} N. latitude). This data set is compared with the presently 120 Polish dates (i.e south of 51^{o} N latitude).

Probability density functions (PDF) for speleothem growth were calculated from the scewed PDF for each date, using the original $^{230}Th/^{234}U$ and $^{234}U/^{238}U$ with the corresponding analytical errors. Filters were used to screen out dates with excessively low precision (10%). Confidence bands for determination of significant peaks and throughs in the PDF curves were determined by means of Monte Carlo experiments of 100 data sets of 150 random ages with 10% error. Throughs and peaks in the growth PDF curve that lie outside these boundaries may be taken as significant signals of decreased and increased sepeleothem growth, respectively. Because the time resolution becomes extremely low for -counting based U-series ages greater than about

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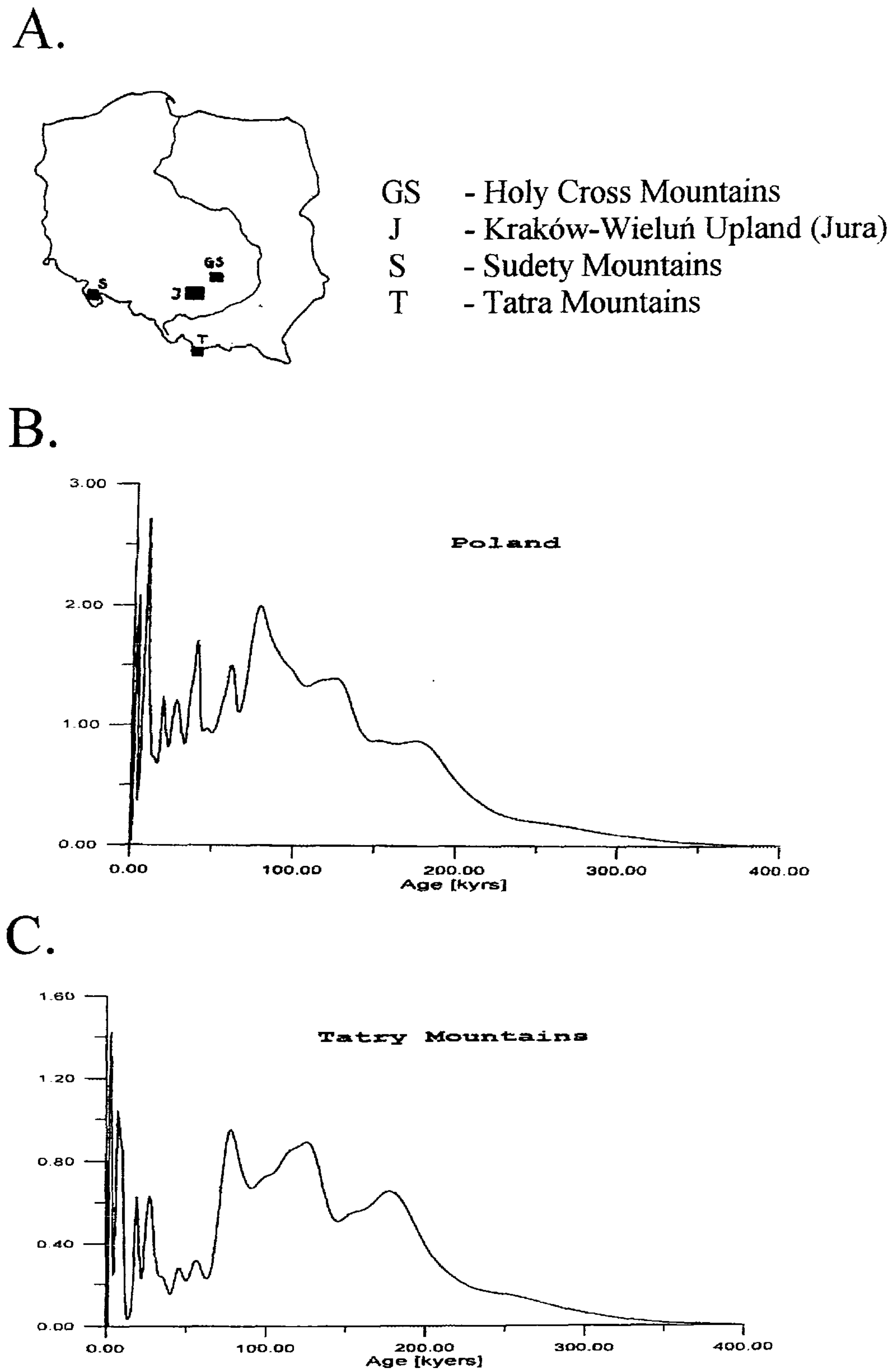

Fig. 1.

Uranium-series age data for Polish speleothems. A- locality of studied areas; B- frequency curve for Polish speleothems; C- frequency curve for the speleothems from Tatra Mountains.

150 ka, meaningful comparison can at present only be done for the last interglacial/glacial cycle, i.e. through the Eemian and Vistulian (Weichselian) stages. This limitation will be reduced when our TIMS dates (work in progress) becomes available.

In all regional age frequency distributions of speleothem dates the Holocene signal is the dominant, with decreasing frequency with time. This is due to two effects. First, Holocene speleothems dominate the available surfaces in caves. Second, speleothems tend to be destroyed over time, and therefore, older specimens are rarer than younger ones. However, this distiribution is not continuous; peaks and throughs in age histograms that broadly correlated with known warm periods during the upper Pleistocene were early reported.

The Norwegian PDF curve display strong speleothem growth through isotope stage 5 , where the substages 5a, 5c and 5e can be identified as minor peaks on the larger, broad signal. Speleothem growth wa sabsent during isotope stage 4, but a strong peak represent isotope stage 3. The Holocene is represented with proliferent growth, in which a minor peak and through can be attributed to Allerod (14 ka) and Younger Dryas (11.5 ka), respectively.

The Polish data display a similar, strong signal during isotope stage 5, but speleothem growth did not decrease significantly during the Vistulian stages. Allerod is visible as a prominent peak.

The two distributions confirm the conclusion from earlier studies (Lauritzen 1993) that there is a significant latitudinal variation in time-dependent speleothem growth frequency. beyond the limits of the Vistulian glaciation, speleothem growth PDF tend to become continuous through stadial stages. At high latitudes, in an area which experienced thick ice cover during the Vistulian glaciations (i.e. north Norway), the climatic deterioration and ice cover was sufficient to inhibit speleothem deposition.

The effect of local glaciations in the Carpatian ranges may be illustrated by the local subsample from the Tatras. Except for displaying more pronounced peaks for the stage 5 substages (which is in part due to higher U- content and more precise dates in this area) there is a significant depletion in speleothem growth PDF during isotope stage 4. In spite of a significant *peak* at stage 3 (ca 30 ka) the corresponding *through* in stage 2 is not significant. We take this as evidence for that the local glaciations in the Tatras may have been more severe during isotope stage 4 than during stage 2. The same effect is evident in the Sudetes (Hercman et al. submitted), where we have demonstrted continuous growth of single stalagmites through stage 2, but with hiatuses corresponding to stage 4.

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Annually resolved stable isotope data from speleothem calcite by laser ablation/ mass spectrometry

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Seen on the background of the very high stratigraphic and chronological resolution attained for speleothems (i.e. Shopov *et al.* 1989, 1994, Baker *et al.* 1993, Genty & Quinif 1996), it is challenging to try expanding the resolution of stable isotope measurements. With sufficiently high subsample resolution, information may be gained on possible seasonal variation of $\delta^{18}O_c$, which could then be tested against the seasonal banding of organic, fluorescent material in speleothem. Moreover, in order to test possible correlation between the $\delta^{18}O_c$ signal and historical temperature variations, and thereby calibrate the $\delta^{18}O_c$ function (Lauritzen 1996), annual or even higher resolution on $\delta^{18}O_c$ measurements is needed. Using a dentist's drill, calcite samples can be taken down to about 1 mm diameter or slightly less. Except for very fast-growing broomstick stalagmites, this correspond to several years. Using Laser Ablation microprobing, the calcite can be sampled at intervals of about 20 µm. Here, we demonstrate the use of this new technique on a Holocene stalagmite from north Norway. Laser Ablation microprobing was combined with fluorescence excitation-emission micro-spectroscopy (i.e. Kihle 1995) to try coupling the Shopov-bands with $\delta^{18}O_c$.

Sample description and stratigraphic resolution.
The sample is a 16 cm tall, macrocrystalline and translucent stalagmite (SG-95) from the same locality as sample SG-93 (Lauritzen 1996) from Mo i Rana, north Norway (66° 20' N). The sample was actively growing in July 1991 when the cave was instrumented with Aanderaa data loggers for measurement of drip rates and microclimatic parameters (Einevoll and Lauritzen 1995). From July 1995, the dripping from the feeding stalactite was intercepted by a drip-rate gauge and sampled for chemical analysis. In contrast to SG-93, this sample shows no growth disturbances at the apex, which is quite regular.

The sample has not yet been dated, but based on analogy with the nearby growing SG-93, we may assume that the base is 8 000 - 10 000 years. This converts to an *average* growth rate of 16- 20 µm/ year. The sample display visible, opaque growth bands, without any detrital banding. The upper 27 mm from the drip apex was sectioned into a 100 µm thick polished wafer and analyzed for fluorescent banding, using the equipment described in Kihle (1995). The wafer displayed distinct banding across its entire length, with an interval varying between 10 and 40 µm. The last 40-50 cycles are shown in Figure 1.

Figure 1. Shopov-bands for the last ~ 40 cycles before 1991 when deposition was interrupted. The section measures 1.37 mm (1cm = 90 μm), starting from right (July 1991).

IFE Carbonate (black) & Silicate (red) Laser Ablation Micro Probe line flow sheet, Dec. 1995

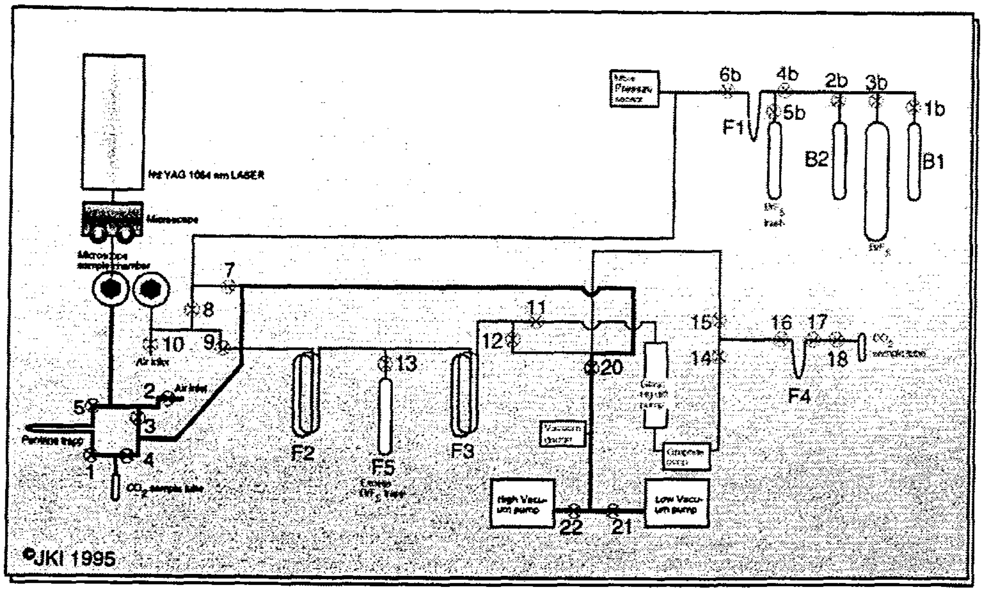

Figure 2. The IFE gas extraction line for Laser Ablation. Thick black lines: carbonate line, thin lines: silicate extraction line with BrF_5.

Laser ablation/ mass spectroscopy.

The Laser Ablation Micro-Probe line used at IFE[1] is shown in Figure 2. The wafer is placed on a tungsten 'anvil' inside an evacuated steel ablation chamber with transparent sapphire or quartz lid. The chamber is connected to a vacuum line with freeze traps as shown in Figure 2. The produced CO_2 gas is collected in sample tubes, which is transferred to a Finnigan MAT 251 mass spectrometer, where it is measured. The Ablation chamber is placed under a NIKON Optiphot Microscope with 5x and 10x objectives (yielding 3.7x and 7x magnification). The beamsplitter is coated with ZrO_2/SiO_2 which gives 98% reflection at $\lambda = 1064$ nm (ablation laser wavelength) and 50/50% reflection/transmission at $\lambda < 700$ nm. The table can be moved by hand or at a programmed rate in both directions. Focusing and targeting is done with a red pilot laser (He:Ne). In order to ease the reconstruction of subsample positions (during ablation, the wafer may move or split), the whole process can be watched (and recorded) on a video screen.

In transparent speleothem calcite, optical transmissivity may be so high that 'ignition' is impeded. Once ignited, stripes that are sufficiently long to yield enough CO_2 is easily obtained

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[1] IFE= Institutt For Energiteknikk.

by moving the X-table during the process. In order to increase the probability of 'ignition' we have tried various light-absorbing or reflecting coatings (on the *verso*), which do not contain O or C that may interfere with the analyses, like Ag mirrors (using Tollen's reagent, Vogel 1967, p. 330). The simplest remedy we have found so far, is sputtered Au/Pd coatings of about 25 Å on the *verso* of the wafer. Using this, the track width was 25- 32 µm. By cutting successive tracks from the top end of the wafer, sample width can be reduced to about 20 µm. Due to the reaction:

$$CaCO_3 \rightarrow CaO + CO_2$$

a calibration factor of + 11.7‰ is necessary for compensating isotope fractionation of oxygen between MeO and CO_2. This is based on repetitive measurements on standards which are measured in parallel with Laser Ablation and conventional H_3PO_4 dissolution (Smalley *et al.*, 1989). The precision obtained on the present extraction line is ±0.1 and ±0.2‰ for $\delta^{18}O$ and $\delta^{13}C$, respectively.

Preliminary results.
At the moment of writing, laser ablation was performed at the 20 µm outer layer at the apex (probably corresponding to the years 1990 and 1991), at 9 mm and at 20 mm from top. The 'last annual cycle' yielded $\delta^{18}O_c$ = -6.53 ±0.14‰ and $\delta^{13}C_c$ = -0.76 ±0.09 ‰ (PDB). This is in good accordance with previous results of Einevoll & Lauritzen (1994), who measured stalactite tips and dripwater in various positions in the cave, which yielded $\delta^{18}O_c$ = -6.96± 0.59 ‰ (PDB) [n=10] and $\delta^{18}O_w$ = -10.46±0.11‰ (SMOW) [n=10, 3 years] for stalactite tips and dripwater, respectively. This convert to a cave isotopic temperature of +1.70 ± 2.0 °C, as compared to the measured cave temperature of +2.5 - 3.0 °C.

It can be concluded that ablation can be done at sufficiently small intervals to allow comparison between $\delta^{18}O_c$ and recorded temperature and precipitation on an annual basis. Further results will be presented during the conference.

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Late Quaternary Climatic History of the Helderberg Plateau, New York, USA: Preliminary Results from U/Th Dating of Speleothems

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The Helderberg Plateau is a gently dipping sequence of Upper Silurian to Middle Devonian carbonates that outcrops across the center of New York State, USA (Figure 1). The Plateau supports a well-developed karst and has undergone multiple glaciations during the Pleistocene. Stalagmites and flowstone were collected from four caves that cover a 50 km traverse, WNW to ESE, along the strike of the outcrop. A total of 29 U/Th alpha count dates were obtained. While the number of samples is low, some preliminary observations are possible.

Oesquethaw Cave, developed in the Middle Devonian Onondaga Formation, in the southeastern portion of the Plateau, contains almost 2 km of small, active passage. Two stalagmites from this cave yielded 5 dates, all less than 10 ka in age (Table 1). Palmer (1972) argued that Onesquethaw Cave might be post glacial in origin, as its passages are small, active, and in accordance with the glacially re-arranged topography. The U/Th dates from the cave support this argument.

Caboose Cave is developed in the Lower Devonian Manlius and Coeymans Limestones approximately halfway along the Plateau traverse, and consists of 250 m of passage, with one large trunk fragment. Five stalagmite and flowstone samples were collected from the cave, and provided 13 dates (Table 1). The dates range from 56 ka to 207 ka, with a distinct clustering from 56-100 ka and 172-207 ka. Some of the samples (C-1, C-3, C-5) were flowstone clasts in coarse sediment, so their growth position cannot be determined. The cave is underdrained by small, youthful passages during low flow but older, higher passages flood to the roof during high discharge events (Mylroie, 1977). The older nature of these upper level passages is supported by the U/Th dates.

Schoharie Caverns is located a few km west of Caboose Cave, in the same rock units, and consists of over 1.5 km of passage, the last half of which is accessible only by divers. One flowstone sample was collected from this cave, part of a large mass directly against the cave wall. Six samples from this flowstone all dated to in excess of 350 ka (Table 1). The cave was originally dug open, the entrance and the cliff containing it having been buried in glacial till. The U/Th dates support the field evidence (Mylroie 1977) of the cave being at least older than one glaciation.

Barack Zourie Cave is located at the northwestern end of the traverse, in the same units as the previous two caves, and it contains over 5 km of passage on several levels. Two stalagmites were collected from large passages, and they yielded 5 dates (Table 1). The dates all cluster at about 144-161 ka, except for one, an obvious younger overgrowth that had a 61 ka date. Two previous dates, from a stalagmite in the upstream end of the system, were 165 ka and 277 ka (Dumont, 1995). The cave drains a glacially-blocked valley, indicating it existed at least prior to the last glaciation; the U/Th data support this interpretation.

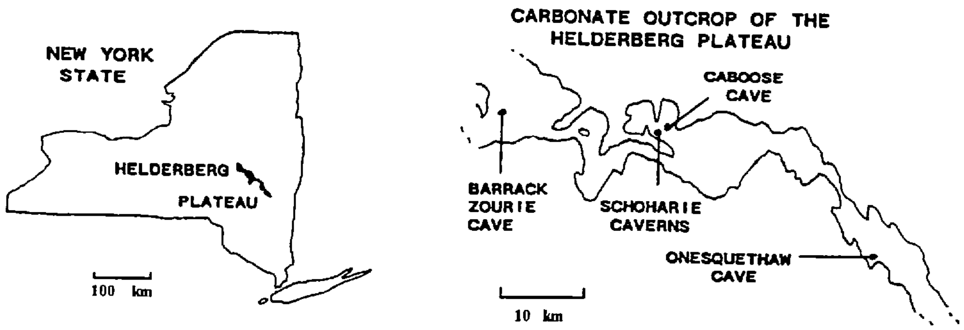

Figure 1. Location of the helderberg Plateau and the investigated caves.

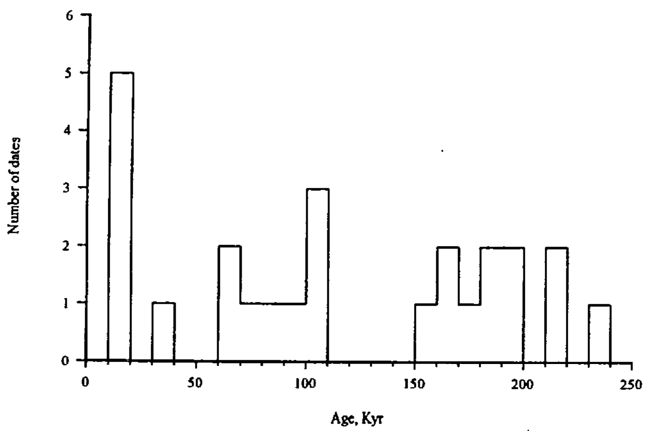

Figure 2. Histogram of the U-series dates. Class interval 10 kyr.

The dates collected so far are insufficient in number to allow any sort of detailed paleoclimatic interpretations to be made. The dates do indicate that both pre and post glacial (last glaciation) caves exist in New York. The clustering of dates in the 56-100 ka and 170-207 ka range is a bit surprising, as are the lack of dates during the last interglacial time period (which may be an artifact of the sampling number). The existence of dates beyond equilibrium (>350 ka) indicate that New York caves, as has been shown elsewhere, can survive multiple glaciations.

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Interstadial/ Interglacial fauna from Norcemgrotta, Kjøpsvik, north Norway.

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Vertebrate taphonomy in glacial environments.

Terrestrial fauna remains of pre-Holocene age are extremely rare in Norway. This is in part due to the unfavorable taphonomy of vertebrates in a high energy glacial environment, where the rate of destruction is large compared to the rate of burial (Hanson, 1980). The ratio of fossils to sediment may be extremely low in such environments, unless exceptional conditions of concentration processes and preservation can be met. It is therefore not surprising that the most complete and diverse fossil assemblages come from well-protected sites, like the entrance facies sediments of karst caves. Proper excavation in a cave is a complicated and manpower- consuming process. It is therefore exceptionally fortuous to find the fossiliferous sediment fills in a very large cave passage readily exposed for study, like in the Kjøpsvik karst, where a large, fossil karst conduit fragment was intersected by tunnel constructions in the limestone quarry. Here, we present the fauna remains, their environmental provenance, chronology and paleoclimatic implications of the deposits in «*Norcemgrotta*».

The cave and its stratigraphy.

Together, *Norcemgrotta* and *Nygrotta* form two fragments of a single (in part paragenetic) conduit which leads upwards towards the paleospring. Except for a few air pockets along the ceiling, it is totally filled with sediments that were transported from deeper inside the cave system towards the spring (Nese and Lauritzen. 1996, Lauritsen and Lauritzen 1996).

The sediment choke is more than 13 m thick, consisting of sands, gravel and diamictic sediments, Figure 1. It consits of two, now separate sections, which can be correlated. neither of them are excavated down to bedrock. These sediments occur in at least 3 cyclic upwards coarsening units. Each of these units consists of laminated silts (which drape around protruding clasts in the underlying surface), followed by well- sorted sands which grade upwards into gravel beds that are terminated with very coarse clasts before the cycle is repeated. Except for the top sequence, each cycle is terminated with a diamictic layer that contain large, angular, mostly autogenic blocks. These sedimentary sequences are interpreted as reflecting various degrees of ice-contact, i.e. cyclic variations in the hydraulic conditions in the overlying glacier. The laminated silts are interpreted as representing deep subglacial conditions, when the ice surface had a low gradient, producing stagnant, phreatic conditions in the cave. The progressive fluvial character of the subsequent sediments is most probably

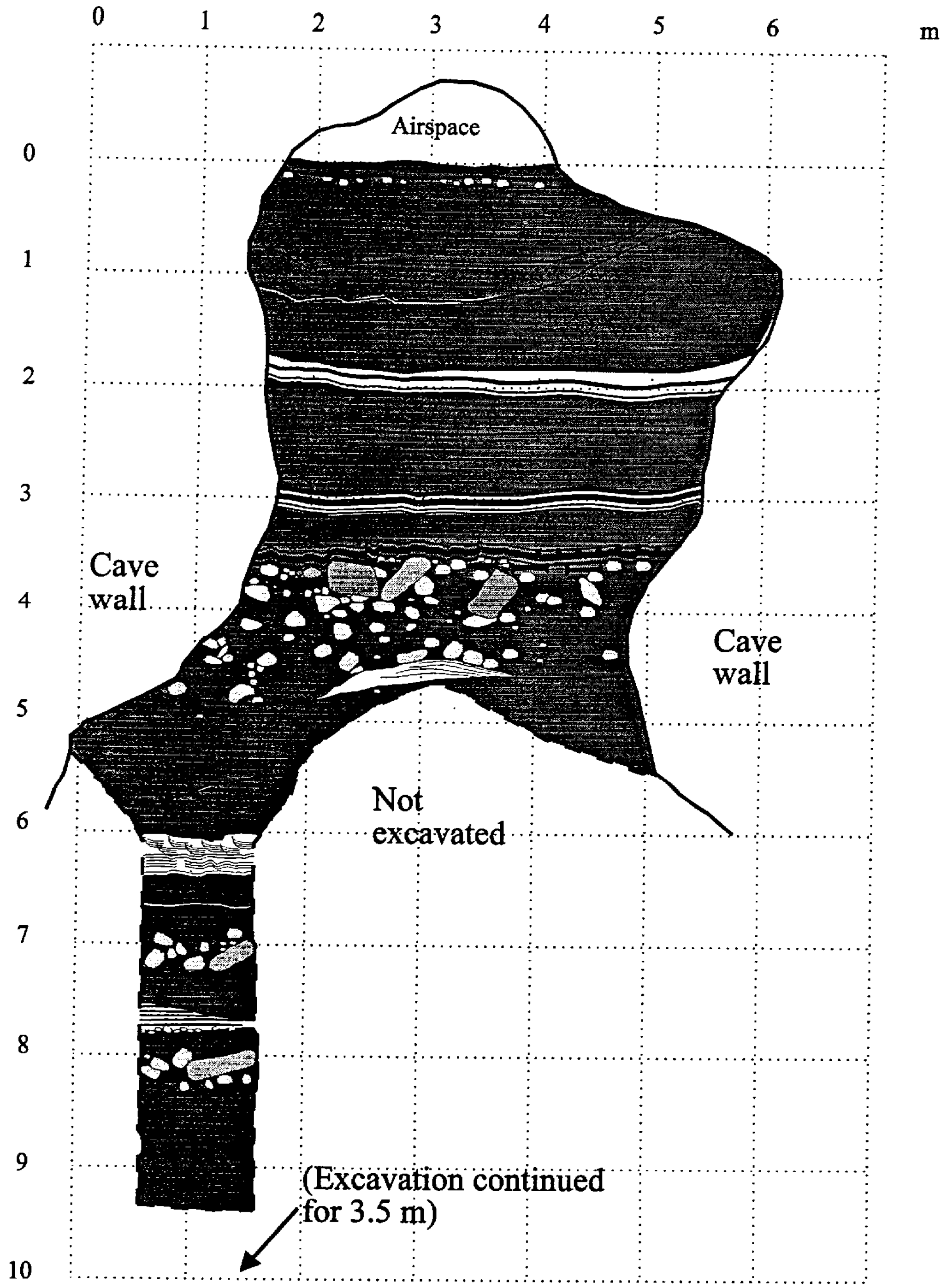

Figure 1. cross-section of the sediment fill (Section 1) in Norcemgrotta.

associated with deglaciation, when the ice necessarily was of the temperate type, with more water available and with a much steeper surface gradient. Finally, the capping diamicts are interpreted as subaerile, cryoclastic deposits that have formed by mass movements from the then dry cave entrance, downslope, deeper into the cave. It is possible that each fluvial/ subaerial cycle may correspond, albeit not necessarily completely preserved, to a full glacial/ interstadial cycle.

Paleontology.
In contrast to the great majority of sediment chokes in Norwegian caves, the top surface of the second diamicton from top, was fossiliferous. This layer was christened *"Ursus horizon"*, and have yielded bone fragments of *Ursus sp., Ursus maritimus, Canis Lupus, Allopex lagopus/Vulpes vulpes, Martes martes, Microtus agrestis, Lemmus sp., Somateria spectabilis (s. moilissima), Phallacrocorax carbo, Lagopus mutus, Gadus morhua*, a large carnivore rib and some 440 indet fragments. Marine, littoral invertebrates (*Littorina sp.* and *Mytilus sp.* occur in a fragmentary form. A low count of deciduous pollen is associated with the bones. A single bone fragment (ulna) of *Ursus maritimus* comes from the gravel beds in the unit above.

Chronology.
^{14}C dating of the bones from the *Ursus horizon* yielded 'finite' ages in the range of 39- 42 ka, whilst the *Ursus maritimus* bone from the overlying gravel dated at 22 ka. Calcareous concretions in the laminates above the *Ursus horizon* was dated by the $^{230}Th/^{234}U$ method (isochron technique), yielding a minimum age of 70 ± 8.5 ka for the laminae capping the *Ursus horizon.* We therefore regard the ^{14}C dates from this layer as infinite and slightly contaminated by modern ^{14}C. The chronostratigraphy is summarized in Figure 2.

Within the *Ursus horizon* an almost vertical paleomagnetic direction was determined, which is not compatible with continuous paleomagnetic records from Holocene lacustrine sediments for N. Europe. The vertical NRM directions is in principle only compatible with a spot reading of transitional field configurations probably representing the onset or termination of a paleomagnetic excursion. Taking the minimum U-series age into account, this could correlate with either the Norwegian-Greenland Sea Event at 70- 76 ka (Bleil & Gard 1989), or the Blake event at $\approx$105 ka (Denham *et al.* 1977).

Discussion.
The fauna assemblages of the *Ursus horizon* fall into two groups that are not climatically compatible with each other. The 'cold' fauna assemblage consists of Polar bear, Arctic fox, Greenland seal and varuous arctic birds, strongly suggesting open sea in close contact with the glacier front. Marten, Field mouse, and to some degree also the Wolf, allude to a much warmer environment with grass and trees.

The mixture of both arctic (ice-contact) and more temperate (forest) fauna elements suggest either two separate climatic episodes that was subsequently mixed, or a climatic development during fossil deposition. The mixing is compatible with the diamictic, mass- movement character of the host sediment. The paleomagnetic signature, U-series and AMS dating of concretions and bones suggest that the fauna horizon represent an interstadial, or possibly an interglacial/glacial transition prior to 70 ± 8.5 ka, probably either the marine isotope stage 5a or 5e. The choice depends on whether the 'warm' fauna component can be associated with a true interglacial (i.e. 5e) or not.

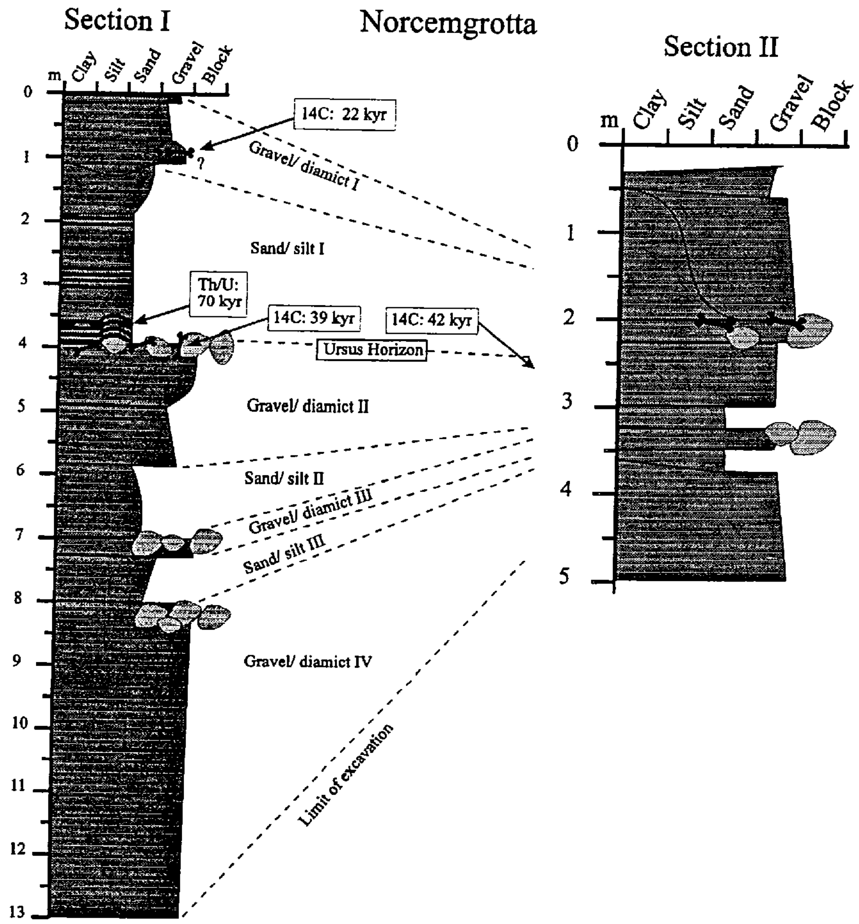

Figure 2. Chronostratigraphy of Norcemgrotta.

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A high resolution record of climate change in a stalagmite from Panlong Cave of Guilin since 36,000 years B.P.

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In view of the climate change on large scale, the climate changes in China show no difference from the global climate changes. But because of the strong uplift of the Qinghai-Tibet plateau since the Cenozoic era, the climate has been changed from a planet wind system to a monsoon system, namely, the climatic change in China may have some special characteristics .

There have been a lot of researches on the ice cores, the lacustrine deposit on the Qinghai-Tibet plateau, and the loess profiles in the north China, and important progress has been made. But in south China, for lack of similar climate change information sources, it is necessary to apply other loads of climatic change information. As is known to all, the karst area is about 500 thousand km^2 in south China, and the karst features are rich and varied. Accordingly, we made a comprehensive studies on a stalagmite in Panlong Cave, Guilin, China, and the cave

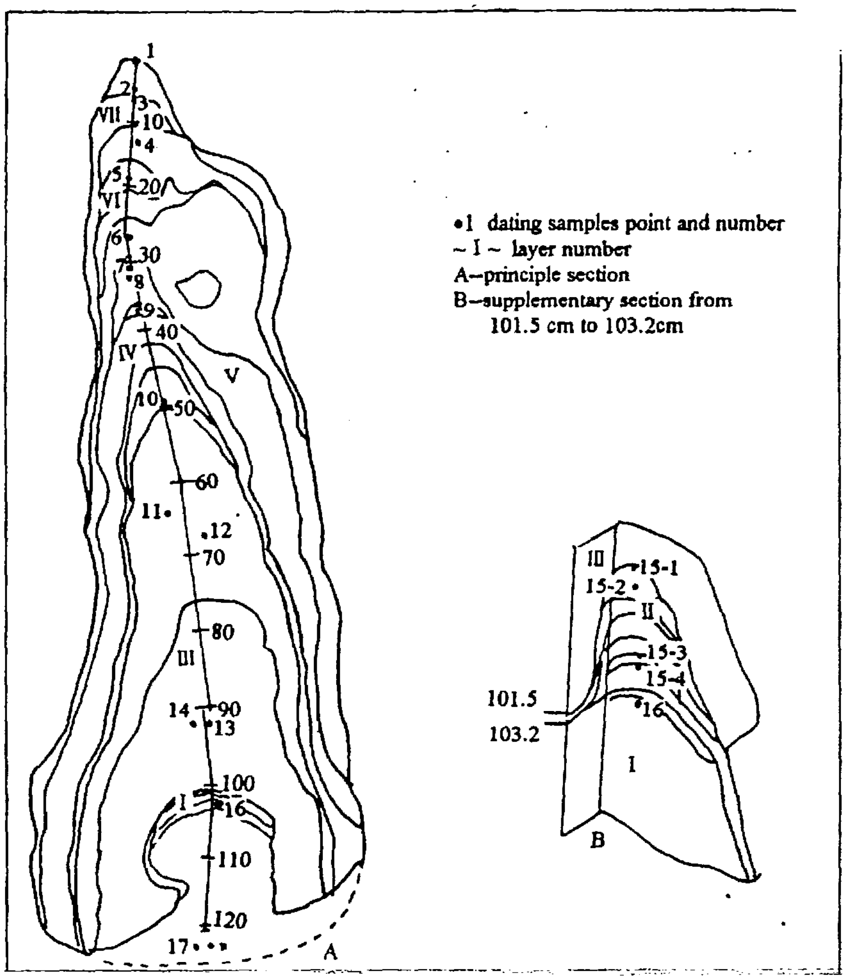

Fig.1 Sketch profile of the stslagmite

environmental conditions, and stable isotopes in the present drip water and in the carbonate deposit.Panlong Cave is located on the western side of Guilin-Yangsu highway about 37 km to the south of Guilin City. The elevation of the cave's entrance is about 190 m a.s.l.. The country rock is the upper Devonian limestone. The cave is about 251 m long, 6-12 m high (only 2 m at the northern entrance), and 11-15 m wide (only 5 m at the southern blocked end) . The thickest part of the overlying roof is up to 120 m. The stalagmite selected for the research is located at the part about 191 m away from its entrance, and 122 cm high, with a diameter of 45 cm at its bottom (Fig.1).

Fig.1 shows that there are two hiatus surfaces with a long period of duration at the lower part of the section (on the top of layer 1 and 2). There are some hiatus at the middle and the upper part, but the duration is short. Accordingly, these parts may be thought as continuous deposition.

On the basis of careful sedimentological studies on its thin laminae, the samples were taken for the analysis of stable isotopes ($\delta^{18}O$, $\delta^{13}C$, δD) of about 150 samples, AMS^{14}C dating , LSC-^{14}C dating and α-counting $^{230}Th/^{234}U$ dating of about 30 samples. In addition, we also analysed the stable isotopes of 9 present cave carbonate and the relative drip water for one year.

Tab.1 shows the dating results.

