Quantitative Annual Speleothem Records of Temperature, Precipitation and Solar Insolation in the Past – A Key for Characterization of Past Climatic Systems

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ABSTRACT. We studied the luminescence of speleothems from Cold Water Cave, Iowa, USA, and Rats Nest Cave, Alberta, Canada. A reconstruction of the past annual precipitation rates for the last 280 years for Kananaskis country, Alberta, Canada has been obtained from speleothem annual growth rates.
Depending on the soil surface exposition, we measured either solar-sensitive or temperature-sensitive paleoluminescence speleothem records:
- In the case of Cold Water Cave, Iowa, USA, we obtained high correlation coefficient of 0.9 between the luminescence record and Solar Luminosity Sunspot index and reconstructed sunspot numbers since AD 1000 with a precision within the experimental error of their measurements;
- in the case of Rats Nest Cave, Alberta, Canada, a correlation coefficient of 0.67 was obtained between luminescence intensity and air temperature record for the last 100 years and reconstructed annual air temperatures for the last 280 years at the cave site with the estimated error of 0.35 °C, while the error of the direct measurements is 0.1 °C.

KEY WORDS: past climate and solar insolation, annual records.

Introduction

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

Methods and material studied

Speleothem growth rate variations represent mainly rainfall variations (Shopov et al., 1992, 1994). Speleothem luminescence visualizes annual microbanding (Shopov et al., 1991). We used it to derive proxy record of annual precipitation at the cave site by measuring the distance between all adjacent annual maxima of the intensity of luminescence. The resultant growth rates correlate with the actual annual precipitation (summed from August to August). We studied the top of a 35 mm long stalagmite from Rats Nest Cave (RNC), Alberta, Canada to obtain quantitative record of annual temperature and precipitation. For this purpose we obtained a stacked paleotemperature record of 66,000 data points from Rats Nest Cave, Kananaskis karst region, Alberta, Canada. This covers the last 1450 years with an average resolution of about 8 days. Paleoclimatic record was derived from speleothem luminescence, calibrated by actual climatic records from the near climatic station in Banff, Alberta. The sample was dated by two 14-C dates, TIMS U/Th dating, autocalibration and annual bands counting dating. All produced a consistent age, best estimated at 1450 ± 80 years. The 14-C data were corrected for "dead" carbon, by its measurement in modern speleothem calcite.

Results and analyses

We obtained a high correlation coefficient of 0.9 between the luminescence record from Cold Water Cave, Iowa, USA, and Solar Luminosity Sunspot index (Fig. 1) and the reconstructed sunspot numbers since AD 1000 with a precision within the experimental error of their measurements. This luminescence record is a part of a 7075 ± 295 years record well dated by five U/Th TIMS dates (Shopov et al., 1994).

A reconstruction of the past annual temperature for the last 280 years was obtained from average annual speleothem luminescence intensity calculated from the 66,000 px record, calibrated by actual temperature record from the near climatic station in Banff, Alberta, Canada. We obtained reasonably good correlation (correlation coefficient of 0.68) between the annual temperature for the last 105 years (recorded at the closest weather station - Banff, located in the same valley, 50 km north of the cave) and the average annual speleothem luminescence intensity (Fig. 2). We used the obtained regression coefficients to reconstruct annual temperature for the last 280 years at the cave site (Fig. 3). The estimated statistical error is 0.35 °C. Intensity of luminescence was not dependent on actual precipitations and sunspot numbers (zero correlation).

Speleothem growth-rate variations represent mainly rainfall variations. A reconstruction of the past annual precipitation rates for the last 280 years was obtained from speleothem annual growth rates, derived from the distance between annual speleothem luminescence bands, calibrated by actual precipitation record from the near climatic station in Banff, Alberta, Canada. We obtained a reasonably good correlation (correla-

