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CLIMATIC EVENTS IN THE EASTERN MEDITERRANEAN
REGION: UNRAVELING THE COMPLEX STABLE ISOTOPE
RECORD OF KARSTIC CAVE DEPOSITS

Miryam Bar-Matthews and Avner Ayalon

Final report for the time period October 1995- September 1998
Submitted to the Israel Science Foundation

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**CLIMATIC EVENTS IN THE EASTERN MEDITERRANEAN
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RECORD OF KARSTIC CAVE DEPOSITS**

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Final report for the time period October 1995 - September 1998

Abstract

The $\delta^{18}\text{O}$ variations in present-day speleothems reflect changes in the average annual temperatures, in the isotopic composition of cave water, which are directly related to those of the rainfall and the rainfall amount. Most of the rainwater originates in the Atlantic Ocean and they pass over the Mediterranean Sea. The average $\delta^{18}\text{O}$ of rainwater is $\sim -6.5\text{‰}$ (SMOW), those of the cave water $\sim -5\text{‰}$ to -5.5‰ and the temperature of speleothems deposition is 18 to 20°C . Thus, the average $\delta^{18}\text{O}$ of most present day speleothems is about -5.5‰ . The $\delta^{13}\text{C}$ values of the speleothems depend on the vegetation cover, and water-soil-rock interactions. In most present-day speleothems $\delta^{13}\text{C}$ values are -12 to -11‰ , as a result of equilibrium reactions between dolomitic host-rocks and soil- CO_2 .

The climate in the Eastern Mediterranean region of the last 180 Ky was determined by high-resolution studies of oxygen and carbon isotopic composition of about 4,000 samples from 25 different speleothems from various locations within the Soreq cave. The chronology was provided by 102 alpha ages and 78 precise ^{230}Th -U TIMS ages. The interpretation of the isotopic record was strongly influenced by our understanding of the present-day isotopic system. To reconstruct the past climate we have used a model that relates the isotopic composition of speleothems to that of the rain, to the annual rainfall amount and to the average annual temperature.

The $\delta^{18}\text{O}$ record from the Soreq Cave speleothems can be correlated with regional and global records, indicating that they are a powerful climatic indicators of the Eastern Mediterranean climate. The maximum $\delta^{18}\text{O}$ values (about -2.5‰) of the speleothems occur at time of extreme cooling and sharp decrease in the annual rainfall. Higher $\delta^{18}\text{O}$ values occur during warming and an increase in precipitation. The transition from the end of the glacial to the peak of an interglacial period (from 140 to 120, and from 17 to 10 Ky), are associated with the sharpest decrease in $\delta^{18}\text{O}$ (~ -4 to 6‰), and sharp changes in $\delta^{13}\text{C}$. These are due to a sharp increase in the temperatures, annual precipitation and changes in the vegetation and weathering processes.

D/H measurements of fluid inclusions in the speleothems seem to indicate that important paleoclimate information can be obtained and that generally low evaporation processes took place above the Mediterranean Sea during glacial periods relative to present-day.

List of Publications

I. Reviewed papers

1. *Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1997).
Late Quaternary paleoclimate in the eastern Mediterranean region from stable isotope analysis of speleothems at Soreq Cave, Israel.
Quaternary Research, 47, 155- 168.
2. Bar-Matthews, M. and Ayalon, A. (1997)
Stalactites "chatter" about the weather.
Kimat 2000, 16; 22-25
3. Halicz, L., Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1998).
Determination of low concentrations of U and Th in Carbonate Rocks Using FI-ICP-MS.
Atomic Spectroscopy, 18, 175-179
4. Ayalon, A., Bar-Matthews, M., and Sass E. (1998).
Rainfall-recharge relationships within a karstic terrain in the Eastern Mediterranean semi-arid region, Israel: $\delta^{18}\text{O}$ and δD characteristics.
Journal of Hydrology, 207, 18-31.
5. Kaufman, A., Wasserburg, G.J., Porcelli, D., Bar-Matthews, M., Ayalon, A. and Halicz, L. (1998).
U-Th isotope systematics from the Soreq Cave Israel and climatic correlations.
Earth and Planetary Science Letters, 156, 141-155.
6. Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1998)
Middle to Late Holocene (6500 years period) paleoclimate in the eastern Mediterranean region from stable isotopic composition of speleothems from Soreq Cave, Israel.
In: *Water, Environment and Society in times of Climate Change*, (A.S. Issar and N. Brown, eds.), Kluwer Academic Publishers, B.V., the Netherlands. pp.203-214.
7. Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1998).
Paleoclimate evolution in the eastern Mediterranean region during the last 58,000 yr as derived from stable isotopes of speleothems (Soreq Cave, Israel).
Proceedings of an International Symposium on Isotopes Techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and the Atmosphere organized by the Inter. Atomic Energy Agency, Vienna IAEA-SM-349/17, 673-682.
8. Bar-Matthews, M., Ayalon, A., Kaufman, A. and Wasserburg, G.J. (1998).
The Eastern Mediterranean paleoclimate as a reflection of regional events: Soreq Cave, Israel.
Earth and Planetary Science Letters, ("in press")
9. Bar-Matthews, M., Ayalon, A., and Kaufman A. (1998).
Timing and hydrological conditions of Sapropel events in the Eastern Mediterranean as evident from speleothems, Soreq cave, Israel.
Chemical Geology ("invited")
10. Ayalon, A., Bar-Matthews, M., and Kaufman A. (1998)