Tab.1 Dating results of the stalagmite in Panlong cave, Guilin, China

Number	Sampling Points (from top to bottom cm)	AMS-^{14}C (a B.P.)	LSC-^{14}C (a B.P.)	$^{230}Th/^{234}U$ (a B.P.)
1	1.0	1060±80		
2	6.1	2190±120		
3	7.9	2250±140		
5	19.4	2380±140		
6	27.3	2520±150		
7	31.1	3970±180		
8	32.0	4110±150		
9	37.7	4260±190		
10	49.7	5490±190		
11	64.2	5770±220		
12	67.5		5556±110	
13	92.6	6050±110		
14	93.0		5900±170	
15-1		6930±290		
15-2	layer-2	7990±120		
15-3		11,080±280		
15-4		28,960±650		
16	103.2	32,440±380		
17	122.0	>35,000	36,000 ±18,000	36,400+2900 - 2800

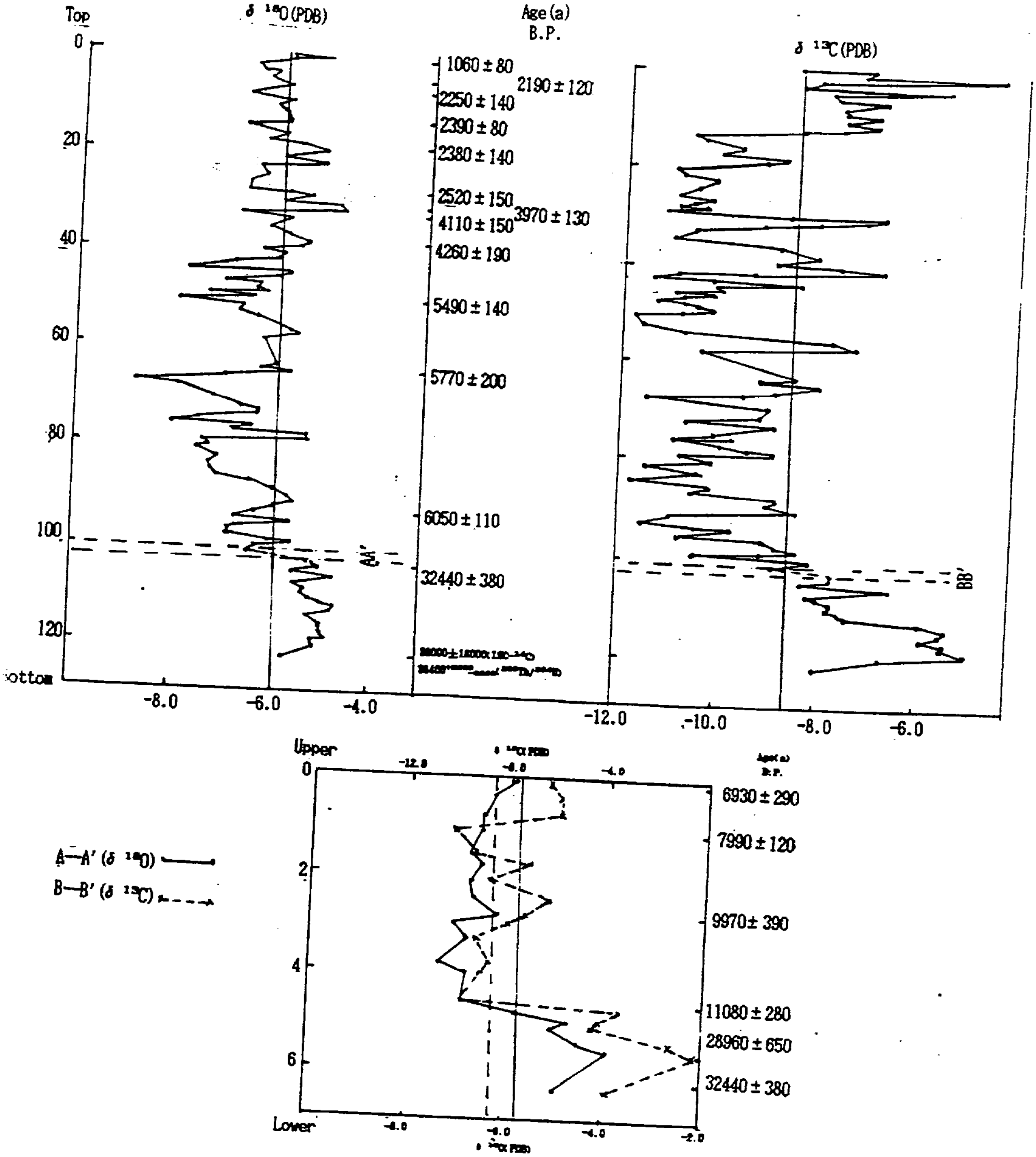

Fig.2 $\delta^{18}O$ and $\delta^{13}C$ record of the stalagmite in Panlong cave, Guilin, China

Fig.2 shows the variations of the $\delta^{18}O$ and $\delta^{13}C$ of the stalagmite. Based on the analysis of $\delta^{18}O$ and $\delta^{13}C$, as well as the dating data, the climate changes in Guilin area may be suggested as follows:

(1) The last glacial period

Because of the influence of the global dry and cold climate, the karst processes in this karst area were greatly weakened and the growth of stalagmite was slow. During some stages, the drip water might stop and the deep brown weathering front was formed.

A. During 36,000 years B.P. to 32,000 years B.P. : $\delta^{18}O$ and $\delta^{13}C$ values are high, which reflects a dry and cold period that corresponds to the coldest period of the middle Dali sub-glacial period in China.

B. Around 28,000 years B.P. : $\delta^{18}O$ is up to -3.92 ‰- - 4.53 ‰, and $\delta^{13}C$ 0.17 ‰- - 1.27 ‰, which may record the coldest event in this area.

The two dry and cold periods above would be the reflection of H_4, H_3 (Heinrich) event in this area.

C. Before 11,000 years B.P.: $\delta^{18}O$ and $\delta^{13}C$ are high, but after 11,000 yeras B.P., the values abruptly become low, and this area might enter warm and humid period, which would be the record of Younger Dryas in this area.

(2) Holocene Epoch:

The jamp-like rise of the temperature after 11,000 years B.P. resulted in a distinct leap between the last glacial period and the Holocene Epoch. But during the Holocene Epoch, there are several climate variations. The obvious periods are 4,000-2,500 years B.P., around 2,400 years B.P. and about 1,000 years B.P. that can be compared to the phenology records and a Qilianshan ice core record. Especially around 4,000 years B.P., there was a marked drop in the temperature, which correspond with other records in the world. In addition, around 5,800 years B.P., there was a dry and cold period.

This is our preliminary study in Guilin area, but the results show that there is a good potential for reconstructing environmental changes with high resolution from karst records in south China. By applying the comprehensive method of TIMS U-series dating, AMS-^{14}C dating , stable isotopes and other geochemical information, we may get further details of the climate changes in this region.

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Life cycle and morphology of an epigean and a hypogean population of *Gammarus lacustris* G.O. Sars (Amphipoda) in South Norway.

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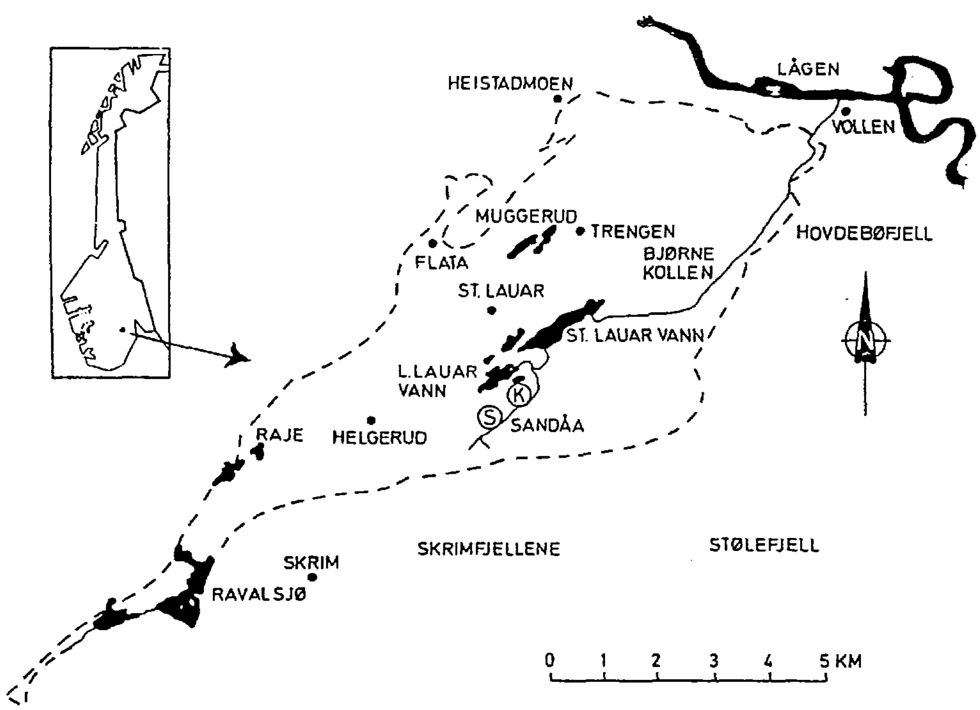
The crustacean amphipod *Gammarus lacustris* has a widespread holarctic distribution, and is a common inhabitant in calcium-rich or cold lakes in Norway from lowland to high mountains. It has been found in only one hypogean habitat located in the Sandågrotta limestone cave system in the municipality of Kongsberg (county of Buskerud, South Norway)(Fig. 1). The cave is situated in a coniferous forested area at 370-400 m a.s.l. The ice-sheat retreated from this area approximately 9-10 000 years b.p.

The aim of the study was to compare life cycle patterns, and "regressive evolution" of morphological characters in the light of 1. The natural selection hypothesis, 2. The negative pleiotropi hypothesis, and 3. The neutral mutation hypothesis in an epigean and a hypogean *G. lacustris* population. Only preliminary results from this study will be presented here. Both populations are situated in the same watersystem, but high waterfalls forms at present a barriere for animals from the lake to communicate with the cave dvelling population, while animals from the latter could drift downwards along a creek during flood periods. The genetic exchange between the populations are however considered to be minimal at present due to physical conditions.

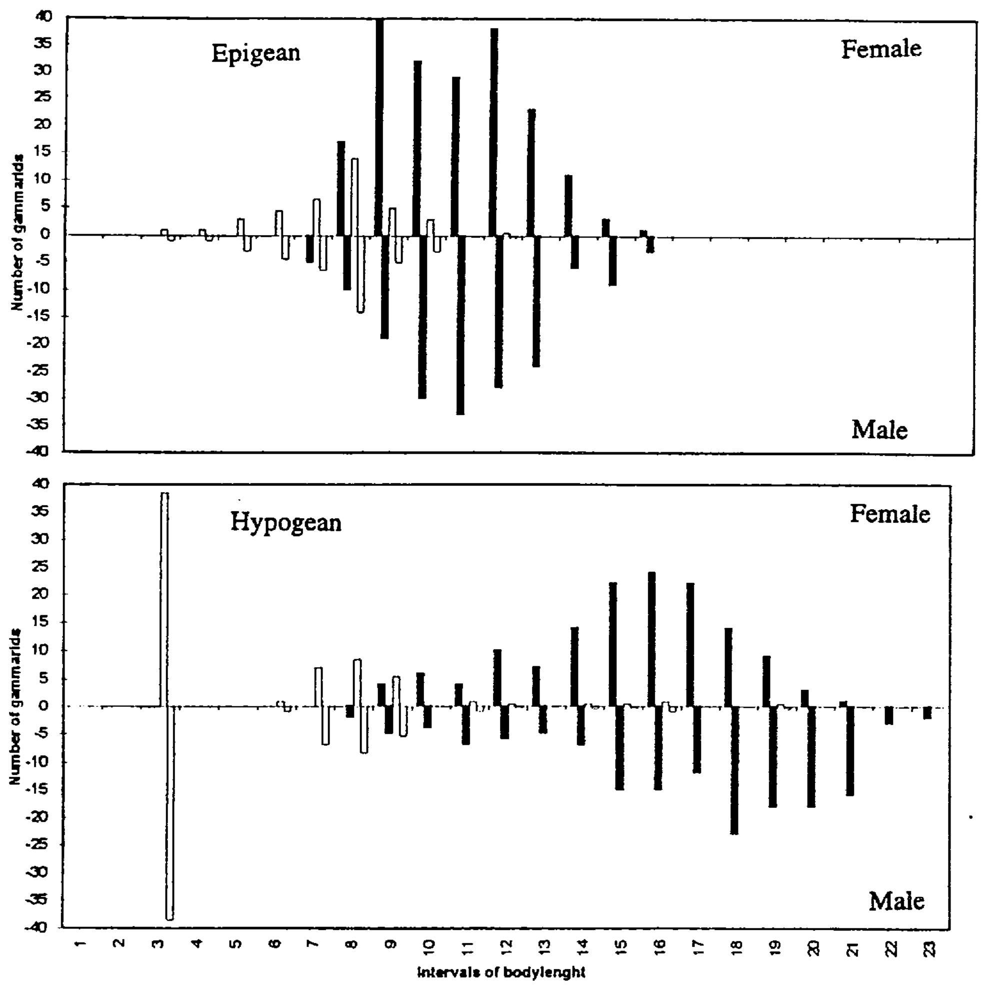


Figur 1.The location of the study area situated in the municipality of Kongsberg, county of Buskerud, South Norway. S and K denotes the extension of the Sandågrotta cave system. The epigean population studied was sampled in the lake Lille Lauarvann.

Life cycle

In lowland Norwegian lakes *G. lacustris* has a one-year life cycle, were hatching of eggs take place during spring-early summer, maturation occurs during autumn-winter, and pairs can be observed in precopula during late autumn-winter and early spring. However, in one mountain lake a two-year life cycle have been observed.

In contrast to the one-year life cycle in the epigean population, the hypogean population seems to follow a two-year life cycle, possibly extending it to three years (Fig. 2). Monthly recordings of the temperature at the two locations during the year shows that the yearly temperature sum (in degree-days in °C) is twice as high in the epigean as in the hypogean habitat. The Q10-rule could explain the prolonged life-cycle in the hypogean habitat, as it states that a 10 °C lowered or raised mean temperature would lead to a 2 or 3 fold lowered or raised metabolic rate in poikilotherms. To be able to fullfill the life-cycle in a colder and even less food rich habitat, the gammarids in the cave at least must use twice the time epigean relatives do. Even if the cave gammarids have an elevated metabolic rate (as sometimes is observed in cave animals) it would have to be twice the metabolic rate compared to the epigean gammarids to accomplish a one year-life cycle. The assumption of a two-year life cycle is further supported by counts of the number of articles in the first antenna, assuming that the number increase by 1-4 articles for each moult.



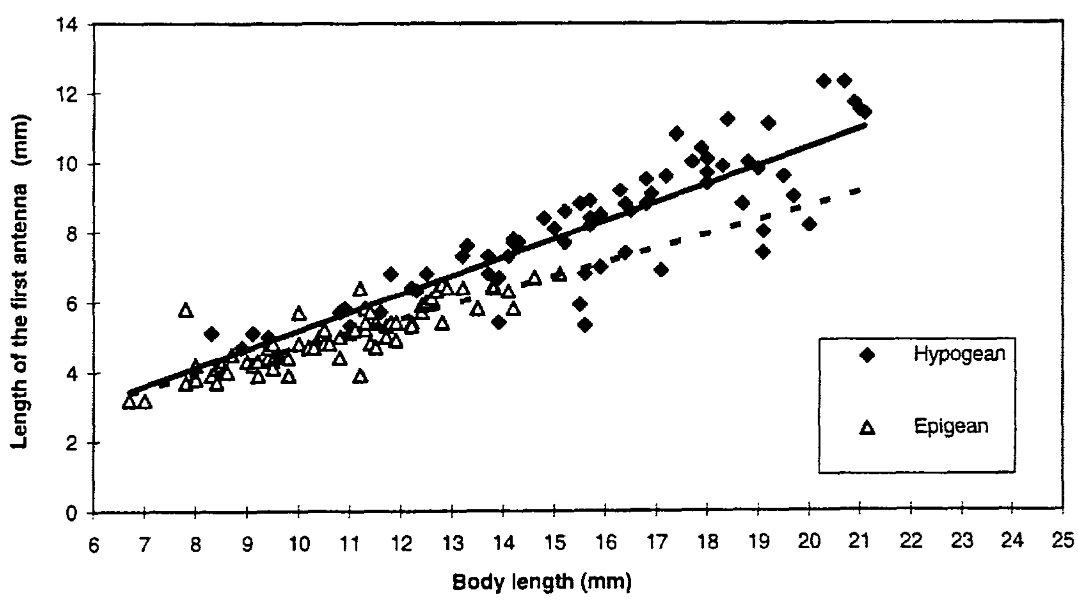
Figur 2. Age structure (expressed as body length in mm) of the total sample from the epigean (n=427) and hypogean population (n= 448). White bars denotes unmature specimens (total number / 2), black bars denotes mature specimens. The hypogean animals are significantly larger than the epigean (ANOVA).

The reproductive cycle in the hypogean habitat follows a similar cycle as in the epigean, probably triggered by the same environmental cues (lowered water temperature in autumn and/ or rising water temperature in spring) initiating the reproductive activity. Even though the timing of maturation of eggs and subsequent hatching seems to be the same in the two habitats, the growth of the young are though slower in the cave where very small individuals can be observed in late autumn or vinter. Pairs in precopula are also found in late autumn and winter in the cave population, possibly due to lowered female densities or other patterns explained by sexual selection.

Morphological development

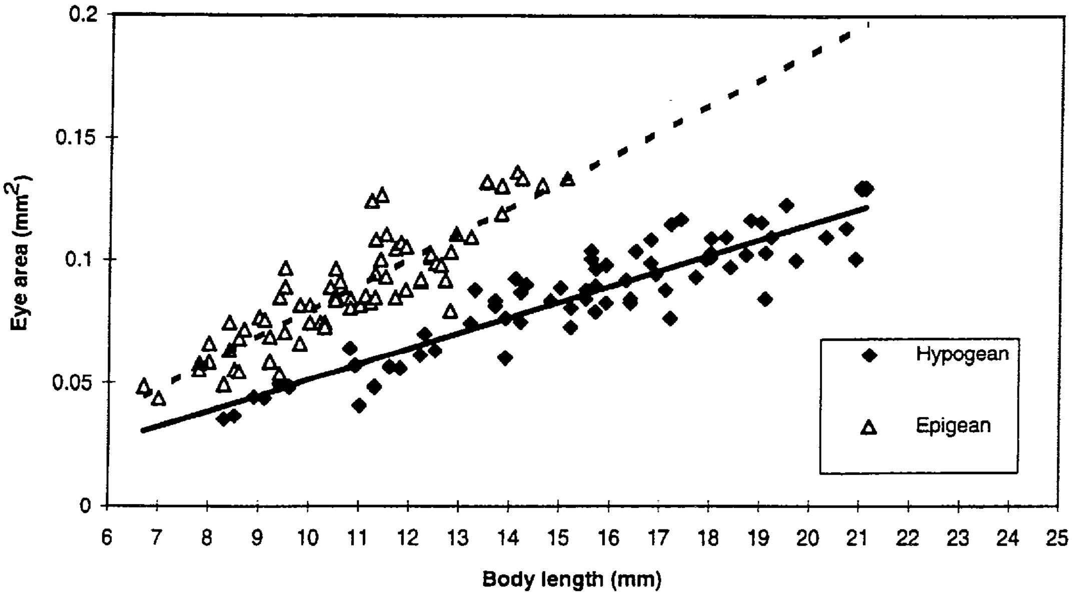
To compare morphological divergence between the two populations we measured the length of the head capsule, the total body length, the length of peduncles and antenna flagellum in both the first and second antenna. Further we counted the number of articles in the first and second antenna flagellum. The eye area was calculated from the length and breadth measures using the formula of an elipse. In addition the number of discernible ommatidia in the eye was counted. We further counted eggs and measured the eggvolume of some individuals (small sample) from each habitat. In these morphological comparizons a total of 140 sexual mature individuals was used, divided in 70 epigean and 70 hypogean specimens, separated in females and males.

In a dark habitat organs for sensing and orientation obviously are important at least when regarding feeding patterns and reproduction. These assumtions may be supported by the findings that both the length of the first and second antennae in the cave animals are increasing at a faster rate (higher slope) than in the epigean population (both sexes pooled)(Fig. 3). When comparing the sexes as a function of habitat, the length of the first antennae in both males and females are longer (higher intercept) in the cave population. Cave females have longer second antennae than epigean females, while the second antennae of cave males increases at a faster rate than in the surface males. Within each habitat the males have longer first antennae than the females, while the length of the second antennae increases at a faster rate in males than in females. However, the growth divergence in first and second antennae between the sexes within each habitat is at the same level.



Figur 3,The length of the first antenna (in mm) in the epigean and hypogean populations (ANCOVA).

Both ommatidia number and eye-area have higher slopes in the epigean habitat (Fig. 4). No difference in eye-area or ommatidia number between sexes were observed within each habitat.



Figur 4. The eye-area (in mm^2) in the epigean and hypogean populations (ANCOVA).

The mean length at maturity are larger in the cave population than in the epigean population (both sexes pooled)(Fig. 2). Hypogean individuals are further whitish to pale yellow in colour, while epigeans are olive-green. Our material further indicates that the hypogean females produce fewer (or have higher embryo mortality) and larger eggs than the epigean females.

Our data show that the hypogean *G. lacustris* population studied inhabits many of the features earlier found for other crustacean cave populations: prolonged life cycle, larger body size at sexual maturity, whitish appereance in body colour, increased length of sensory appendages such as the first and second antenna, reduction in eye-area due to a reduced number of ommatidia, and possibly economizing the cost of energy connected with reproductive investment in female gonads. The species have the potential to be used as a model organism for studies similar to those on *G. minus* in USA.

Hopefully results from mtDNA and isoenzyme studies in the near future will reveal information significant to indicate the time of divergence and subsequent morphological divergence i.e. the rate of morphological development between these populations. These studies might also shed some light on the mechanism of "regressive evolution".

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Caves and Coral: high precision dating of flowstone and coral reefs constraining the 5a Sea level in SE Florida and the Bahamas

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Sea level is a proxy indicator of ice volume and indirectly of climate change. In order to understand the controls on the interplay of orbital geometry, climate change, ice volume and sea level it is important to know when sea level changed and its elevation. *In situ* fossil corals indicate former high sea stands; submerged cave calcites show when sea level was lower than the cave level. Information from the two sources can be integrated to provide a detailed sea level history. In this study calcites from a flooded Bahamian cave and corals from SE Florida were precisely dated by U-Th dating using Thermal Ionization Mass Spectrometry (TIMS). Here we report on evidence of the 5a sea level elevation and timing.

Extensive cave passages in Lucayan Caverns, Grand Bahama Island, show multiply-layered flowstone which was deposited on top of a pre-existing mud layer. During the glacial-interglacial cycles sea level oscillated down and up in relation to the Bahamas Platform and the caves were thus alternately air-filled and water filled. Calcite is deposited only when the cave is air-filled (Fig 2d); the episodes of flooding (Fig 2b) are apparent in depositional hiatuses and sometimes flowstone erosion. Dating of the flowstone layers immediately below and above a hiatus constrain the time window when sea level was at a higher elevation than the flowstone. The caves are now flooded (Fig 2f). The flowstone sample was collected at -15±0.5 m MSL but it had broken off and fallen when the underlying mud layers were undermined by rapidly rising Holocene sea levels. Thus the original elevation was at least 2 m above -15 m MSL (constrained by the cave ceiling).

In south-east Florida, Substage 5e reefs (Fig 1a) were exposed after sea level fall and now form the Key Largo Limestones on the mainland. Massive Pleistocene reefs occur seaward of the modern reef tract, situated below the main shelf on a terrace (Fig 2e). These were the focus of this study. They were cored in two transects. Twenty-eight *A. palmata* and head corals were U-Th dated (again by TIMS with a typical precision of ±1%). All dated samples showed 0.0% calcite on XRD analyses. With few exceptions, initial $^{234}U/_{38}U$ ratios fell within 1% of modern sea water (1.44 ±0.008). The main episode of reef growth dates to Substage 5a and there is a Holocene capping reef. The locus of modern reef growth has moved back to the mainland coastline.

The elevation of the 5a sea level high has been a source of controversy for some years. The evidence comes from coastal and marine deposits such as elevated reef tracts. For elevated reef tracts both a precise date and the rate of uplift are usually required for

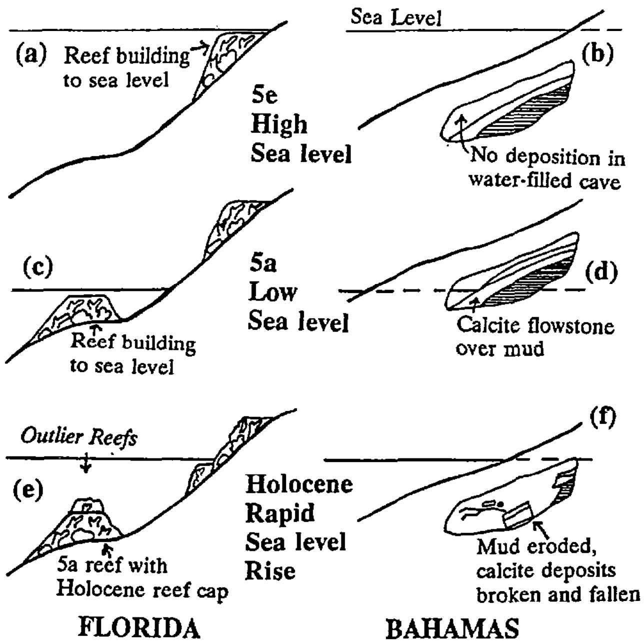

Figure 1: Diagrammatic view of the geomorphology of SE Florida and Bahamas during three sea level episodes. (a)(b): The 5e stage in Florida (high level reefs) and Bahamas (water filled cave, depositional hiatus in flowstone. (c) (d): the 5a stage in Florida (reef building offshore) and Bahamas (calcite deposition in air-filled part of the cave). (e) (f): Modern stage in Florida (Outlier reefs made up of 5a reefs capped by Holocene reef, modern reef growth at mainland coast) and Bahamas (water-filled cave).

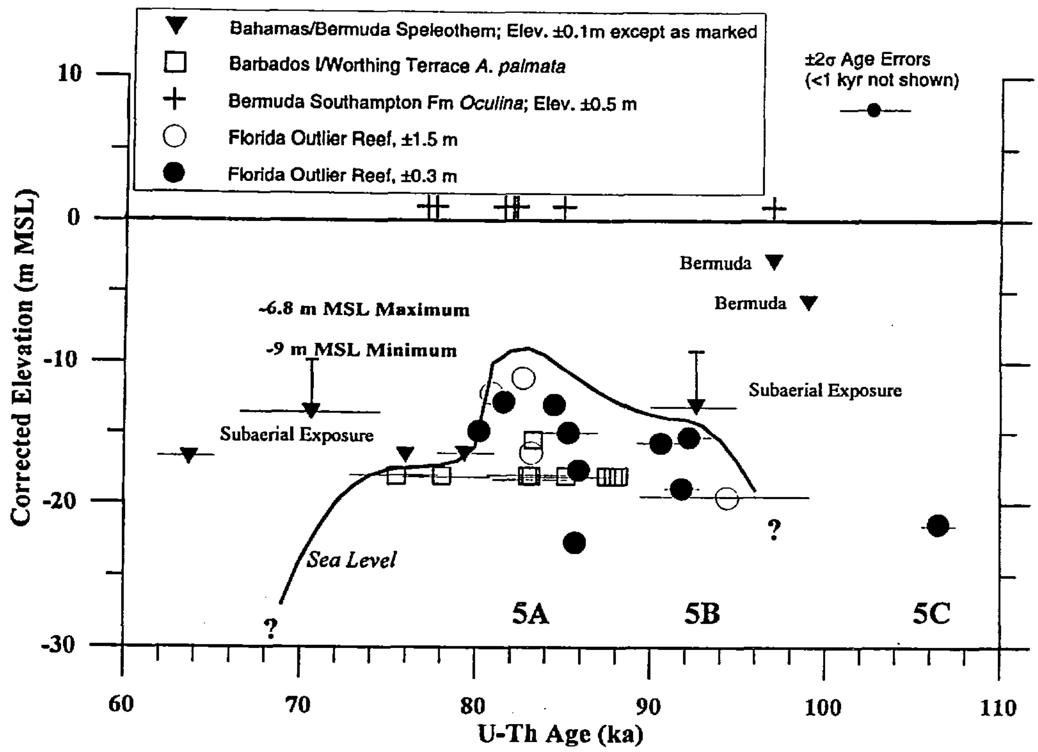

Figure 2: Late Quaternary sea level data, Florida, Barbados, Bahamas. Bahamas and Bermuda speleothem indicate subaerial exposure bracketing reef growth. Outlier reef growth occurred under relatively high sea levels during Substage 5a. Bermuda *Oculina* (the coral of detrital origin in the +1 m coastal deposit) is included.

accurate reconstruction. Other marine deposits are dated by enclosed fossils which unfortunately are often of detrital origin and may only indicate that the deposit is younger than the enclosed fossils. The bulk of the evidence in the literature places sea level below -6.6 m MSL. However, Vacher and Hearty (1989) and Ludwig *et al* (1996), using dates on enclosed detrital fossil coral, have interpreted Bermuda's youngest coastal deposit to indicate a sea level at +1 m MSL at the end of Substage 5a.

Synthesis of the two records from this study gives a tight window on the date and elevation of the 5a sea level in the SE Florida and Bahamas area (Fig 2). The records do not suffer from the limitations of knowing the uplift history for uplifted reef tracts; nor do they suffer from the problems of transported fossil corals in shoreline sedimentary deposits. The flowstone record indicated a continuous deposition of calcite in an air-filled cave throughout the 5a isotope stage at an elevation of at least 2 metres above ~-10 m MSL (the present evelation, corrected for the subsidence rate). The Pleistocene reef remnants of the Florida Outlier Reefs show a reef crest at ~-9 m MSL (again the present elevation corrected for the subsidence rate) which grew from 86 to 80 ka with a very brief subaerial exposure of a part of the reef. If all errors are included then the maximum sea level over the Outlier Reefs at ~83 ka (Substage 5a) would have reached only -6.8 m MSL.

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Late Weichselian palaeomagnetic chronostratigraphy of sediments in four cave systems in Nordland, N-Norway.

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The karstic caves in Nordland, N-Norway, provide important paleoclimatic information by the precipitation of speleothemes during ice free periods, and the deposition of sediments during periods of complete ice-cover. While radiologic age determinations of speleothemes provides time series of ice free intervals, the sediments are not readily dated. Hence, the depositional history of sediment sections representing periods of complete ice cover is largely unknown.

We have attempted to use time variations of the paleomagnetic signal retained in sediment sections for providing time frames for the sub-glacial depositional history in 10 cave systems in Nordland, N-Norway. The sediments vary from gravel to clay, and reliable paleomagnetic signals have been encountered in sediments ranging from fine sand to clay. The low degree of consolidation in some sediment sections has been a problem due to mechanical disintegration during transportation.

Standard paleomagnetic methods have been applied, and progressive alternating field demagnetization usually reveal the presence of one component magnetizations of high magnetic stability. The carrier of the natural remanent magnetization (NRM) is magnetite, probably in a highly stressed state. This is likely to be due to strain acquired during the abrasional erosion by glaciers.

The paleomagnetic signals are characterized by variations in declination between 90°W and 40°E, in accord with the range of paleosecular variation. Inclinations are often too shallow for a Late Quaternay geomagnetic field configuration and is attributed to the 'classical' inclination error. The inclination error strongly suggest a true detrital remanent magnetization (DRM) acquired at the time of sediment deposition and which has not been modified by any postdepositional processes commonly acting in lacustrine and marine evironments.

Sub-glacial sedimentation in caves requires transportation by flowing water which may modify the directions of DRM. Magnetic fabric properties, derived from determination of the anisotropy of magnetic susceptbility (AMS), do not reveal any systematic relationship to distributions of NRM directions, suggesting that currents have not modified the NRM.

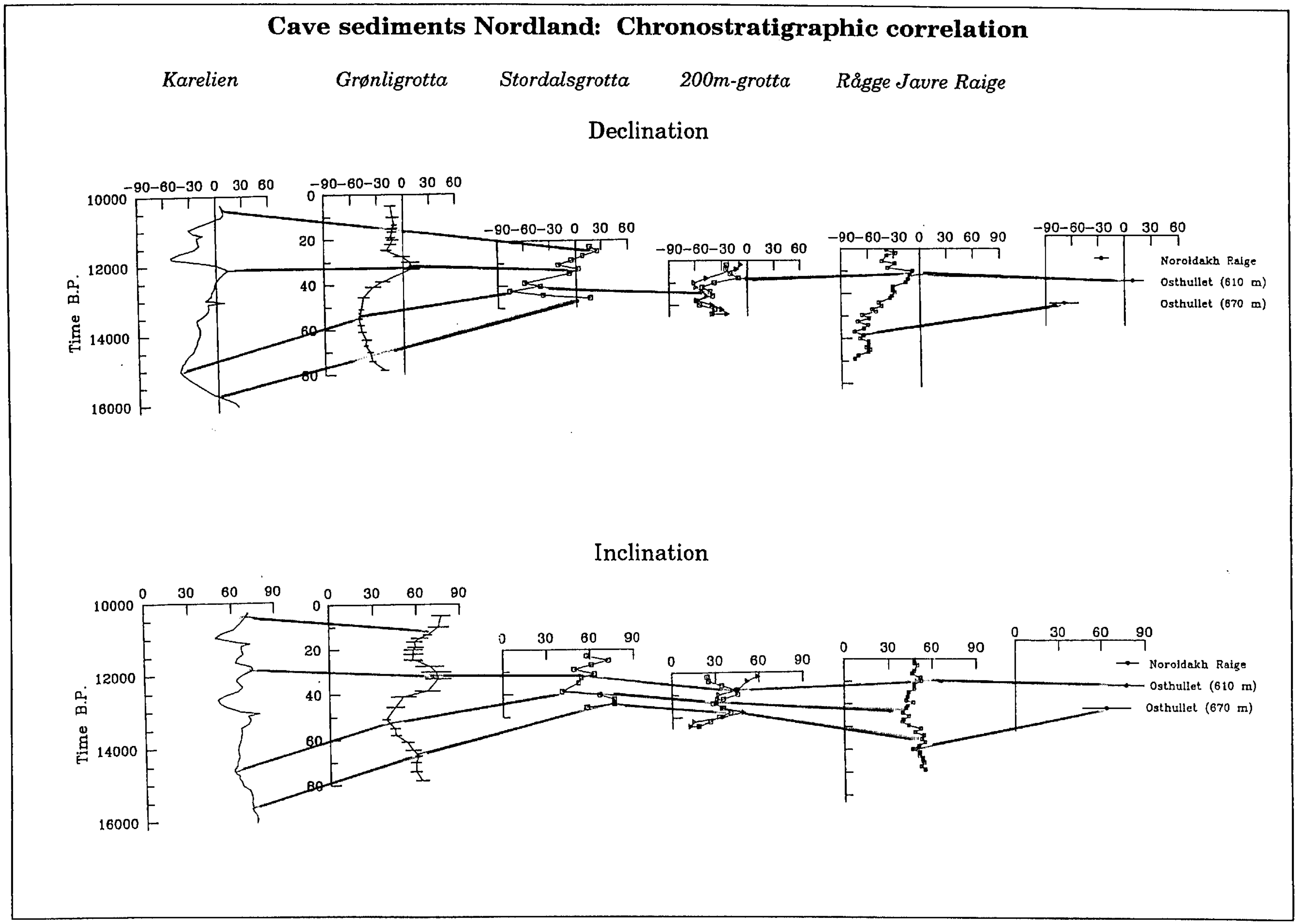

Figure 1. Paleomagnetic correlation between dated varved clay sections from Karelian (left) and sediment sections from four cave systems from Nordland, N-Norway. Proposed correlation lines are based on visual pattern recognition.

The declination pattern from 4 cave systems (Grønligrotta, Stordalsgrotta, 200m-grotaa and Rågge Javre Raigi) can be correlated in fairly great detail, suggesting synchronous sediment accumulation in these caves.

Although age control is absent, it is reasonable to assume that caves from the same region have been exposed to comparable climatic and hence depositional histories. On the assumption that the observed variations reflect genuine paleosecular variation (PSV) of the geomagnetic field in Late Weichselian, a chronostratigraphic correlation with dated PSV records in varved clay sections from Soviet Karelia (Bahkmutov & Zagniy 1990) is proposed based on declination and inclination. The Karelia data set has been converted to 67°N, 5°E by the conversion via pole method (Noel & Batt 1990) to increase the precision. Since PSV patterns are aperiodic and hence may be repetitive in time, the proposed correlation must be regarded as tentative.

The correlation reveal that:

- *Accumulation of preserved sediments commenced between 16 to 15.5 ka B.P. and ended between 11.5 and 10.5 ka B.P.*
- *The thickness of the sediment sections appear to be linear related to the present height above sea level*
- *There is no systematic relationship between the duration of deposition and height above sea level*

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Stratigraphy of the Biśnik rock-shelter sediments on the background of the others caves in Polish Jura.

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The central part of the Polish Jura is built up of the Upper Jurassic limestones which are covered by Quaternary, mainly Pleistocene sediments. The morphological culminations reaching 496 m a.s.l. are built by massive Oxfordian limestones.

The Biśnik rock-shelter is formed in the western slope of an inselberg - the Biśnik Hill (405 m a.s.l.) on the left side of the waterless valley.

The rock-shelter is connected with a cave which consits of three small chambers and two narrow passages. The excavations in the rock-shelter were started in 1992. During the field works a very interesting profile of cave sediments 5 m thick was exposed. The sediments reflect climatic changes, as well as geological and geomorphological processes.

The whole profile of sediments consist of three main series of deposits containing 20 layers. The particular layers differ in colour, grain-size composition, amount and weathering degree of limestone rubble. Below the first series, in the lowest part of the rock-shelter, autochthonic residual clays of terra rossa-type were situated, accumulated in Tertiary, probably in Pliocene. The similar deposits were found in the Nietoperzowa Cave, Żabia Cave and several other caves in northern part of Polish Jura. The clays are overlained by series I - a sequence of several loam layers. They are composed of autochthonous limestone rubbel, with products of limestone weathering and allochthonous silts and sands. The loams contain bones and teeth of vertebrates and archaeological materials in several horizons.

On the ground of results of geological, archaeological and palaeontological data several sets of layers were separated :

- layers accumulated during the Warthanian (150 ka);
- layers formed during the Eemian Interglacial (the Biśnik rock-shelter is the second site after Nietoperzowa Cave in Polish Jura, where deposits and archaeological materials of the Eemian and the Warthanian are present);
- layers accumulated during the Vistulian.

The red clays and the whole series I originated when the present rock-shelter was a fragment of bigger cave. Then the cave ceiling collapsed and the rock-shelter was made. Next series of sediments (II and III) were accumulated in the rock-shelter.

