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Assessing the variability of precipitation during the Holocene from stalagmite records

A. Mangini

Heidelberger Akademie der Wissenschaften
e-mail: Augusto.Mangini@iup.uni-heidelberg.de

Abstract. Stalagmites can be dated very precisely with Th/U. The growth rate of stalagmites is generally in the range between 30 and 100 μm year. Stable isotopes sampled at a resolution of 50-100 μm yield information with a resolution ranging from a sub-decadal to centennial scale. Precipitation determines the growth periods of the stalagmites and the stable isotope signal is mainly a proxy for the intensity of precipitation. Stable isotopes in Holocene stalagmites from Central Germany (S. Niggemann, Bochum) record the intensity of winter precipitation in the past, because it is mainly winter precipitation that contributes to ground water formation. From the records of two stalagmites we reconstruct several periods of reduced winter precipitation during the last 5,000 years. These periods are recorded as kinetic enrichment of d18O proportional to enrichment of d13C. They are apparently correlated with the intensity of the sun, derived from D14C in tree rings. Meteorologists find that at present drier winters in Central Europe are related to a NAO- index, whereas NAO+ index corresponds to wet and mild winters. If this rule applies also in the past, our results suggest that periods of enhanced sun activity favored NAO+ conditions in Central Europe and vice versa also during the past 5,000 years. Spannagel Cave in the Central Alps is another area in Europe that we are studying intensively (C. Spoetl, Innsbruck). Three Holocene stalagmites cover the time period over the last 5,000 years and partly overlap each other. The stable isotope records show no significant correlation between d13C and d18O suggesting that kinetic effects are not significant. The precisely-dated isotopic composition of stalagmite SPA12 is then translated into a high-resolution record of atmospheric temperature at high elevation during the past 2,000 years. Temperature maxima during the Medieval Warm Period between 800 and 1300 AD are about 2C higher than the minima in the Little Ice Age and slightly higher than present-day values. The good correlation of this record with D14C suggests that solar variability was a major driver of climate in Central Europe during the past 2 millennia. The temperature reconstruction from SPA 12 shows a pattern similar to other climatic archives from the Northern Hemisphere including Greenland ice cores, sea-surface temperatures (SST) from the Bermuda Rise, as well as to the reconstruction of glacier advances and retreats in the Alps.

Key words. Stalagmites

1. Introduction

Stalagmites that form in caves several meters below the surface are an archive for precipi-

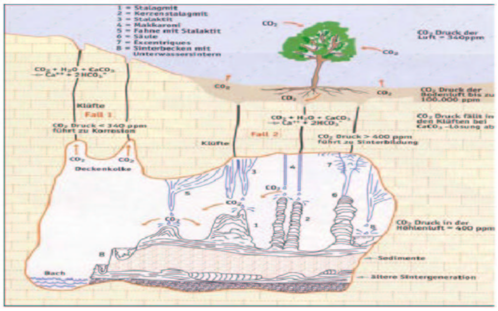

Fig. 1. Formation of stalagmites.

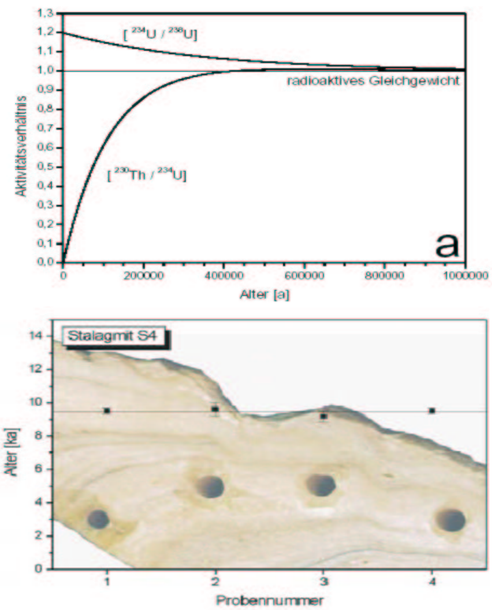

Fig. 2. Dating of stalagmites with the Th/U-Method.