Petrography, strontium, barium and uranium concentrations, and strontium and uranium isotope ratios in speleothems as paleoclimate proxies: Soreq cave, Israel. *Holocene* ("invited")

II. Abstracts

11. *Ayalon, A., Bar-Matthews, M. and Kaufman, A. (1996).
Late Quaternary paleoclimate in the Eastern Mediterranean - stable isotope systematics of Soreq Cave speleothems.
Isr. Geol. Soc. Ann. Meeting, Eilat, p. 4.
12. *Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1996).
Late Quaternary paleoclimate derived from stable isotope systematics of speleothems Soreq Cave.
G. Friedman Conference, The Hebrew University of Jerusalem.
13. *Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1996).
Late Pleistocene - Holocene paleoclimate in the eastern Mediterranean as evident from stable isotope systematics of Soreq Cave speleothems.
Water, Environment and Society in Times of Climate Change (International Workshop), Ben-Gurion University of the Negev, Sede Boker, p. 13-14.
14. *Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1996).
Late Quaternary paleoclimate in the Eastern Mediterranean - stable isotope systematics of Soreq Cave speleothems.
Climate Change: The Karst Record, Karst Waters Inst. Spec. Pub. 2, University of Bergen, Norway.
15. *Ayalon, A., Bar-Matthews, M., Matthews, A. and Kaufman, A. (1996).
Carbon and oxygen isotope study of the active water - carbonate system in a karstic Mediterranean cave: implications for paleoclimate research in semi-arid regions.
Climate Change: The Karst Record, Karst Waters Inst. Spec. Pub. 2, University of Bergen, Norway.
16. Ayalon, A. and Bar-Matthews, M. (1997).
Rainfall - recharge relationships in the Eastern Mediterranean semi-arid regime.
In: *International Symposium on Isotope Techniques in the Study of Past and Current Environmental Changes in the Hydrosphere and the Atmosphere*.
Int. Atomic Energy Agency, Vienna, p. 124-125
17. Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1997).
Paleoclimate evolution in the eastern Mediterranean region during the last 58,000 yr as derived from stable isotopes of speleothems (Soreq Cave, Israel).
Environmental Changes in the Hydrosphere and the Atmosphere.
Inter. Atomic. Energy Agency, Vienna, p. 50-51
18. Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1997).
The paleoclimate evolution from the last glacial to the present in the Eastern Mediterranean as recorded by cave deposits.
Israel Soc. Prehistory, Ann. Meeting, Haifa University.
19. Bar-Matthews, M., Ayalon, A. and Kaufman, A. (1998).
Eastern Mediterranean paleoclimate during the last 60,000 years as derived from cave deposits.

Isr. Geol. Soc. Ann. Meeting, Mitzpe Ramon, p.10-11.

20. Ayalon, A. , Bar-Matthews, M. and Kaufman, A. (1998).
The transition from the last glacial maximum to the early Holocene in the Eastern Mediterranean region as recorded by cave deposits.
1st IGBP PAGES Open Science Meeting, University of London, UK, p.41.
21. Bar-Matthews, M. Ayalon, A. and Kaufman, A. (1998).
 $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ climate record of cave deposits during interglacial periods in the Eastern Mediterranean region.
1st IGBP PAGES Open Science Meeting, University of London, UK, p. 42.
22. Bar-Matthews, M. Ayalon, A., Kaufman, A. and Wasserburg G.J. (1998).
Mediterranean paleoclimate during the last 60 Ky as derived from speleothems, Soreq cave, Israel.
Mechanisms of Millennial Scale Global Climate Change, Chapman Conference, Snowbird Utah, p. 15
23. Bar-Matthews, M. Ayalon, A., Kaufman, A. and Wasserburg G.J. (1998).
Paleoclimate evolution of the Eastern Mediterranean region during the last 60,000 years: chemical and isotopic systematics of cave deposits (Soreq cave, Israel).
Mineralogical Magazine, Goldschmidt Conference 1998, Abstract Volume Part 1, p. 112-113.

Summary of Scientific achievements

In order to unravel the climate events in the Eastern Mediterranean region, we have studied the oxygen, carbon and hydrogen isotopic systematics of the present-day cave carbonate - cave water - rain water system, and the paleoclimate record covering the last 180,000 years as derived from fossil speleothems. Our study was in complete accordance with the work plan and time schedules described in the proposal.

The main goals of our research proposal were two related subjects:

(a) A stable isotopic study of the active (i.e., present-day) carbonate-water system in the Soreq cave and the derivation of limiting criteria for the use of fossil speleothems in the determination of paleoclimate in the eastern Mediterranean region.

(b) In the light of the data on the active system, a reconstruction of the Pleistocene to recent continental paleoclimate history of the eastern Mediterranean region through studies of the carbon, oxygen and hydrogen isotopic composition of low magnesium calcite speleothems and fluid inclusions of the Soreq cave speleothems, and the U-Th series determination of their ages using TIMS and alpha counting methods.

The active (i.e., present-day) carbonate-water system

The isotopic composition of water percolating into the Soreq Cave is related to the regime of rainwater composition, intensity and distribution, and to the mode of water incorporation and flow within the soil and upper vadose zone. The water in Soreq cave originates mainly from rain events associated with fronts passing over the Mediterranean Sea. This is evident from the δD - $\delta^{18}O$ relationship, which falls on the MMWL (Mediterranean Meteoric Water Line) with a slope of ~ 8 and d-excesses of 20 - 30 ‰ (Figure 1) (Pub. No. 4, 16).