On the sequence of clays and loams three layers of fluvial sands - series II occured, formed during the Interplenivistulian than loess and eolian sands - series III accumulated during the Upper Plenivistulian. The deposits evidence an intensive fluvial and eolian accumulation during main stage of Vistulian. The fluvial accumulation in cave is result of the low morphological situation in the valley. The eolian sediments

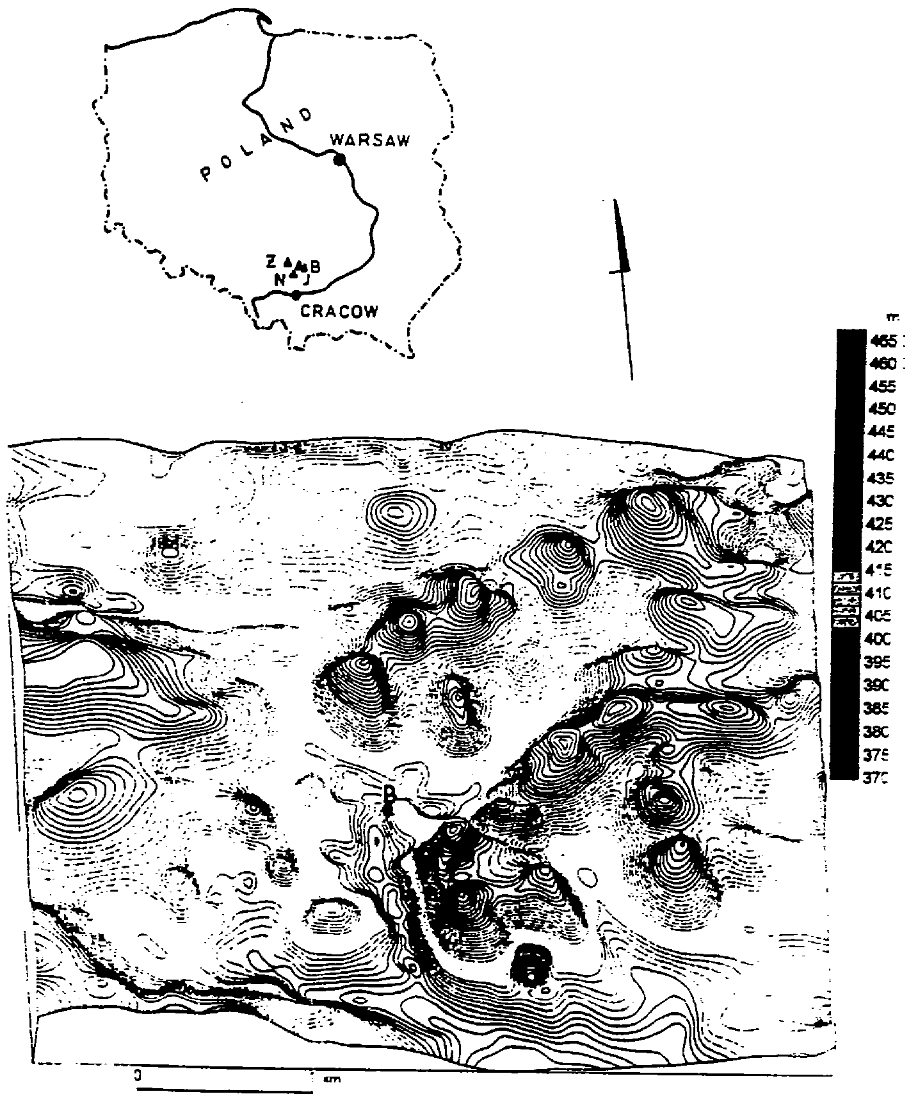

Figure 1: Location and topograpic sketch of the Biśnik rock-shelter. B - Biśnik rock-shelter. J - Jasna Cave. N - Nietoperzowa Cave. Ż - Żabia Cave.

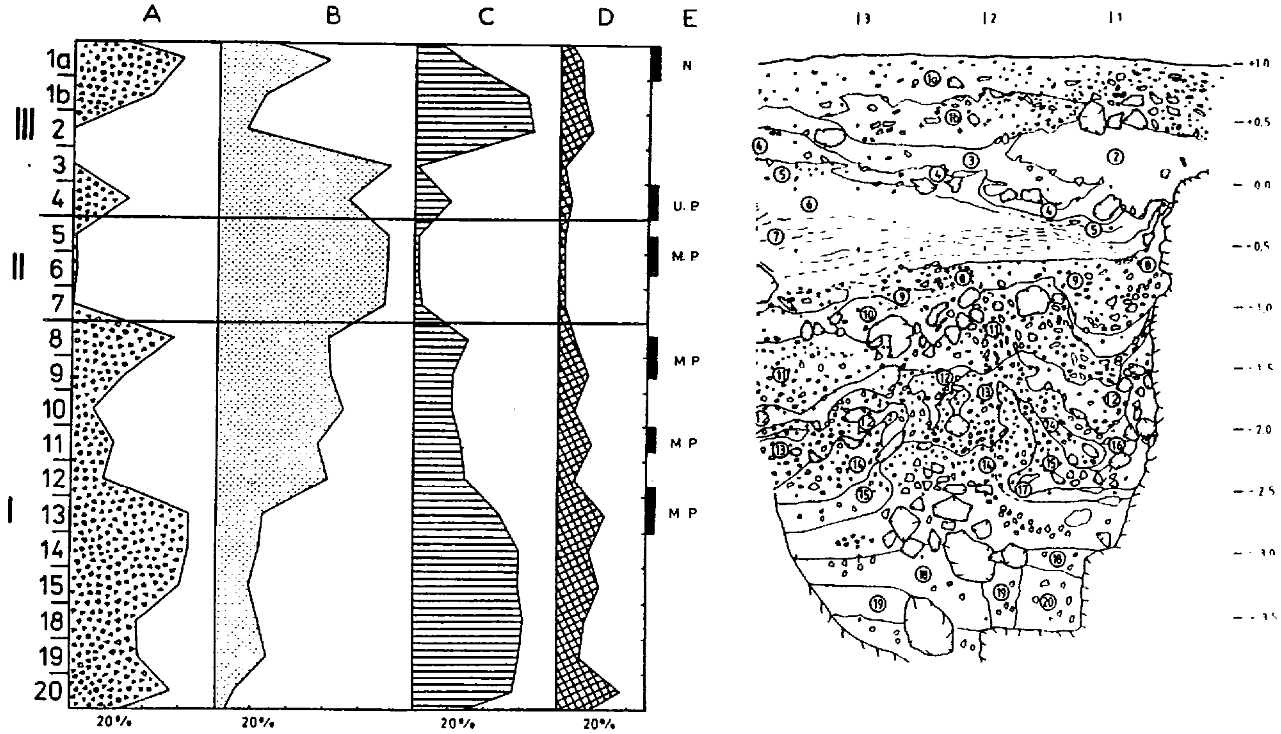

Figure 2: Profile and grain-size composition of the Biśnik rock-shelter sediments. I, II, III - numbers of series of sediments; A - D - grain size distribution: A - above 1 mm, B - 1 - 0,05 mm, C - 0,05 - 0,002 mm, D - smaller than 0,002 mm; E - archaeological horizons:2 N - Neolothic, UP - Upper Palaeolithic, MP - Middle Palaeolithic2.

occur generally and are present in several caves for example Nietoperzowa Cave, Jasna Cave. The top of the profile was formed by the Holocene humus.

Except very interesting geological profile, in Biśnik rock-shelter very absorbing archaeological assemblages were found. The assemblages consist of flint and bone tools. Basing on the investigations of the archaeological materials, 8 stages of settlement - short duration camps were separated. They represents Middle and Upper Palaeolithic cultures : Micoqueo-Prondnician and Mousterian with Acheulian apperance. It is first site in Polish Jura, where Acheulian-type flint tools were found.

It is new important Palaeolithic site in Poland and the deposits filling the rock-shelter make possible to reconstruct the climatic changes and geomorphological processes not only in the cave but as well in its neighbourhood.

The Biśnik rock-shelter has a double scientific value : geological and archaeological.

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What can Cave Beetles tell us about the Climate?

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The climatic and ecological implications of the glacier periods on the beetles have been studied by different authors. The basic assumption is that if the present day climatic tolerance range of a beetle species is known, then fossil occurences of that species imply a palaeoclimatic which was within the same tolerance range;

For the underground beetles these kind of researches are impossible to undertake for different reasons. The main reasons are : no cave beetles fossils have been mentioned till present ; most cave species are detritivorous and that's why no extrapolation concerning the aboveground vegetation can be made.

The question as to how organisms entered caves and how they become adapted to cave existence has been under considerable amount of evolutionary investigations.

The classical theory is pleading for a passive origin of the majority of the cave species. These are very young, from the beginning of the Quaternary. The alternance between glacier and interglacier periods "forced" the penetration of the hygrophilic species in the karstical massif cracks network. Probably the ancestors of the actual species have lived in the forests humus during their expansion period. If the climate had changed they have gone deeper, persisting only in a part of their distributional area (fig. 1).

The other, more recent theory concerning the hypogean environment colonization considers this one as a free niche, offered for colonization to the preadapted forms (fig. 2). The organisms entered caves for avoiding physiological stress , competitors, predators, or simply because this empty "space" was unsaturated in species. The colonization and penetration in the hypogean environment break the gene flow and the underground population evolves toward a different species.

No matter which of these theories is valid, certain is that the climatic changes during the end of Tertiary and during Quaternary periods have had an important direct (through the areas covered by the glaciers) or indirect role (by the influence on the general terrestrial climate), on the present distribution of the underground species in the temperate zones.

The direct impact has been thoroughly studied in Europe for different faunistical groups. The present day distribution of some underground species is in agreement with the glaciers limit in the pleistocene valleys, to each glacier corresponds a certain species from the genus.

The indirect impact causes the altitudinal displacement of the forest and of the invertebrates communities from the forest soil, the break up of the vegetal cover and the appareance of the geomorphological and pedological barriers for the hemiedaphical and edaphical populations.

Several speciation processus models, caused by glacier events, have been proposed for the north-american and french cave fauna. One of the best studied is that of *Speonomus delarouzeei* complex, an pyrenean underground beetle species.

The first break up of the complex has taken place during the first glacial period (2,3 - 2,1 MY) which established the mediterranean climate, dry in summer and cold in winter, at lower elevation and established a more temperate and cold climate in the mountains. The range of ancestors of *S. delarouzeei* was breaked up in two basic species : *S. delarouzeei* sensu stricto in the mediterranean zone and *S. brucki* in the mountain forests zone. The differences between the two species are important in behaviour, genetics and biochemistry. During the second glaciation (1,7 - 1,3 MY) *S. charllotae*, a sibling species of *S. brucki* diverged from this one , due to isolation and divergence rather than adaptive shift. The third glaciation (0,9 - 0,8 MY) or an even a more recent one represents the moment of the birth of the third sibling species of *S. brucki*.

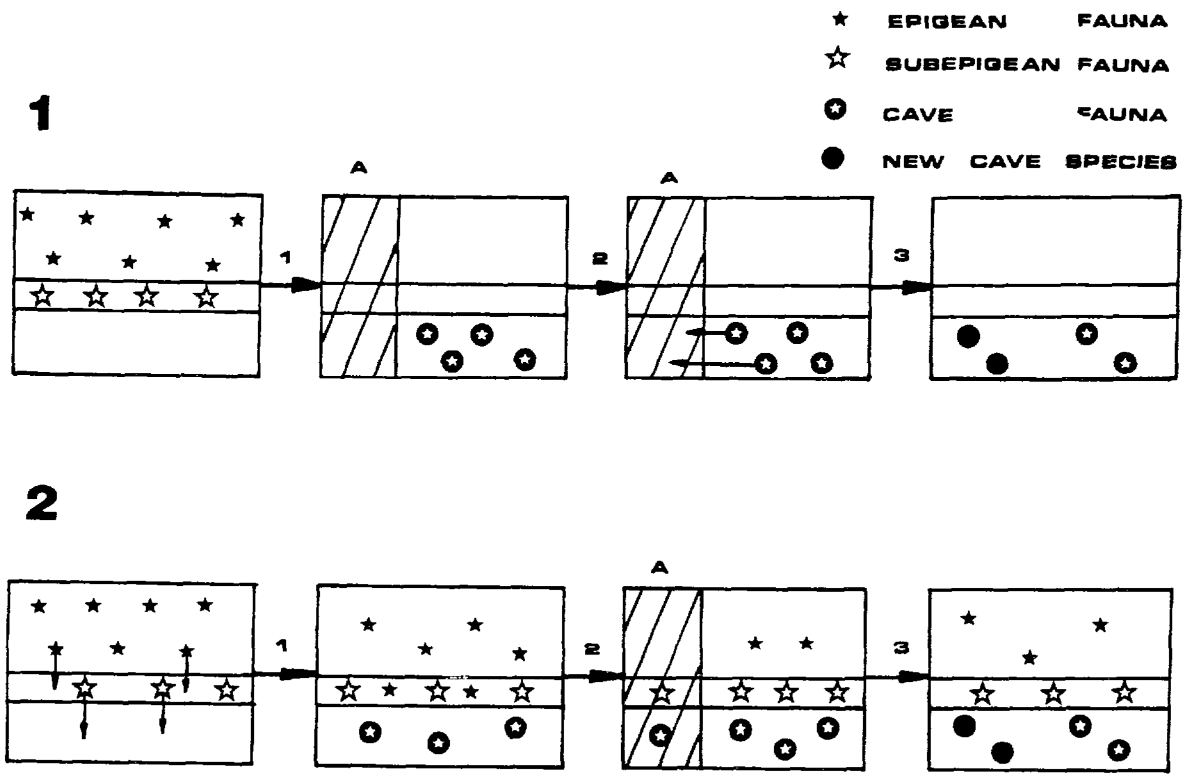

FIG. 1. The classical theory of the underground colonization. Preadapted species will concentrate in caves (1) that are not directly affected by the glaciars (a). During the interglaciar periods (2) some of these species will migrate back to the affected zones, generating new species (3).

FIG. 2. The modern theory of the underground colonization. Due to the competitive pressures the caves will be colonized (1). During the glacial - interglacial periods a part of the populations will separate, generating new species (2 + 3).

Each glacial period displaced the forest belt several hundred meters downward in elevation and was a period of errosion that generated cracks, voids and M.S.S. The migration to lower elevation, following the forest, by the ancestors of the underground species, through cracks and voids and then the migration to upper elevation in the interglacier periods determinated the separation of the new established populations.

This is an example of microspeciation that occured three times during the Quaternary, producing neoendemical cave beetle species in the Bathysciinae subfamily.

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Climatic Change - The Karst Record From Carbonate Islands

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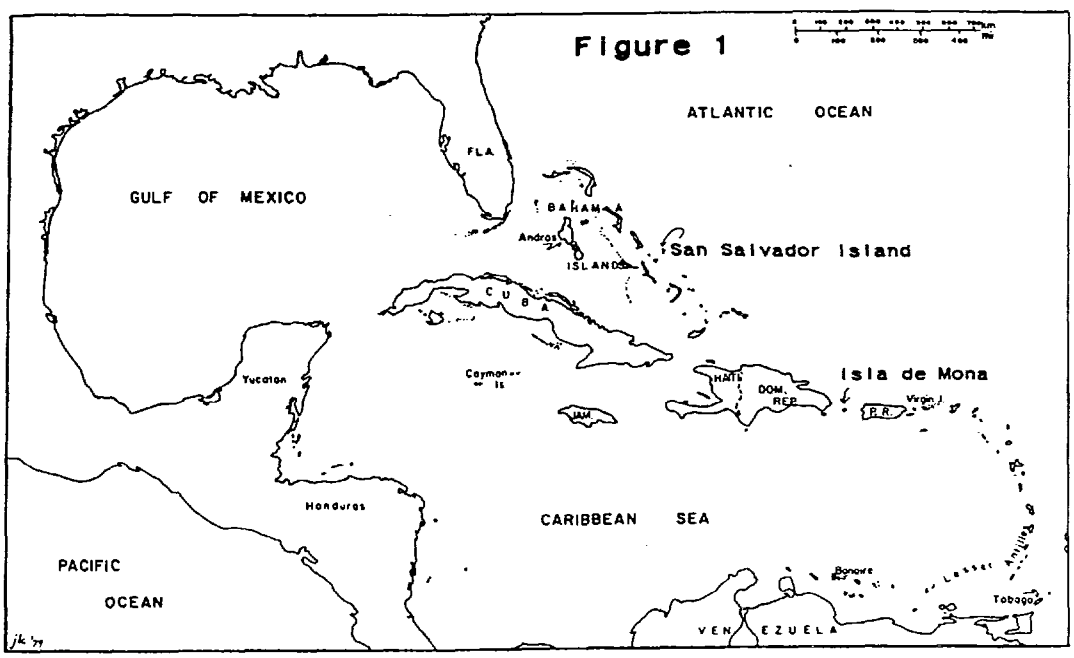
Karst development on carbonate islands is constrained by limited areal extent, so recharge is limited and entirely meteoric. Karst development is further constrained by glacio-eustatic sea level changes. High sea levels (10^4 years in length) partially flood the carbonate banks, producing carbonate deposition and an elevated fresh-water lens position; low sea levels (10^5 years in length) expose the entire carbonate platform and drop the fresh-water lens more than 100 m below the platform surface.

Carbonate islands can be divided into three hydrologic types: carbonate islands, carbonate-cover islands, and carbonate-rimmed islands. Carbonate islands are entirely carbonate from the land surface to a depth exceeding the lowest Quaternary glacio-eustatic sea-level lowstand. Carbonate-cover islands are those in which the land surface is entirely carbonate, but a carbonate/non-carbonate contact exists within the range of Quaternary glacio-eustasy. Carbonate-rimmed islands are those in which non-carbonate rocks are present on the island surface. In the Atlantic Basin, the Bahamas, the Caymans, and Isla de Mona, Puerto Rico are examples of carbonate islands; Bermuda is a carbonate-cover island; and Jamaica, Puerto Rico, and Barbados are carbonate-rimmed islands (Figure 1).



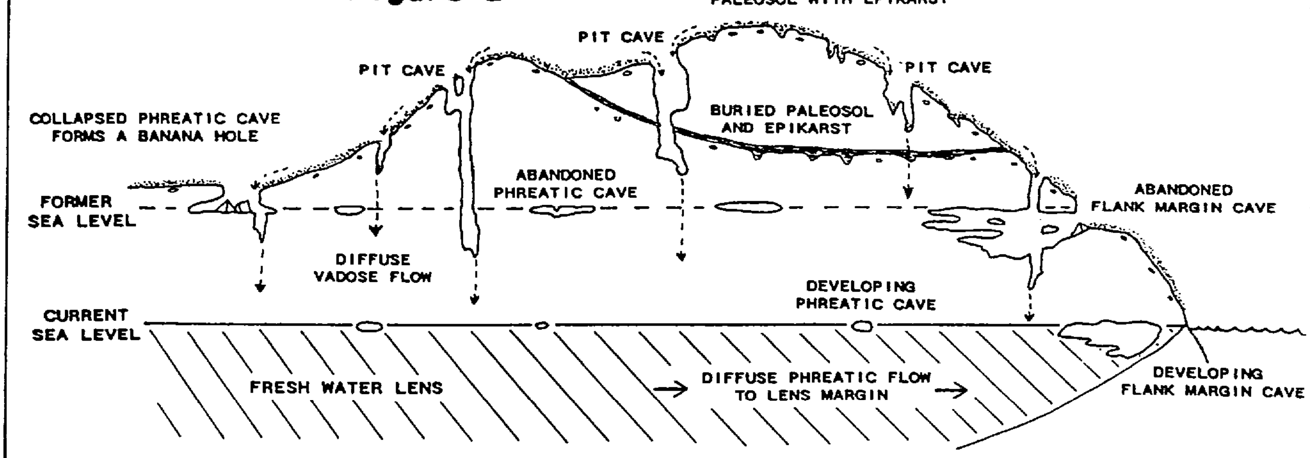
Carbonate-rimmed islands are analogous to continental karst areas at similar latitudes, despite island limitations in size, and will not be discussed further. Carbonate-cover islands represent a special case where vadose flow is deflected in the subsurface by the carbonate/non-carbonate contact. Carbonate islands provide a simple case in which spatially-limited autogenic recharge creates a fresh-water lens within the island. Karst development occurs at the land surface (epikarst), within the vadose zone (pit caves), and at the boundaries of the fresh-water lens (banana holes and flank margin caves) as shown in Figure 2. Quaternary glacio-eustatic sea level changes have caused the fresh-water lens and its karst environments to migrate through a vertical range of 130+ meters.

The Bahamas are tectonically-stable islands. Flank margin cave development is tied to sea level position, and only those caves developed during the last interglacial (oxygen isotope substage 5e, circa 125 ka) are subaerial today. All earlier flank margin caves have subsided below modern sea level and have been overprinted by multiple glacio-eustatic sea level changes. The youthful age of the subaerial flank margin caves is demonstrated by their lack of speleothems with ages older than 89 ka (+/- 7 ka). Whereas, blue holes, which have been repeatedly drained and flooded, contain speleothems with ages up to 350+ ka. While most flank margin caves are in rocks older than 125 ka, some are in rocks that have been dated by U/Th techniques to ages of 125 ka, indicating rock deposition and syngenetic development of the caves during the last interglacial sea-level highstand. Pit caves and epikarst have also developed in rocks dated to 125 ka. Carbonate island caves and karst develop rapidly yet persist through time, indicating that they can provide high-resolution landform histories.

The climatic changes associated with glacio-eustasy have resulted in the fossilization of epikarsts beneath red, resistant micritic paleosols. Paleomagnetic analyses indicate that paleosols (and epikarsts) from different climatic episodes of the Quaternary can be identified and correlated. One particular paleosol horizon, found on rocks older than 125 ka, has an anomalous SE positive direction that may relate to a specific event in magnetochronology. Work is in progress to specifically date the times at which these paleomagnetic signatures became fixed, in order to date the time at which climatic change altered an active soil and epikarst into a paleosol and fossil epikarst.

In contrast to the Bahamas, Isla de Mona, Puerto Rico, an uplifted carbonate island, has subaerial caves that formed at a variety of lower glacio-eustatic sea levels. Paleomagnetic analysis of cave fills there indicate, from top to bottom, a reversed-normal-reversed-normal sequence of speleothem and sediment layers. The most conservative application of magnetostratigraphy indicates the oldest cave material has an age of at least 1.7 ma (1,700 ka). In contrast, surface paleosols show no reversals, but the anomalous SE positive direction seen in the Bahamian paleosols is present, perhaps providing a time correlation between the two island settings. The presence of anomalous SE positive paleomagnetic directions may also indicates that the climatic change that turned active soils into paleosols on these carbonate islands may have affected a broad region.

Figure 2



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Quaternary Stratigraphy of the Storsteinshola cave system Kjøpsvik,north Norway

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Introduction

Storsteinshola cave system is located in Kjøpsvik, northern Norway (Figure 1). The cave system is developed in marble, and consists of four main caves; *Storsteinshola, Dynamitthola, Norcemgrotta* and *Nygrotta* (Figure 2). Norcemgrotta contains a well-dated, fossiliferous and stratigraphically complete sediment sequence (Lauritzen *et al.* 1996). The purpose of this work is to describe and explain the different sedimentary facies located in the whole cave system, develop an internal correlation in Storsteinshola and to correlate the sediment sections in Storsteinshola with the master sequence in Norcemgrotta.

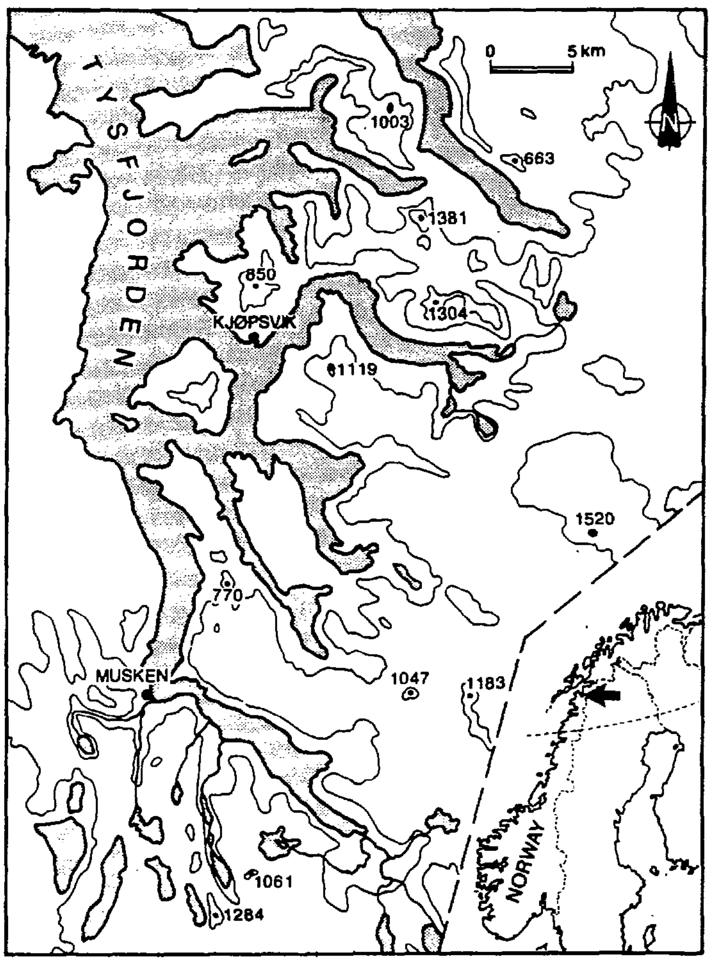

Figure 1: Location map.

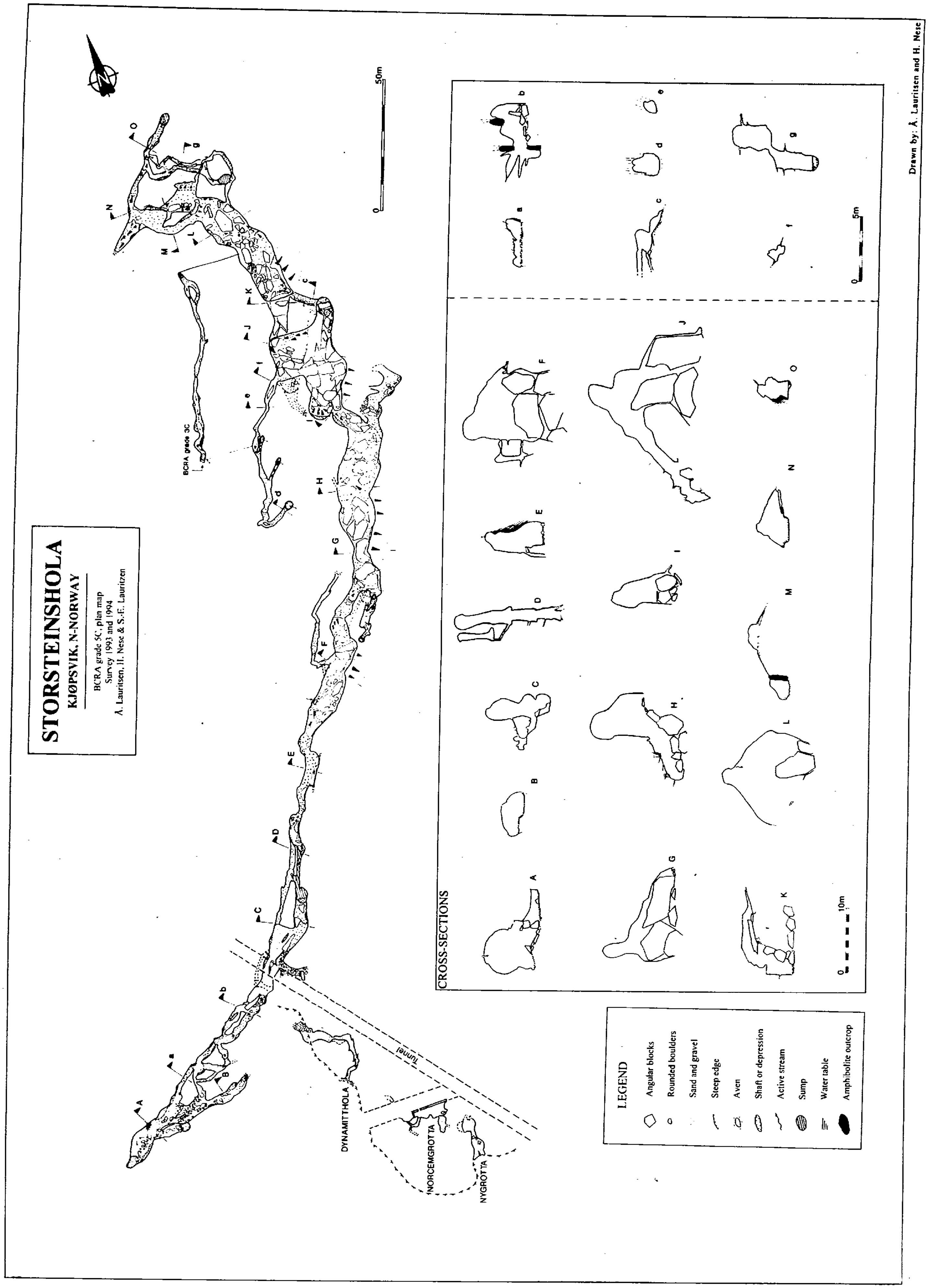

Figure 2: Plan map of Storsteinshola cave system.

Sediment facies/lithostratigraphy

Several characteristic cave-environmental sediment facies is located in Storsteinshola cave system; laminated silt and clay facies, well sorted sand facies, gravel facies and polymodal and bimodal unsorted facies. The relations between the characteristic sediment facies and various depositional environments are described below (Table 1).

Table 1: Lithofacies in Storsteinshola cave system.

Lithofacies	Depositional environment
Laminated clay and silt	Stagnant phreatic conditions
Sand	Slow circulating phreatic conditions
Gravel	Vadose conditions with variable flow rate
Polymodal or bimodal unsorted sediments	High energy phreatic conditions

Clay and silt facies is related to stagnant phreatic conditions, which we associate with ice-contact damming of the cave system. These sediment facies probably reflects periods with full glacial conditions in the area. Sand facies are also related to ice-contact conditions, but reflects an environment with moderate water movement. Polymodal and bimodal, unsorted sediments, are on the basis of grain size distribution and location, interpreted as sliding bed sediments, deposited under phreatic, high energy drainage conditions. In Norway this depositional mode has earlier been connected with deglaciations (Valen *et al.* 1995). The gravelly facies is related to vadose transport, and reflects most probably sediments eroded and redeposited during the last drainage phases in the cave system. These sediments are mainly connected to fluvial/glaciofluvial surface-input.

In the cave these various sedimentary facies combine into cyclic upwards-coarsening sequences. The cycles commence with laminated silt and clay (often enveloping the termination of the previous cycle), followed by well-sorted sands and capped with a gravelly/ unsorted bed which is coarsest in the top stratum. Finally, the upper gravelly/ unsorted bed is most often capped with a lag of coarser, angular cryoclastic blocks. Such sedimentary cycles in caves, may reflect a glacial cycle (Ford 1979, Mylroie 1984), where the laminated silt, clay and sand reflects full glacial conditions and the sliding bed deposits reflect deglaciation. The angular blocks is deposited during subaerile, principally ice-free conditions, when frost shattering and roof collapse could produce them.

The lateral distribution of sediment sections in Storsteinshola is restricted, which hamper further correlation. In contrast to Norcemgrotta, which contains at least three full coarsening-upwards sequences, only one and a half such sequence can be confidently identified in the main cave. Anyway, the cyclic sections in Storsteinshola is located at several levels, and on the basis of the various phases of collapse, at least two different sedimentary cycles (section B and C in Figure 3) can be identified. Based on lithostratigraphy, characteristic sedimentary facies and location, the upper cyclic sediment unit in Norcemgrotta (section A) is correlated with the unit A in section B in the main cave (Figure 3). The Norcemgrotta section is well-dated by uranium series (concretions) and ^{14}C (bones). Precipitation of concretions proceed in water-saturated sediments shortly after deposition (Theakstone 1984, Hillarie-Marcel & Causse 1989), and uranium series dating of the concretions therefore provide a minimum age for the host sediments. Uranium series dating of four levels of concretions located in the upper laminated unit in Norcemgrotta, indicates that this unit is of Weichselian age (section A fig 3). In Storsteinshola only one level of concretions in section B is dated with the uranium series method (Figure 3), yielding an unprecise minimum age of 15.5±6 kyr, which indicate that this sequence must also be of Weichselian age. These results support the lithostratigraphical correlation between the section in Norcemgrotta (section A) and section B in Storsteinshola (Figure 3).

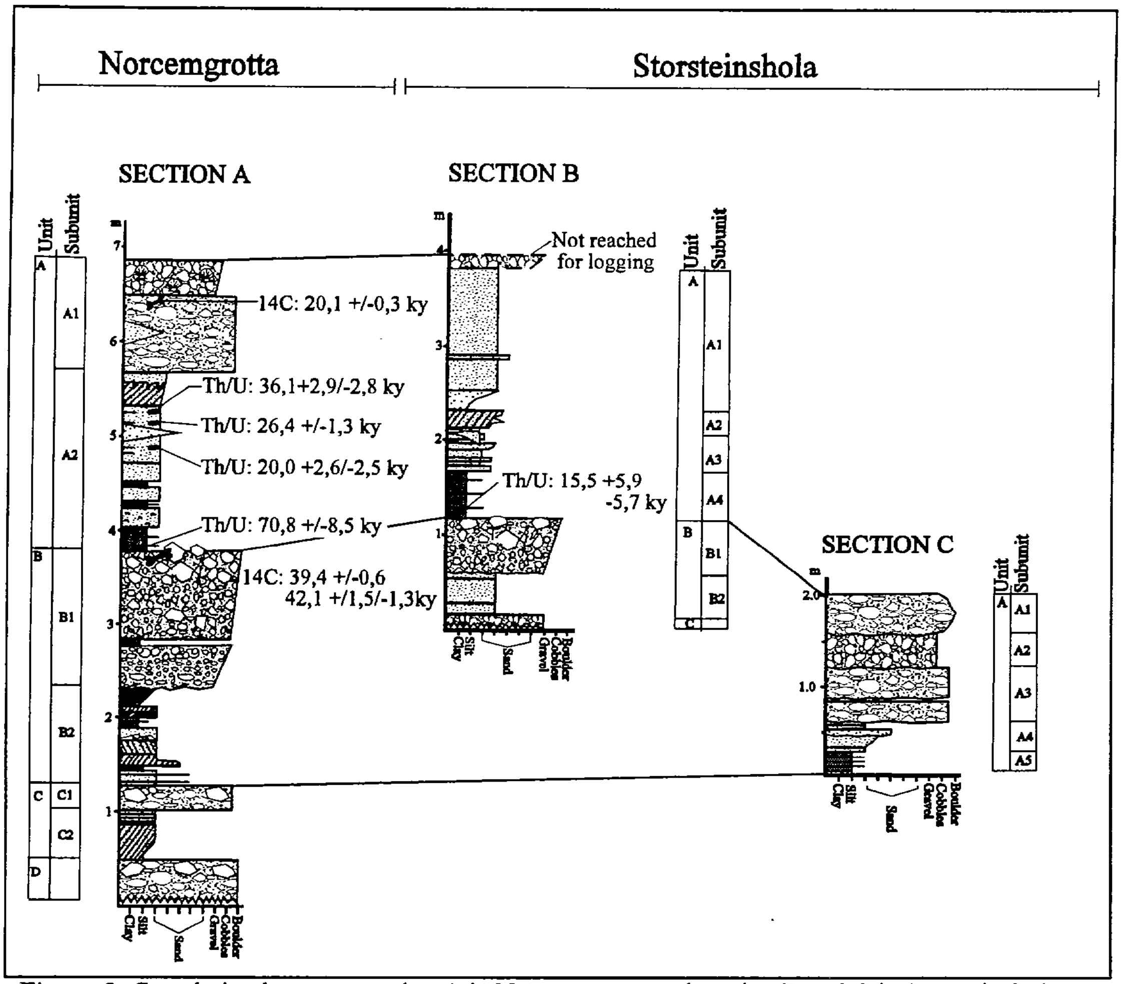

Figure 3: Correlation between section A in Norcemgrotta and section B and C in Storsteinshola.

Conclusions

The sediment facies in the Storsteinshola cave system varies from clay and silt deposited in a stagnating water environment, to unsorted gravelly sediments deposited under very high flow velocities. This reflects the enormous range of hydrological regimes encountered in glacio-karst caves. The sediment facies occur in some cases as cyclic sequences, which are thought to reflect at least a part of a glacial cycle. In Norcemgrotta three coarsening-upwards sedimentary cycles is located in one section. In Storsteinshola only one and a half such cycle is located in one section, but different sections is thought to reflect at least two different cyclic sedimentation phases. On the basis of lithostratigraphy, section B in the main cave is correlated with the uppermost cyclic section in Norcemgrotta (A). Uranium series dates lend support to this correlation.

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Environmental Change on Karst since the Last Glacial in the Akka Limestone Area, Northeastern Japan

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The Akka Limestone is distributed (50 km wide in N-S, 1-4 km wide in E-W, and NNW-SSE strike) in the northeast part of the Kitakami Mountains. The Akka Limestone is a member of the Akka Formation (700 m thick) which consists of bedded limestone, alternating beds of limestone and chert, and chert in upward sequence. The Akka Formation is considered to be formed on seamounts in late Triassic. Many dolines and caves are developed in the Akka Limestone.

In the study area the limestone bedrock is overlain by several late Quaternary tephras which provide important time-markers. The identified marker tephras were as follows:

Towada-a (To-a: 915 AD), Towada-Chuseri (To-Cu: 5.5 ka BP), Towada-Nanbu (To-Nb: 8.6 ka BP), Towada-Hachinohe (To-HP: 12-13 ka BP), Iwate-Oide (Iw-Od: 35-40 ka BP), Towada-Okoshi? (To-Ok, 60-70 ka BP).