tation. High concentrations of dissolved CO_2 in the soil dissolve carbonates that precipitates in the cave, where excess CO_2 degasses and forms stalagtites (ceiling) and stalagmites (bottom) (fig. 1). Temperature in caves represents the average yearly temperature and has only a minor variability. Growth periods in this cave therefore allow to precisely determine the transition from the colder glacial periods, with temperatures significantly below the freezing point, into the warmer interglacials when stalagmite growth started again. A second and more sophisticated application results from the

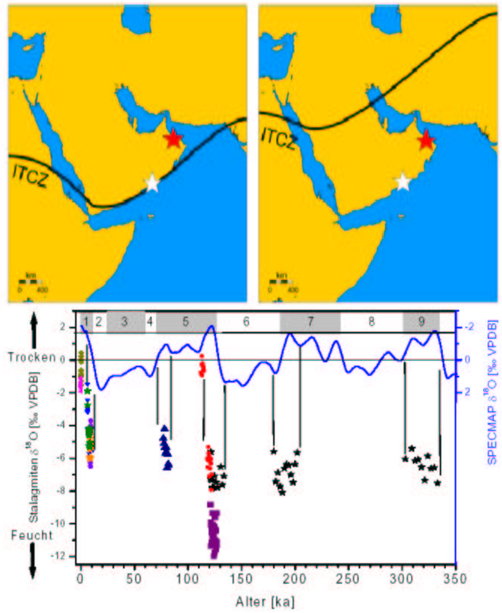

Fig. 3. Growth periods of stalagmites in Oman reveal periods of a shift of the Intertropical Convergence Zone.

measurement of stable isotopes composition of the carbonate ($^{18}O/^{16}O$ and $^{13}C/^{12}C$ ratios), which are sensitive to temperature, as well as to the initial composition of the precipitation (trajectory) and to Rayleigh fractionation (kinetic effects). In most stalagmites kinetic effects are responsible for the largest part of the observed variability of isotope ratios. The relationship between precipitation and degree of kinetic fractionation is presently not well assessed and a matter of studies. However, the general rule is that higher precipitation corresponds to less kinetic effects in stalagmites and viceversa. The variable kinetic effect is thus an indicator for precipitation in the past. In my presentation I show four applications of stable isotopes on stalagmites from Oman and from Central Europe in conjunction with precise Th/U dating that we have performed in the past. All these data and results have been published (see references). The first example shows results from a stalagmite from Qunf Cave in southern Oman, an area which is presently very close to the northernmost position of the Intertropical

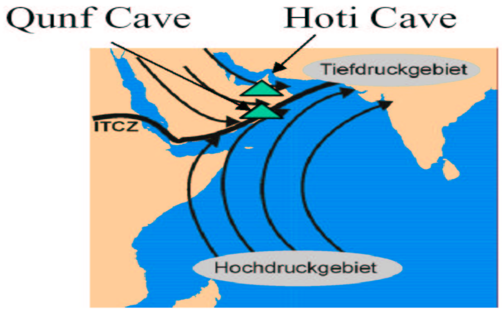

Fig. 4. Location of the two studied caves in Oman. Precise dating of stalagmites is achieved with the Th/U-Method, which is based on the incorporation of traces of dissolved uranium into the carbonate. The U-contents ranging between 100 ppm and 0.01 ppm obviously depend on the composition of the solution. The dating method has a range between few decades and 400,000 years, provided that the system has remained closed (fig. 2). The simplest application of stalagmites is by determining growth periods, which correspond to wet periods, suggesting that enough water was then available. For example, growth periods of a stalagmite in Oman, in an area that is presently very dry, proofs that the rain belt shifted northwards at some times in the past (fig. 3). Another nice example are growth periods of stalagmites in caves located at 2,500 m height in the Central Alps, where the present temperature in the cave is only about 2C.