The average $\delta^{18}O$ of the rainfall is $\sim -6.5\text{‰}$ during years when the rainfall amount is close to the mean annual value (500-550 mm). When the rainfall significantly deviates from the average, there is a negative correlation between the $\delta^{18}O$ values of rainwater and the amount of rainfall ("amount effect") (Figure 2) (Pub. No. 1, 4, 16).

During the migration of the rainwater through the upper vadose zone, some evaporation processes occur cause the $\delta^{18}O$ values of the cave water to be ~ 1.0 to 1.5‰ higher relative to the rainfall [Pub. No. 1, 4, 11, 15, 16].

Under present-day climatic conditions the cave water originates from the relative massive rainstorms (more than 20 mm). About $\sim 2/3$ of the annual rainfall is lost by evaporation processes. Negligible amounts of the water penetrate into the cave during the summer months (Pub. No. 4)..

The $\delta^{18}\text{O}$ of speleothem carbonate is affected by the isotopic composition of the cave water and the temperature at which the carbonate precipitates. At 18 to 20°C (the typical modern Soreq cave temperature range), the $\delta^{18}\text{O}$ of modern speleothem averages at around -5.4‰. Thus, the $\delta^{18}\text{O}$ variations in speleothems reflect changes in the average annual temperature and in the isotopic composition of cave water, which are directly related to those of the rainfall and the rainfall amount (Pub. No. 1, 8 and Bar-Matthews et al., 1996).

The $\delta^{13}\text{C}$ values of most present-day speleothems are -12 to -11 ‰, as a result of equilibrium reactions between dolomitic host-rock (0 to +2 ‰) and soil- CO_2 derived from C3 type vegetation (-27 to -24 ‰) (Pub. No. 1, 8 and Bar-Matthews et al., 1996). A few speleothems have higher $\delta^{13}\text{C}$ values due to fractionation accompanying CO_2 degassing and carbonate precipitation, or due to flooding (Pub. No. 1, 8, 9, 15, 21).

The reconstruction of the Pleistocene to recent continental paleoclimate history of the eastern Mediterranean region

Our work has shown that with the assumption that the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ variations in the past were controlled by similar physical factors as today, it becomes possible to use the isotopic variations to reconstruct the paleoclimate conditions of the eastern Mediterranean region (Pub. No. 1, 6, 7, 8, 9).

In order to determine a well dated isotopic profile from which we interpret the paleoclimate conditions in the past, we have developed for the U-Th dating by alpha and Thermal Ionization Mass spectrometry TIMS, a method to separate the detrital phases from the authigenic carbonate (Pub. No. 1, 5). We have shown that precise and reliable ^{230}Th ages maybe obtained using the TIMS method on speleothem samples that have low ^{232}Th contents or for those with high ^{232}Th contents after subtracting out the ^{230}Th which accompanied this ^{230}Th (Pub. No. 5).

In order to quickly select samples that are suitable for U-Th dating we have used the Flow Injection Inductively Coupled Plasma Mass Spectrometry (FI-ICP-MS) analytical

method. We have demonstrated that this method is the most suitable, accurate, and fast procedure for determining the U and Th concentrations in calcite samples in the range of 250 to 600 $\mu\text{g/kg}$ and 10 to 50 $\mu\text{g/kg}$, respectively. Although the FI-ICP-MS is not as precise and accurate as TIMS, it is a fast technique and sufficiently precise and accurate to analyze calcite samples, and thus this is the most appropriate method for the selection of speleothems for further TIMS dating analysis (Pub. No. 3).

The climate of the Eastern Mediterranean region of the last 180 Ky was determined by high resolution studies of the oxygen and carbon isotopic composition of ~4000 samples from 25 different speleothems, 60 to 250 mm in diameter, from various locations within the cave. The chronology was provided by 102 alpha ages determinations and 78 precise ^{230}Th - ^{234}U (TIMS) ages for which a continuous isotopic profile was determined (Pub. No. 1, 5, 6, 7, 8, 9, 10 and Figures 3 and 4).

The interpretation of the isotopic record was strongly influenced by our understanding of the present-day isotopic system and enabled us to reconstruct the paleoclimate conditions of the Eastern Mediterranean region by means of the model presented by Bar-Matthews et al 1997, 1999 (Pub. No. 1, 8), that relates the isotope composition of speleothems to that of the rain, the annual rainfall amount and the cave temperature.

The main results are:

- The Soreq cave speleothems are unique because they provide a very well dated continuous isotopic profile. Up to this stage of the research we have reconstructed an isotopic profile for the last 180 Ky.
- The isotopic record of the Soreq cave speleothems, located 40 Km inland from the Eastern Mediterranean Sea, is directly related to the isotopic composition of rain water that originates in the Atlantic Ocean and the Mediterranean Sea.
- The $\delta^{18}\text{O}$ record from the Soreq cave speleothems is similar to the isotopic record obtained from deep sea sediments and ice cores from the North Atlantic. This similarity indicates that Soreq Cave speleothems are powerful climatic indicators of the Eastern Mediterranean climate.