The tephra overlying a slope indicates that the slope has been stabilized since the tephra fell. Pleistocene tephras are observed on the limestone plateau or in the bottom of karst depressions. However, in several outcrop on the plateau it is observed that To-Of is unconformably covered with loamy soil included To-HP. In the Kitakami Mountains two periods of mass movement by periglacial processes are confirmed during the Last Glacial (Higaki, 1987). The first period was in the early Last Glacial Stage, around 50 ka BP, and the second was in the late Glacial Stage, between 30 and 10 ka BP. At such times, involution was formed in the Northern Kitakami Lowland area (Inoue *et al.*, 1981). Thus, it is considered that Pleistocene tephras on the slope in the study area were removed by periglacial processes in the cold phases of Last Glacial, associated with the frost shattering of the underlying limestone. On the gentle slope greenish black soil which originated from limestone is covered with Holocene tephras. On the other hand, Holocene tephras are not recognized as layer on the steep slope. Therefore, Holocene tephras are thought to be removed on the steep slope by soil creep. Besides, it is supposed that the clearance of forest promoted soil erosion as mentioned later.

Human Impact in the Akka Limestone area

The first appreciable human occupation in the study area was about 40-50 ka BP in Hyotan-ana Cave (Hyotan-ana Cave research group, 1995). In some dolines buried black soil (10YR2/1) included To-Nb is covered with To-Cu. According to recent plant opal analysis (Hosono *et al.*, 1994; etc.), buried black soil were formed under grassland vegetation. It is considered that the changes of vegetation was affected by human impact such as burning forest. There are many ruins of settlements about 5-6 ka BP on the fluvial terraces and in caves. Therefore, deforestation is supposed to begin from Jomon Period, about several thousand years ago. Intensive deforestation on karst took place from 16th century. The trees had been periodically felled for charcoal and fuel, because the iron sand mining used weathered granitic rock which is distributed around the Akka Limestone and the iron smelting industry thrived around the study area between the 16th to 19th centuries.

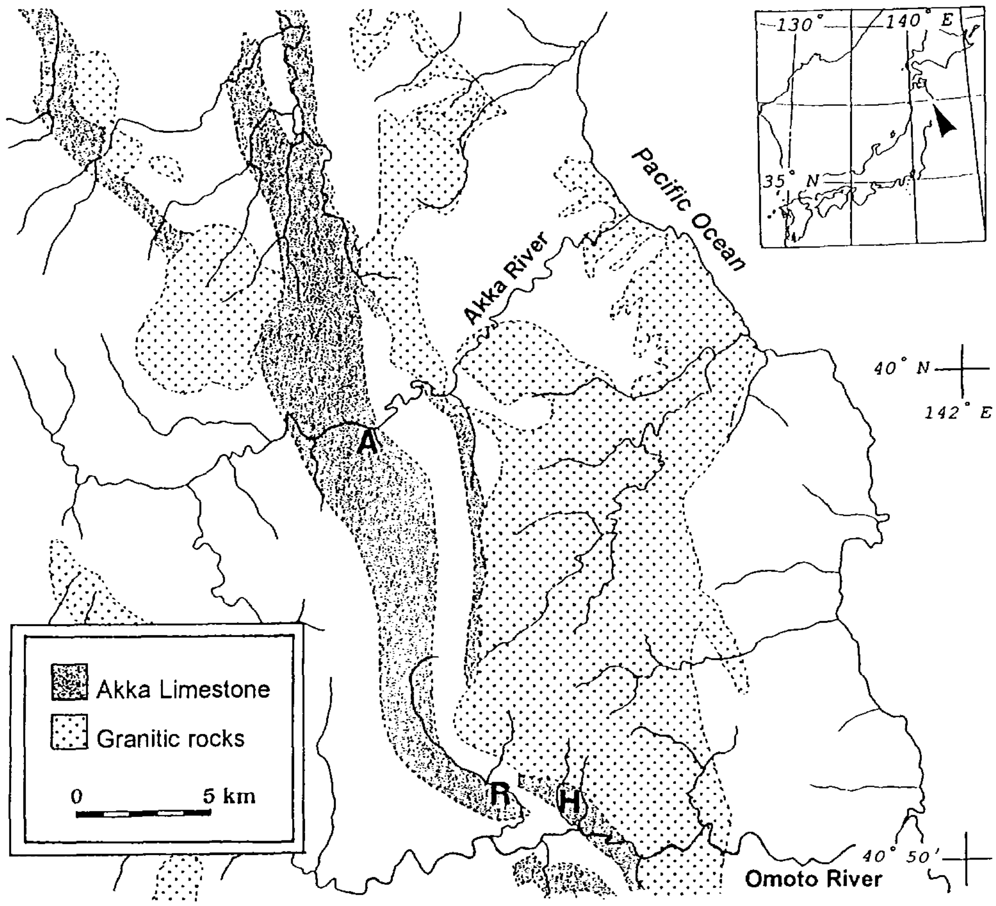

Fig.1 Geological map of the study area.
R: Ryusen-do Cave, A: Akka-do Cave, H: Hyotan-ana Cave.

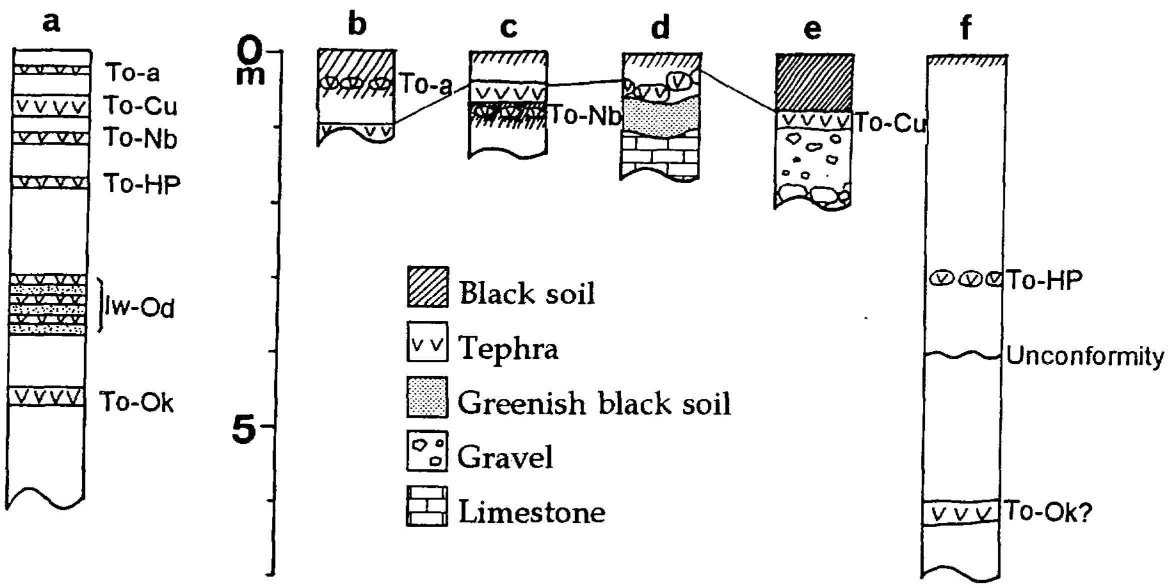

Fig.2 Columnar sections in the study area.
a) schematic columnar section of tephra in the study area.
b) c) bottom of dolines. d) gentle slope in doline.
e) footslope. f) gentle slope on the plateau.

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Quaternary Climatic Changes Derived From Surface-Subsurface Coupling in Karst Geomorphic Systems: Matienzo, Northern Spain.

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Natural archives traditionally utilised in reconstructing climatic change such as lakes, peat bogs and other sedimentary environments are often rare in karst regions. As such significant areas of the Earth's surface have been neglected in palaeoclimatic reconstructions. However karst, and in particular cave, environments contain abundant quantities of allogenic clastic sediments and autogenic carbonates, a point clearly made by Ford and Williams (1989). In addition the protective cave environment affords longevity to these deposits. Calcite precipitates from within these sites can also provide Uranium-series dates that much aid geomorphological reconstructions. This study aims to utilise such sites and materials in a palaeoclimatic reconstruction for the karstic region of northern Spain.

Many studies of cave deposits focus on speleothems. Whilst these are of great value in palaeoclimatic studies, Gascoyne (1992) being a good example, other cave sediments have been under utilised. Allogenic, clastic, sediments are clearly associated with surface hydrogeomorphic processes and hence climatic conditions in the wider environment outside the cave. The morphology of cave systems can also be linked to long term climatic changes within a wider region. This is particularly appropriate where large scale changes in palaeohydrological flow paths are evident. Coupling of sediment deposition locations within a cave system and the physical properties of these sediments enables a chronology of geomorphic processes and climatic change to be established.

Such a study is being undertaken in the Matienzo region of northern Spain, location map figure 1. The 26.4 km^2 Matienzo depression has been shown to have been evolving due to karstic processes for at least 1.8 Ma, a time scale calculated for the removal of material below the lowest point on the topographical divide (364m), Wlatham (1981). Extensive cave systems have been sequentially explored and mapped in the area. To date some 1115 speleological sites have been catalogued, with over 200km of cave passage surveyed and mapped. The most striking feature of these caves is the occurrence of at least six distinct phreatic levels of cave development, within which are found extensive suites of deposits, figure 2. The lowest and youngest of these is the present day active phreatic and epiphreatic zone with sequentially higher and older levels above. In the context of this study the abandoned levels have been assigned numbers from one to five with the lower level being 'level 1' up to the highest level 'level 5'. These phreatic levels are interpreted as reflecting periods of regional climatic stability punctuating episodes of regional climatic change. Sediment mineralogy and stratigraphies are investigated using magnetic susceptibility measurements and used in conjunction with extensive cave survey data and dating techniques. This integrated approach has enabled a model of climatic change and geomorphic evolution to be developed.

Magnetic susceptibility measurements, using a Bartington MS2C sensor, are utilised to describe varying sediment mineralogy throughout extensive cave systems and between distinct cave

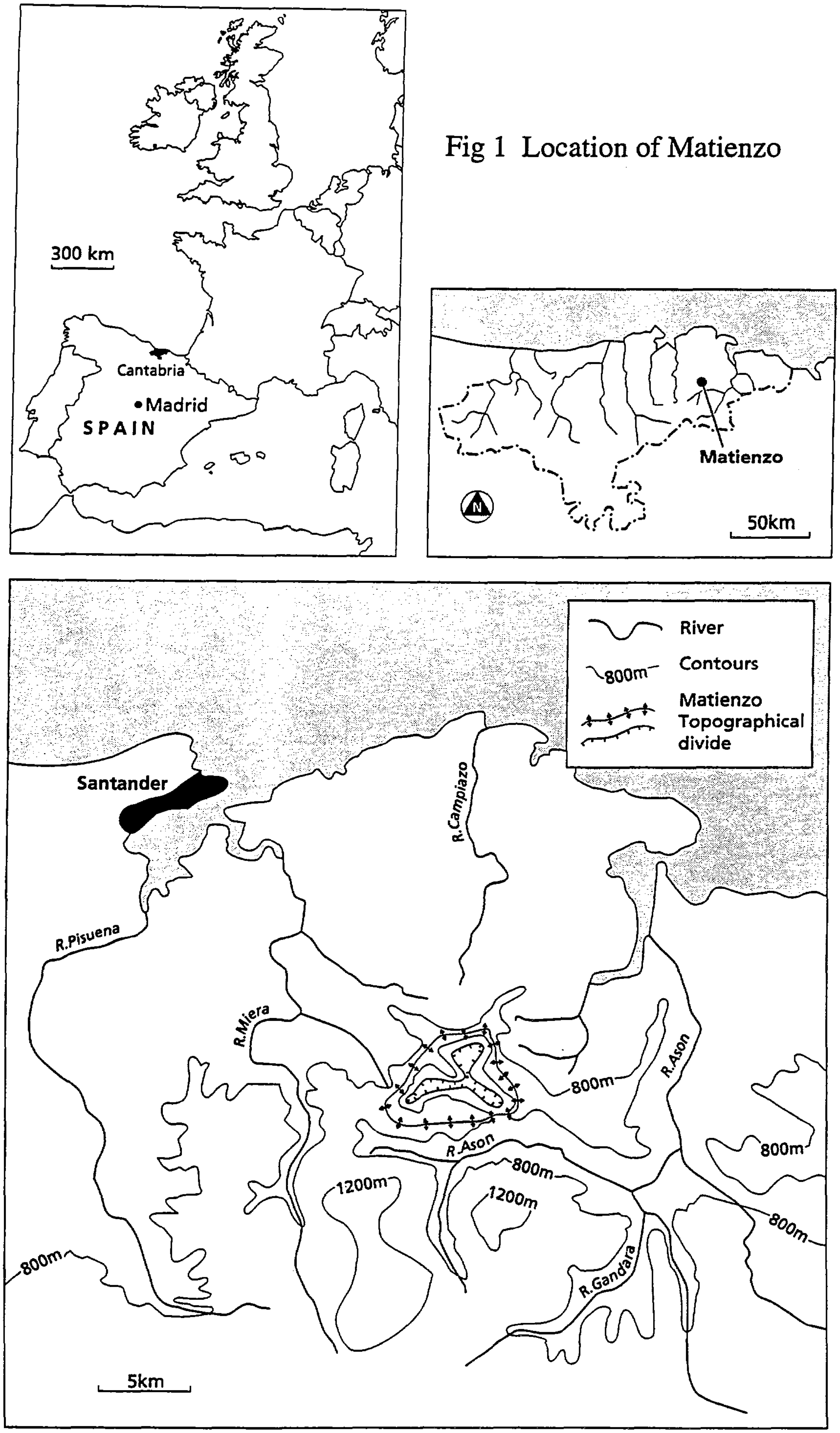

Fig 1 Location of Matienzo

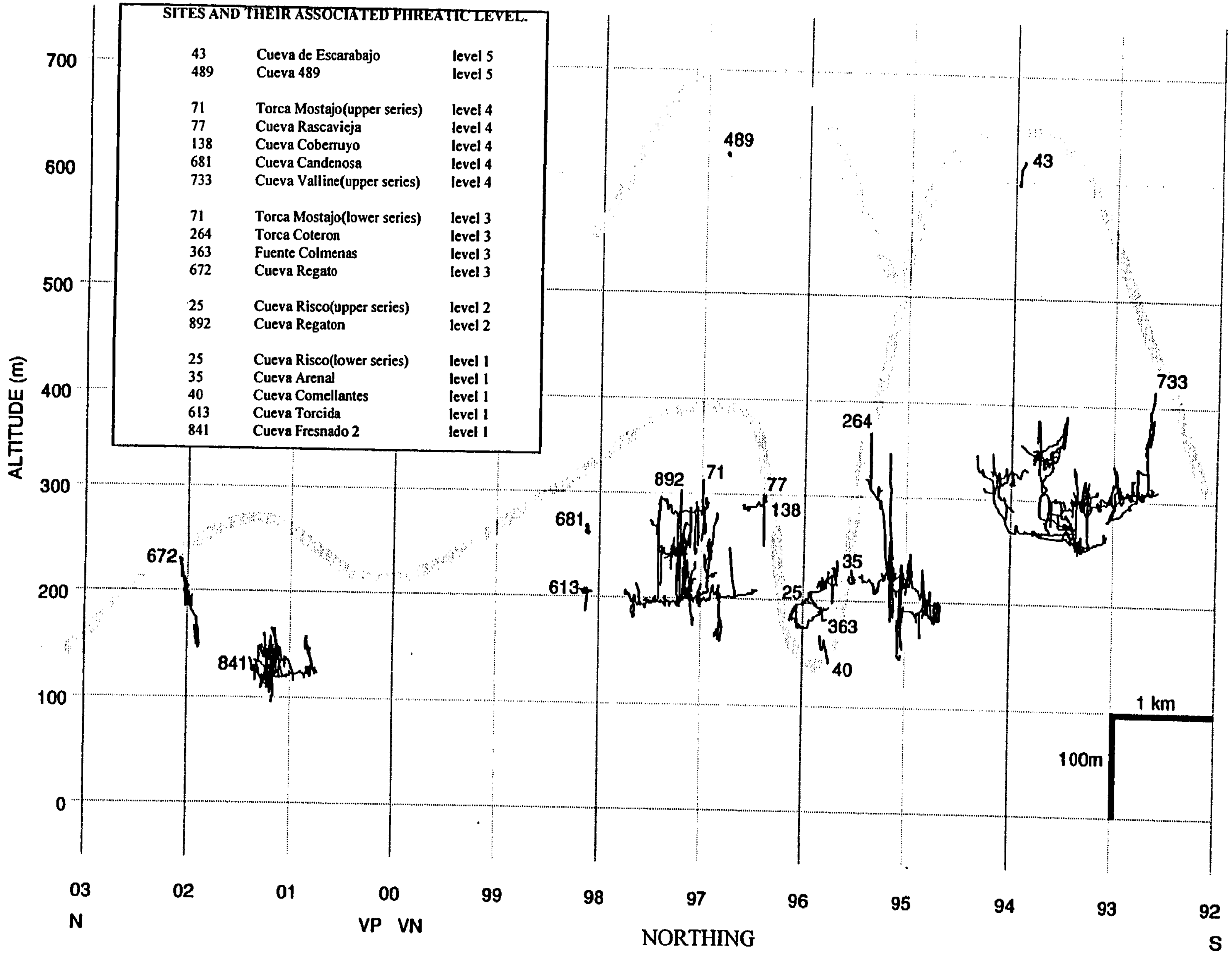

Fig 2 LEVELS OF CAVE DEVELOPMENT AS INDICATED BY MAGNETIC SUSCEPTIBILITY MEASUREMENTS
(Sites from both multi-levelled and distinct cave systems have been attributed to a level of phreatic development by means of morphometry and clastic sediment mineral properties).

sites and hence to distinguish phreatic levels and to place caves in an appropriate episode of development. The changing provenance of these sediments, as indicated by susceptibility measurements is reinforced by the palaeohydrological reconstructions determined from cave survey data. In particular changes in palaeoflow directions have been identified. A chronology for the abandonment of these phreatic levels is being established by means of a continuing series of dating, utilising a variety of techniques. Clear evidence of inhabitation by Palaeolithic man in the lowest dry level, Straus (1992) & Romanillo & Sainz (1995), indicate a minimum age for the draining of this phreatic level. Likewise minimum ages of abandonment can be assigned to levels one and two by the adoption of U/Th radiometric techniques to calcite precipitates found within these passages. Clastic sediment from phreatic levels three, four and five have been collected for thermoluminescence dating, establishing a date for sediment transport into the cave and hence phreatic activity. The probable antiquity of the highest of these sites suggests that palaeomagnetic techniques will have to be employed in order to establish this data. The position of this level some 240m above the 364m level used to calculate the 1.8Ma time scale of the depression suggests an age considerably older than this. The dating techniques used or expected to be used and dates established for the phreatic levels are set out in Table 1.

TABLE 1

PHREATIC LEVEL	DATING TECHNIQUE	DATES DETERMINED
0	ACTIVE LEVEL	Present Day
1	U-Series + Archaeology	17500a +- 700a*
2	U-Series	26200a +- 200a*
3	TL	awaiting data
4	TL	awaiting data
5	TL + Inferred	1.8Ma (inferred)

*Openshaw (1996)

Changes recorded in the Matienzo cave systems are intrinsically linked to wider, regional scale changes throughout the Quaternary of the north of Spain, thus enabling a fuller understanding of a relatively unknown regional Quaternary history. The evidence collected to date suggests a sequence of at least six major episodes of cave development interspersed with periods of relatively rapid readjustment. It is envisaged that this ongoing programme of sample collection and analysis will yield more detail to the Quaternary climatic picture in northern Spain. What can be clearly concluded however at this stage is the usefulness of the combined study of clastic cave sediments and cave morphometry in describing long term and regional scale palaeological changes.

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COMPLEX STRATIGRAPHIC SERIES IN BELGIAN CAVES : CORRELATION WITH THE PAEOCLIMATIC VARIATIONS DURING MIDDLE AND UPPER PLEISTOCENE

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The message of endokarstic sediments.
Deposits in karstic cavities are very good indicators of **palaeoenvironmental conditions.** But the message is complex. We can recognize four influences. Geological environment determines mineralogical and sedimentological nature of the detritic sediments. Tectonic evolution modifies the energetic inputs into the karstic network and determines the nature of the sedimentation (high or low energetic levels). Climatic factors, of course, have a determining role through the bio-rhexistasy. Finally, human actions modify very much the "natural" mechanisms. Thus, the sedimentary recordings in caves reflect, because of their stratigraphic complexity, many parameters in which climate is only one.

The deposits in Belgian cavities.
Belgian karstic cavities are very good sediments traps. They belong to a low plateau karst, with long horizontal galleries which contain complex sedimentary series. Detritic units (roundstones, sands, clays) alternate with stalagmitic complex (flowstones, stalagmites). The supply of matter and energy is determined by morpho-structural context. Allochtonous rivers go deep into the limestones from sandstones and shales, because of the peneplanation of the hercynian fold structures in the paleozoïc rocks. accordingly, there are three main types of deposits. **[i]** : The river deposits (roundstones, sands, clays) are coming principally from allochtonous terranes. **[ii]** : Loams are removed from the cover above the karst and go down by fissures into the galleries. **[iii]** : Speleothems covers detritic deposits and can be also covered by other detritic sediments. All these sedimentary units are integrated in complex stratigraphic series, with erosion forms into sediments.

The climatic message.
In the regional context, we have demonstrated that those litho-stratigraphic characteristics are a major consequence of climatic variations during the Quaternary and, thus, constitute a very good tool to study those palaeoenvironmental variations. Indeed, the Pleistocene modifications of the relief because of the tectonic factors are low and, thus, sediments reflect particulary climate modifications. The detritic sediments settle in cold conditions (rhexitasy period = glacial period), rivers deposits during wet cold periods and loams during dry cold periods. Speleothems are grown in temperated and wet conditions (biostasy periods = interglacial or interstadial periods). But, more, we can have mechanical erosion of detritic sediments with formation of hollowings, and chemical corrosion of speleothems. This combinaison of sedimentation and erosion process are the consequence of the base level fluctuations, like a consequence of detritic sedimentation in the bottom of the valley during glacial periods.

Because of those phenomena, the sedimentary series in belgian caves are complex, with an stratification of the different types of deposits. The reconstitution of palaeoenvironments must go through the utilisation of different parameters : litho-stratigraphy, mineralogy, palynology,

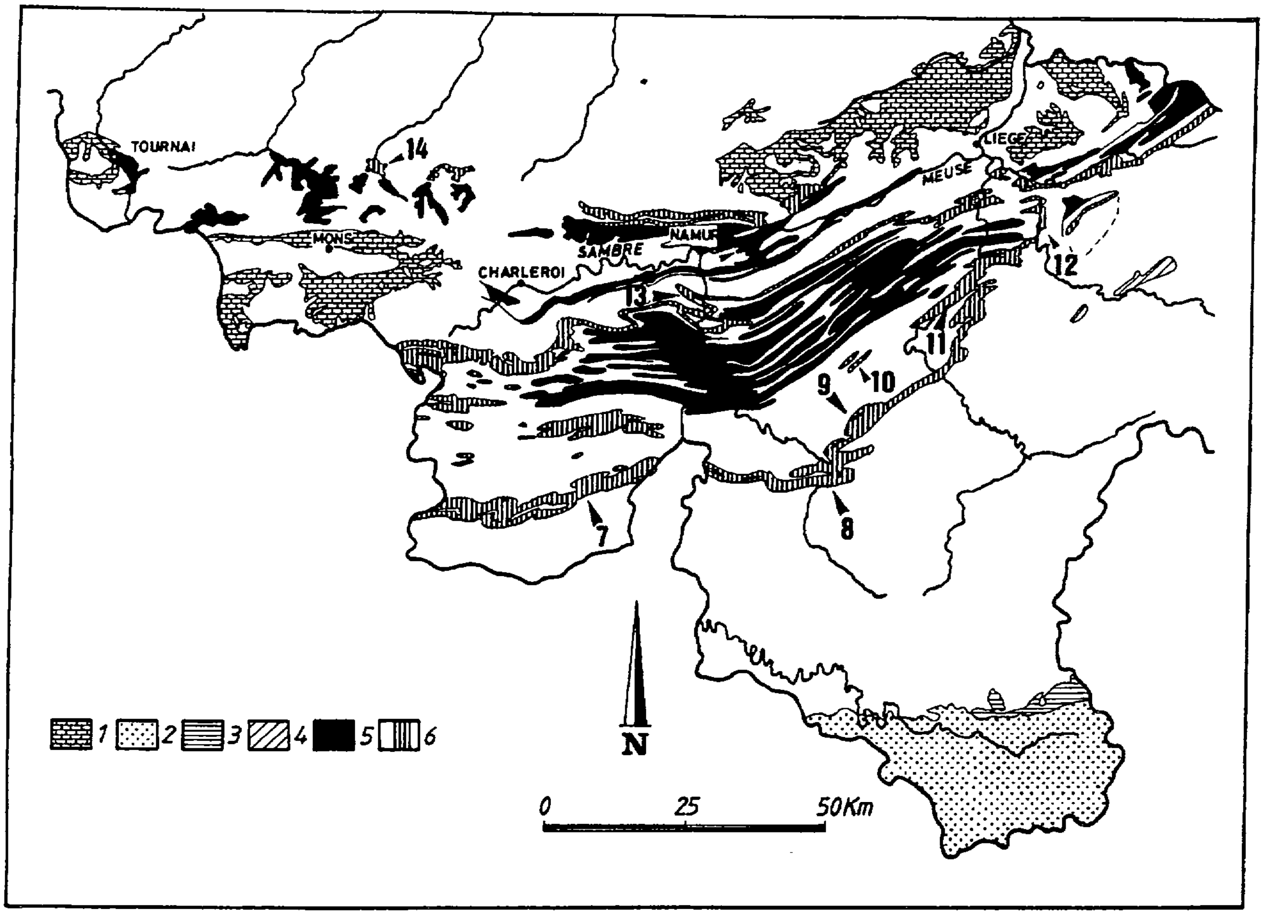
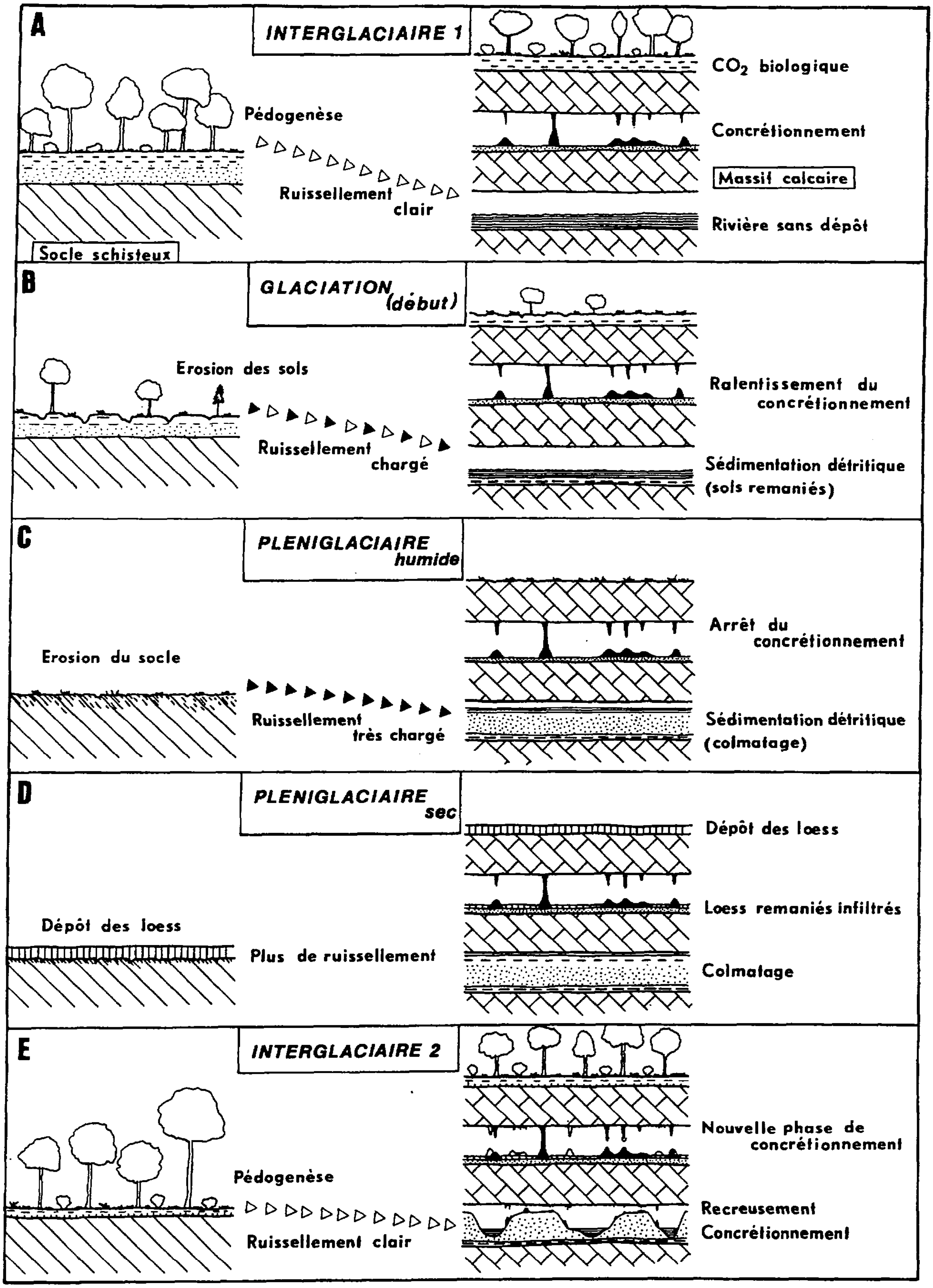


Figure 1. **Localisation of the caves, in the geological context. 1.** Cretaceous chalk. **2.** Jurassic terranes. **3.** Triasic terranes. **4.** Permo-triasic conglomerates. **5.** Carboniferous limestones. **6.** Middle devonian limestones. **7.** Grotte de Neptune. **8.** Massif de Han (Grotte de Han, Grotte du Père Noël). **9.** Grotte de Rochefort. **10.** Trou de la Louve. **11.** Grotte de Bohon. **12.** Grotte de Remouchamps. **13.** Grotte de la Vilaine Source. **14.** Grotte de Feluy.

Figure 2. **Evolution of a karstic network during a climatic cycle.** Left : allochtonous terranes (shales, sandstones) of the alimentation basin ; right : section through a limestone massif with active and inactive levels.
A. First interglacial period. The river does not carry sediments because of the pedogenesis. There is much biological CO_2 and the speleothems grow. There is no detritic sedimentation in the cave.
B. Beginning of the glacial period. The disparition of the forest permit the erosion of the soils. The running is loaded ; there is detritic sedimentation in the karst. The development of the speleothems slows down.
C. Wet glacial period. A intense freezing erosion provokes a big sedimentary load in the river. The caves are completely filled in. The speleothems development stops.
D. Dry glacial period. Because of the dryness, we have loess sedimentation. These eolian loams can go down in the karst by the fissures.
E. Second interglacial period. Clear river, without sedimentary load, cut the detritic sediments in the caves. A new speleothems generation develops.


A
INTERGLACIAIRE 1
Pédogenèse
Ruissellement clair
Socle schisteux
CO2 biologique
Concrétionnement
Massif calcaire
Rivière sans dépôt
B
GLACIATION (début)
Erosion des sols
Ruissellement chargé
Ralentissement du concrétionnement
Sédimentation détritique (sols remaniés)
C
PLENIGLACIAIRE humide
Erosion du socle
Ruissellement très chargé
Arrêt du concrétionnement
Sédimentation détritique (colmatage)
D
PLENIGLACIAIRE sec
Dépôt des loess
Plus de ruissellement
Dépôt des loess
Loess remaniés infiltrés
Colmatage
E
INTERGLACIAIRE 2
Pédogenèse
Ruissellement clair
Nouvelle phase de concrétionnement
Recreusement
Concrétionnement

paleontology. The speleothems only cannot be used for complete paleoclimatic reconstitution.

The Pleistocene-Holocene rupture. The transition takes place around 12 ky with a speleothems generation (Alleröd) after an important detritic sedimentation during isotopic stage 2 (Rochefort cave). Younger Dryas is a period of hollowing into the sediments, following by the speleothems growing during Holocene, which seal the erosion forms. This period is very well known by palynology which shows the installation of forest (Louve, Han, Remouchamps caves).

The glacial period sedimentation. Several series prove the input of rivers deposits during the stage 4 (cold and wet) and removed loams during stage 2 (cold and dry). Pollinic analysis has demonstrated this fact, for example finding *Selaginella Selaginoïdes* (Vilaine Source, Bohon caves). Those cold periods correspond to an complete filling of the active caves. Different sedimentary sequences can be recognized, like drying sequences.

The isotopic stage 3. This interstade (equivalent to "Interstade des Cottés") is characterized either by a hollowing of stage 4 river deposits (Bohon, Vilaine Source caves) or speleothem generation. The double sequence of the Père Noël cave can date the isotopic stage 4 (56,5 - 72,3 ky). In other cases, we see an incision through the detritic deposits sedimented during the stage 4.

Interstadial periods. Some speleothems are situated into glacial stages (Han, Neptune caves). They indicate that, during short times, a climate improvement has permitted the return of better conditions (forest of *Pinus* and *betula*). For example, we find two periods around 17 and 20-21 ky.

The transition between stages 4 - 5. This transition consists in the passage between stalagmitic sedimentation to detritic sedimentation. U/Th datings situate this transition around 70 ky. Pollinic analysis shows the disparition of forest to steppe environment (Sclayn, Père Noël, Feluy caves).

The stage 5. We find essentially big speleothems in which we have detected the different substages by U/Th datings and palynology (Han cave). Sometimes, when there was no river flow, one finds colluvial loams (Sclayn cave). The sedimentation is not continue, but is cut by river incisions and corrosion of speleothems (Vilaine Source cave). Cold substages 5.2 and 5.4 are recorded in speleothems (Han cave) or in loams (Bohon cave). Another perturbation is the consequence of earthquakes (stop of the growth, cementery of stalactites and stalagmites). All those speleothems permit by the pollen analysis to reconstruct the aspect of the forest.

Middle Pleistocene. The isotopic stage 6 is characterized by river deposits, like sands and clays in the upper passage of the Han cave and in the Bohon cave. The isotopic stage 7 is not well represented. Lower part of the big flowstone in the Han cave is dated around 200 ky. Many speleothems can not be used, because of their age older than 350 ky.

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A HOLOCENE PALAEOCLIMATE DOCUMENT: THE CAVE "GHEȚARUL DE LA SCĂRIȘOARA"

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The cave "Ghetarul de la Scarisoara" is located in Bihor Mountains, the central unit of Apuseni Mountains (Transylvania, Romania). It is at 1165 m altitude, on the left side of Gârda Seaca Valley, an affluent of Ariesul Mare river.

Giving the fact that it appears as a generally descending cavity (having a total depth of -105 m and a development of 700 m), with only one external entrance (a 50 m deep shaft) this cave is characterised by intermittent bi-directional ventilation with an active stage in the winter season, the effect of which is a repeated accumulation of cold air. As a result, the temperature of the subterranean atmosphere falls at negative values in wintertime, being sometimes possible to pass beyond -10°C, becoming stable , around + 0.5°C, in summertime.

Such a glacial topoclimate type makes possible in this cave the development of some perennial ice speleothems. Among these, the most important is an ice block having at least 20 m in thickness and a total volume of about 75.000 m^3 that lies in the central zone of the cavity, closed to the cave entrance (Fig. 1).

The ice building-up the block is not homogeneous, but shows a layered structure, given the seasonal variations of the subterranean temperature. During summer the ice and the snow accumulated at the bottom of the shaft is partly being melt. Because of this, the uppermost part of the ice block (an almost plat surface) will be covered by a film of water in which limy dust and alohtone materials (soil, vegetable remainder, pollen) will be deposit. When the water film freeze in the winter time all this material will be trapped inside a thin ice layer. Therefore, the ice block structure shows couples of ice layers (clean and with impurities) each of these couples being an *elementary stratigraphic unit*.

After the pollenic analysis undertaken on a 759 cm high profil from the base of the northern flank of the block, it had been establish that the first ice layers within this profile have been formed about 3000 years ago, in the post-glacial beech forest phase. Taking into consideration the genetic conditions, it is logical to admit that the morphological and structural parameters of each stratigraphic unit (thickness, the nature of the materials, the isotopic composition, the presence of some solid or gaseous inclusions etc.) depend on the meteorological peculiarities of each annual cycle; thus, the stratigraphic profile of the ice block, on the whole, must reflect all the climatic oscillations which had been produced along thousand years. It is the reason the perennial ice deposit preserved in the cave "Ghetarul de la Scarisoara represents an unusual paleoclimatic document for the Late Holocene period.

The solving of the paleoclimatic information included in this deposit implies, in the first place, the determination of the correlation degree between the variation of the external meteorological factors and the structural elements of the ice or, in other words, the determination of the time span in which the climatic oscillations can be recognised in the succession of these elements.

