Seasonal climate change as revealed by ion microprobe analysis of $\delta^{18}O$ in a Soreq Cave (Israel) speleothem

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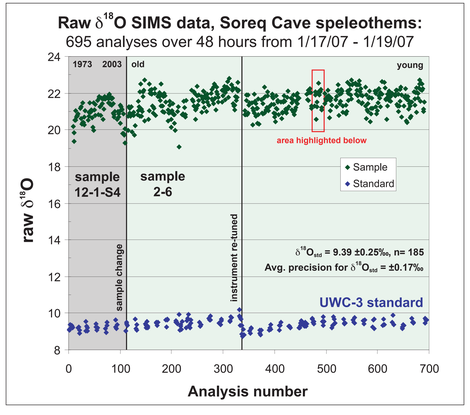
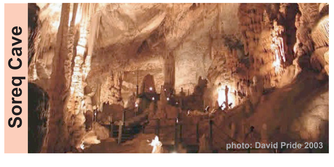
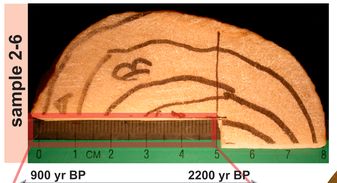
Hypothesis: High resolution analysis of $\delta^{18}O$ along the growth axis of a speleothem (cave deposit) by a CAMECA 1280 Ion Microprobe (SIMS) will reveal sub-annual climate variation.

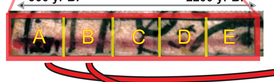
Sample characteristics: The sample, with a U-series age of 2200 - 900 BP, is a drip-formed stalagmite from Soreq Cave composed of low-magnesium calcite with no evidence of aragonite inclusions.

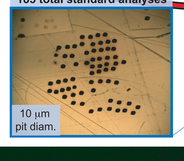
Experimental Set-Up: Portions of the speleothem were mounted in 3 epoxy plugs and imaged using optical, laser confocal, and SEM microscopy before being analyzed for $\delta^{18}O$ and $\delta^{13}C$ by SIMS. This process is outlined below. The raw data from the SIMS analysis are shown at right; note the stability of the standard calcite (UWC-3) analyses. Although the data were essentially analyzed in chronological order, compiling their spatial distribution will further illuminate any trends.

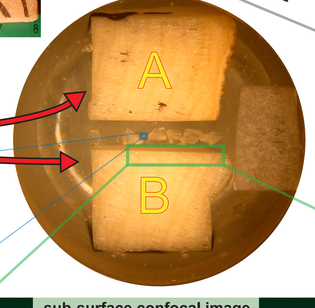












$\delta^{18}O$ correlates to growth bands:

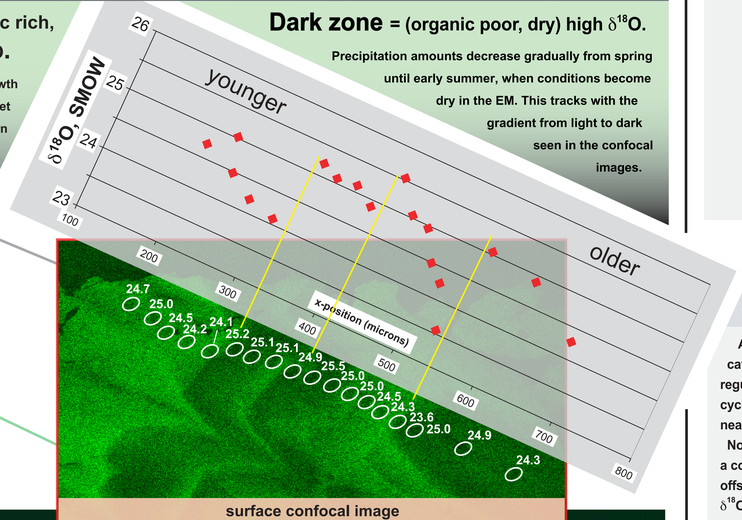
Does the pattern of light and dark zones represent an annual cycle?

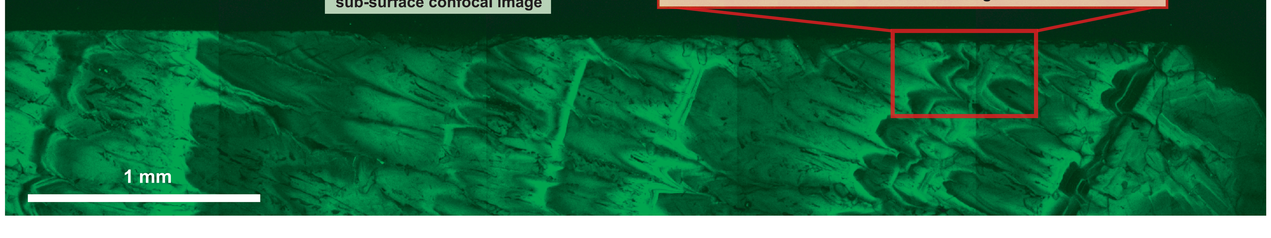
Light zone = (organic rich, wet season) low $\delta^{18}O$.

The sudden appearance of this growth band may represent the arrival of wet season rain storms in the eastern Mediterranean (EM) region.

Dark zone = (organic poor, dry) high $\delta^{18}O$.

Precipitation amounts decrease gradually from spring until early summer, when conditions become dry in the EM. This tracks with the gradient from light to dark seen in the confocal images.