The major features of the isotopic profile of the Soreq Cave speleothems are divided into 6 major time periods, which are correlative with the marine isotopic stages one to six (Figure 3). The isotopic stages I and V occur during interglacial periods, isotopic stages III, IV and VI occur during glacial periods. The $\delta^{18}\text{O}$ values during glacial periods reach the maximum values of $\sim -2.5\text{‰}$, values that are $\sim 6\text{‰}$ less negative relative to the minimum

observed at 122 Ky (peak of the interglacial at stage V). Low amplitude $\delta^{18}\text{O}$ “oscillations” (less than 1.0‰) lasting for a few hundred years, and higher amplitude “oscillations” (of $\sim 3.0\text{‰}$) lasting for a longer time are typical to the glacial periods. $\delta^{18}\text{O}$ maxima, with the highest values up to $\sim -2.5\text{‰}$ occur at ~ 160 , 140, 46, 35, and 19 Ky, and fairly low values of ~ -4.5 , -5.5 , -5.0 , -6.5 and -6.0‰ occur at 36, 54, 74, 155 and 176 Ky, respectively. The maximum $\delta^{18}\text{O}$ values occur during periods of extreme cooling and sharp decrease in the annual rainfall, whereas higher $\delta^{18}\text{O}$ values occur during warming and an increase in precipitation (Pub. No. 1, 7, 8, 9). The transitions from the end of glacial to the peak of interglacial periods (from 140 to 122 Ky and from 17 to 10 Ky) are associated with the sharpest decrease in $\delta^{18}\text{O}$ and sharp changes in $\delta^{13}\text{C}$ (Figures 3 and 4). These are due to a sharp increase in the temperature, annual precipitation and changes in the vegetation and weathering processes (Pub. 10). The main peaks of enhanced hydrological activity in the region usually occurred during periods equivalent to interglacial, interstitial periods occurring at 124 to 120 Ky, 108 to 100 Ky, 85 to 80 Ky, and 8.5 to 7 Ky (Pub. No. 1, 8, 9), apart for the two major events between 175 to 176 Ky and 155 to 150 Ky that occurred during glacial period, i.e., isotopic stage VI (Figure 3). At ~ 6.5 Ky the climatic conditions became more similar to those of present-day. The isotopic oscillations during the last 6.5 Ky, and the correlation with archeological findings were summarized in Pub. No. 6.

We have correlated the isotopic events with regional and global climatic events, such as Heinrich events, Sapropel formations, Younger Dryas etc. (Pub No. 1, 6, 7, 8, 9).

D/H measurements of fluid inclusions in speleothems as a proxy for the $\delta^{18}\text{O}$ of paleowaters.

One of the aims of the research was to develop the use of D/H fluid inclusion measurements as a climate proxy. Although, technically it is possible to measure the $\delta^{18}\text{O}$ of fluid inclusions, such measurements are not considered reliable because of post-depositional oxygen isotope exchange between the water and the carbonate. Hydrogen on the other hand cannot exchange with carbonate and therefore the D/H composition of the fluid inclusion potentially retains a record of the depositional water. Combining D/H data of fossil fluid inclusions with knowledge of the relations between $\delta^{18}\text{O}$ and δD of waters, enables to estimate the oxygen isotope composition of the fossil water.

This study used a decrepitation method for extracting the fluid inclusions for D/H analysis, in which the speleothem samples were heated at high-temperature (ca 900°C) in a vacuum. This procedure is known to carry a δD fractionation between the water released by

decrepitation and the original fluid-inclusion water. The calibration of this fractionation was made by measurements of speleothem samples 5-9-33 and 5-7-33 which have grown during the present day from a Soreq Cave pools (Figure. 5). The average δD values in both pools are similar about $-16 \pm 3.0\text{‰}$. The δD value of the decrepitation water released from the speleothem growing in these pools is $-46.2 \pm 4.3\text{‰}$. Thus a fractionation of 30‰ is determined. This value is similar to the value suggested by Yonge (1982).

About 200 measurement of δD values of fossil speleothems were made, several grams of each sample were prepared, thus allowing replicate measurements (Each measurement require 100 mg of calcite). The samples were chosen to represent various age intervals but with minimal $\delta^{18}\text{O}$ scatter. The results for the eight fossil speleothems studied in this work are given in the table below:

<u>sample</u>	<u>No. of Analyses</u>	<u>$\delta^{18}\text{O}$ (‰PDB)</u>	<u>δD (‰SMOW)</u>	<u>age (Ky)</u>
2-Z	11	-5.25 ± 0.1	-22.5 ± 4.6	3.2 to 3.7
7-23B	12	-2.83 ± 0.26	-25.2 ± 5.2	19.0 to 21.0
7-23A	7	-3.29 ± 0.26	-15.7 ± 3.1	18.5 to 19.0
12-ZBC	13	-3.17 ± 0.33	-11.8 ± 4.2	19.0 to 22.5
11-23C	11	-3.97 ± 0.1	-18.0 ± 4.7	73.5 to 74.0
11-27D	3	-4.51 ± 0.16	-23.0 ± 3.7	75.0 to 78.0
11-27E,F	4	-4.66 ± 0.54	-24.3 ± 3.1	96 to 100
3-35A	11	-6.96 ± 0.22	-35.9 ± 5.4	106 to 107.5

In order to determine the cave δD - $\delta^{18}\text{O}$ relationship, we calculated the $\delta^{18}\text{O}$ of the cave water from the $\delta^{18}\text{O}$ of the speleothems, assuming temperature for each time period ($10\text{--}14^\circ\text{C}$ for the glacial, $16\text{--}20^\circ\text{C}$ for the interglacial period), based on various independent data as described in Pub. No. 1. The results of these calculations are presented in the following table.