The northern flank of the block - actually a natural section springed up in an ice ablation process - shows the existence of three great stratigraphic sequences morphological differentiated; the median one is characterised by more layers of impurities, thicker and richer in vegetable remainders;

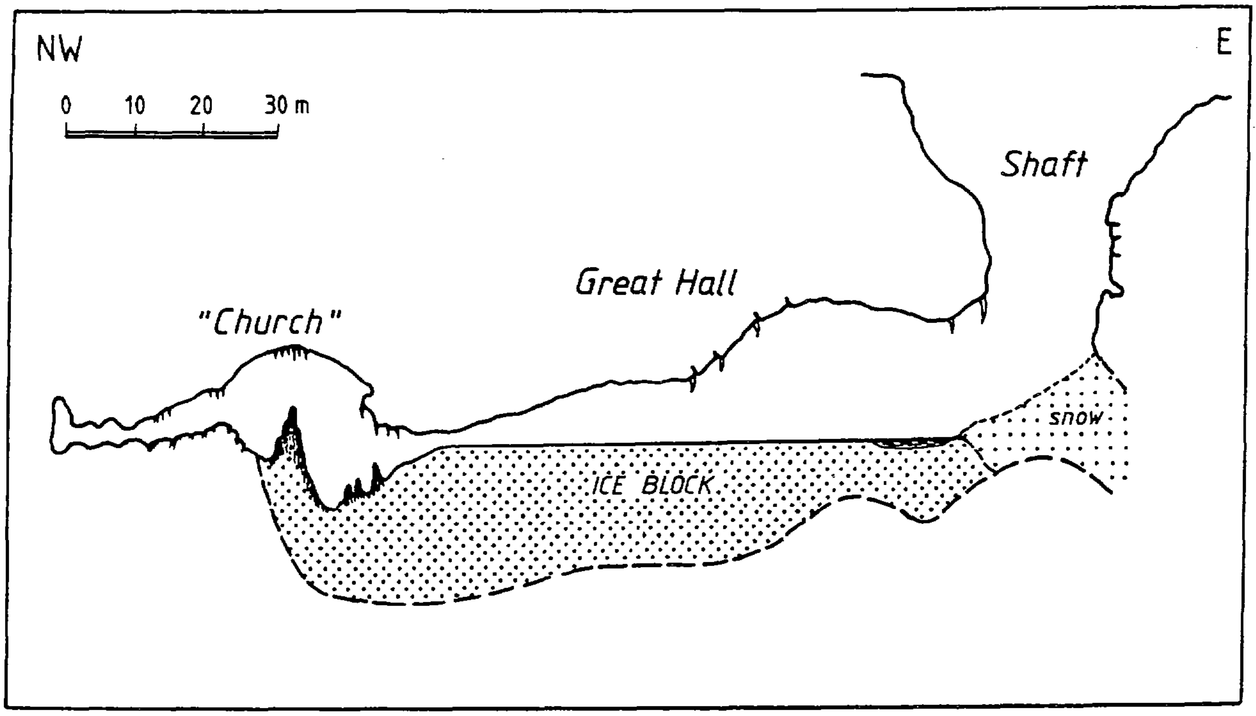

Fig. 1. - Longitudinal profile between the entrance and north-westestern extremity of the cave "Ghetarul de la Scarisoara".

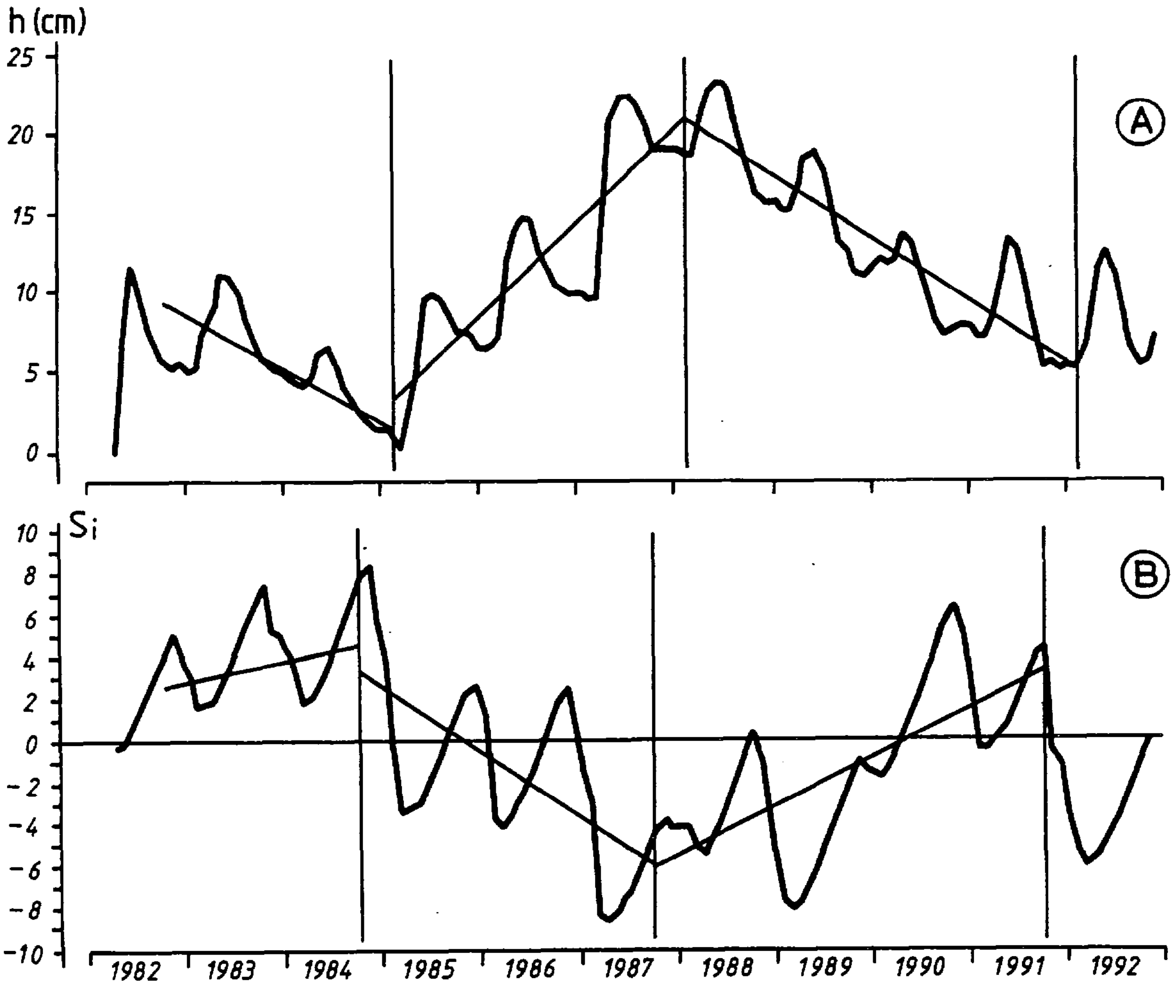

Fig. 2 - The oscillation of the superior surface level of the ice block (A) and the adjusted curve of the subterranean temperature oscillation in the glacial sector of the cave (B).

thus, it can be inferred that it had been formed in a warmer and more rainy period, probably in the same period in which the Histrian transgression of the Black Sea took place, in the first part of our millennium. But this is only raw estimated.

For knowing in detail the meteorological conditioning of the cave glaciation phenomenon, a research programme on long term regarding the subterranean topoclimate and the dynamics of the ice speleothems has been initiated. Unfolded in 1982-1992 period, this programme ended in very useful results, since they demonstrate two major facts.

The first is the establishment that, besides the seasonal, normal variations, of its level, (summer decreases and winter increases), the superior surface of the ice block (the floor of Sala Mare) has multiannual oscillations as well, but of superior degree. These are, in fact, tendencies of progressive increase or decreases, which continue on a term of 3-4 years and are clearly pointed out by the regression straight lines, calculated for each of these phases (Fig. 2 A).

The second fact is that exactly the same multiannual oscillations are found in the evolution of the subterranean temperature as well. The strictly parallelism between the two dynamic parameters becomes striking if the tendencies which this evolution entails are thrown into relief through an adequate statistic processing of the thermometric data. The Ballot-Besson method has been applied (the progressive addition of the deviation from the arithmetical average of the whole values row), because the adjusted curve of the S_i sums obtained this way amplifies the periodicities in the succession of the primary data (Fig. 2 B). The same statistic analysis shows that between the oscillations of the subterranean temperature and those of the external temperature a close correlation can be established, as well.

The essential conclusion to which these results conduct is that, at least probably at the level of 11 years meteorological cycles, the periodicities which appeared in the evolution of the regional macroclimate could be reconstituted through a detailed study of the morpho-structural peculiarities of the ice perennial deposit in the cave "Ghetarul de la Scarisoara". It is the required and sufficient premise from which any research effort can start.

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Submerged speleothems from the Bahamas: Sea levels, palaeoclimate and uranium-series disequilibria

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Summary - The pattern of growth in a submerged flowstone and stalagmite sequence from Grand Bahama serves as an important source of sea-level and palaeoclimate information for the middle and late Pleistocene and is compared with other sea-level data; a flowstone record from the same island (Lundberg and Ford, 1994), ^{230}Th ages of coral reef terraces and oxygen-isotope records from deep-sea cores. Elevations and mass-spectrometric ^{238}U-^{234}U-^{230}Th ages of multiple phases of calcite growth in submerged speleothems provide maximum constraints on sea-level elevation because calcite deposition could only have occurred when the cave passages were air-filled. Elevation constraints are good because the Bahamas have remained tectonically stable for the period of growth. Non-depositional hiatuses can be attributed to submergence during high sea stands or cessation of drip during periods of aridity, lack of soil cover or fissure blockage. Ages for initiation of growth after major high sea-stand events in the Sagittarius sequence are $384 \pm ^{20}_{17}$ ka, 315 ± 13 ka, 190 ± 5 ka and 80 ± 2 ka, and constrain the timing of the oxygen-isotope stage boundaries 11/10, 9/8, 7/6 and 5/4, respectively. Numerous hiatuses occur in isotope stage 8, indicating that deposition was sensitive to climate change at this time.

Few studies have investigated the U-Th systematics of dissolution and precipitation in carbonate platforms. The longest sequence of flowstone growth from the Bahamas (Sagittarius Cave, Grand Bahama) exhibits a first-order trend of decreasing initial ^{234}U/^{238}U along the axis of growth. This is ascribed to closed-system decay of the overlying carbonate unit since deposition of material with of modern sea water at ~ 300 and ~ 400 ka. Second-order variation is probably caused by subsequent periods of more limited deposition of marine carbonates with elevated ^{234}U/^{238}U during high sea-stand events and development of the network of flowpaths to the drip source.

Samples and methods - Six speleothem samples from -13 to -18 m in Sagittarius Cave, eastern Grand Bahama, show multiple phases of calcite growth separated by growth hiatuses. U and Th isotope measurements were made on 45 sub-millimetre wafers of calcite from the Sagittarius samples, typically 0.2-0.5 g (^{238}U = 100-500 ng g^{-1}), using mass-spectrometric techniques at the University of Minnesota (Edwards *et al.*, 1987; Richards *et al.*, 1994). Duplicate and replicate analyses agreed within analytical precision. Twenty-six analyses were made on sub-samples older than the last interglacial and only 2 of these, from the top of the same growth layer, showed age inversions when compared with stratigraphically related sub-samples.

Hiatuses and sea level (or palaeoclimate?) events - The composite flowstone sequence from Sagittarius Cave exhibits nine or more depositional hiatuses (Fig. 1). Some of these can be attributed, in part, to submergence during high sea-stands because at least three middle to late Pleistocene platform-flooding events are found in shallow marine carbonates from the Bahamas (Aurell *et al.*, 1995). The elevations of high sea-stands below present sea level are poorly known and the Sagittarius sequence (-13 to -18 m) can provide important sea level data, but definitive evidence for submergence during hiatuses is needed. Palaeoclimatic control inhibited speleothem growth in the Bahamas during the last deglaciation (Richards *et al.*, 1994) and may be important during earlier growth phases, particularly during isotope stage 8, for which three distinctive hiatuses are evident, and late glacial stage 6, when growth ceased prior to the penultimate deglaciation. Discrepancies in timing and elevation of sea-level events > 200 ka can be seen in two often cited oxygen-isotope records (Fig. 1). Our data provide useful estimates for the maximum or minimum ages of stage boundaries for the Pleistocene. Deposition of calcite in the Sagittarius sequence commences immediately after sea level regression to below -13 to -18 m based on ages of high sea levels from coral reef terraces (Fig. 1). The minimum age estimates for stage boundaries 11/10, 9/8, 8.5/8, 7/6 and 5/4 can, therefore, be considered as chronological control points. This is in contrast to cessation ages, where other controls on growth, such as aridity and drip cessation may occur.

Uranium isotopic variation - Speleothems preserve a record of the $^{234}U/^{238}U$ of meteoric waters. Higher resolution sampling and increased precisions of mass-spectrometric analyses in comparison with alpha-spectrometric methods have revealed significant secular variation of initial $^{234}U/^{238}U$ in the Sagittarius sequence. The $^{234}U/^{238}U$ ratio in the secondary calcite is inherited from the marine carbonates overlying the cave which were deposited with $^{234}U/^{238}U$ similar to present sea water (~ 1.144). The first-order trend towards lower values along the axis of growth can be explained by radioactive decay to secular equilibrium of the overlying unit. Superimposed on this is a saw-tooth, or step-like, pattern. This second-order trend is likely to be caused by 1) deposition of additional marine carbonates with elevated $^{234}U/^{238}U$ during high sea-stands and, 2) increasingly lower and older material dissolved during glacials because of fissure development and input of organic material.

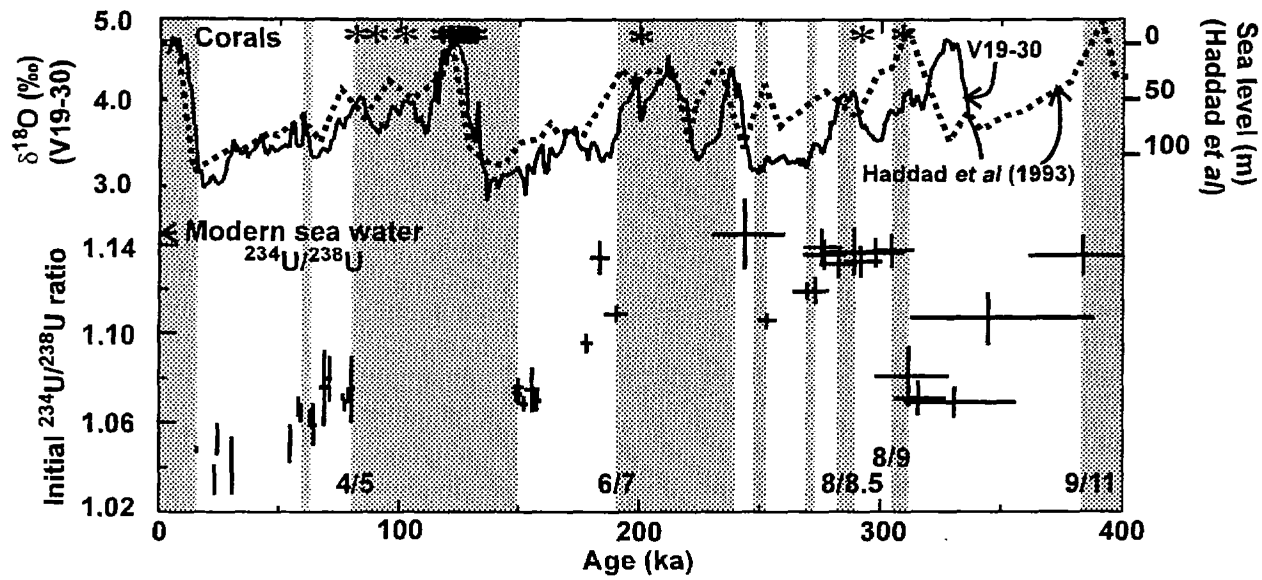

Figure 1. Ages and initial $^{234}U/^{238}U$ ratios of sub-samples from the composite Sagittarius sequence. Hiatuses are shown by shaded regions. Two sea level curves based on oxygen-isotopes in deep sea cores are shown as well as ^{230}Th ages of high sea-stands from various coral reef terraces.

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U-Pb dating of Quaternary age speleothems

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Abstract
U/Pb dating techniques are based on the ingrowth of stable isotope ^{206}Pb from deacy of the parent isotope ^{238}U and have the potential of dating speleothems beyond the range of the more usual $^{230}Th/^{238}U$ methods. We obtained a $^{206}Pb^{*}/^{238}U$ age of 250 ± 12 ka for a stalactite from Winnats Head Cave, Peak District, concordant with a $^{230}Th/^{238}U$ age of 255 ± 30 ka, assuming an initial state of uranium-series disequilibrium with initial $^{234}U/^{238}U$ ratio of 1.32 ± 0.05 and negligible initial ^{230}Th and daughter isotopes.

Introduction
Important information about past climates and landscape evolution can be obtained from speleothems (secondary calcites precipitates in caves, such as stalactites and stalagmites). However, the limited range of $^{230}Th/^{238}U$ dating techniques (less than 500 ka using high-precision thermal ionisation mass-spectrometry or TIMS) means that many potentially important geological samples of Quaternary and Tertiary age remain undated. U-Pb dating techniques are commonly used for materials with a range in age of a few million years to the age of the earth. Successful application of U-Pb techniques to limestones and calcite spars of ancient carbonates and their late stage diagenesis have been made (Smith *et al.*, 1991; Jones *et al.*, 1995). Here we assess the application of U-Pb methodology to much younger deposits where the initial state of uranium-series disequilibria must be taken into account.

Methods and Results
We demonstrate that a stalactite from Winnats Head Cave in the Peak District, England, analysed by $^{230}Th/^{238}U$ methods (Rowe, pers. comm), can be dated using U-Pb methodology. Sub-millimetre wafers, almost entirely composed of clear calcite with a small detrital component, were analysed by TIMS for U and Pb. The calcite phase has high U content (16-30 $\mu g\ g^{-1}$), and low Pb content (< 10 ng g^{-1}). Using the Pb isotopic results plotted below (Figure 1), we obtain an initial $^{206}Pb/^{204}Pb$ ratio of 17.11 ± 0.04, identical to the measured detrital, low-μ (i.e. $^{204}Pb/^{238}U$) phase $^{204}Pb/^{206}Pb$, 17.17 ± 0.09. The extremely large range of μ values obtained (800 to 1.2 x 10^6) enables $^{206}Pb^{*}/^{238}U$ and $^{207}Pb^{*}/^{235}U$ to be estimated with reasonable precisions. Using the independently estimated initial activity ratio for $^{234}U/^{238}U$ of 1.32 ± 0.05, and assuming negligible initial ^{231}Pa, ^{227}Ac, ^{230}Th, ^{226}Ra and ^{210}Pb, near-concordant ages of 250 ± 12 ka and 318 ± 54 ka (minimum 2σ errors) have been derived. The age calculation uses the Bateman equations for closed-system decay (Ludwig, 1977). These ages compare very well with the alpha-spectrometric ^{230}Th age of 255 ± 30 ka.

The feasibility of dating further speleothem deposits is discussed. Only samples with high U/Pb ratios are suitable for U/Pb techniques. Results of a preliminary survey of U and Pb concentrations of many samples from various locations across the globe indicate that U/Pb ratios vary by eight orders of magnitude and it is clear that pre-screening must be adopted before attempts are made to date samples.

Conclusions

We demonstrate that U-Pb dating of speleothems is feasible by obtaining ages concordant with $^{230}Th/^{238}U$ ages. This has been acheived on an ideal sample with an extremely large range in μ values. It is clear that further samples must be attempted before wider applicability can be demonstrated.

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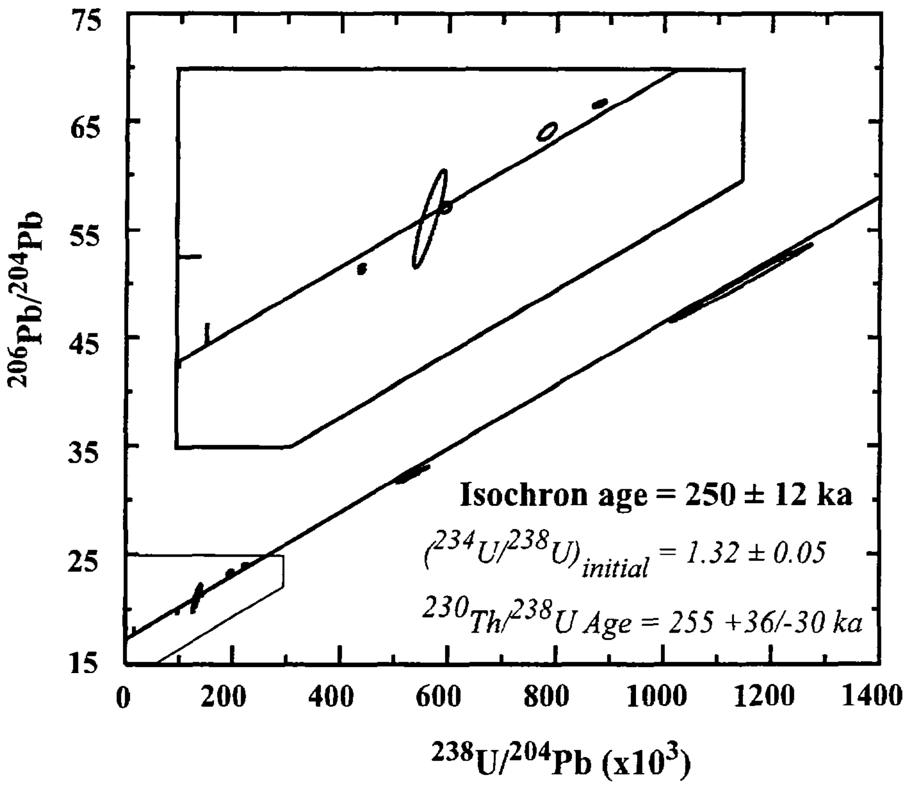

Figure 1. $^{206}Pb^{*}/^{238}U$ isochron for a stalactite from Winnats Head Cave, Peak District, England.

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TRACE ELEMENTS IN HOLOCENE SPELEOTHEMS

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The potential of the trace element record in speleothems to provide a reliable high resolution palaeoenvironmental record is assessed on the basis of analyses of three stalagmites of Holocene age (8 to 1 ka) from the Great Chamber of GB Cave in the Mendip Hills, south-west England. The trace element records (Mg, Sr, Ba, U) were obtained using laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS). The chronology for the trace element records was determined on the basis of high precision TIMS U-series ages.

Mg partitioning between water and calcite is temperature dependent. It has been suggested[1,2] that Mg variations in speleothem calcite may provide information on palaeotemperatures. This approach is dependent on the absence of any temporal variation in dripwater Mg content. Sr partitioning between water and calcite is independent of temperature and therefore, the Mg/Sr ratio should be solely controlled by changes in temperature, assuming that changes in Mg and Sr concentrations in dripwaters are controlled by the same processes and change in parallel.

The records presented here suggest that a coherent trace element record cannot be obtained from coeval stalagmites from the same cave and that sample-specific processes play a significant role in controlling speleothem geochemistry (see figure 1). The results of this study suggest that the application of simple partition coefficients to speleothem calcite may be inappropriate. The observed changes in the Mg/Sr ratio in two of the stalagmites (see figure 1) are significantly greater than that predicted on the basis of equilibrium partitioning between water and calcite under Holocene climatic conditions. In order to develop this approach, it is critical to improve models of contemporary cave hydrochemical systems. Factors which need to be addressed include:

- The supply of trace elements from surficial deposits
- The spatial variability of trace element distribution within the bedrock
- The residence time of waters in the soil and in the bedrock
- The routing of waters through the bedrock
- The partitioning of trace elements at the water/calcite interface

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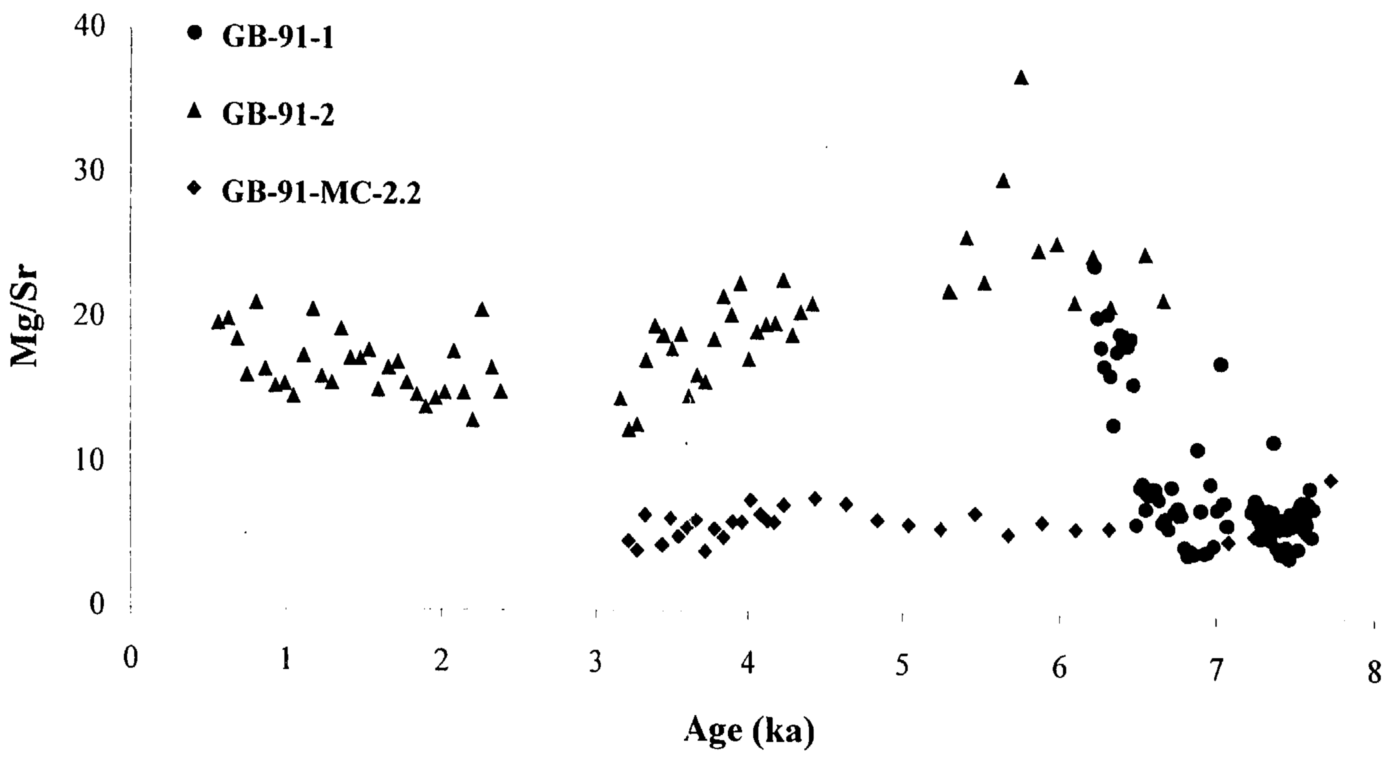
[2]**Goede, A. and Vogel, J.C.** 1991. Trace element variations and dating of a late Pleistocene Tasmanian speleothem. *Palaeogeography, Palaeoclimatology, Palaeoecology,* **88**, 121-131.

Figure 1: Mg/Sr variations in three Holocene stalagmites from GB Cave, Mendip Hills, south-west England.



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Conservation of Cave Sediments

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KEY WORDS: conservation, natural heritage, cave sediments, Slovenija.

A term cave sediments means huge quantitiy of different kinds and series of material which fills up karst caverns. So, at first, one can ask oneself a question why to safeguard such huge quantities of the materials. It looks extraordinary to deal with the matter, but if we are aware of meaning of the sediments from points of view of the natural history or aesthetic values of spelaeothems, which make part of the sediments, there is no doubt about a need to safeguard the sediments. It is impossible to treat all types of the sediments, but there is a demand for inventarisation and conservation of the most important sediments. Theoretical starting-points of the sediments inventarisation and conservation as natural heritage, some examples of degradation and conservation of the sediments in Slovenija are presented in the paper.

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Modelling the Genesis of Karstified Limestone Aquifers

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Abstract: The quantification of groundwater flow and the transport of dissolved substances poses generally problems in parameter identification as well as in the modelling of the above processes. The lack of information on the geometry and the heterogeneity in the hydraulic properties as well as the difficulties encountered in the investigation of these parameters are frequently the cause that the model has to be simplified and that parameters have to be averaged over large rock volumes. The intoduction of these simplifications imply that the prognostic value of the model predictions are reduced considerably. On the other hand, available qualitative and quantitative geological information on the history of the development of the karst aquifer, which can provide information on the distribution of karstified horizons within the modelled domain, are generally not considered.

It is the aim of the project, presented in this poster, to understand the process, the spatial extension and the temporal development of karstification for a typical karst aquifer in SW. Germany. Mathematical models will be used to simulate the interactions between the different processes, i.e. flow, transport coupled with carbonate dissolution, taking into account the varying boundary conditions, e.g. changes in geological and geomorphological (base level) and climatic conditions (recharge depth, temperature). The numerical model will also be used to test various genetic hypotheses. The generated karst aquifer model is expected to provide quantitative information on the aquifer geometry, the spatial distribution of hydraulic parameters and the fluxes of dissolved carbonates under variable geological and climatic conditions over time.

Aims:

- Modelling of the genesis of a karst aquifer taking into account the most important geological, tectonic, hydrological, hydrogeological, hydrogeochemical and geomorphological processes
- Identification of the most important factors, influencing Karstification
- Quantification of the process parameters
- Implementation of the model for testing of various hypotheses of the development of the karst aquifer in SW Germany
- Use of the generated hydraulic parameters as input for discrete flow and transport modelling in karst
- Use of the model as a prognostic tool, for modelling the effect of climatic changes on karst - water ressources and on the karst water quality of different climatic regions

The Role of the Climate for the Development of Karst:

The dominant determining factor for carbonate dissolution, the erosional and hydraulic processes is the climate, and knowledge of its temporal variation is an important prerequisite for reliable predictions of the intensity of karstification and the spatial distribution of the karstified zones.

Together with other factors, such as geomorphological-hydrological processes, the lithological variation within the aquifer, the climate constitutes the controlling mechanism for the development of a karst system. Figure 1 (changed after Ford & Williams, 1989) shows the importance of the influence of the climate on karstification and illustrates the different feed-back mechanisms inherent in such a complex system.

Geological Model of the Development of the Karst System on the Swabian Alb (SW. Germany)

Based on the available information (Villinger, 1986) and our own work, the following conceptual model of the karstification in the area of the Swabian Alb and the northern part of the Molasse Basin could be developed. (Fig. 2):

End of Jurassic - Middle Oligocene: Shallow karstification and carbonate denudation at the surface (Paleokarst, Bohnerz formation) during tropical and subtropical climatic conditions; deposition of the Molasse sediments prevents further karstification at depth.
Obere Meeresmolasse (OMM, Lower to Middle Miocene): intensive karstification at the interface salt- and fresh water close to the Miocene coast line (Cliff).
Middle Miocene: Uplift and rifting in the area of the Upper Rhine graben and change in the slope of the carbonate plateau. This change in slope increases the hydraulic gradients and karstification can proceed at greater depth and at a higher rate.
Upper Miocene: Rivers cut into the plateau (Aare-Danube). Lowering of the level of discharge and also of the level of the most intensive karstification into the massive limestones. Karstification in colder climatic conditions. Basin drainage occurs only in the subsurface (dry river valleys).
Quaternary: Surface runoff only during very cold glacial times, when the frozen soil prevents drainage to the karst aquifer. Reactivation of old paleo-karst due to the lowering of the discharge level of the river danube.

Processes and Determining Factors:

The degree of karstification and the variety of different karst features are determined by the interaction between different processes, which are controlled by "intrinsic" and "extrinsic" factors. "Extrinsic" factors comprise factors such as climate (precipitation, evapotranspiration, temperature), level of discharge (absolute height and relief, level of sea water, lakes and rivers), type of vegetation (humid, tropical, arid etc.) and especially the time period available for karstification. The term "intrinsic" factors summarises the lithological and petrographic characteristics and also the type of structural elements.

There are fundamental differences in the type of karstification between a terrestrial and in a marine environment. While karstification on land is mainly determined by the depth of precipitation, evapotranspiration, type of vegetation and hydraulic gradient, in a marine environment the carbonate dissolution processes at the fresh- salt water interface have to be taken into account as well.

Methodological Approach:

A numerical model has been developed, which simulates in discrete steps the development of the karst system and the changes in hydraulic conductivity. In analogy to the sedimentological basin models, the numerical karst model simulates the dependancy of the karst genesis on spatial and temporal changes in hydraulic boundary conditions, in the various climatically controlled input

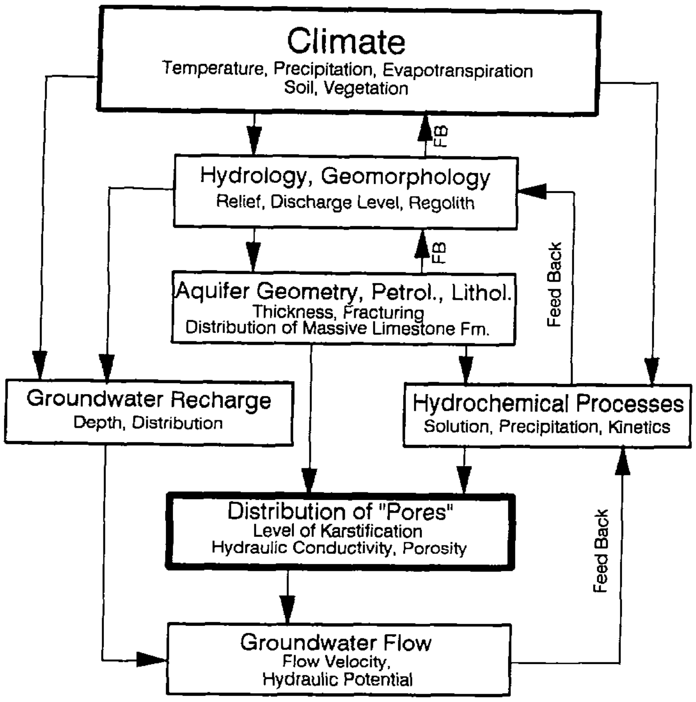

Figure 1

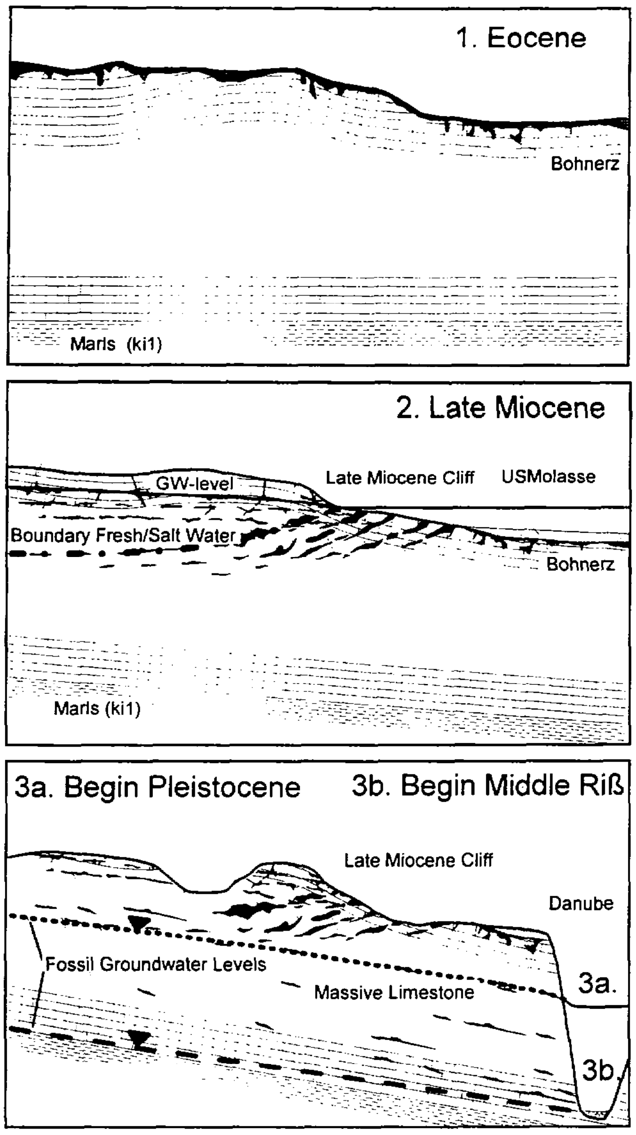

Figure 2

parameters (groundwater recharge, CO_2-partial pressure, ambient temperature) and on the geological-lithological initial conditions. This implies the provision of a considerable volume of data. The detailed approach is as follows:

1a) Definition of geological-hydrogeological conceptual model of the development of Swabian karst
1b) Quantification of initial conditions, boundary conditions, input parameters and the present state of karstification
   - Determination of initial conditions (spatial variation in the lithological characteristics, fracture characteristics)
   - Determination of the hydraulic boundary conditions and their temporal and spatial variation (level of discharge)
   - Determination of the climatic boundary conditions, their temporal variation and evaluation of input parameters for the hydraulic and the hydrochemical sub-model (temperature, CO_2-partial pressure, evapotranspiration)
   - Determination of the present day karstification as well as intermediate stages of karstification for model evaluation (stages of karstification, degree of back fill)
2) Model development (flow and transport model, coupled hydrogeochemical transport model)

Initial Results:

First results show that for a correct simulation of the development of a karst groundwater basin, it is necessary next to the simulation of flow in the conduits to also include flow in the less permeable fissured system (inter-conduit blocks). The development of karst systems in the upgradient direction, i.e. upstream from the spring, which is frequently postulated, can only be modelled if this type of flow is considered.

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Paleoclimate inferences from stable isotopic studies of speleothem

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The concept of using variation in the ratios of stable isotopes of oxygen to determine paleotemperatures in caves was first suggested by Hendy and Wilson (1968). They noted that speleothems deposited in the deep interior of caves were formed at isotopic equilibrium with the drip waters from which they precipitated. Hendy (1971) showed that we could identify equilibrium deposits by the presence of uniform $\delta^{18}O$ values along growth layers. Therefore, past cave temperatures could, in principle, be determined from the isotopic fractionation between speleothem calcite and drip water. Since T in deep caves tracks the average annual surface T, this provides a much-needed continental paleotemperature record.

Unfortunately, $\delta^{18}O(w)$ could not be easily inferred for past times due to the temperature dependent variation in $\delta^{18}O$ of meteoric precipitation (from which the drips were derived) and the ice-volume effect of variation in $\delta^{18}O$ of sea water on the isotopic composition of meteoric precipitation. Various methods have proposed to infer past variations in drip waters. Within the Holocene, the normal T-dependence for local meteoric water should closely describe the T-dependence of cave drips. Combining this with the T-dependence of the calcite-water fractionation gives $\delta^{18}O(ct)$ as a function of T (see e.g., Dorale et al., 1992).