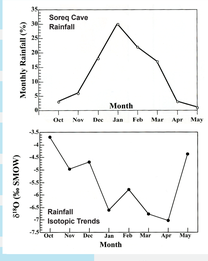


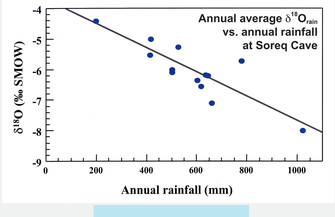
Isotopic characteristics of rainfall at Soreq Cave

graphs courtesy of: Ayalon et al., 2004

The modern climate above Soreq Cave is strongly seasonal. Precipitation increases from 0 mm during the summer months to as much as 300 mm/month between December and March (adjacent fig.) [1, 2]. This period of intense rainstorms delivers low $\delta^{18}O$ water to the groundwater system above Soreq Cave. Thus, we should expect to see a negative pulse in the $\delta^{18}O$ of speleothem growth that occured during the rainy season.

The plot below shows the weighted annual average $\delta^{18}O_{rain}$ versus precipitation amount for the years 1990-2003 above Soreq Cave [2]. Note that evaporation and temperature effects will raise the $\delta^{18}O$ of the groundwater at the end of the annual wet season, causing an increase in $\delta^{18}O_{speleothem}$.

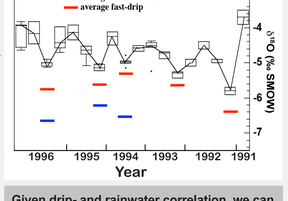




Isotopic characteristics of dripwater in Soreq Cave

As a result of the seasonal variability of rainfall above the cave, the $\delta^{18}O$ of dripwaters collected from within Soreq varies regularly through time [1]. The figure below shows the annual cyclicity of this pattern, with the lowest $\delta^{18}O$ values occuring near the beginning of each year, when the wet season begins.

Note that there is a consistent ~1‰ offset between the $\delta^{18}O$ of the average annual rainfall (in blue) and the average "fast-drip" waters (red) that are observed at the onset of each wet season.



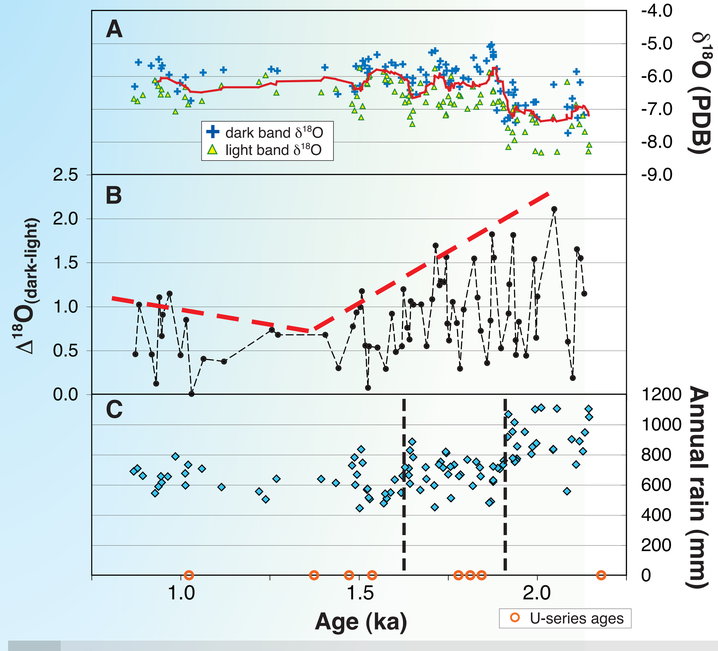
graph courtesy of: Ayalon et al., 1998

Given drip- and rainwater correlation, we can study past climate using $\delta^{18}O_{speleothem}$ data.

References: [1] Ayalon, A., Bar-Matthews, M., and Sass, E., (1998). *J. Hydro.* **207**, 18-31. [2] Ayalon, A., Bar-Matthews, M., and Schilman, B., (2004). *GSI Reports* **GSI/16/04**.

High resolution paleoclimate proxy

Climate deterioration in the Eastern Mediterranean from 2.2 - 0.9 ka: A seasonal record



A $\delta^{18}O$ of wet and dry season growth (lightest and darkest fluorescing calcite from same layer). **The increase in $\delta^{18}O$ through time indicates a drying climate in the region.**

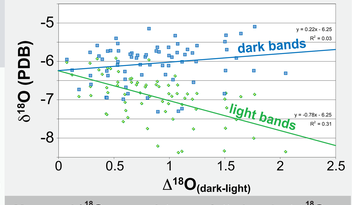
B $\Delta^{18}O = \delta^{18}O_{dark\ calcite} - \delta^{18}O_{light\ calcite}$ within a single annual band. **A decrease in amplitude of $\Delta^{18}O$ indicates drier summers.**

C Estimates of annual precipitation based on $\delta^{18}O$ values of wet season growth. **Dashed lines indicate large drops in max. annual rainfall at AD ~100 and 400.**

Record of vadose zone mixing characteristics

Dark band $\delta^{18}O$ values are relatively constant across the full range of observed $\Delta^{18}O$ values, suggesting that the vadose zone $\delta^{18}O$ values remained similar through time, whether during wet or dry periods.

It follows that light band $\delta^{18}O$ values are the lowest when $\Delta^{18}O$ is maximized during wet years. This pattern reflects the mixing relationship - driven by wet season rains - observed in modern drip waters.



Measured $\delta^{18}O_{speleothem}$ data are plotted against $\Delta^{18}O$ values, showing a relative homogeneity of $\delta^{18}O_{dark\ calcite}$.