<u>sample</u>	<u>$\delta^{18}\text{O}$</u>	<u>assumed T°C</u>	<u>calculated $\delta^{18}\text{O}_w$ (‰SMOW)</u>
2-Z	-5.25	18	-4.49
	-5.25	20	-4.04
7-23B	-2.83	10	-3.88
		12	-3.40
		14	-2.92
7-23A	-3.29	10	-3.87
		12	-3.39
		14	-2.93
12-ZBC	-3.17	10	-4.23
		12	-3.75
		14	-3.27
11-23C	-3.97	16	-3.63
		18	-3.17
		20	-2.72
11-27D	-4.51	16	-4.19
		18	-3.73
		20	-3.28
11-27E,F	-4.66	16	-4.34
		18	-3.88
		20	-3.43
3-35A	-6.96	16	-6.72
		18	-6.26
		20	-5.81

Plotting the results on a $\delta^{18}\text{O}$ vs. δD diagram (Figure 5) shows that only the present-day speleothems (5-7 and 5-9) sample 12-Z and 3-35 fall close to the Mediterranean Meteoric Water Line (MMWL) similar to the present-day waters. All the other samples fall either between the MMWL and the Meteoric Water Line (MWL), on, or below the MWL. These differences may suggest generally lower evaporation processes above the Mediterranean Sea relative to present-day.

The work on the D/H proxy method therefore seems to indicate that important paleoclimate information can be obtained provided careful analytical protocols are observed.

During the research we have presented the results in number of international scientific meeting as evident from the number of abstracts (Pub. No. 11 to 23). The results of the study were cited in number of international papers, but also in the local and international news magazine (such as Jerusalem Post (June, 97); Maariv, (August, 1997); Yediot

(August, 1997); Masa Aher (September, 1997); Science Tips (June, 1997); Sciences Avenir (September, 1997); Pages (August 1997). We also have published our results in a Scientific Journal Kimaat 2000 dedicated for the youth (Pub. No. 2).

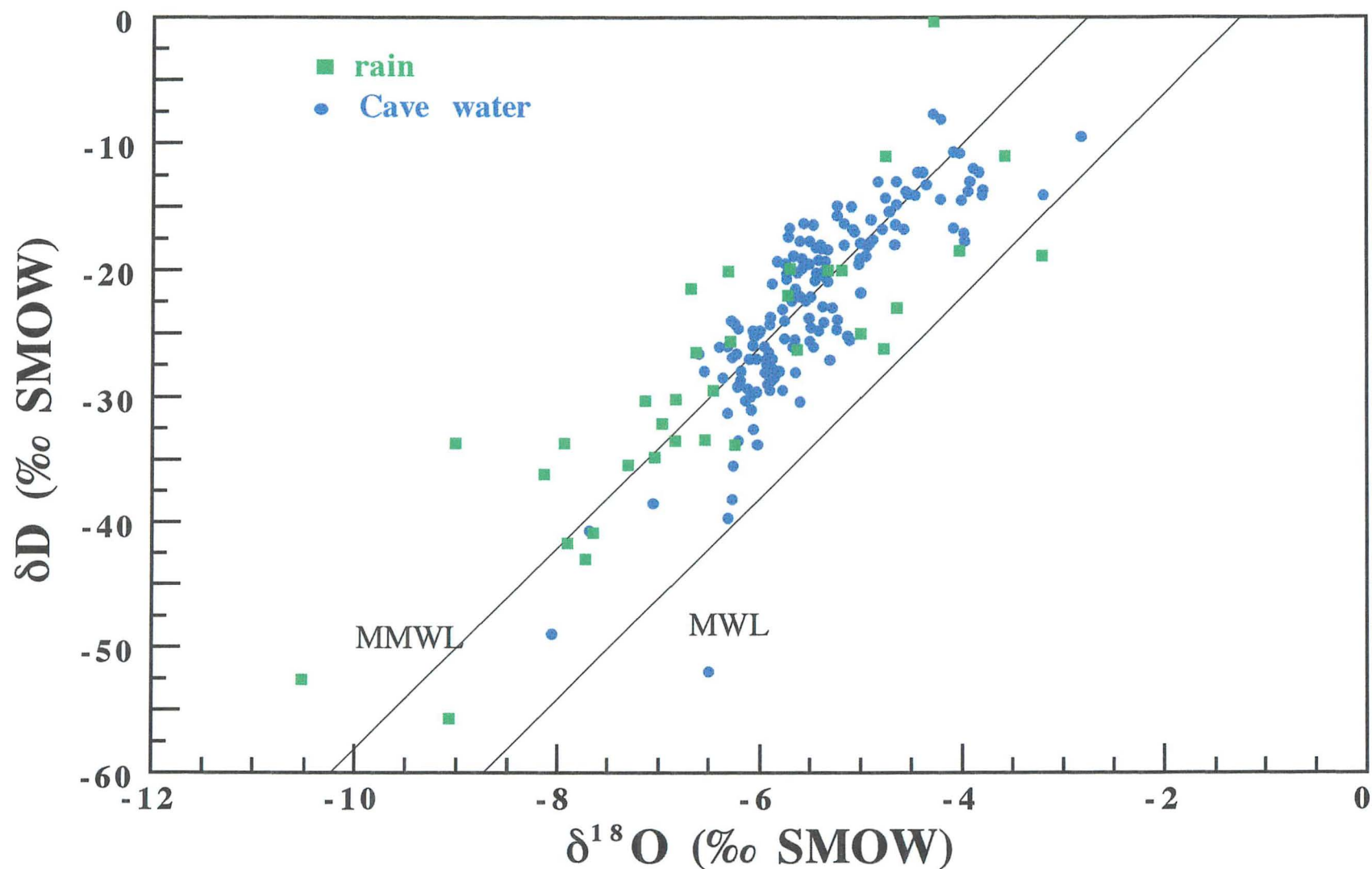


Fig. 1. $\delta^{18}\text{O}$ vs. δD of the rain and infiltrating water - Soreq Cave. Also shown are the Meteoric Water Line (MWL) and the Mediterranean Meteoric Water Line (MMWL)