For older deposits, Schwarcz et al. (1976) suggested using δD of fluid inclusions in speleothems as a proxy for $\delta^{18}O(w)$, assuming that $\delta D = 8\delta^{18}O + 10$, as in present-day meteoric waters. Although minor problems with this method were noted by Schwarcz and Yonge (1983), no serious tests of the method have followed. Unpublished work by Atkinson and Rowe suggests that serious fractionation effects can occur during outgassing. Also, Yonge showed in his thesis that much water is strongly bound to calcite, and liberated only during calcining (> 800°C).

While there is serious question as to whether $\delta^{18}O$ records from speleothems can give us records of *paleotemperature*, there seems to be general agreement that isotopic variations do give us records of *paleoclimate*, that is, of some generalized function of the change in temperature, storm tracks, amount of precipitation, etc. This can best be understood by considering the derivative of $\delta^{18}O$ with respect to temperature: $\gamma = d(\delta^{18}O(ct)/dT)$. γ ranges from negative to positive values, and locally may be close to zero. The reason for this variation is the coupled and opposed T-dependences of $\delta^{18}O(w)$ and the calcite-water fractionation, together with the implicit T-dependence of $\delta^{18}O$(sea water), and the unknown effect of changes in positions of the polar front or monsoonal system-boundaries on the source of water vapor. Examples of $\gamma < 0$ and $\gamma > 0$ are given by Gascoyne (1992) and others. A possible example of $\gamma = 0$ was shown by Harmon et al. (1979).

It appears that, a given site, γ has the same *sign* (positive or negative) for a long time. Therefore we can use this fact to estimate the paleoclimatic significance of $\delta^{18}O$ records at a site, if we also determine $\delta^{18}O$ of modern calcite forming at the site. Alternately, we can use the present-day T and $\delta^{18}O(w)$ for the site to calculate the expected modern value of: $\delta^{18}O(c)$. We know that modern temperatures are greater than or equal to surface temperatures experienced at any site during glacial stages of the Pleistocene. Therefore if, for glacial-age speleothem, $\delta^{18}O(c) < \delta^{18}O(c,modern)$, then $\gamma < 0$, and vice versa.

A further limitation can be set where speleothem deposition stops during the coldest part of a glacial stage (as has been observed in studies of speleothem frequency vs. age). We can expect that the temperature of deposition of the last calcite deposited before freeze-up in the cave was formed at $T \approx 0$ °C. This gives us a fixed point on the relationship between $\delta^{18}O(c)$ and T which, together with $\delta^{18}O(c, modern)$ allows us to determine a crude *value* for γ.

Speleothems have enormous potential as paleoclimate recorders. Although they grow very slowly, we are able to dissect them into layers a few μm thick which may record less a few years of growth. Such highly resolved records are not available in marine sediments. Speleothems are datable with high precision (< 1%) using TIMS U-series analyses. Short time-scale oscillations in climate (Dansgaard-Oeschger cycles, etc.) have been recognized in mid-continent deposits. Temporal climatic resolution is however limited by the residence time of drip waters in the feeding aquifer. Subaqueous deposits such as Devil's Hole, deposited from aquifers with long transit times cannot provide such high-resolution records.

Correlated variation in $\delta^{13}C$ of the calcite can provide a parallel record of climate-controlled changes in the nature of the vegetation above the cave (C4 grass vs. trees, for example). This together with $\delta^{18}O(c)$ data has the potential to provide some of the best records of continental paleoclimate for the Pleistocene and Holocene.

This work was all done in collaboration with Derek Ford, and was supported by grants to HPS and DCF by the Natural Sciences and Engineering Research Council of Canada.

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SPELEOTHEM RECORDS OF ENVIRONMENTAL CHANGES IN THE PAST - POTENTIAL IN COMPARISON WITH THE OTHER PALEOENVIRONMENTAL ARCHIVES AND RELATED UIS INTERNATIONAL PROGRAMS.

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Potential, resolution and limitation of high resolution speleothem records of Paleotemperature, Paleosoils, Paleoseismics, Past Precipitations, Rock displacement, Solar Insolation, Geomagnetic field, Plants Populations, Chemical Pollutions, Air Composition, Sea Level advances, Advances of Hydrothermal Waters, Cosmic Rays Flux variations, Cosmogenic Isotopes production and Supernova Eruptions in the Past are discussed (table 1). An international working group on "Speleothem Records of Environmental Changes in the Past" of the Commission on Physical Chemistry and Hydrogeology of Karst of International Union of Speleology is dedicated to study this records. It is coordinated by Y.Shopov and have different topic leaders (table 1).

Potential of speleothem records of environmental changes in the past is compared with other paleoenvironmental archives. It is demonstrated, that speleothems are the best paleoenvironmental archives of many properties of the environment.

Highest resolution of speleothem records (6 hours) is higher than that achieved from any other paleoenvironmental record.

Table 1. Speleothem Records of Environmental Changes in the Past

	Type of the Process Method	Obtainable information leader; best time resolution	Time range [a]
I	Changes beyond the	Solar System	
1	Past Supernova eruptions	primary cosmic ray flux variations in the past beyond the Solar System, Past Supernova eruptions Y.Shopov (Bulg); 20a	0- 10000
II	Changes within the Solar	System	
1	Cosmic Rays Flux Variations; Cosmogenic Isotopes Variations	cosmic rays flux and solar activity in the past D.Lal (USA); 20a	0- 40000
2	Solar Insolation; Laser Luminescent Microzonal Analysis (LLMZA)	Quantitative reconstructions of Solar activity variations in the past, speleothem growth interruptions, volcanic eruptions Y.Shopov (Bulg); 6hours	unlimited
III	Global Earth Processes		
1	Paleomagnetism; Magnetometry of speleothems	paleomagnetism, rock orientation changes in the past; less than 50 a A.Latham, R.Gilson (UK)	unlimited

2	Geomagnetic dipole intensity; LLMZA	quantitative reconstructions of Geomagnetic dipole intensity, solar wind flux at Earths magnetosphere in the Past Y.Shopov (Bulg); 40a	unlimited
IV	Regional Processes		
1	Paleoclimate and Paleotemperature in calcite speleothems; stable isotopes	Paleotemperature, possible plant population, precipitations and climatic cycles in the past; D.Ford, C.Yonge (Can), T.Arakawa (Jap); 25a	unlimited
2	Past Precipitations; annual growth rate observed by LLMZA	quantitative reconstructions of past annual rainfall, past floods, cycles of draughts and floods Y.Shopov (Bulg); 1a	unlimited
3	Past Paleotemperature; LLMZA	quantitative reconstructions of air paleotemperature during speleothem growth, temperature cycles, glaciations etc. Y.Shopov (Bulg); 6 hours	unlimited
4	Paleotemperature in speleothem ice; Stable isotopes	air paleotemperature, air CO_2, air isotope composition in the past C.Yonge, W.MacDonald (Can); 25a	unlimited
5	Paleotectonics and Paleoseismics; Orientation of speleothem growth	paleoseismics, rock displacements and bending P.Forti (It), N.Nori (Jap); <100a ?	unlimited
V	Local Processes		
1	Pollen analysis	plants population and paleoclimatic changes G.Brook (USA); <10a ?	unlimited
2	Soil type variations; Luminescent spectra analysis	soil and plants population variations W.White (USA); 1a	unlimited
3	Chemical microanalysis; Laser emission spectral analysis	chemical pollutions ?; 1a?	unlimited
4	Dating of sea levels; U/Th dating	sea level variations J.Lundberg (Can); 100a	0-500000
5	Luminescent records of hydrothermal activity; Time resolved photography of phosphorescence	advances of hydrothermal waters, estimations of their temperature, mixing of surface and hydrothermal waters, uplift of bedrocks Y.Shopov, L. Tsankov (Bulg); 1a	unlimited

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SPELEOTHEMS AS NATURAL CLIMATIC STATIONS WITH ANNUAL TO DAYLY RESOLUTION

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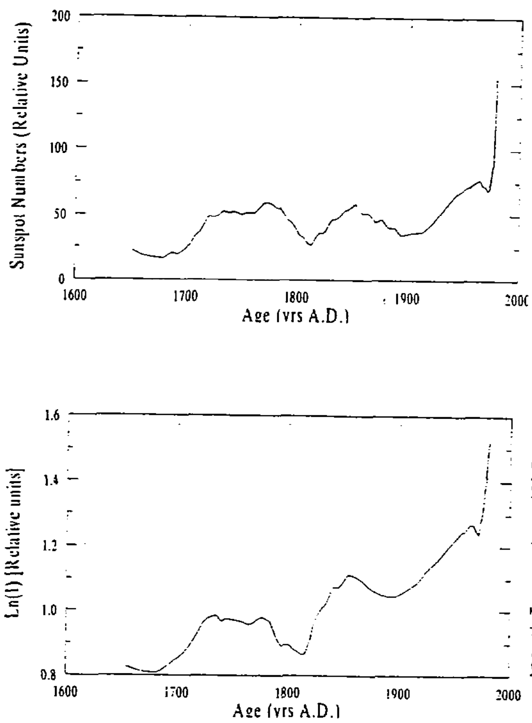
Calcite speleothems luminescence depends exponentially upon soil temperatures that are determined primarily by solar infrared radiation in the case when that cave is covered only by grass or upon air temperatures in case that cave is covered by forest or bush. In the first case, microzonality of luminescence of speleothems can be used as an indirect Solar Insolation (SI) index, but in the second - as an paleotemperature proxy. So, in dependence on the cave site we may speak about "solar sensitive" and "temperature sensitive" luminescent speleothem records like in treering records, but in our case record may depend either only on temperature or on solar irradiation:

- In case of Cold Water cave, Iowa, US we obtained high correlation coefficient of 0.9 between the luminescence record and Solar Luminosity Sunspot index (fig.1) and reconstructed sunspot numbers since 1000 AD with precision within the experimental error of their measurements;
- in case of Rats Nest cave, Alberta, Canada we measured correlation coefficient of 0.67 between luminescence intensity and air temperatures record for the last 100 years (fig.2) and reconstructed annual air temperatures for last 1500 years at the cave site with estimated error of 0.35 ^{0}C, while the error of the direct measurements is 0.1 ^{0}C.

Intensity of luminescence was not dependent on actual precipitations and sunspot numbers (zero correlation). Speleothem growth rate variations represent mainly rainfall variations. Speleothem luminescence visualizes annual microbanding we used to derive proxy records of annual precipitations for the cave site. In case of Rats Nest cave, Alberta, Canada we reconstructed annual precipitations for last 280 years at the cave site with estimated error of 80 mm/year. By comparison of luminescent records with other solar proxy records we obtained a reconstruction of growth rates and precipitations in Bosnek karst region near Duhlata cave, Bulgaria for the last 50000 years, and for the last 6400 years (with averaged time step of 41 years) for Iowa, near Cold Water cave, US. Achieved time step of 6 hours in speleothem luminescence records allows resolution of several days in some best speleothem samples. Annual luminescence microbanding was used very successfully for relative and absolute dating of speleothems by Autocalibration dating. This dating method appear to be more precise than TAMS ^{14}C and AMS U/Th dating for relative dating of short time intervals and only dating method for speleothems with little uranium, younger than 2000 years.

It is demonstrated, that speleothems can be used as natural climatic stations with annual resolution for purposes of climatology and agrometeorology for a time span far exceeding all historic records.



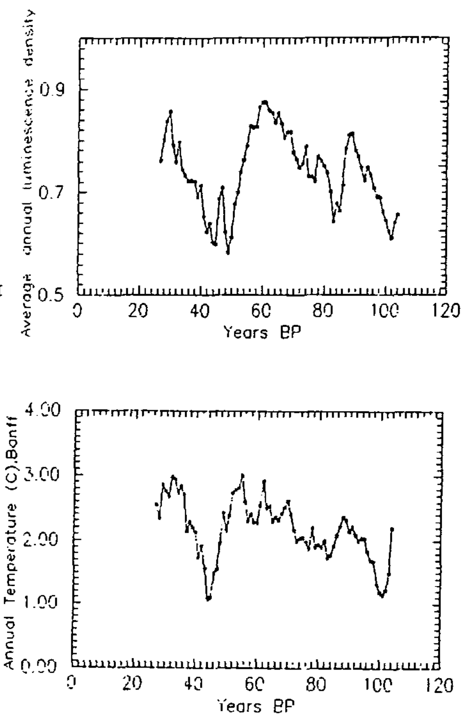


Fig. 1. (left up) Twenty year average sunspot records since 1700 AD
(left down) Optical density of luminescence of a speleothem from Coldwater Cave, Iowa (USA).
Fig.2. (right up) Average annual luminescence density of a speleothem from Rats Nest Cave (Canada)
(right down) Annual temperature, Banff, Alberta (Canada).

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SPELEOTHEM RECORDS OF PROCESSES BEYOND THE SOLAR SYSTEM (Supernova Eruptions)

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We used the standard Calibration ^{14}C record (Stuiver et al., 1987) to derive a proxy record of Cosmic Rays Flux. This ^{14}C record represents the Cosmic Ray Flux (CRF) and modulation of the CRF by the solar wind.

Striking correlation (with a correlation coefficient of 0.8) was demonstrated between the calibration residual delta ^{14}C record and a LLMZA speleothem record. Using a luminescent record from Duhlata cave, Bulgaria we obtained a reconstruction of the solar modulation of the CRF during the last 50000 years with time resolution of 28 yrs.

Luminescence microzonality was used to reconstruct Galactic Cosmic Rays Flux (beyond the Solar System) during the last 6500 years with 20 yr resolution by subtracting of an inverted luminescent solar activity record (sample from Cold Water cave, Iowa) from the residual ^{14}C record. Last result (fig.1) presents a picture of past Supernova explosions in our Galaxy. It is a quantitative confirmation of recent views on origin of Cosmic Rays from superposition of Supernova explosions in our Galaxy and agrees with astrophysical observations. It completely disapproves the hypothesis of origin of a significant part of Cosmic Rays Flux from relic rays of the Big Bang.

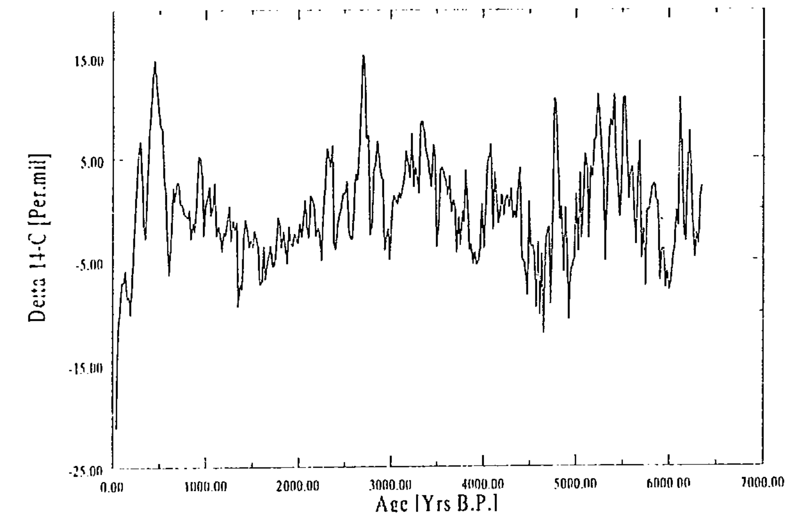

Fig.1. Relative variations of the primary cosmic rays flux, expressed by cosmogenic ^{14}C variations.

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SPELEOTHEM LUMINESCENCE PROXY RECORDS OF GEOMAGNETIC FIELD INTENSITY

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The geomagnetic field is electromagnetic rather than pure magnetic field, so it depends on the far stronger solar magnetic field and the solar wind magnetic field.

Solar wind determines dimensions of the Earths magnetosphere and modulates the intensity of the geomagnetic dipole. Using a luminescent record from Duhlata cave, Bulgaria we obtained a reconstruction of the geomagnetic dipole during the last 50000 years with resolution of 28 yrs. Original luminescent record exhibited correlation coefficient of 0.78 with an independent record of variations of intensity of the geomagnetic dipole for the same time span (Fig.1.).

Observed dependencies of the geomagnetic dipole intensity on the orbital variations and solar luminosity variations correlates excellent with the established theoretical equations.

Obtained reconstruction of the geomagnetic field is of vital importance for calibration of cosmogenic isotope (^{14}C, etc.) dating techniques.

NASA used a record of luminescence of a flowstone from Duhlata cave, Bulgaria to establish a standard record of variations of Solar Irradiance ("Solar constant") for the last 10000 years by calibration of the luminescence record with satellite measurements.

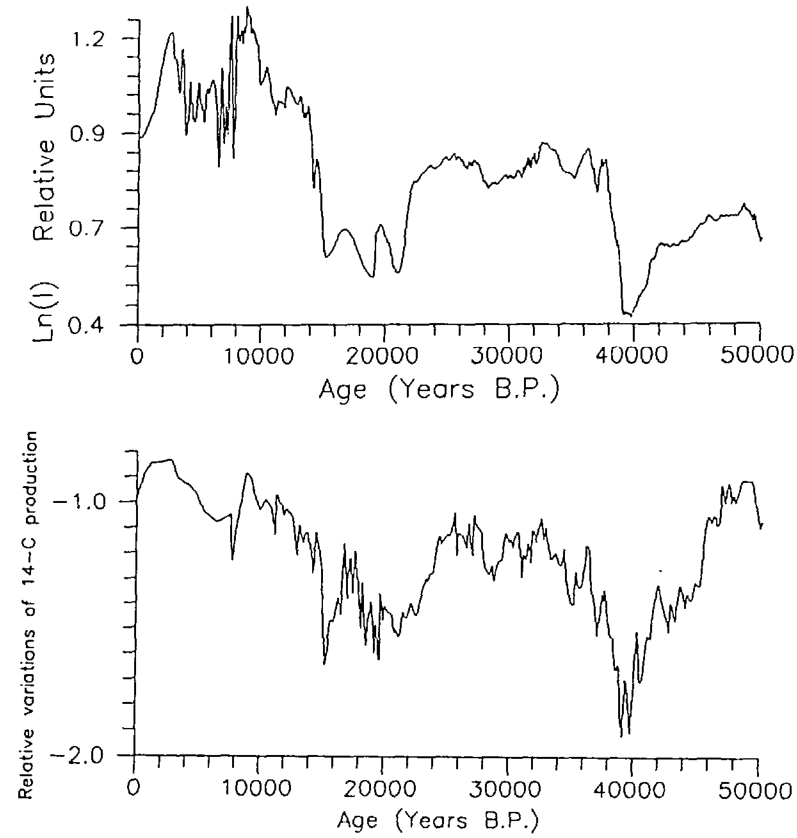

Fig.1.(up) Optical density of luminescence of a cave flowstone
(down) Past variations of intensity of the geomagnetic dipole expressed by inverted production of ^{14}C (Mazaud et al, 1991)

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TIME RESOLVED PHOTOGRAPHY OF PHOSPHORESCENCE- A NEW TECHNIQUE FOR STUDY OF THERMAL HISTORY AND UPLIFT OF THERMAL CAVES.

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A new technique for time- resolved photography of phosphorescence is developed. It is very useful for study of hydrothermal cave minerals and the thermal history of hydrothermal and epithermal caves. It is used to study the thermal history of the caves in Guadeloupe Mts.,New Mexico, in Black Hills, South Dakota, USA and in Budapest, Hungary very successfully, confirming the stable isotopes data. The advantages of this technique are that it is very fast and non- destructive, visualizes layers in the speleothem formed at different temperature and can be used in situ directly in the cave. Uplift of the bedrock with the cave can be detected and precisely dated if speleothem luminescence is due to epithermal mineralforming waters in the older part of speleothem, but some mixing of these waters with surface waters containing organics appears in younger parts of the speleothem. Time-resolved photography of phosphorescence allows determination of lifetime of the luminescent center and easier determination of its origin.

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SPELEOTHEM LUMINESCENCE PROXY RECORDS OF ANNUAL RAINFALL IN THE PAST.EVIDENCES FOR "THE DELUGE" IN SPELEOTHEMS.

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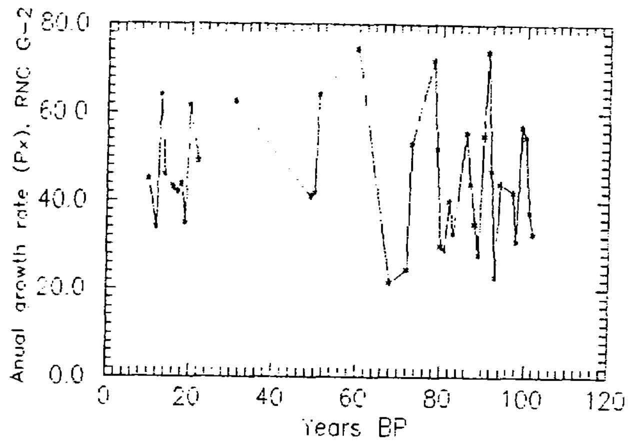
Speleothem growth rate variations represent mainly rainfall variations. Speleothem luminescence visualizes annual microbanding we used to derive proxy records of annual precipitations for the cave site. In case of Rats Nest cave, Alberta, Canada we obtained good correlation (correlation coefficient of 0,57) between annual precipitations (from Banff station 50 km north of the cave) and annual growth rate of the speleothem (Fig. 1). We used obtained regression coefficients to reconstruct annual precipitations for last 280 years at the cave site with estimated error of 80 mm/ year. Annual speleothem growth rate was not dependent on intensiy of luminescence, on annual temperature and solar luminosity for the same time span (zero correlation).



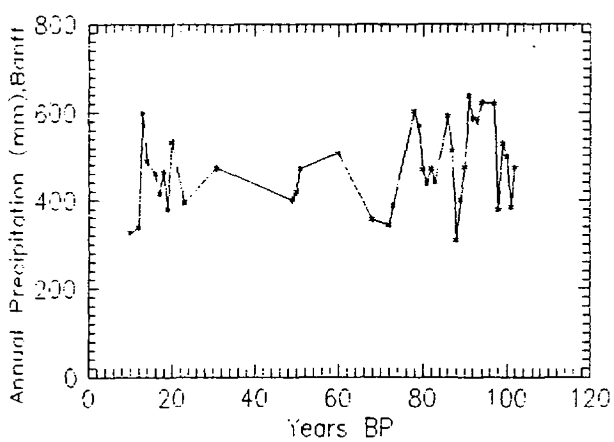
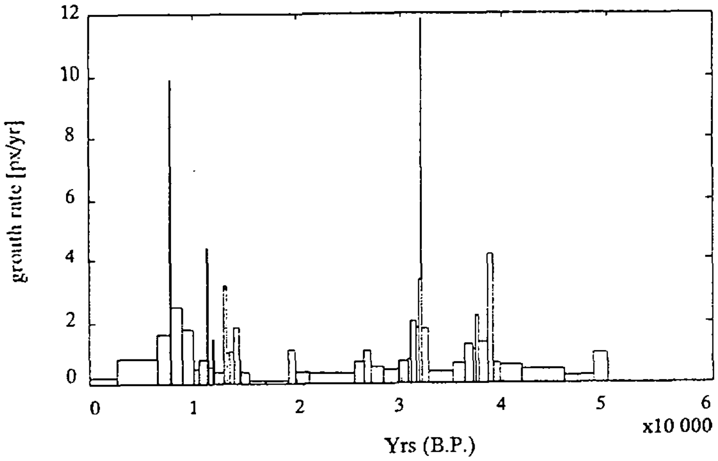


Fig.1 (Up) Annual growth rate of a stalagmite from Rats Nest cave, Alberta, Canada (Down) Annual precipitations (from August to August) for Banff station, 50 km north of the cave

By "tuning" of the time scale of a luminescent record with a geomagnetic dipole intensity record (Mazaud et al., 1991) we obtained a reconstruction of growth rates and precipitations in Bosnek karst region near Duhlata cave, Bulgaria for the last 50000 years (Fig.2). This record show a very prominent peak at 7000- 8000 years B.P., when annual growth rate was over 53 times higher than today. Considering that cave site is located in the place of the oldest civilizations (Mediterranean basin) this event can be related to the Bibles "Deluge". The age of the recorded event is about the age of "The Creation of the world". The duration of the recorded event is of several hundreds years, because of the low resolution of the record. In case that the real flood happened for a short time span it suggests enormous rainfall. Present day precipitation at the cave site is 685mm/yr. This speleothem was dated with 8 TAMS 14- C dates.

By "tuning" of the time scale of a luminescent record with the calibration ^{14}C record (Stuiver and Kra, 1986) we obtained a reconstruction of growth rates and precipitations for the last 6400 years with averaged time step of 41 years for Iowa, near Cold Water cave, US (fig.2). It suggests higher speleothem growth rate and higher precipitations between 6400- 2500 years B.P. at the cave site. This speleothem was dated with 7 AMS U/Th dates



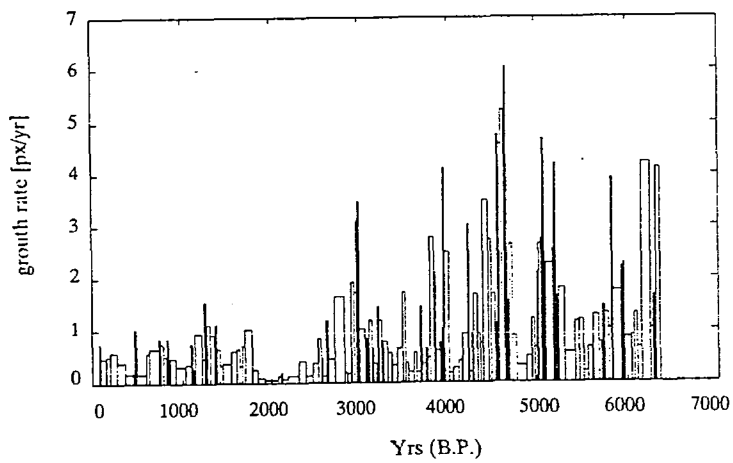


Fig.2. (Up) Reconstruction of growth rates (proxy of precipitations) of a flowstone from Duhlata cave, Bulgaria for the last 50000 years;

(Down) Reconstruction of growth rates (proxy of precipitations) for the last 6400 years with averaged time step of 41 years for Cold Water cave, Iowa, US.

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PALAEOCLIMATE DETERMINATION FROM SPELEOTHEMS - A CRITICAL APPRAISAL OF THE STATE OF THE ART

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Despite the considerable time that has elapsed since the first palaeoclimate studies of speleothems were undertaken, their present acceptance by the wider Quaternary community is at times uncritical, and we believe that much remains to be done before they yield reliable and unambiguous records of terrestrial palaeoclimate. In considering some of our work and other recently published studies, we identify several general problems which we believe must be addressed.

1. Many early studies, for instance the definition of periods of active speleothem growth, employed a sample of many individuals drawn from the population of speleothems in a particular geographically defined area (Gascoyne et al, 1983; Baker at al, 1993). However, in more recent studies the emphasis has shifted to records derived from individual specimens (Dorale et al, 1992; Goede, 1994; Holmgren et al, 1995; Goede et al, 1996; cf. Gascoyne et al, 1980, 1981). These individuals may be subject to essentially random site-specific controls which may modulate any regional paleoclimate signal in a complex manner (see the rather different mass-spectrometrically dated growth records of Baker et al (1996) for Stump Cross Caven and Lancaster Hole).

We believe that records from individual specimens are inadequate and an essential aspect of the scientific process should be duplication of the palaeoclimate record and demonstration of its reproducibility.

2. There is a need for development of theory in interpretation of the palaeoclimate record. In some cases this may be difficult because of non-linear system response and the presence of variable thresholds, e.g. in cave inlet hydrology (Smart and Friedrich, 1987; Baker et al, 1995). It may not yield unique palaeoclimate interpretations, often being a net response to several simultaneously varying controls through time. The latter is clearly the case with speleothem growth rates which depend on water composition, temperature and discharge to variable extents (Buhmann and Dreybrodt 1985; Baker and Smart, 1995). The use of multiple proxy indicators and targeted sampling of selected speleothem types may help here.

3. There is a need for field validation of theory, and also for the empirical investigation of palaeoclimate indicators both spatially and temporally. Whilst there are some short term studies over 1-2 years (e.g. Bar-Matthews et al, 1996), we lack information at the 10-100 year timescale, and this makes the link between the averaged signal recorded in Holocene speleothems and present day samples less secure than is desirable. The utility of annual growth-banding in rapidly growing samples and long historic climate records offers much here (L.A.Gonzalez (http://www.ncdc.noaa.gov/ogp/papers/gonzale.html); Genty and Quinif, 1996).

4. Where developed theory is available it must be rigorously applied in interpretation of the record. We are surprised at the number of studies of $\delta^{18}O$ in calcite which ignore the potential effects of changes in storm tracks and precipitation source areas in their enthusiasm to derive palaeotemperature records.

5. As natural scientists we are familiar with the problems of noise within the systems we study. However, the use of simple filtering techniques to eliminate such natural variation may well be illusory, particularly when the signal to noise ratio approaches one. Furthermore, such high variability may indicate an inherent lack of integrity in the recording and preservation of the palaeoclimate signal. We need to understand the source of such variation, and derive criteria for specimen selection and sub-sampling to avoid it, if possible. Improved understanding of speleothem petrography is needed to assess possible crystallographic mediation of the palaeoclimate signal (cf. Gonzalez et al, 1992, 1993a,b; Dickson, 1993; Kendall, 1993).

6. There is a need for the development of reliable growth rate models from which to transform sample axial distance to age. The advent of high precision mass-spectrometric uranium-series dating (Edwards et al, 1987; Li et al, 1989, Richards et al, 1994) offers enormous potential, but careful matching of sample thickness, growth rate and achievable age precision is needed. Many studies also rely on the simple assumption of linear growth and a minimal number of analyses. Furthermore, we do not yet have sensitive techniques (other than gross disturbance of the isotopic system and stratigraphic concordance) to demonstrate the reliability of an age - although the development of mass spectrometric $^{231}Pa/^{235}U$ dating is a significant breakthrough (Cheng et al, 1996). We also caution against the application of ^{14}C dating to speleothems (Broecker et al, 1960; Vogel, 1983; Holmgren et al, 1994) because of the complex and variable origin of speleothem ^{14}C.

7. The recognition of non-linear axial growth of speleothems has important implications for sample spacing, and for the temporal resolution and aliasing of the palaeoclimate record (Winograd and Ludwig, 1996). In many cases it may be better to vary sub-sample size and spacing to try to maintain this at a constant value. Consideration should also be given to the use of time domain signal filtering compared to the space domain technique normally used.

8. Finally, there is a very real problem of sample availability, both in terms of conservation of the often limited speleothem deposits present in our caves, and in terms of continuity and duration of growth. Our experience has been that even in the Holocene, where conditions in the UK were conducive to deposition, many samples show limited growth duration, and long-term records are difficult to obtain. We must also remember that this is coupled with the absence of deposition in the UK in glacial and stadial times. Thus, there is considerable difficulty in developing a continuous, long-term multiple sample record. Furthermore, given that in some cases our record is more one of gaps than deposition, it is surprising that we have not attempted to characterise the nature of hiatuses in terms of their origin by petrographic and geochemical analysis.

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DO CAVE SEDIMENTS FROM THE SPIRALKA CAVE (CZECH REPUBLIC) RECORD ENVIRONMENTAL CHANGE (PART 2)?

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Over the past three years we have been investigating a 4 m high profile in clastic sediments deposited during flooding in the interior of Spiralka Cave (Moravian Karst), Czech Republic. Sroubek et al. (1995) reported a possible correlation between the record of ferromagnetic susceptibility (MSferro) and smoothed (10-year running mean) winter temperature anomalies determined from data collected at the Prague-Klementinum observatory over the past 200 years (Brazdil and Dobrovolny, 1992). Variations in the concentration and grainsize of non-stoichiometric magnetite and/or maghemite are responsible for the observed changes in MSferro.

We revisited the site during the fall of 1995 and sampled the bottom 2 meters of the section. In this part of the profile brown silts and sands typical of the upper part of the profile are interbedded with a layer of gray organic rich material overlain by a thin flowstone bed. The variation in lithology suggests to us that the sediments record periods of significant climatic change. Samples from the same stratigraphic level show similar values of magnetic susceptibility (MS) while MS varies by up to the magnitude of two throughout the profile. Preliminary measurements of Saturation Isothermal Remanent Magnetization (SIRM), Susceptibility to Anhysteretic Remanent Magnetization over MS (MSarm/MS), MSarm/SIRM, Isothemal Remanent Magnetization (IRM) acquisition and S-ratio (e.g. Thompson and Oldfield, 1986) suggest that MS variations in the cave section are responding to variations in the magnetic mineralogy, concentration and grainsize.

The correlation between MSferro and a direct temperature measurement is very intriguing and to our knowledge has not been previously reported. In order to confirm this interesting observation we are currently undertaking the following tasks:

1) Age dating

Currently, 2 radiocarbon dates (one using the AMS technique) on charcoal samples have been obtained for the upper half of the profile. Unfortunately the young age (0 - 350 years B.P.) of the sediments have resulted in a very large error in the dendrochronologically corrected dates for the charcoals. The lead-210 dating technique was applied on the topmost part of the sediments of the profile, however the results showed a dependance on lithology rather than age. In central part of the profile a large wood fragment was found which is being age dated at the Technical University in Zvolen (Slovakia) using the dendrochronological method. Lastly, another charcoal fragment from the base of the profile has been sent off for radiocarbon dating.

2) Determining the driving mechanism of the change in mineral magnetic properties

We are seeking an explanation for the observed correlation between MSferro and temperature. It is improbable that minor temperature oscillations may be driving changes in concentration and grainsize of magnetic minerals. However climatic change can trigger other processes influencing the catchment area from which the sediments are derived. The change in concentration of magnetic minerals previously observed in lake sediments is known to be a sensitive indicator of changes in the erosional rates and the energy of transport. Therefore we are searching historical records to identify climatic/environmental changes which are tied to temperature and could affect erosional rates. The historical record of rainfall in Moravia shows a good correlation with the MS record, however the rainfall has been recorded only since 1880 A.D. Records of severe floods are being available but only since 1930 A.D. A proposed correlation between these floods and sedimentation episodes in the cave will be discussed. Historical records of forest clearance in the catchment area of the cave are available only in a very limited amount. Records of other human activities such as industrial development and agriculture are being investigated.

3) Confirmation that MS is truly an erosional indicator

Detrital iron oxides in the sediments have been identified using an optical microscope, authigenic iron oxide overgrowths are also present. Microprobe analysis aided by magnetic force microscopy will serve to determine the elemental composition of the grains present and to estimate their contribution to the mineral magnetic signal. Another method of testing whether MS is truly an erosional indicator is by comparing it with the records of concentration of Ti and Zr, which reflect the heavy mineral influx rate. This is also being currently done and will be reported on.