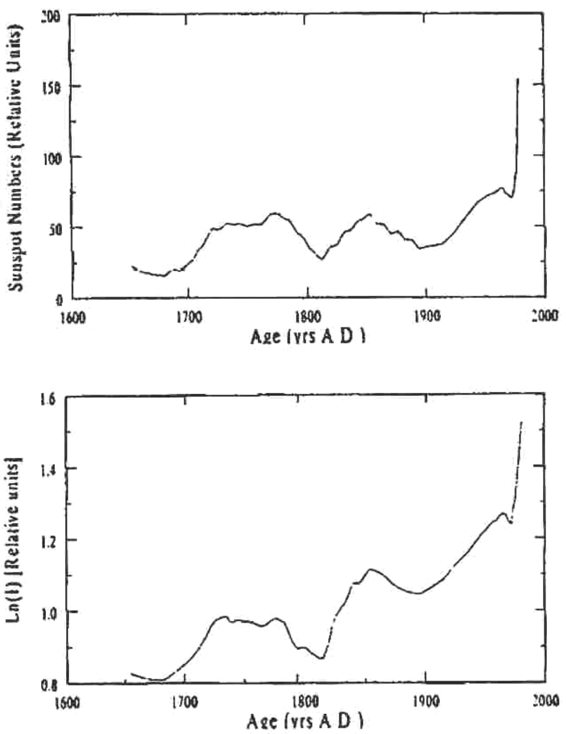

Fig. 1. (Top) A twenty-year average sunspot record since AD 1700, (bottom) Optical density of luminescence of a speleothem from Coldwater Cave, Iowa (USA).

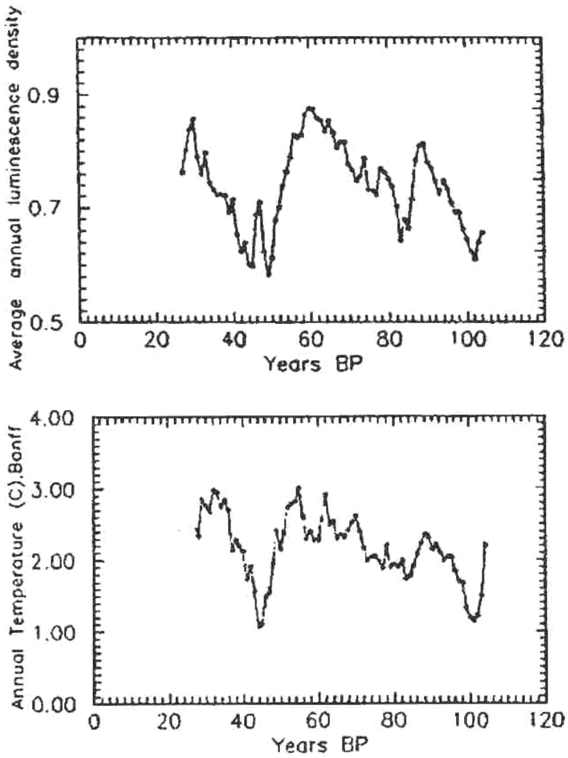

Fig. 2. (Top) Average annual luminescence density of a speleothem from Rats Nest Cave (Canada), (bottom) Annual temperature, Banff, Alberta (Canada).

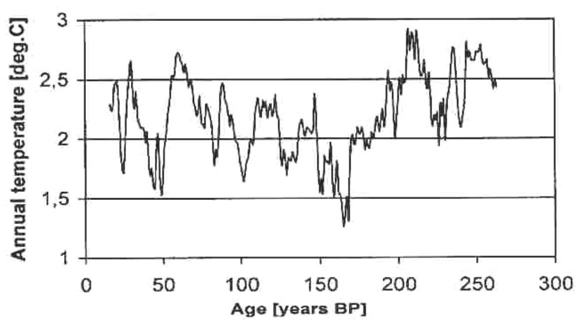

Fig. 3. Annual temperature in the last 280 years for Kananaskis country, Alberta, Canada derived from annual intensity of luminescence of a stalagmite from Rats Nest Cave, Alberta, Canada.