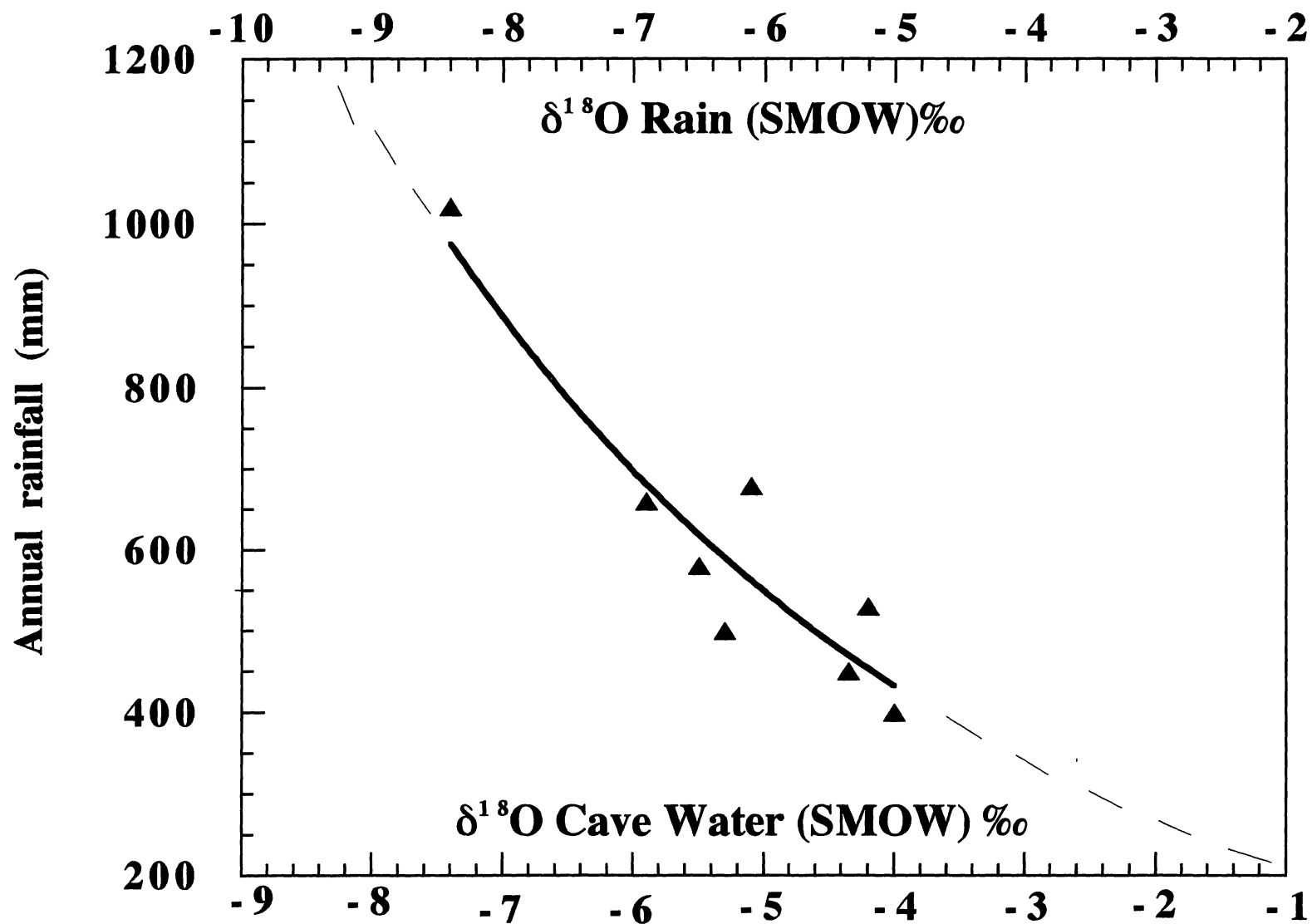


Fig. 2. The relationship between $\delta^{18}\text{O}$ values of rain and of Soreq cave water vs. the annual rainfall. The relation has a negative slope in which $\delta^{18}\text{O}$ of the cave water increases with a decrease in rainfall.