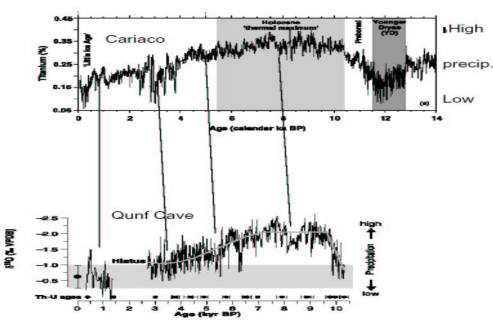

Fig. 5. Comparison of the isotipe record of Qunf Cave (precipitation) with the precipitation record in Cariaco Basin.

Convergence Zone (ITCZ), which delimits the Indian Summer monsoon (fig. 4 and 5). The isotopic record shows lighter (more negative values) during the period of stronger insolation in the N. Hemisphere, with a maximum between 9,000 and 6,000 years before present. The lighter isotope record then suggests enhanced precipitation. The comparison of these results with those obtained from marine sediments, such as the Sea surface temperature in the Nordic Sea and the Cariaco Basin, a proxy for the amount of precipitation on the Area of the Amazonas River shows a very good agreement, one may even detect similar pattern in the high resolution records. This good agreement demonstrates that the information from the stalagmites reproduces global patterns. The second example shows results obtained from Hoti cave, located in Oman north of Qunf Cave. Expectedly, the wet period in Hoti Cave was shorter than in that in Qunf Cave. The stalagmite grew only between 9,800 and 6,200 years B.P (fig. 4 and 6). The very exciting result of this sample was the very strong correlation of the ^{18}O signal with the ^{14}C signal recorded in tree rings. As the 14^{C} is meant to reflect the intensity of the activity of the sun (a stronger magnetic field corresponds to less 14C produced by cosmic rays), the good correlation suggested that the position of the northward shift of the ITCZ is controlled by the activity of the sun. This result delivered a strong argument that the even smaller variations of the sun may have a strong control on Earths climate. The third example shows stalagmites from two adjacent caves in Central Germany (fig. 7). Here we studied two samples from two different caves, some 50 km apart, which partly covered the same period of time. Stalagmite AH-1 grew between 6 and 1 kyr before present, Stalagmite B7 between 4,000 years and present. Similar to the stalagmite from Oman we again found a good relationship of the ^{18}O signal (representing the amount of precipitation) and ^{14}C (the sun) in both samples. As mentioned above we interpret the heavier isotopic signal in the stalagmites as a proxy for less precipitation. However, opposite to Oman, where the precipitation mainly reflects the intensity of the Summer monsoon, the precipitation in Central Europe which recharges ground water consists mainly of Winter precipitation (the balance between the precipitation and soil transpiration in Europe is negative in Summer, a

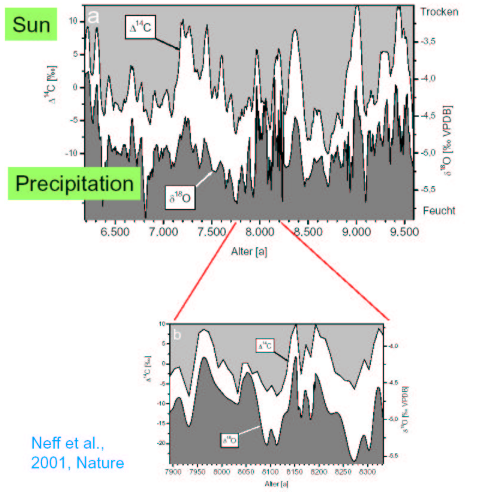

Fig. 6. In Hoti cave we observe a relationship between ^{18}O (precipitation) and the intensity of the Sun ^{14}C

