Quantitative Annual Speleothem Records of Temperature and Precipitation in the Past – A new tool for Reconstruction of past karst denudation rates

Yavor Y. SHOPOV 1**; Ludmil T. TSANKOV** 1**; Leonid N. GEORGIEV** 1**; Elena MARINOVA** 1**; Derek C. FORD** 2**; Chas J. YONGE** 3

1 - Faculty of Physics, University of Sofia, James Baucher 5, Sofia 1126, Bulgaria.
e-mail: yyshopov@phys.uni-sofia.bg
2 - Geography Dept., McMaster University, Hamilton, Ontario, L8S 1K4, Canada.
3 - Dept. of Physics, University of Calgary, Calgary, Alberta, Canada.

Abstract

Calcite speleothem 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" paleoluminescence speleothem records like in tree ring records, but in our case record may depend either only on temperature or on solar irradiation (SHOPOV et. all, 1996 a,b).

In case of Rats Nest cave, Alberta, Canada we reconstructed annual air temperatures for last 1450 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. For this purpose we obtained a stacked 66000 data points paleotemperature record from Rats Nest cave, Kananaskis karst region, Alberta, Canada. It covers last 1450 yrs with resolution of about 8 days for most of the time span. Paleoclimatic records has been derived from speleothem luminescence, calibrated by actual climatic records from near climatic station in Banff, Alberta. The sample was dated by two14-C dates, U/Th dating, autocalibration and annual bands counting dating. All produced consistent age, best estimated as 1450 +/- 80 years.

A reconstruction of the past annual precipitation rates for the last 280 years has been obtained from speleothem annual growth rates, derived from the distance between annual luminescence bands, calibrated by actual precipitation record from near climatic station in Banff, Alberta, Canada

We demonstrated the potential of the quantitative theory of solubility of karst rocks (SHOPOV et. al, 1989,1991a) in dependence of the temperature and other thermodynamic parameters to make reconstructions of past carbonate denudation rates.

Obtained data are important for estimations of the significance of the contribution of karst denudation to global CO_2 amount and cycle.

Introduction

Speleothem growth rate variations represent mainly rainfall variations (SHOPOV et al.1992, 1994). Speleothem luminescence visualises annual microbanding (SHOPOV et al. 1991b). We used it to derive proxy records of annual precipitation around 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).

Results and Analyses

We studied the top of a 35 mm long stalagmite from Rats Nest cave (RNC), Alberta, Canada. We measured a stacked 66000 data points luminescent record from Rats Nest cave, Kananaskis karst region, Alberta, Canada. It covers last 1450 yrs with resolution of about 8 days for most of the time span (SHOPOV, et al., 1998). Paleoclimatic records has been derived from speleothem luminescence by calculation of average annual intensity of luminescence and measurement of annual growth rate values.

Obtained annual records has been calibrated by actual climatic records from near climatic station in Banff, Alberta, located in the same valley, 50 km northern of the cave (SHOPOV et. all, 1996 a, b). This way we reconstructed annual air temperatures for last 1450 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. For this purpose we obtained a reconstruction of annual precipitation for the last 280 years at the cave site. The estimated statistical error is 80 mm/ year. Annual speleothem growth rate was independent on the intensity of luminescence, on annual temperature and on solar luminosity for the same time span (zero correlation). This stalagmite was dated by 14- C and autocalibration dating . Both methods produced consistent age of 1450 +/- 150 years (2 sigma) of the base of the stalagmite. The 14-C date is corrected for “dead” carbon, by its measurement in modern speleothem calcite in RNC.

Intensity of luminescence was not dependent on actual precipitations and sunspot numbers solar luminosity index (zero correlation). Speleothem growth rate variations represent mainly rainfall variations. Speleothem luminescence visualises annual microbanding we used to derive proxy records of annual precipitation for the cave site.

By comparison of luminescent records with other solar proxy records we obtained a reconstruction of growth rates and precipitation in the last 6400 years (with averaged time step of 41 years) for Iowa, near Cold Water Cave, US. For small parts of this speleleothem formed about 2000 years ago we achieved record time step of 6 hours per measurement in speleothem luminescence record allowing resolution of several days (SHOPOV et al., 1994).

Annual luminescence microbanding was used very successfully for relative and absolute dating of speleothems by Autocalibration dating (SHOPOV ET AL, 1991-b). This dating method appear to be more precise than TAMS ^{14}C and AMS U/Th dating for this young sample. It produced date which completely agrees with the results of the other methods in the frames of their experimental error, but have better precision of 1450 +/- 80 years.