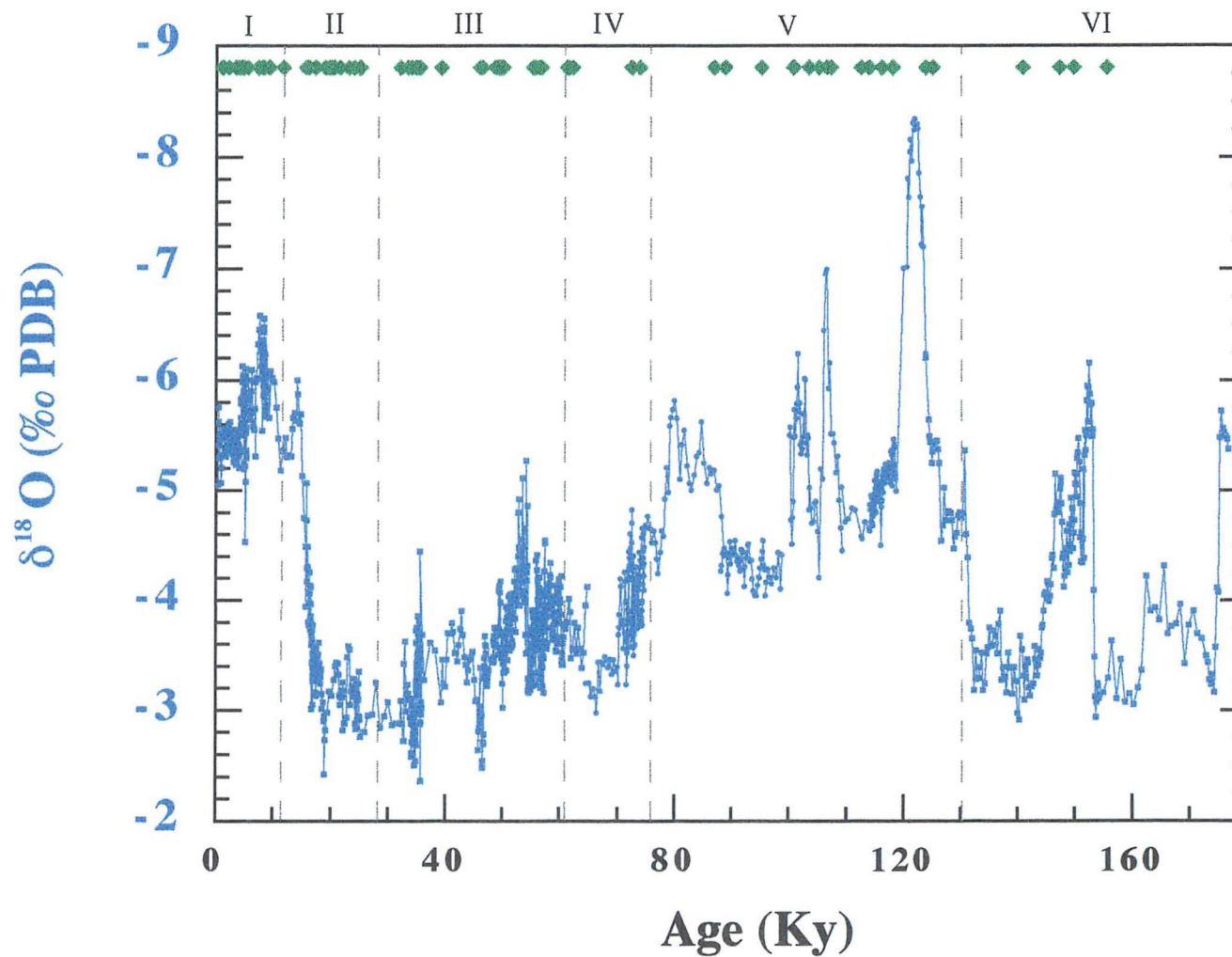


Fig. 3. $\delta^{18}\text{O}$ values of Soreq cave speleothems deposited during the last 180 Ky. The marine isotopic stages I to VI are divided by vertical lines. TIMS ages are indicated in green at the top of the diagram.