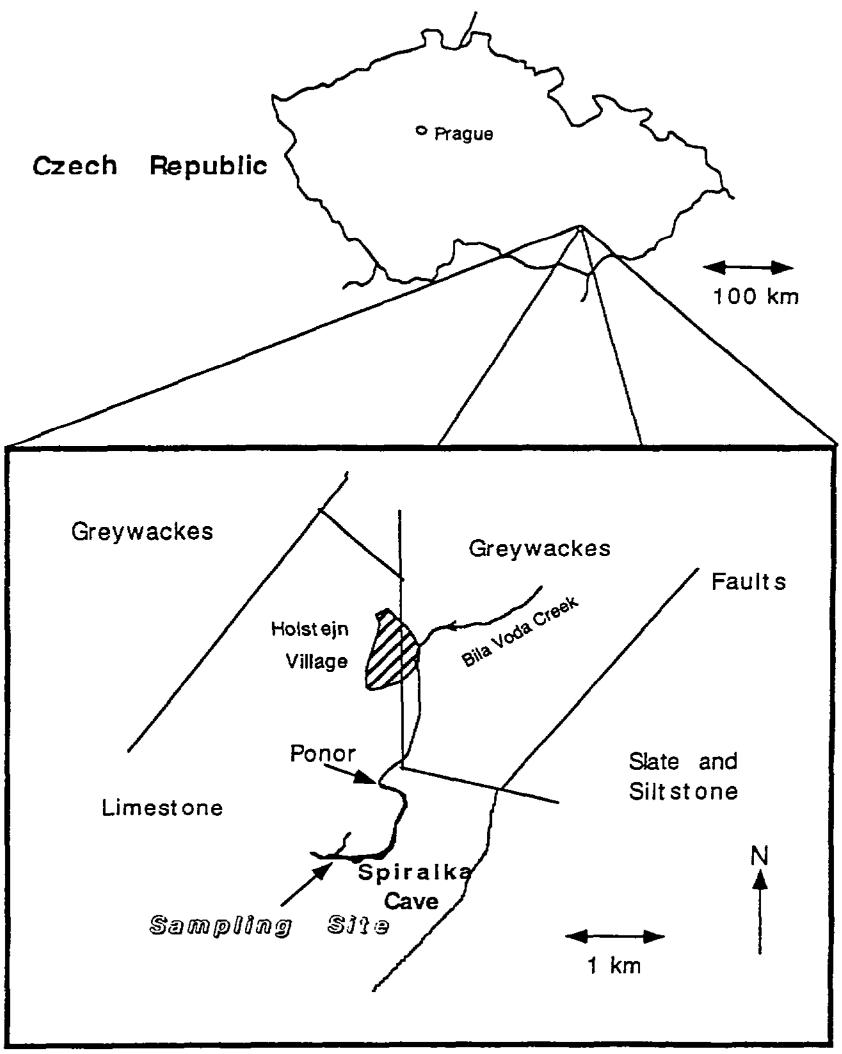

Fig. 1. Location of the sampling site in Spiralka Cave (Moravian Karst, Czech Republic)

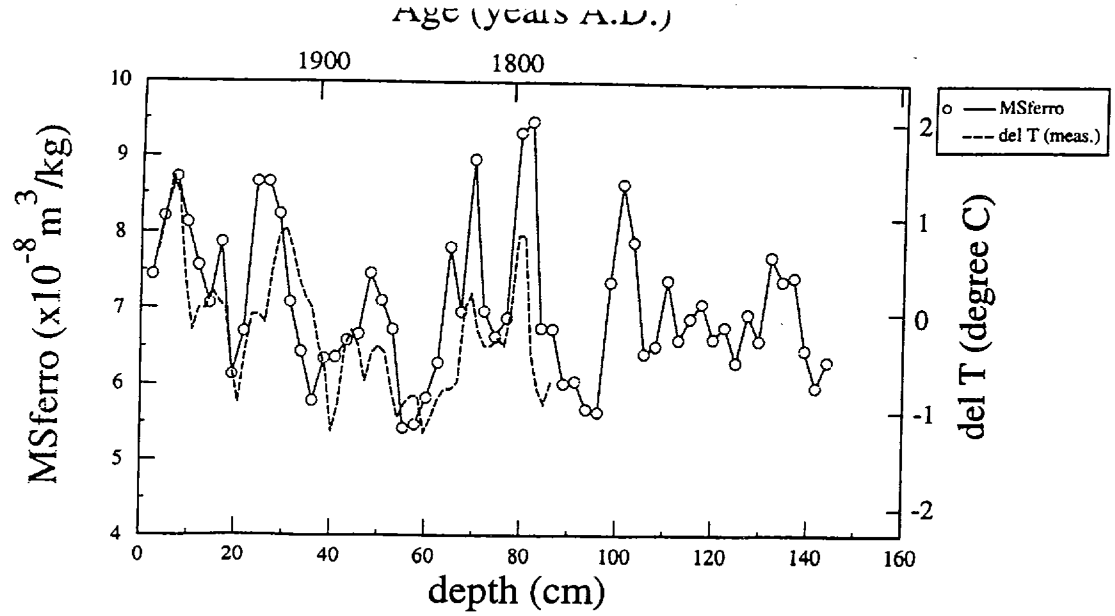

Fig. 2. Comparison of ferromagnetic susceptibility record obtained from the Spiralka Cave with smoothed winter temperature anomalies measured in the Prague-Klementinum observatory

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MONSOON DATA FROM OXYGEN ISOTOPE OF SPELEOTHEMS IN EAST CHINA—— AN EXAMPLE FROM BEIJING SHIHUA CAVE

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East China is apparently affected by the monsoon climate.The $\delta^{18}O$ of precipitation varies with the temperature and the amount of rainfall. According to the data accumulated from eight stations in China(Zheng Shuhui et al.1983),the relationship between the mean values of $\delta^{18}O$ and the mean temperature is

$$\delta^{18}O(‰) = 0.28T(°C) - 11.49$$

(where T is temperature,the correlation coefficient is 0.8)

The correlation shows that there is about a +0.28‰/°C shift in $\delta^{18}Ow$($\delta^{18}O$ of water). And the correlation of $\delta^{18}O$ in cave calcite with temperature illustrates that there is about a -0.22 ‰ /°C shift at 20°C and -0.24‰/°C at 10°C in $\delta^{18}Oc$($\delta^{18}O$ of calcite), which was confirmed by inorganic experimental studies(O'Neil et al.1969).So there really is only a +0.05‰/°C shift in $\delta^{18}O$ of speleothems with the mean annual temperature increasing 1°C.In addition,there is the negative correlation between the $\delta^{18}O$ of precipitation and the amount of rainfall, i.e. the heavier the amoumt of rainfall, the lower the concentration of $\delta^{18}O$ in precipitation as the summer monsoon that brings the most of annual rain come from the distant sea(Fig.1), which is also recorded in speleothems(Fig.2). As a result the $\delta^{18}O$ sequence of speleothems from East China could mainly tell the history of precipitation which presents the change of summer monsoon if the fluctuation of the temperature was small within the time concern ,say, in Holocene and the resolution can come up to 10^0 yr by drilling the samples at a polishing section of a stalagmite for MS with a 0.5mm-diameter drill and no sampling interval.

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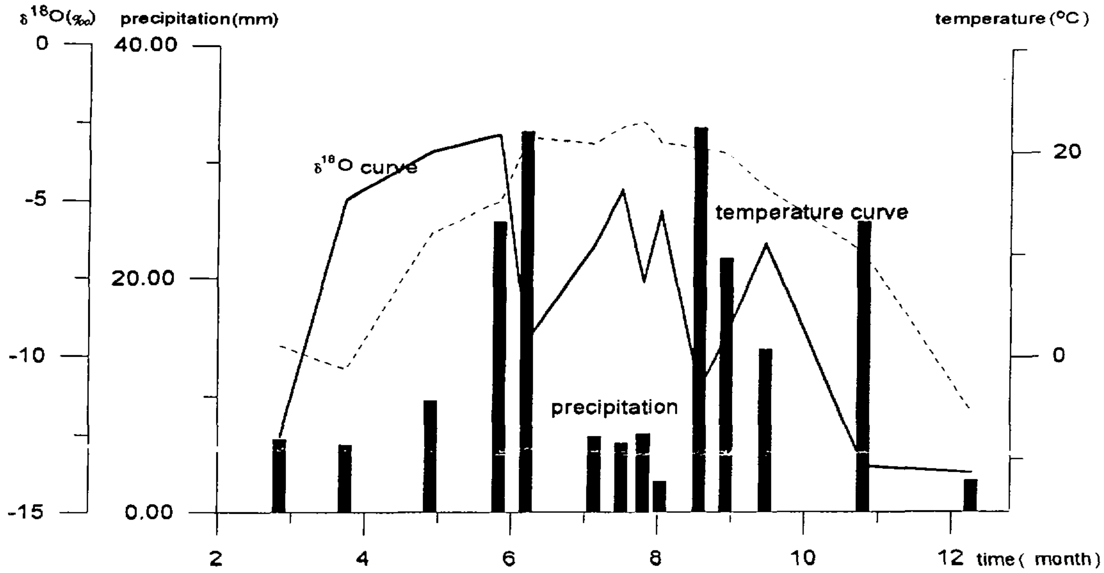

Fig. 1 The relationship among $\delta^{18}O$ of precipitation, temperature and the rainfall in Beijing, 1980.

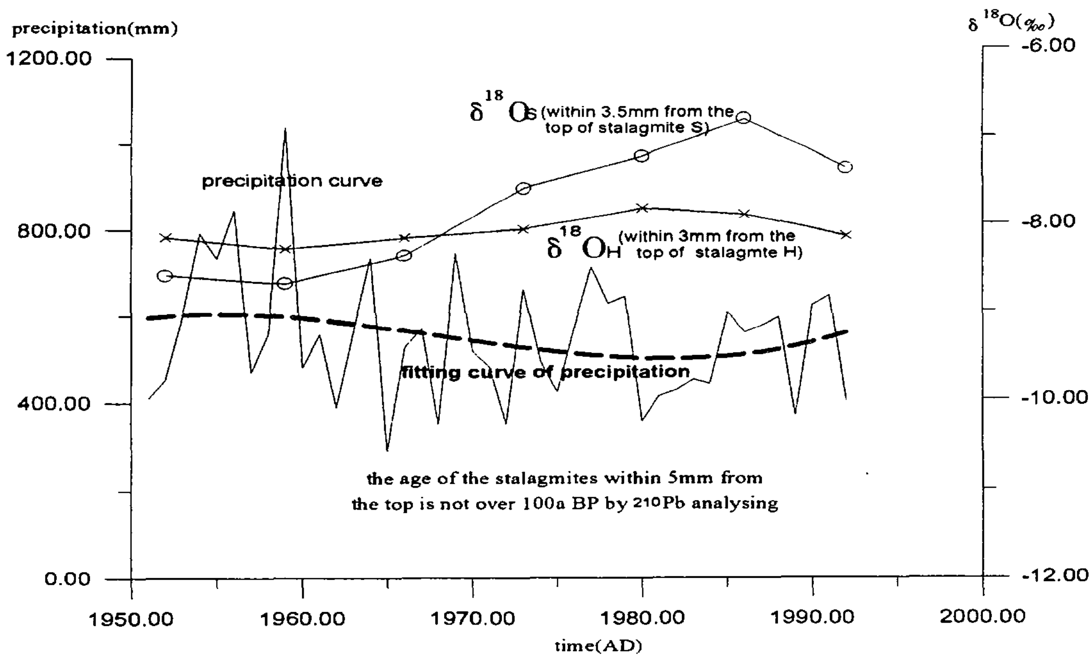

Fig.2 $\delta^{18}O$ of two growing stalagmites from Beijing Shihua Cave and the records of precipitation of Beijing from 1951 to 1992

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Timing and causes of speleothem dissolution on Cayman Brac, Cayman Islands, BWI.

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Introduction

Cayman Brac is one of the three Cayman Islands situated in the Caribbean Sea, between Cuba to the east and the Yucatan Peninsula, Mexico, to the west. The islands are located on separate volcanic fault blocks on the Cayman Ridge which is parallel to the Cayman Trench, a complex feature reaching more than 7000 m in depth. The Cayman Ridge and the Nicaraguan Plateau have been moving apart at an average rate of 0.4 cm/a since the Eocene (Woodroffe, 1988). A general dip to the west on all three islands (but especially Cayman Brac) is in accord with Horsfield's (1975) theory of a domed regional uplift centred on eastern Cuba and northwestern Haiti.

Cayman Brac has an elevated core of Tertiary dolostone and limestone (the Bluff Group; Jones *et al.*, 1994) which is fringed by a coastal platform of Pleistocene limestone, the Ironshore Formation. The Tertiary rocks form a cliff around most of the island, in which cave entrances and a horizontal notch are visible. The consistency of the elevation of the Ironshore Formation and the notch indicate that there has not been any substantial tectonic movement since their formation during the Last Interglacial: elevations are consistent with the oxygen isotope substage 5e high sea level determined elsewhere in the Caribbean (Woodroffe *et al.*, 1983).

Although the Cayman Islands are situated in a tectonically unstable region, the periods of unconformity in their geological records as determined by Jones *et al.* (1994) roughly agree with the periods of global low eustatic sea level during the Tertiary as described by Hallam (1984; Lips, 1993).

Timing

Most speleothems on Cayman Brac do not appear to be actively growing at present and many display growth hiatuses in their records. Three of these growth cessation periods were dated by alpha spectrometry at >350 ka, around 200 ka (oxygen isotope substage 7) and between 75 ka and 20 ka (oxygen isotope substage 3 and 4; Lips, 1993). Dating by Thermal Ionisation Mass Spectrometry (TIMS) is in progress to better pinpoint the timing of these hiatuses. It appears that these cessation periods show a general similarity with the ones obtained by Lundberg (1990) for DWBAH, a flowstone collected from -15 m in Lucayan Caverns, Grand Bahama Island. However, not all the dated samples displayed growth cessation at the same time and samples are found to have grown both during glacial and interglacial periods. Thus, a simple climatic correlation, as is the case with DWBAH, cannot be accepted as yet for the samples of Cayman Brac.

Causes

At present, most speleothems display evidence of dissolution after deposition. This was also found to be the case during earlier periods of growth cessation. The caves are of the sea coastal, mixing zone type and exposed in cliff faces up to 30 m above sea level; flooding and speleothem dissolution by meteoric storm waters is not a feasible mechanism. The majority of sites are above the reach of marine storm surges, even during hurricanes.

An alternative mechanism for the dissolution is condensation corrosion. To find out if it occurs at present, 26 pieces of gypsum were suspended on nylon fishing line in four caves for one year. Nine pieces lost more than 10 % of their weight and 6 lost between 5 and 10 wgt%/a. A reference sample which was never exposed to the air lost only 0.17 wgt%/a. It was also found that the samples suspended closer to the floor lost more weight than the ones closer to the ceiling.

At the same sites condensation was induced with the help of plastic bottles filled with water and frozen. Condensation water formed on the outside of the bottles was analysed for total and calcium hardness, alkalinity, pH, conductivity and temperature. The chemical composition of this water lies between that of rainwater and cave drip water. It is, in general, undersaturated with respect to calcite and dolomite but this changes from location to location and from time to time at the same site.

Temperature and relative humidity (RH) behaviour were measured over time and space in five caves. In First Cay Cave (FC) a more complex setup included wind direction and speed, hooked up to a datalogger for continuous recording over four weeks. According to Hill (1987) three conditions need to be satisfied if significant condensation corrosion is to occur:

1. a high CO_2 content in the air,
2. relative humidity close to 100% and
3. a strong thermal gradient.

In FC the greatest gypsum weight loss was in the entrance area where the outside air has a large influence and where the greatest diurnal RH and temperature fluctuations occur. RH measured in this zone never reached 100% and the CO_2 content will not be high because of the good air circulation.

Conclusion

Periods of speleothem growth cessation and/or dissolution have occurred in the past and are occurring at present. The exact timing of these periods is not fully known but it is clear that a simple relationship between growth cessation/dissolution and glacial/interglacial periods can not be established. Instead it seems that cave configuration and cave microclimatology play important roles, encouraging processes like condensation corrosion to occur.

Better dating of the speleothem samples and of similar samples collected from Isla de Mona, Puerto Rico, will establish when dissolution occurred and whether it was a more widespread phenomena. This study is on its way.

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POTENTIAL INTERPRETATION OF PAST CLIMATE FROM SPATIAL AND TEMPORAL VARIATIONS IN WATER AND STALACTITE CHEMISTRY IN CURRENTLY ACTIVE CAVES.

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The karst system generates a chemical signal by leaching during rainfall percolation through the soil zone and fissured carbonate rock. This signal varies spatially with differences in the materials undergoing dissolution and the route through the catchment area, and temporally with variations in water throughput rates. Degassing in the cave environment causes precipitation of speleothems which may preserve a geochemical record of temperature change from stable isotopic compositions.

In principle leachates will be dependent on the original composition of solid carbonates and other karst system minerals coupled with water residence time. Dolomite dissolves more slowly than calcite and therefore longer water residence times are necessary for higher Mg/Ca ratios. Sr may vary antipathetically with Mg if calcite has a greater Sr content than dolomite. Conversely, incongruent carbonate dissolution may dominate in the case of low water content and Mg/Ca and Sr/Ca ratios will increase sympathetically (Fairchild & Killawee, 1995). Other trace elements should also show variations with differing leaching conditions.

Samples of weathered Mesozoic carbonates collected from the ground above a small cave in Grotta d'Ernesto in northern Italy in September 1994 were subjected to either fast leaching with aeration of the waters over 4 hours, or slow leaching over 1 month. Although leachates from different samples showed antipathetic variations of Mg/Ca and Sr/Ca, consistent with a lower Sr content of dolomite, sympathetic covariations were exhibited between slow and fast leachates of the same sample, possibly due to incongruent dissolution effects. Slow leachates were significantly higher in both Mg/Ca and Sr/Ca than fast leachates and no mixture of them would reproduce sampled cave waters from the same site. However, the cave waters could be modelled by a mixture of those leachates nearer the fast end-member, suggesting a water throughput time to the cave in the range of hours to days at the time of sampling. In principle, therefore, temporal sympathetic Mg/Ca and Sr/Ca variations could be interpreted as reflecting variations in water residence time, and antipathetic variations as reflecting changes in water routing.

Soda straws are c.5 mm-wide hollow tubes characterising the initial form of young, growing stalactites. At several cave sites they have been observed to commonly exhibit repetitive banding (2-5 per mm), representing localised thickening and thinning of the soda straw wall. An annual timescale of such banding is plausible from general principles, supported by the finding of slightly smaller thicknesses of annual banding in stalagmites (Baker & Smart, 1995; Genty & Quinif, 1996). The degree of cave water supersaturation, as modified by (seasonal) variations in organic productivity and hence soil CO2 content, may cause banding due to variations in growth rate.

Variations in soda straw chemistry studied by microprobe and ion probe analyses show that trace element concentrations, which should primarily reflect variations in the ratios of the trace elements to calcium in cave waters, do not vary in a pattern directly related to thickened bands. For example, samples from Père Nöel in Belgium exhibit thinner zones between poorly developed mm-spaced thickenings approximately 15mm from the growth tip of the soda straw which were either high or low in Mg content. However, a traverse closer to the growth tip illustrates covariation of Mg, Na, Sr and Ba. Conversely a sample from Crag Cave, County Kerry, Eire, exhibits correlated variations in Mg and Na whereas independent Sr variations are less marked. Leaching studies of source materials for the solutes of these karst systems will facilitate the interpretation of such variations.

The time of water retention in the soil zone, along with that in the karst system, may have a crucial bearing on the trace element composition of waters and speleothems. In order to further studies of karst chemistries the complex dynamic processes of the soil system need to be quantified empirically at individual sites in order to assess the relationship between soil water and karst water and the nature and degree of change in solution composition. The effects of temperature, CO2 availability, pH and Eh on mineral solubility and cation exchange capacity, along with quantity /intensity relationships between solid phase concentrations and aqueous phase activities in the soil need to be delineated.

In the cave environment it is possible to study variations in chemical signals averaged on timescales from days (water chemistry measurements), months to years (water chemistry and speleothem measurements), and decades to centuries (averaged chemical compositions compared with stable isotope data from U-series dated speleothem samples) with the potential to interpret past climate change from this record.

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Stable isotope geochemistry of Holocene speleothems

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Speleothems theoretically provide a reliable paleoclimatic study material. They are chemically and isotopically rather stable and they are not significantly affected by post depositional processes. Since they can be dated with the U/Th method and since the growthrate of speleothems is higher than the deposition rate of deep sea sediments, a much higher resolution can be expected.

U/Th dating combined with oxygen and carbon isotope measurements on a Holocene speleothem provide a paleoclimatic record which is still difficult to interprete in terms of absolute temperatures and vegetation cover. Measurements of recent calcite, dripwater and cave air should lead to a better understanding of the impact of climate on the isotopic composition of speleothems.

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The Vârtop Cave Man and His Radiometric Age

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The Vârtop Glacier Cave lies in the upper part of the Gârda Seaca Valley, Apuseni Mountains (Fig. 1), at about 1170 m a.s.l. (BLEAHU & VIEHMANN, 1963). It is a 340 m long, well-decorated fossil cave. Perennial ice formations (icicle speleothems) are to be found most of the time near the entrance zone. In 1974, one f the authors (Viehmann) discovered behind a massive stalagmite barrier 3 human footprints which were stamped into a now hardened moonmilk flowstone mass (VIEHMANN, 1987). One of them is complete (Fig. 2), and it was removed together with the flowstone floor into which it was impressed, and is now kept in the "Emil Racoviţă" Museum at the Speological Institute in Cluj.

Different biometrical measurements of the main elements (length, width, principal axis) characterizing a footprint have been done. The values we found for these elements being very similar to a neanderthalian character, we have overlaped our footprint contour to a typical neanderthalian footprint discovered in the Sorcière de la Toirano Cave-Liguire (PALES & al., 1960), for comparison. The distance between the big toe and the second toe (about 1.6 cm), is very similar to both footprints. However, the "Vârtop Man" footprint is wider than a typical neanderthalian foot with maximum 1.2 cm. Different ages (from 15kyr up to 80 kyr) had been assigned to the "Vârtop Man" footprint on the basis of these anthropometrical measurements made by RIŞCUŢIA (VIEHMANN, 1975) and VIEHMANN (1987).

Eigth dates have been performed on different subsamples cut out from the moonmilk flowstone into which the "Vârtop Man" footprint has been impressed. Seven of these were used to draw an isochron plot to correct for the ^{230}Th contamination.

The upper sample of the stalagmite (VTP-1) was purer and more massive than the surrounding, hardened moonmilk mass. This produced an age that is well within the limits of reliable determination. The age (22.4 ± 4.2 kyr) may, according to the stratigraphic position of the stalagmite, be taken as slightly older or equal to the footprint itself (LAURITZEN & ONAC, 1995).

In conclusion, the "Vârtop Man", a *Homo sapiens fossilis*, keeping some **neanderthalian** features lived in Würm III, which corresponds to the isotope stage 2.

The anthropological site from Vârtop Cave has been vandalized, the other two footprints being removed from the cave by someone who sawed out the whole flowstone in which these footprints were impressed.

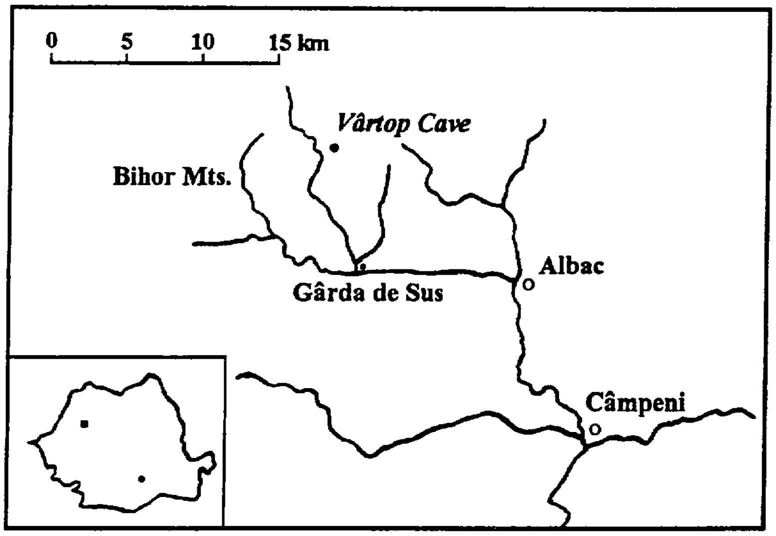

Fig. 1. *Location of the Vârtop Cave*

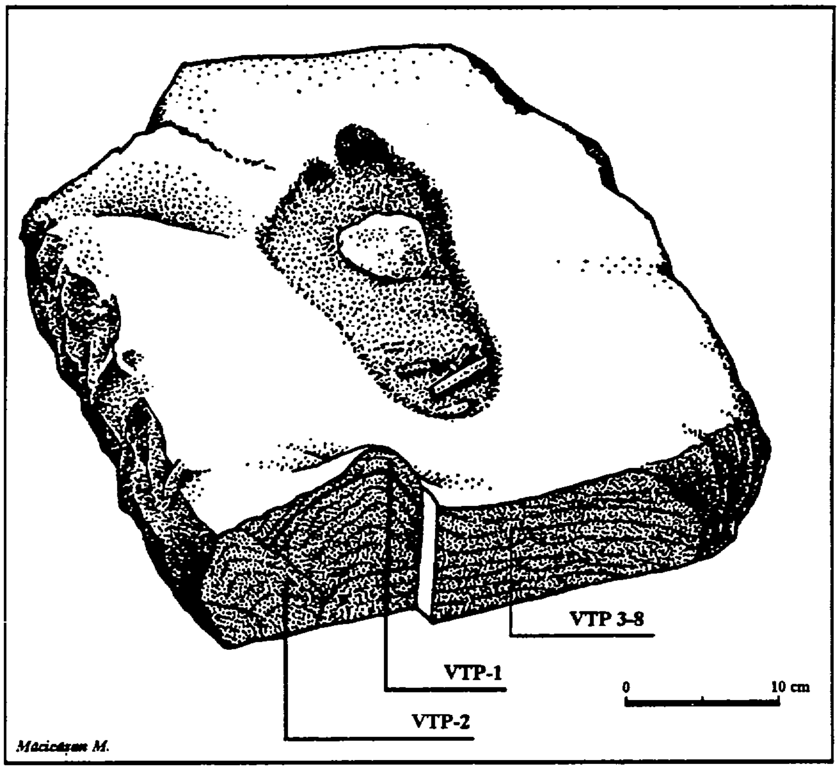

Fig. 2. *"Vârtop Man" footprint and the location of the dated samples*

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A 230 ka record of glacial and interglacial events from Aurora Cave, Fiordland, New Zealand

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Caves overrun by glaciers are known to accumulate dateable evidence of past glacial and interglacial events. Results are reported from an investigation of Aurora Cave on the slopes above Lake Te Anau in Fiordland (Fig. 1). The cave commenced to form before 230 ka B.P. It was sometimes totally overwhelmed by a glacier at least 600m deep, but towards the close of the Last Glaciation was only partly buried by glacier ice. During glacial episodes the cave acted as a sediment trap, but during intervening interstadials re-excavation occurred with speleothem deposition.

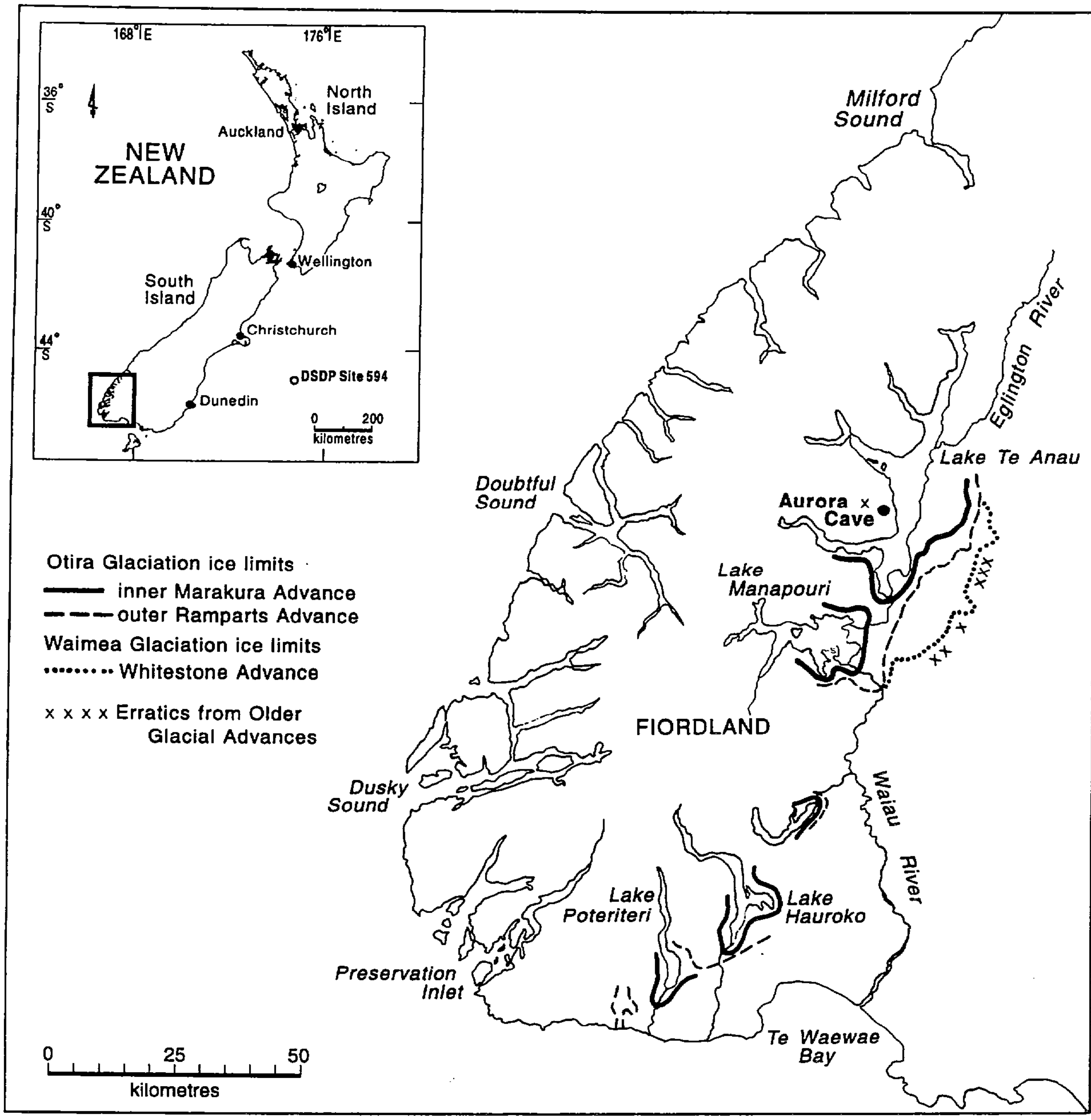
Sequences of glacifluvial sediments interbedded with speleothems are evidence of the number and timing of glacial advances and the status of intervals between them. Twenty-six uranium series dates on speleothems underpin a chronology of seven glacial advances in the last 230 ka (Table 1), with the peak of the Last Glacial Maximum (Aurora 3 advance) at c.19 ka BP. With at least five advances now identified in the interval 90-15 ka BP, the Last Glaciation is more complex than previously recognised in New Zealand.

Comparison of the Aurora Cave record with that accumulated on the sea bed 300 km offshore (DSDP Site 594; Heusser & van de Geer 1994) reveals little matching, but the correspondence of the cave sequence with that interpreted from other onshore deposits is more convincing.

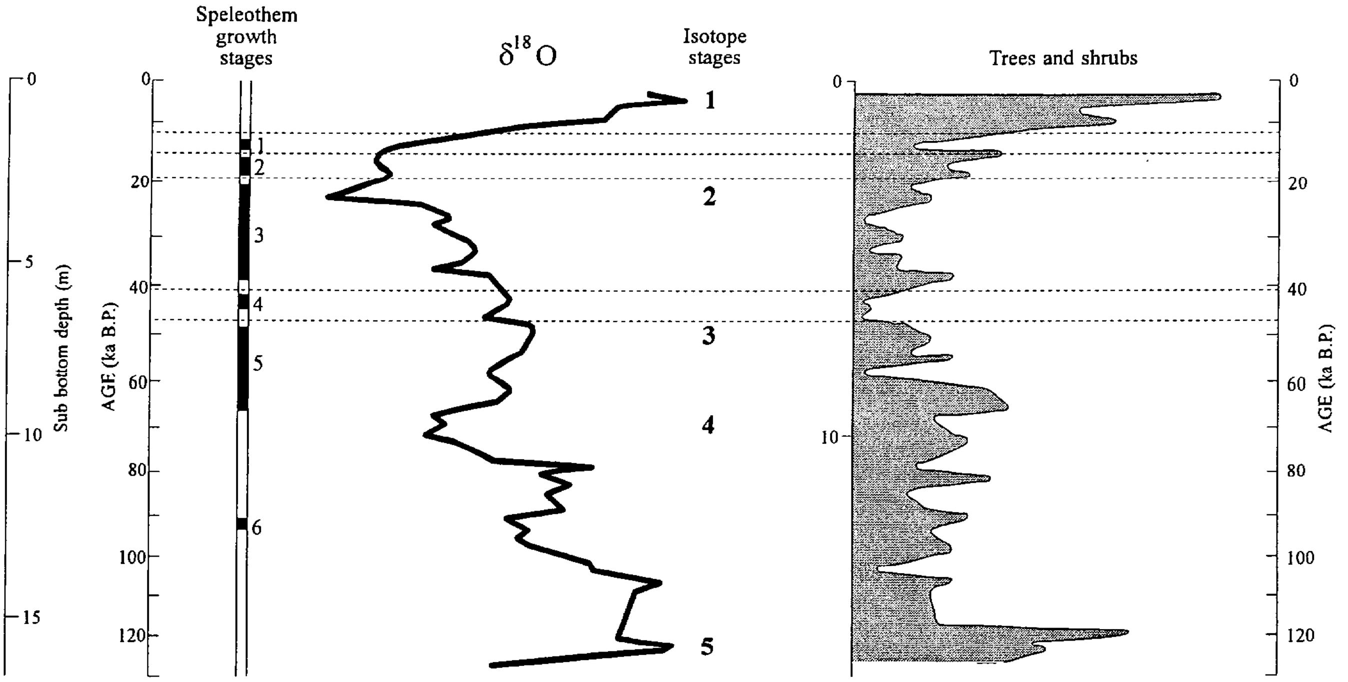
Comparison with glacial events in Tasmania (Fitzsimons & Colhoun 1991) suggests that the Aurora 7 advance may be the equivalent of the Henty Glaciation. An early advance (represented by the Chamouni Formation) and a recent advance (represented by the Dante Formation) of the Margaret Glaciation may correspond to Aurora 5/4 and 3/2, respectively.

Evidence from Aurora Cave indicates that the last glaciation comprised several relatively short lived glacial advances with intervening interstadials that were sometimes also very brief. The results support the ice-core evidence for abrupt climate changes over this period, but do not support synchroneity of onshore/offshore events (Fig. 2).

It is possible that the coldest period of the Last Glaciation (termed the Otira Glaciation in New Zealand), as implied by the deepest $d^{18}O$ trough on Fig. 2, may have been too dry for significant glacial advances and that the Last (late Otiran) Glacial Maximum occurred when climatic conditions commenced to ameliorate and possibly became wetter.



168°E
176°E
36° S
40° S
44° S
NEW ZEALAND
North Island
Auckland
Wellington
South Island
Christchurch
DSDP Site 594
Dunedin
0 200 kilometres
Milford Sound
Eglington River
Lake Te Anau
Doubtful Sound
Aurora Cave
Lake Manapouri
Otira Glaciation ice limits
inner Marakura Advance
outer Ramparts Advance
Waimea Glaciation ice limits
Whitestone Advance
x x x x Erratics from Older Glacial Advances
FIORDLAND
Dusky Sound
Waiau River
Lake Poteriteri
Lake Hauroko
Preservation Inlet
Te Waewae Bay
0 25 50
kilometres



Speleothem growth stages
δ18O
Isotope stages
Trees and shrubs
Sub bottom depth (m)
AGE (ka B.P.)
AGE (ka B.P.)
0
5
10
15
0
20
40
60
80
100
120
1
2
3
4
5
6
1
2
3
4
5
0
10
0
20
40
60
80
100
120

Table 1 Dated interstadials and intervening periods with glacial advances in Fiordland, based on data from Aurora Cave.

Date (ka B.P.)	Glacial Advance	Non-glacial Interval
	Post-glacial	
Aurora 1		11 - 14
	Interstadial 1	14 - 15
Aurora 2		15 - 17
	Interstadial 2	17 - 18
Aurora 3		18 - 20
	Interstadial 3	21 - 39
Aurora 4		40 - 41
	Interstadial 4	41 - 45
Aurora 5		46 - 48
	Interstadial 5	49 - 66
Aurora 6		67 - 91
	Interstadial 6	c. 92
	Last Interglacial	
Aurora 7		after 227
	Penultimate Interglacial	

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The Potential of Perennial Cave Ice in Isotope Paleoclimatology

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Stable isotope measurements, $\delta^{18}O$ and δD, were made on perennial ice from several so-called ice caves in western North America as an approach to better understand its genesis (MacDonald, 1994). Three striking features of the data emerge, especially for cave sites west of the Great Divide (figure 1): firstly, all $\delta^{18}O$ and δD points lie on or to the right of the Global Meteoric Water Line (GMWL), secondly, those points lie on positive slopes less than the GMWL, and thirdly, the ice is more enriched in the "heavy" isotopes than expected. Because of their potential in climate studies, three caves from the Crowsnest Pass (figure 1), and one other cave (Canyon Creek Ice Cave) from the eastern part of the Canadian Great Divide have been selected. The cave ice trend away from the GMWL is in general made up of three components. The nearest (and most depleted in ^{18}O and D) points to the GMWL are from seepage or ground water, followed by those from massive floor ice. Finally, hoar ice formed on the walls and ceiling of the cave are most enriched in ^{18}O and D and lie the furthest off the GMWL. Marshall and Brown (1974) measured high $\delta^{18}O$ values on massive ice from Coultard Cave concluding that although it was glacier ice it had formed during a hypsithermal. We would conclude otherwise.

$\delta^{18}O$-δD trends generated during the formation of ice with Arctic and Alpine isotope compositions have been determined in the field (Jouzel and Souchez, 1982) and laboratory (Souchez and Jouzel, 1984) yielding slopes between 5.99 and 6.63. These experimental slopes were found to be in accordance with their calculated model slopes. Here the mechanism of ice formation is the progressive freezing of water in an open or closed system. Cave ice should be of the former if we assume cave vapour to be unlimited. In a purely open system however, and assuming the cave vapour $\delta^{18}O$-δD to be constant over time, only a single point would be generated representing the vapour-ice fractionation (an enrichment in the ice of around 3 ‰ in $\delta^{18}O$ and around 14 ‰ in δD). Such enrichment is the maximum attainable from this mode of ice formation, whereas in our hoar frost samples enrichments of up to 8 ‰ in $\delta^{18}O$ and 60 ‰ in δD are observed.

Therefore, while vapour-ice fractionation must occur, there needs to be an additional enriched moisture source. Water condensed from the cave atmosphere is generally a mean annual average of precipitation falling at the site, and is positively correlated with the site's mean annual temperature (Yonge *et al.*, 1985). We might expect the cave ice to be derived from this source except that the source is too depleted. Hoar ice therefore appears to be growing mostly from warm moist air entering the cave during the summer months. This warm air being enriched in ^{18}O and D over that of the mean annual average, and being able to carry more moisture than cooler air, could supply the additional moisture source required. The $\delta^{18}O$-δD plot in figure 2 presents a scheme for the formation of cave ice from a vapour source. Line A is the composition of vapour forming over the cave at various temperatures (higher temperatures being towards the origin). Line B is a slightly modified GMWL appropriate for western North America. Line C represents the composition of cave ice derived from the vapour source in Line A sublimating at 0°C. Lines A, and C have been calculated using temperature-dependent vapour-liquid-ice fractionation factors from Jouzel (1986). The crossing lines a, b and c are for vapour formed at 0°C, 10°C and 20°C which then enters the cave and is sublimated as hoar ice at 0°C. The δ-temperature values are based on those for Calgary which is the closest station for which we have collected data. Line *M* is a mixing line between mean annual precipitation at Calgary (starting at line B) and the hoar frost $\delta^{18}O$-δD composition (finishing at line C). Most importantly, this mixing line models the cave ice $\delta^{18}O$-δD values.