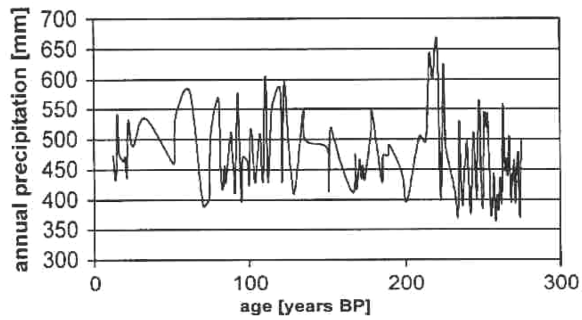

Fig. 4. Annual precipitation (from August to August) in the last 280 years for Kananaskis country, Alberta, Canada, derived from annual growth rate of a stalagmite from Rats Nest Cave, Alberta, Canada.

tion coefficient of 0.57) between the annual precipitations (from Banff, Alberta) and the annual growth rate of the speleothem. We used the obtained regression coefficients to reconstruct annual precipitations for the last 280 years at the cave site (Fig. 4). The estimated statistical error is 80 mm/year. Annual speleothem growth rate was independent of the intensity of luminescence, of annual temperature and of solar luminosity for the same time span (zero correlation).

Speleothem luminescence visualizes annual microbanding, which we used to derive proxy records of annual precipitations for the cave site. Annual luminescence microbanding was used very successfully for relative and absolute dating of speleothems by Autocalibration dating. This dating method appeared to be more precise than the TAMS ^{14}C and AMS U/Th data for relative dating of short time intervals and the only dating method for speleothems with little uranium, younger than 2000 years.

Conclusions

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

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Influence of Solar Luminosity Variation on Glaciations and their Significance for Time Shifting of Termination-II

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ABSTRACT. Calcite speleothems luminescence depends exponentially upon soil temperatures that are determined primarily by solar visible and infrared radiation. Microzoning of the luminescence of speleothems is therefore used as an indirect Solar Insolation (SI) proxy index.

We measured a luminescent solar insolation proxy record in speleothem (JC11) from Jewel Cave, South Dakota. This record was dated by six TIMS U/Th dates with 2 sigma error of 0.8–5.5 ka. It covers 89,300-138,600 years BP with high resolution (34 years) and precision of measurements better than 1%. It reveals determination of millennial and century cycles in the record. This record exhibits a very rapid increase in solar insolation at 139 ± 5.5 ka (2 sigma error) responsible for the termination II. This increase precedes the one suggested by the orbital theory with about 10 ka and is due to the most powerful cycle of the solar luminosity with duration of 11.5 ka superposed on the orbital variations curve. Solar luminosity variations appear to be as powerful as orbital variations of solar insolation and can produce climatic variations with intensity comparable to that of the orbital variations.

KEY WORDS: speleothem luminescence, solar insolation, orbital variations.

Introduction

M. Milankovitch demonstrated that orbital variations of the Earth's orbit cause significant variations of the amount of solar radiation received by the Earth's surface (solar insolation - SI). Scientists believe that glacial periods (ice ages) result from such variations.

Recent measurements of cave deposits from Devils Hole (DH), USA, which is the best dated paleoclimatic record, demonstrated that the end of the former glaciation (Termination II) came 10,000 year earlier than suggested by the orbital theory.

So far, there was no quantitative proxy record able to demonstrate how big the variations of solar luminosity were in geological time scales.

Methods and material studied

Calcite speleothems (stalagmites etc.) usually display luminescence which is produced by calcium salts of humic and fulvic acids derived from soils above the cave. These acids are released by the decomposition of humic matter. Rates of decomposition depend exponentially upon soil surface temperatures that are determined primarily by solar infrared radiation. So the microzoning of the luminescence of speleothems can be used as an indirect Solar Activity (SA) index (Shopov, 1987).

Time series of the SA index "Microzoning of Luminescence of Speleothems" are obtained by Laser Luminescence Microzonal Analysis (LLMZA) of cave flowstones (Shopov, 1987). LLMZA allows measurement of luminescence time series with duration of hundreds of thousands years.

Results and analyses

Jewel Cave, South Dakota, USA (Shopov et al., 1998; Stoykova et al., 1998). This record covers the interval of 89,300–138,600 years BP (Fig. 1b) with high resolution (34 years) and precision of measurements better than 1%. It reveals determination of millennial and century cycles in the record.

We extracted orbital variations from the JC11 record by a band-pass Tukey filter set for frequencies of 41, 23 and 19 ka. So the remaining signal contains only SL self-variations. The most powerful cycle in this record with a period of 11.5 ka