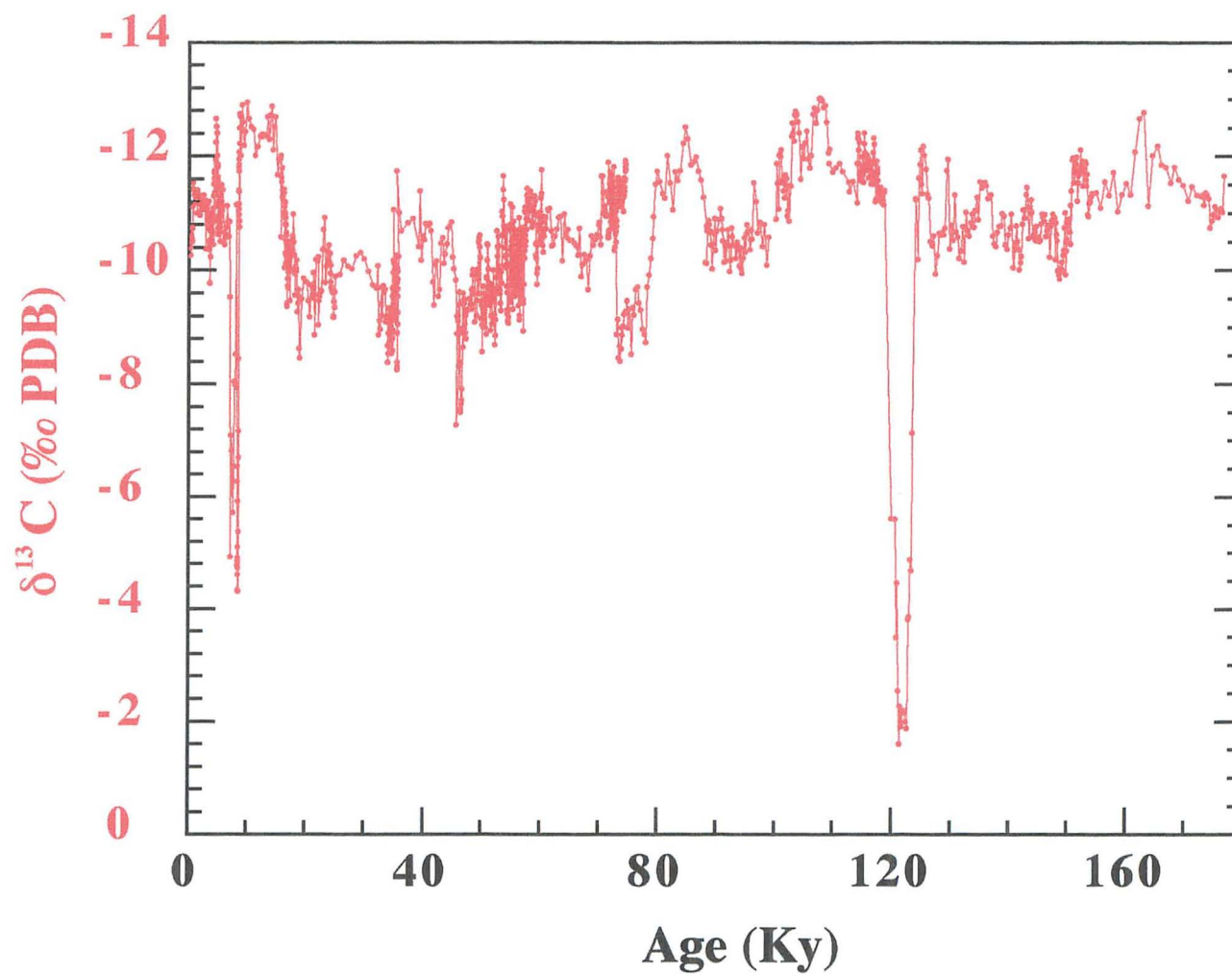


Fig. 4. $\delta^{13}\text{C}$ values of Soreq cave speleothems deposited during the last 180 Ky.

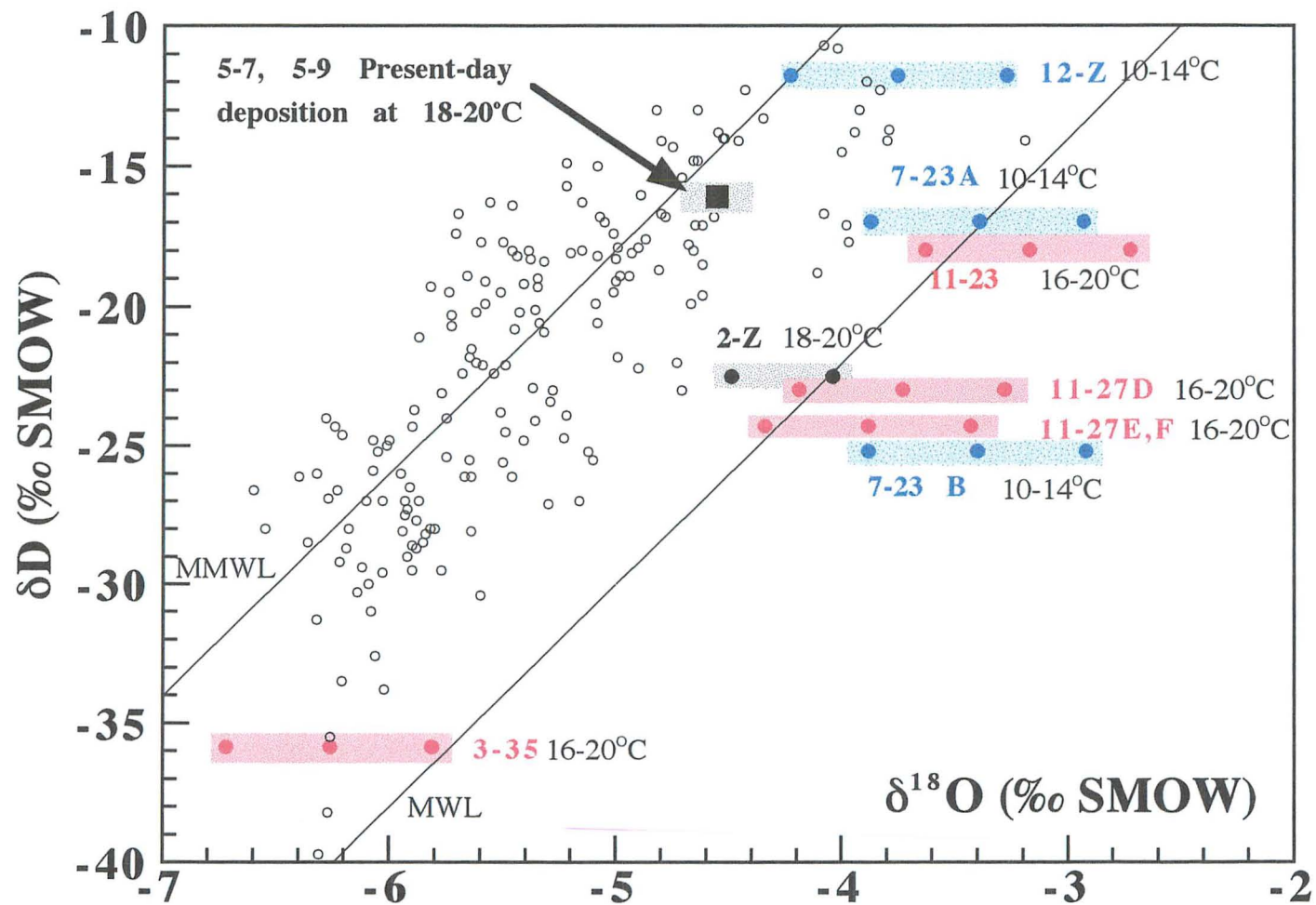


Fig. 5. δD vs $\delta^{18}O$ of cave water (open circles), and of fluid inclusions of present-day and fossil speleothems deposited during interglacial (red) and glacial periods (blue)