well known fact to hydrologists). The relationship between ^{14}C and ^{18}O in the stalagmites therefore suggest a strong control of the sun on the Winter precipitation. Meteorologists tell us that at present the amount of Winter precipitation in Central Europe is strongly related to the intensity of the NAO (North Atlantic Oscillation). A relationship between the intensity of the NAO and the sun has also been suggested by Kodera et al. From our findings in the stalagmites we then may speculate that the observed correlation between precipitation and ^{14}C reveals a possible link between the NAO and the sun also in the past. The fourth example (fig. 8) deals with a Holocene stalagmite from Spannagel Cave located in 2,500 m altitude. This stalagmite has an unusually high uranium content. Even the youngest samples can be dated very precisely. We ascribe the observed variability in the profile of stable isotopes to variations of climate in the past 2,000 years. As kinetic effects are negligible (which we conclude from the missing correlation between ^{18}O and ^{13}C in this sample) we ascribe the variability of ^{18}O to variations of temperature. We derive a calibration curve (^{18}O against temperature) applying the temperature data for the last 500 years for the Alps derived by Luterbacher and applying this transfer function we then determine the temperature in the Alps during the past 2,000 years. These data allow several interesting conclusions: 1) During the Medieval warm Period we observe periods lasting between 20-50 years with temperatures higher then the average during the last 2,000 years. 2) We observe a high correlation between ^{18}O and ^{14}C. 3) Our temperature reconstruction compares rather well with the curve describing the advance and retreat of glaciers in the Alps. Agreement is also found to the reconstruction by Moberg et al., where eleven low frequency temperature records from the N. Hemisphere were stacked to deliver a temperature curve for the last 2,000 years.

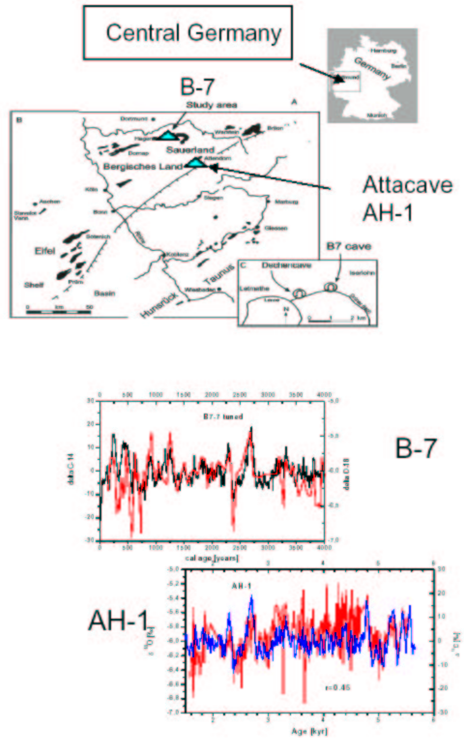

Fig. 7. Location and results in stalagmites from Central Germany.

2. Summary and conclusions

Concluding, our stalagmite archives suggest larger climate variability in the Holocene, as well as a strong influence of the sun on Earths

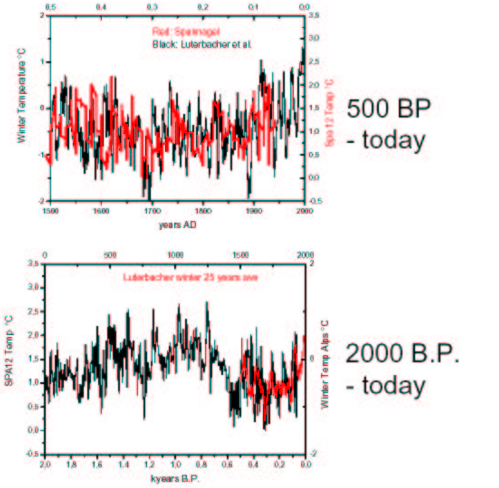

Fig. 8. Temperature derived from the ^{18}O record of Stalagmite SPA 12 from Spannagel Cave, in the Central Alps at 2500 m a.s.l. during the last 2000 years and comparison with historical records for the last 500 years.

climate. These results contradict the temperature reconstruction for the past 2,000 years described in the IPCC report. The reason for the possible influence of the sun on Earth's climate is still a matter of debate.

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