What physical processes lead to this mixing line? Moist, warm air enriched in ^{18}O and D enters the cave subliming as hoar frost on the walls and ceiling. Over the warm part of the year the hoar builds up to such an extent that some of it breaks off and falls to the floor. Along with seepage, melting and recrystallization, it reforms as massive floor ice. As a result, the massive ice has a mixed composition between mean annual seepage and warm-season derived hoar ice. Note for example that 10°C vapour entering the cave and sublimating as hoar ice yields a mixing line slope of around 7.1 with enrichments of about 8 ‰ in $\delta^{18}O$ and 55 ‰ in δD which fits the field data very well.

How might these results be applied to paleoclimatology? For example, Serendipity Cave contains a 15-meter thick plug of massive ice, where guano trapped at a depth of 14.3 meters yields a carbon-14 date of 970 years BP. This preliminary date while viewed cautiously does appear to fall within the Medieval Warm Period and compares to a higher treeline in the Canadian Rockies between 700-1110 AD (Osborn and Luckman, 1988). This site clearly offers the opportunity for an extremely detailed study of the last 1000 years or so, assuming that the isotopic composition of the ice can be interpreted climatologically. What changes in the cave ice would we expect to see during these warmer periods? Assuming the ice did not disappear altogether or be subject to excessive melting and recrystallization, it seems that two opposite effects could result. If there is little hoar ice being developed in the cave then the massive ice composition will tend to reflect seepage and be relatively depleted in the heavy isotopes. Alternatively, warmer and moister air might enter the cave and be frozen as hoar ice which will result in enriched floor ice (note that some floor ice has the same composition as hoar ice). During cold periods where there might be short hot summers, hoar frost might dominate over seepage yielding paradoxically O-18 and D-enriched ice. Alternatively, ice production might cease altogether as the cave is sealed by snow and permafrost prevents seepage from entering the cave. During times of substantial climate change, shifts in mean annual precipitation up and down the GMWL and lateral shifts in the line between glacials and interglacials would have imposed a background signal on old cave ice.

While the scenarios can be complex, it does appear that the caves encountering lower mean annual site temperatures contain massive ice that is more enriched in ^{18}O and D compared to Canyon Creek Ice cave sited in a higher temperature regime (note the hoar ice samples in figure 1 that plot close to {-17,-130}). It therefore seems to be the extent of hoar ice from warm-season air masses that dominates the changes observed in the isotopic composition of massive cave ice. Swings in isotope composition in cave ice cores, interpreted as warming and cooling climate trends, would then be in the opposite direction to conventional glacial or polar cap cores.

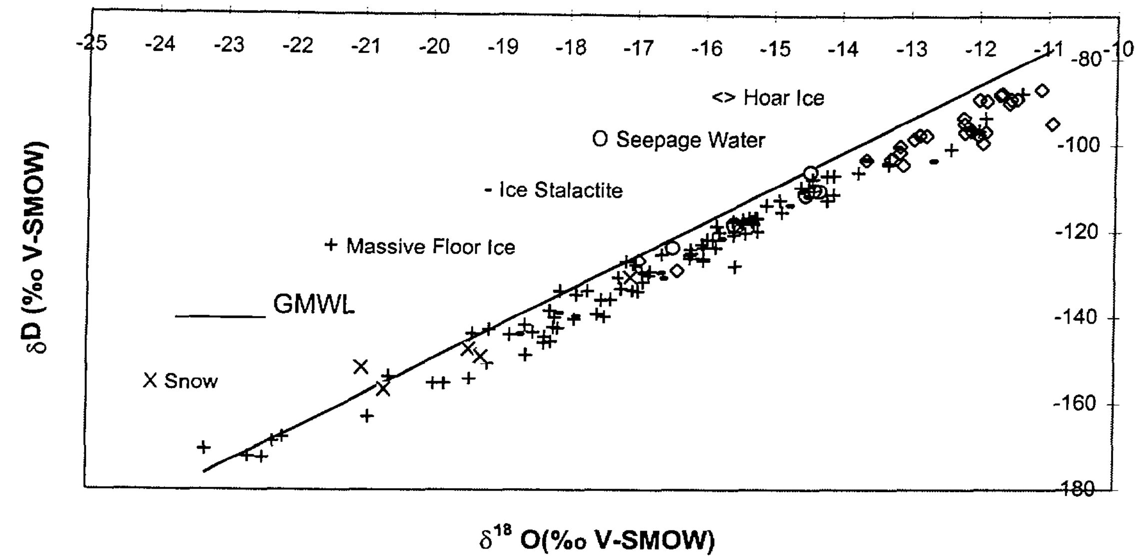

Figure 1. $\delta^{18}O$ - δD of perennial cave ice from three caves in the Crowsnest Pass (Ice Chest, Serendipity, and Rats Hole) and one other, lower altitude cave lake in the Canadian Rocky Mountains (Canyon Creek Ice Cave). The upper line is the Global Meteoric Water Line ($\delta D = 8\ \delta^{18}O + 10$). The line, left out for clarity, which fits all of the cave ice data from the Crowsnest Pass (as a single region) yields: $\delta D = .7.26\ \delta^{18}O - 6.72$ ($R^2 = 0.975$).

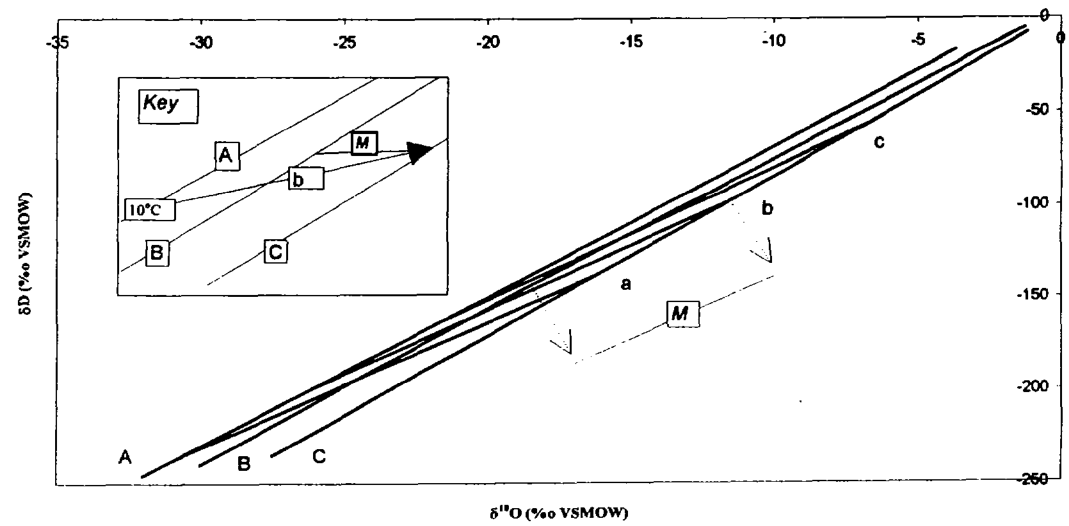

Figure 2. A theoretical plot of $\delta^{18}O$ - δD where vapour (line A) condenses to give precipitation (line B: a modified GMWL for Western North America, $\delta D = 8\ \delta^{18}O + 5$), or sublimes at 0°C to give hoar ice (line C). Crossing lines a,b and c represent the composition of ice formed at 0°C directly from vapour which had initially formed at 0°C, 10°C and 20°C. Line *M* (displaced for clarity) is a typical example of a mixing line where mean annual precipitation (groundwater) from line B mixes with ice formed from 10°C vapour. Line *M* models the data in figure 1. The key box is a schematic which details the relationship between the lines.

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Measuring of corrosion in infiltration zone of karst system

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The percolation of precipitation into the karstic aquifer is one of the determining elements in karstification. This elements is called as karstic infiltration.

A monitoring system has been installed in the Aggtelek Karst in Hungary to study the process of karstic infiltration. This system is equipped with sensors and loggers and can continuously measure the parameters of the infiltration from the surface to the karstwater table.

The units of the measuring system are located in karstic vadose and epiphreatic zones along a vertical section. The first unit (which measures precipitation) is over the surface, the second unit (which measures run-off) is on the surface. The follow five seepage measuring units in the thick soil accumulation at 0.5, 2.5, 5.0 and 8.5 metres. Finally, two units measure the infiltrating water of the ceiling of the Béke Cave, directly at the level of the karstic water table.

Until the humidity of the top 5 cm soil layer is below 92-93 %, and the infiltration capacity is higher than the precipitation, all rainwater infiltrates. At 92-93 % humidity value run-off starts.

Infiltration in forested areas is 1-12 hours later than in grasslands.

The downward velocity of the infiltration front depends on the preliminary water saturation of the soil.

- At 0.5 m, infiltration can even be 44 hours later than the start of rainfall, depending on the humidity of the soil.

- Over forested lands generally 12 hours, on open fields generally 3 hours are needed after the start of raining until the infiltration front arrives at 0.5 metres. In the case of recurring minor precipitation (4-5 mm) the infiltration front normally arrives at 0.5 m in 24 hours.

At medium humidity (40-50 %), the infiltration reaches from 0.5 m to 2.5 m after 15 hours, and usually needs another 17 hours to arrive at 7.5 m.

Figure 1.

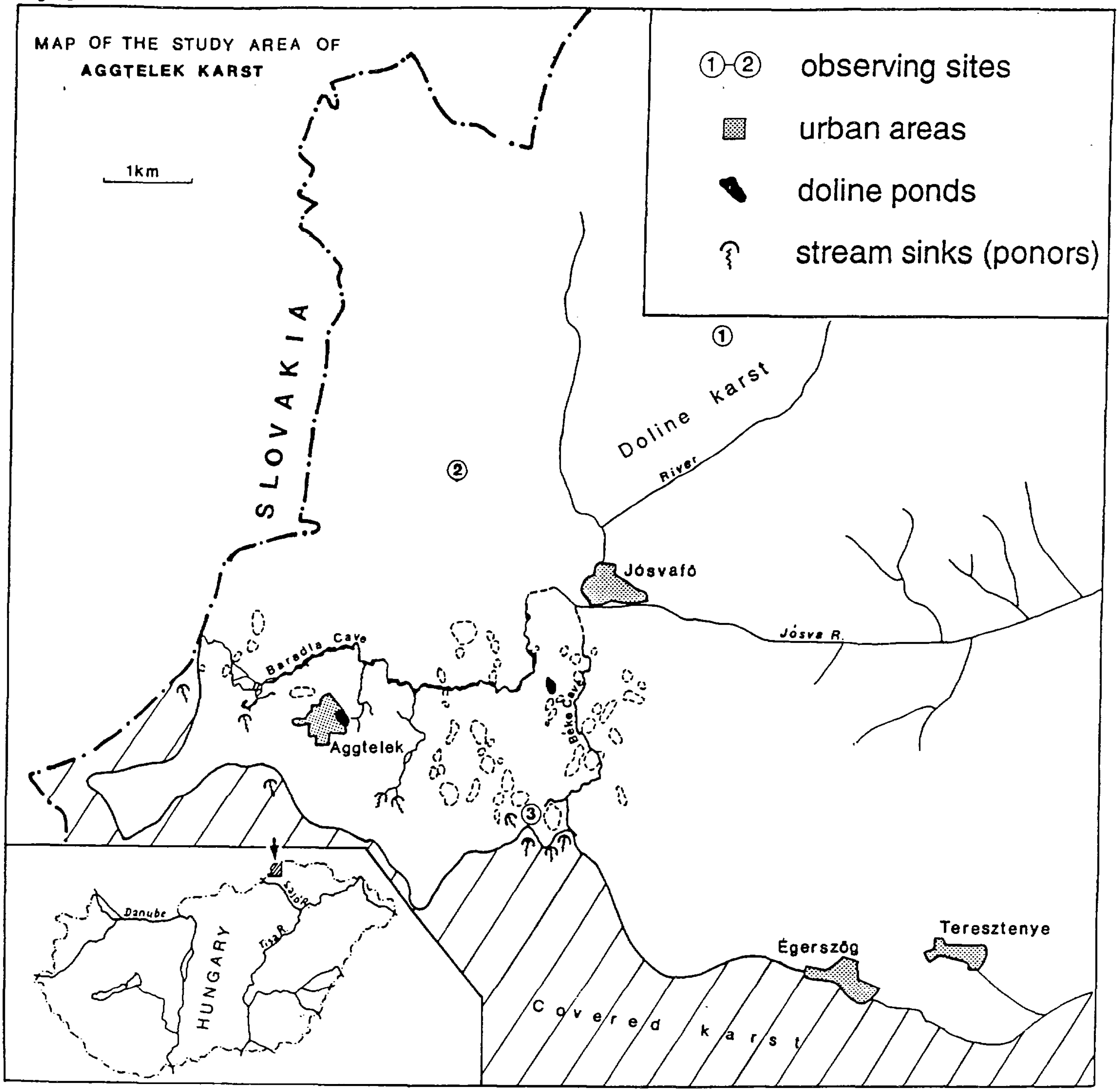
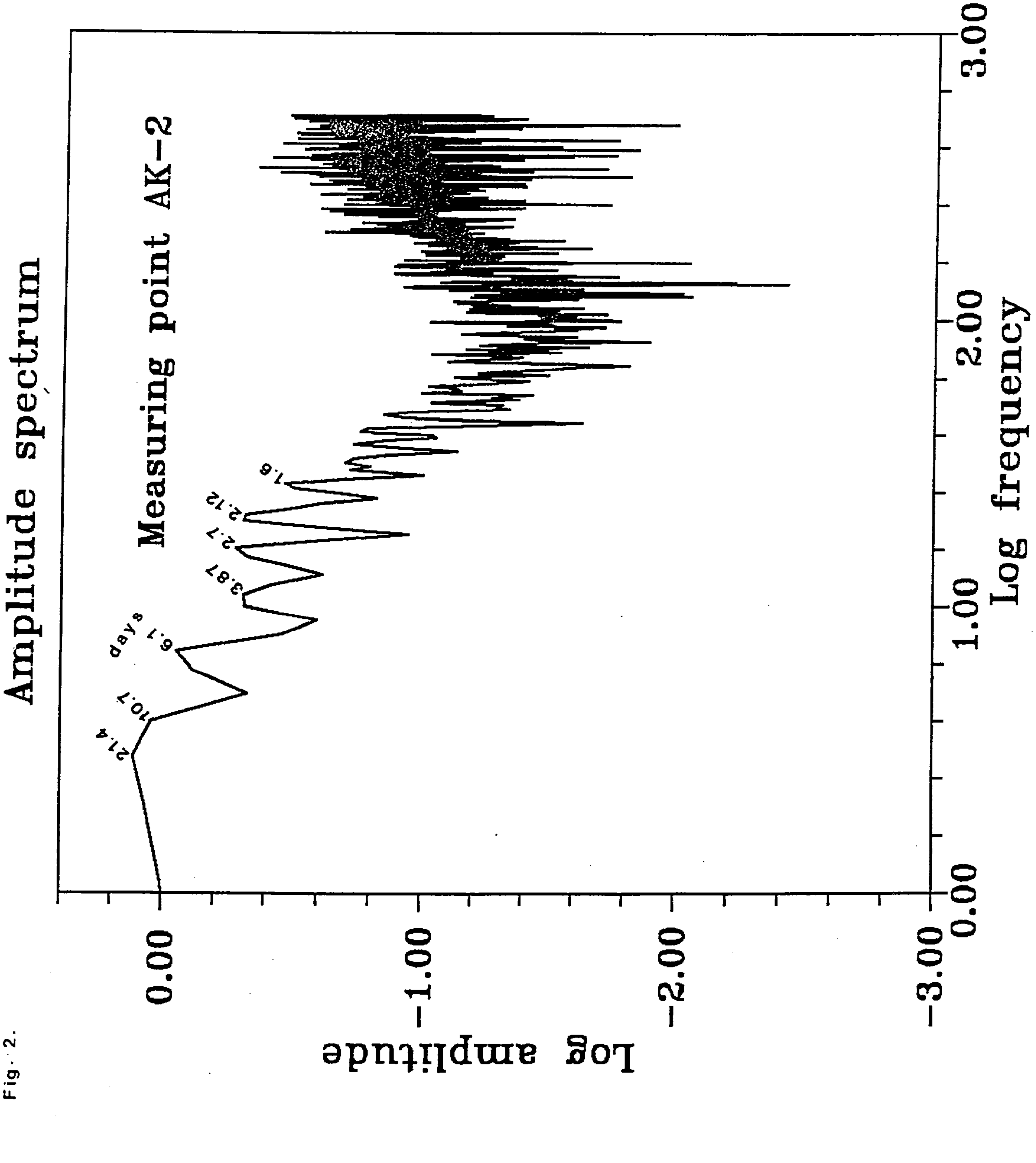

MAP OF THE STUDY AREA OF
AGGTELEK KARST
1km
①-② observing sites
urban areas
doline ponds
stream sinks (ponors)
SLOVAKIA
Doline karst
River
Jósvafő
Jósva R.
Baradla Cave
Aggtelek
Béke Cave
Égerszög
Teresztenye
Covered karst
Danube
HUNGARY
Tisza R.
Sajó R.

Fig. 2.


Amplitude spectrum
Measuring point AK-2
21.4
10.7
6.1 days
3.87
2.7
2.12
1.6
Log amplitude
0.00
-1.00
-2.00
-3.00
Log frequency
0.00
1.00
2.00
3.00

In humid soil (over 87 %), the intensity of infiltration suddenly increases and synchronously changes with the surface swallowing.

The infiltration process becomes more and more balanced as the depth is growing, but certain rhythmical changes in the intensity can be observed up to the karstic water table.

Changes, occasionally periodicity, in the intensity of seepage at various depths can be most easily explained by lunisolar effects, which have already been proved for movements in karstic hollows. The existence of these effects can only be presumed due to the special hydraulique rules that direct infiltration, although the mathematical analyses seem to support this.

Studying the infiltration processes at 2.5 m, the range of the amplitude indicated the existence of the given harmonic factor. The time period of 514 hours starting at 12 o'clock on 11 March 1995 produced 1029 data, which were analysed by Furier transformation. With the help of this analysis it was possible to show some long periods (21, 10.5, 6.1, 3.8, 2.7, 2.12 and 1.6 days) and several short periods. A more complete explanation still needs a bigger data based and further analysis.

Measured data of karstic infiltration gave the opportunity of calculating the average value of limestone solution.

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THE VALUATION OF ABSOLUTE SPELEOTHEM DATINGS FROM SLOVENIA

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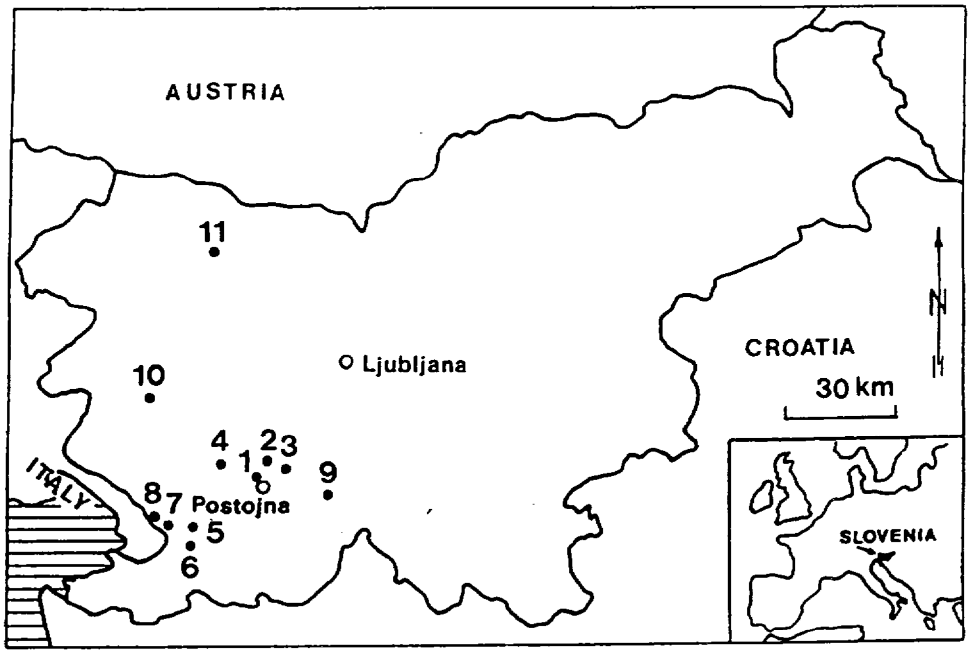
Abstract

In Slovenia the studies of cave sediments of Postojna cave started in the last century. The chronostratigraphy of cave sediments, paleoclimatic interpretations and karstification processes are based mainly on relatively dated mechanical sediments.

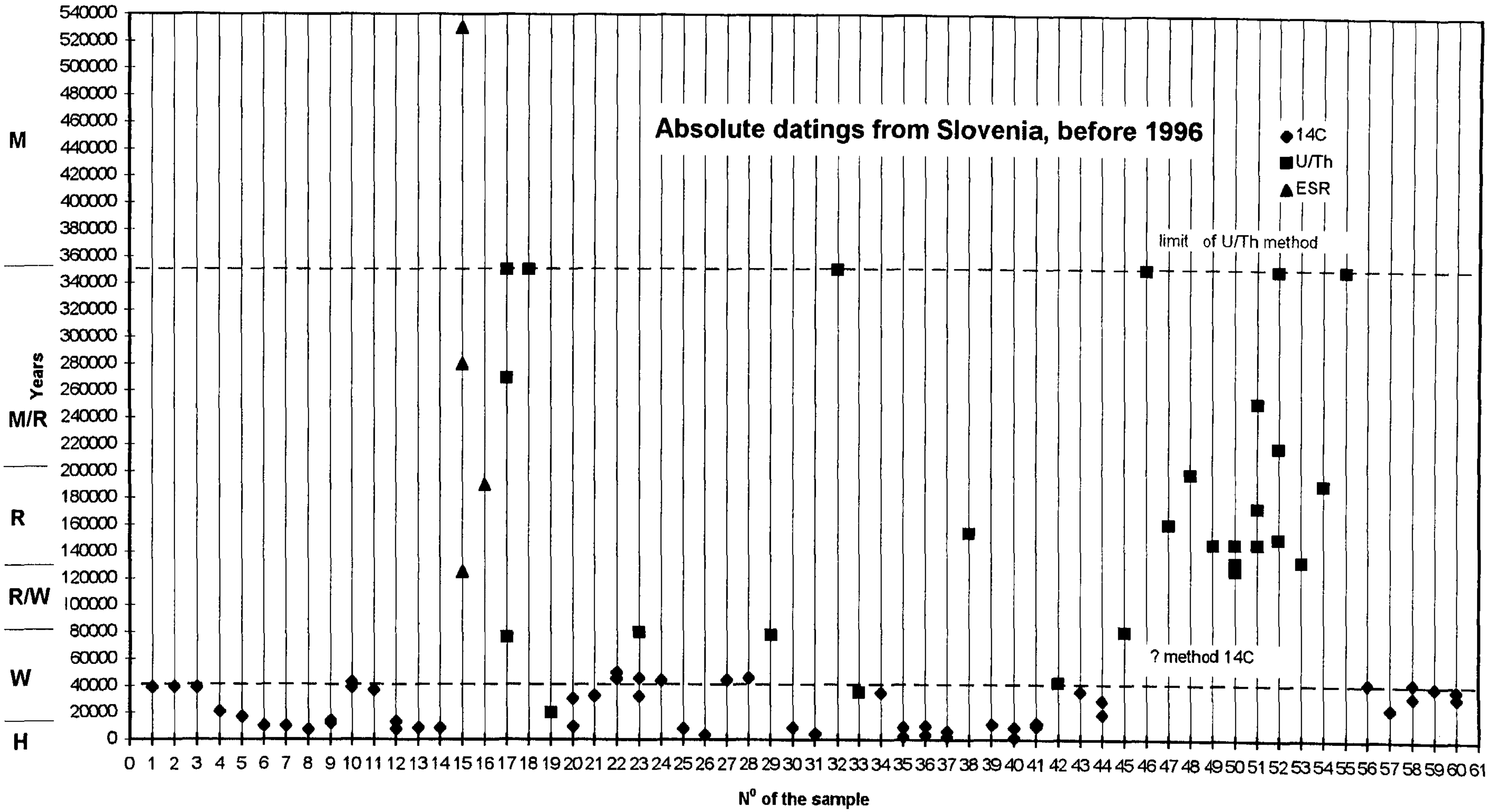
There have been analysed single samples from different caves. The first absolute age of speleothem from Slovenia is known from 1971. Most of the speleothem samples have been analysed by Radiocarbon dating, some of them by U series dating, and just few by the ESR method. In the article are presented results made before 1996 published by Franke & Geyh 1971, Gospodarič 1972 and 1981, Ikeya, Miki & Gospodarič 1983, Ford & Gospodarič 1989 and Zupan 1991.

From Postojna cave different samples were analysed by ^{14}C, U/Th and ESR method. The values of samples dated by ^{14}C method range from 7.500 to 39.500 years. By ESR method the ages of samples are from 125.000 to 530.000 years. Samples analysed by U/Th method are dated from 20.000 to more than 350.000 years. Different speleothems were dated from Planina cave by ^{14}C and U/Th method. The range of results is from 3.600 to 50.000 years by the first method. Seven of the samples are older than 40.000 years. One of it was dated again by U/Th method and the established age was 80.000 years. It is evidenced that these results, got by 14C are not reliable for speleothems older than 37.000 years. From Zelše caves two flowstones were dated by ^{14}C, the first is 4.500 years old and the second 9.000 years old. One stalagmite analysed by U/Th is older than 350.000 years and the age of the stromatolite speleothem sample from collapse doline under Small Natural Arch is 37.000 years. In Predjama cave system stalagmites were analysed by 14C, and the results range from 2.200 to 40.000 years. In Fiženca, nonactive part of the system, the sample of speleothem was dated by U/Th to 154.000 years. Samples from Škocjan caves analysed by ^{14}C were dated from 1.500 to 12.200 years. By U/Th method no results were obtained, because the content of U was to low. The age of the sample from cave Mejame is 42.000 years. The sample from Vilenica cave dated by U/Th method show 80.000 years. Laminated flowstone from Lipiška cave is older than 350.000 years, the base of stalagmite is 160.000 years old. From Križna cave the samples were analysed by U/Th method, they are from 126.000 to 251.000 years old. The flowstone from cave Paradana is also older than 350.000 years. In Babji zob cave samples were analysed by ^{14}C. The results range from 23.000 to 43.000 years, however the question of reliability exists.

By dating limit, the ^{14}C method is out of reach to date most of speleothems from our karst. It seems that these speleothems are older than we have thought, so use of U/Th dating method is recommended. From some results it can be seen that the speleothems, recently analysed by the U/Th method, are older than those, dated by ^{14}C. Maybe just because stratigraphically younger samples have been analysed by ^{14}C. It has to be emphasized that the results, obtained by ^{14}C are not reliable for the speleothems older than 37.000 years and that probably they are older. Some samples have been dated to more than 350.000 years, it means that speleothems from a many caves of our karst are much older. These samples have to be dated by the method with limit more than 350.000 years.



Location of caves in Slovenia
1. Postojna caves, 2. Planina cave, 3. Zelše cave, 4. Predjama caves, 5. Škocjan caves, 6. Mejame cave, 7. Vilenica cave, 8. Lipiška cave, 9. Križna cave, 10. Paradana cave, 11. Babji zob cave.



Number of the sample: 1-19 Postojna caves, 20- 29 Planina cave, 30- 33 Zelše caves, 34- 38 Predjama caves, 39- 41 Škocjan caves, 42 Mejame, 43- 45 Vilenica cave, 46- 47 Lipiška cave, 48- 54 Križna cave, 55 Paradana, 56- 60 Babji zob cave

The great problems for U/Th method are dirty speleothems. Many our caves were flooded more than once during growing of speleothems. Clay minerals and the particles of sediments are bonded into the speleothems or form hyatus in them. Clay particles contain detritial Th, with higher abundance of it, the speleothems seem older than they are. Another very important problem is that relatively dated younger speleothems do not contain sufficient U, from some caves there have been no dating results obtained.

For better explanation and reconstruction of paleoclimatic events of karst in Slovenia not enough absolute datings of speleothems have been made.

Key words: cave, speleothem, absolute datings, 14C dating method, U/Th dating method, ESR dating method, Slovenia

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PALEOGEOMORPHOLOGICALLY INTERESTING DETAIL FROM THE IST ISLAND

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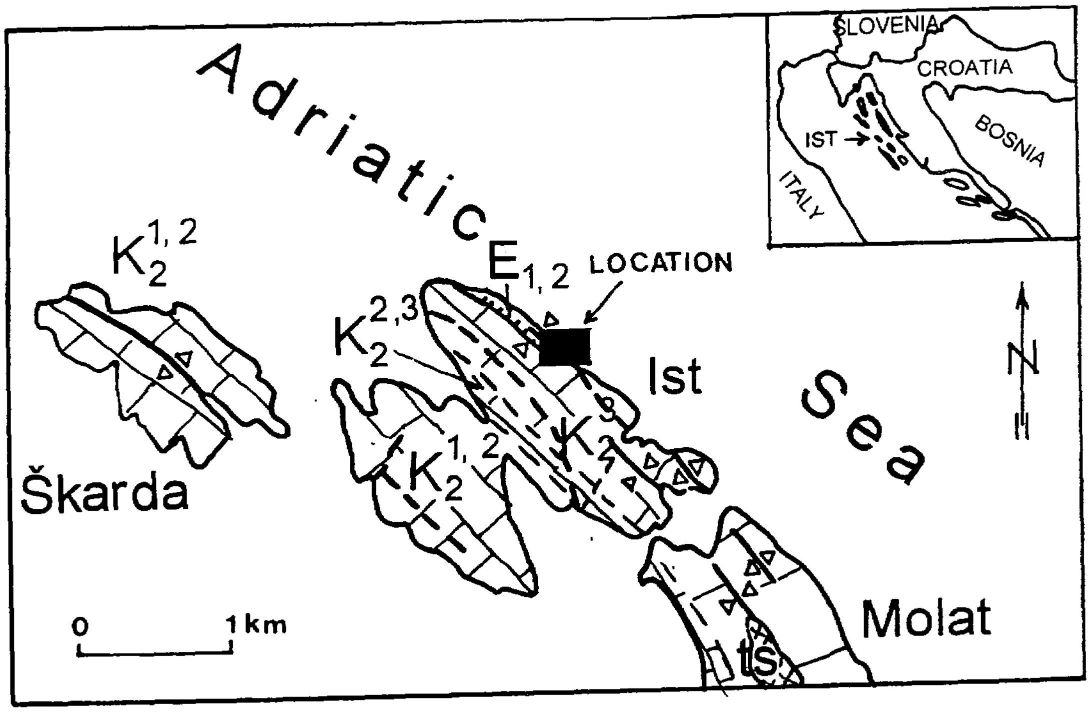
Abstract

The paper deals with profile from the Ist island, Adriatic Sea (Zadar archipelago, 44^0 16' N, 14^0 46' E, the island covers 9,65 km^2, Croatia); on a karstified basement there is a layer of paleosoil and above it a carbonate shallow-sea deposit. The profile at the coast is due to abrasion; such layers cover relatively large surface of the coastal belt on the NE side of the island and are visible in relief and in characteristically sculptured surface. The profile is partly artificial indicating that the rock was exploited.

Ist island is composed mainly of Upper Cretaceous limestones, except the NE part of the island, there is a narrow belt of Eocene foraminiferal limestone. This limestone is tectonically fissured and not very karstified. Directly on the limestone lies around 1 m thick layer of red paleosoil. The colour of paleosoil is red, 2,5 YR 4/6 and structure of it is alveolar. There are many irregular pores, particles are of various sizes ranging from clay to coarse sand with a lot of fossils fragments. It is partly lithificated. Some mineralogical analyses were done by x-ray method and in thin section. In the samples of paleosoil, the quartz prevails in quantity followed by illite and apatite, plagioclase, rutile and hematite. Chlorite and calcite are present in traces. The origin of quartz, plagioclase and rutile is unknown. The presence of hematite indicates the sedimentation in warm climate. Apatite is in microcristalline form and probably it is a product of alteration. The paleosoil is the mixture of the minerals which are weathering product of Eocene limestone and quartz sand with unknown provenience, sedimented in the sea environment and/or by wind. Above the top of the paleosoil there is 5 m thick laminated sediment, mainly composed by skelets of foraminifers, fragments of shells and small gastropods. The mineral composition shows that calcite prevails and that there are same grains of quartz. The sediment is very porous, purely lithificated and it is not tectonically deformed. Bedding planes are more or less horizontal. The surface is very intensively karstified in spongework like form, but no bigger typical karst forms are present and no underground karst features developed. All this indicates relatively young and short lasting karstification.

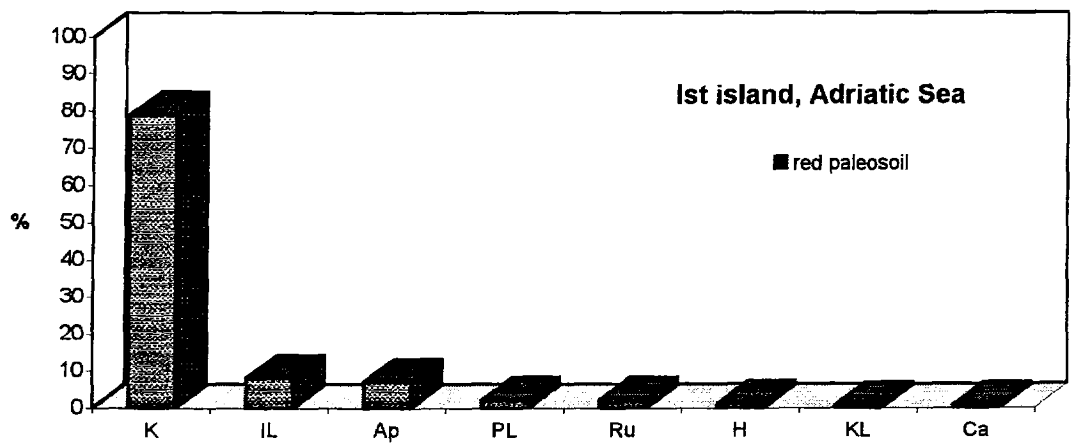
Different authors in their articles determine that after the Middle Eocene a lot of hiatuses caused by emersions can be recognised in Middle Dalmatia. Red paleosoil evidences an important interruption of sedimentation in a sea environment and at the same time displays rather poor karstification of foraminiferal limestones. The weatherig of limestone and quartz sand went on in a warm climate; this is indicated mostly by hematite presence. It means that paleosoil's age is younger than Middle Eocene and probably older than Pleistocene. More detailed dating would require additional paleontological researches of foraminifera within the overlain sediment. Although the paleosoil from Ist island cannot be dated yet the profile may be an important link in studies of tectonics, sea-level changes and changes of the coastal line in the Middle Adriatic illustrating also the surface karstification in recent geological past.

Key words: paleosoil, mineral composition, karstification, sea-level changes, Ist island; Croatia



Location of profile and geological map

Legende: ts - terra rossa, $E_{1,2}$ - limestone, K_2^3 - limestone, $K_2^{2,3}$ - limestone, $K_2^{1,2}$ - limestone



Red paleosoil from Ist island
Legende: K - quartz 80 %, IL - illite 8% , Ap - fluorapatite 7%, PL - plagioclase 2%, Ru - rutile 2%, H - hematite 1%, KL - chlorite and Ca - calcite in traces

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Pleistocene to Holocene climatic record in speleothems on the SE edge of theKras plateau in Slovenia

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There is little geomorphologic evidence of Pleistocene climatic changes on the surface of the plateau Kras, western Slovenia. Because of its low altitude, between 300 - 500 m a.s.l., it was not glaciated, and there are no surface rivers on them. However, on its SE edge the plateu is entered by 18 sinking streams as well as the large streamsink of the Reka river, all having their catchment areas on noncarbonate rocks. Most of the sinking streams have formed blind valleys in which caves of different morphology and hydrological function are accessible.

Morphological studies (Mihevc, 1994) have shown strong structural control on the formation of the blind valleys and caves in them, while fluvial non carbonate sediments (Gospodarič, 1984, 1985) in blind valleys and in caves indicate strong influence of climatic changes. Namely, in the blind valleys we can observe fluvial sediments forming flat bottoms, and in adjacent caves similar coarse or fine sediments, now being out of the reach of rivers. Under the present conditions, intensive washing of these sediments into the karst is prevailing, which transforms the depositional forms. Numerous authors (Melik, 1955, Gams, 1962) have described this as Pleistocene infilling and Holocene outwashing, caused by the climatic changes. However, no absolute dating of speleothems growing on such deposits was available for testing this hypothesis.

Various speleothems, including tall stalagmites and massive sinter deposits have been sampled in seven caves and analysed with the $^{230}U/^{234}Th$ method by α-particle counting. This is a preliminary screening of samples in order to determine approximate ages, ^{232}Th contamination levels and U content, which will ensure more rational utilization of subsequent TIMS dating. These first results demonstrate that the speleothems at the chosen caves in blind valleys were depositing trough different periods.

In several active streamways, massive sinters can be found, which are being eroded by the present streams. They were deposited either during dry periods, or during periods when the sinking streams were supersaturated with respect to calcite. These sinters display ages of 70- 80 ka, or they are > 350 ka. This may indicate periods when the border karst received less sediments and when the rivers were flowing through lower cave passages, or periods of general low discharge.

Several tall stalagmites (up to 238 cm long, and already broken !) were sampled from each environment or part of a cave. Some of them were growing directly on the fluvial sediments which represents the phase of infilling. Each stalagmite was split into two longitudinal halves; one half was used for dating, while the other half was kept as a reference and polished for growth band and stable isotope analysis, which has not yet been completed.

Basal ages of these tall stalagmites show that growth commenced between 16 and 10 ka before present. This converts to average growth rates of approximately 0.2 mm/ year, although it may be higher, as their lower parts display numerous detrital layers and hiatuses that may indicate flood events and interruption of growth. Preliminary measurements of visible growth bands revealed large variations in bandwidth, both between and within caves, although stalagmites that have grown more closely together could in general be correlated on a broad basis.

All samples were dated with the $^{230}Th/^{234}U$ method in the U-series laboratory in Bergen.

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