We used the quantitative theory of solubility of karst rocks of SHOPOV et. al, (1989,1991a) in dependence of the temperature and other thermodynamic parameters to make reconstructions of past carbonate denudation rates. This theory produced equations of the dependence of the carbonate denudation rates in dependence on the temperature or on the precipitation. We used an estimate of the averaged denudation rate in the region based on integrated data of the carbonate hardness or the water from springs, rivers, cave pools and dripping water and average precipitation rate (of 470 mm/yr) from meteorological data. Obtained denudation rate is 14 mm/kyr or 38 t/km^2 per year. We used this as starting point and substituting our proxy records of the annual temperature and the annual precipitation reconstructed variations of the and for the last 1250 years in dependence on the temperature (fig.2). Both reconstructions are made for equilibrium conditions and do not take into account variations of the evapotranspiration, but they produce quite reasonable estimate of the variations of carbonate denudation, which is within observed variation of 8- 20 mm/ kyr (86% variation). Temperature dependence of carbonate denudation due to temperature dependence of solubility of the carbonate dioxide produce only 9.3 % variation in the denudation rate in result of the reconstructed variation of 4.7 deg. C. Precipitation dependence of carbonate denudation produce 79 % variation in the denudation rate in result of the reconstructed variation of 300 mm/yr from the driest to the wettest year.

Conclusion

It is demonstrated, that speleothem luminescence proxy records of annual values of the climatic parameters can be used for reconstruction of the carbonate denudation variations for a time span far exceeding all historic records.

It is demonstrated, that variation of carbonate denudation due to temperature dependence of solubility of the carbonate dioxide is negligible relatively variation due to precipitation variations.

Acknowledgements

This research was supported by grant NZ 811/ 98 of Bulgarian Science Foundation to Y. Shopov and a NSERC strategic research grant to D.C. Ford.

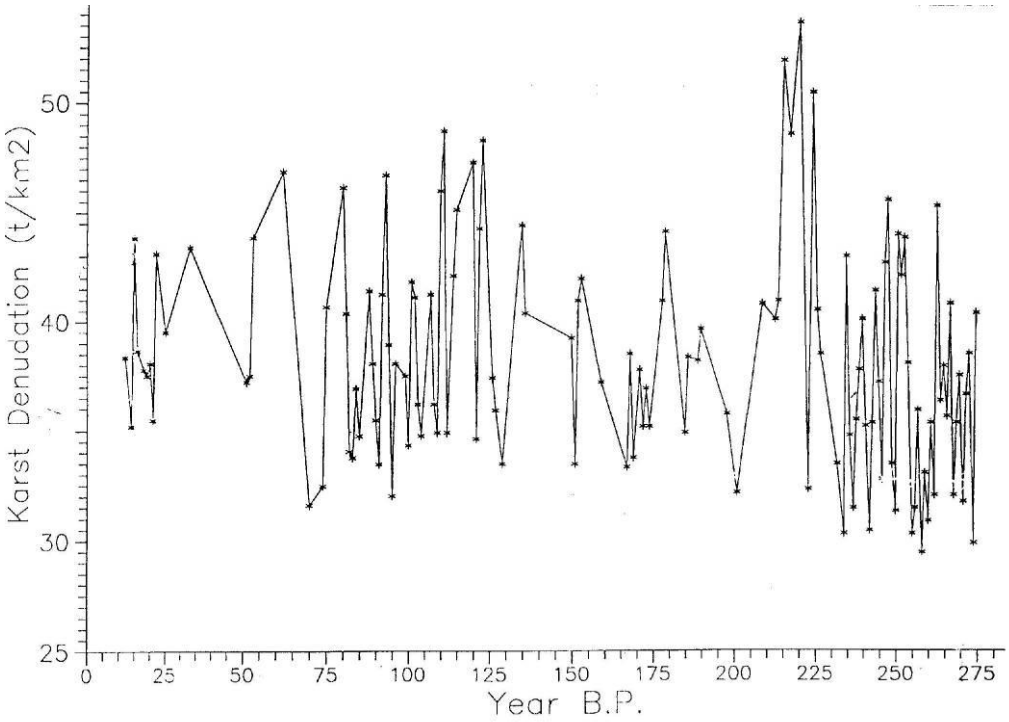

Fig.1Reconstruction of variations of carbonate denudation rate in Kananaskis karst region, Alberta, Canada in the last 280 years in dependence on the precipitation

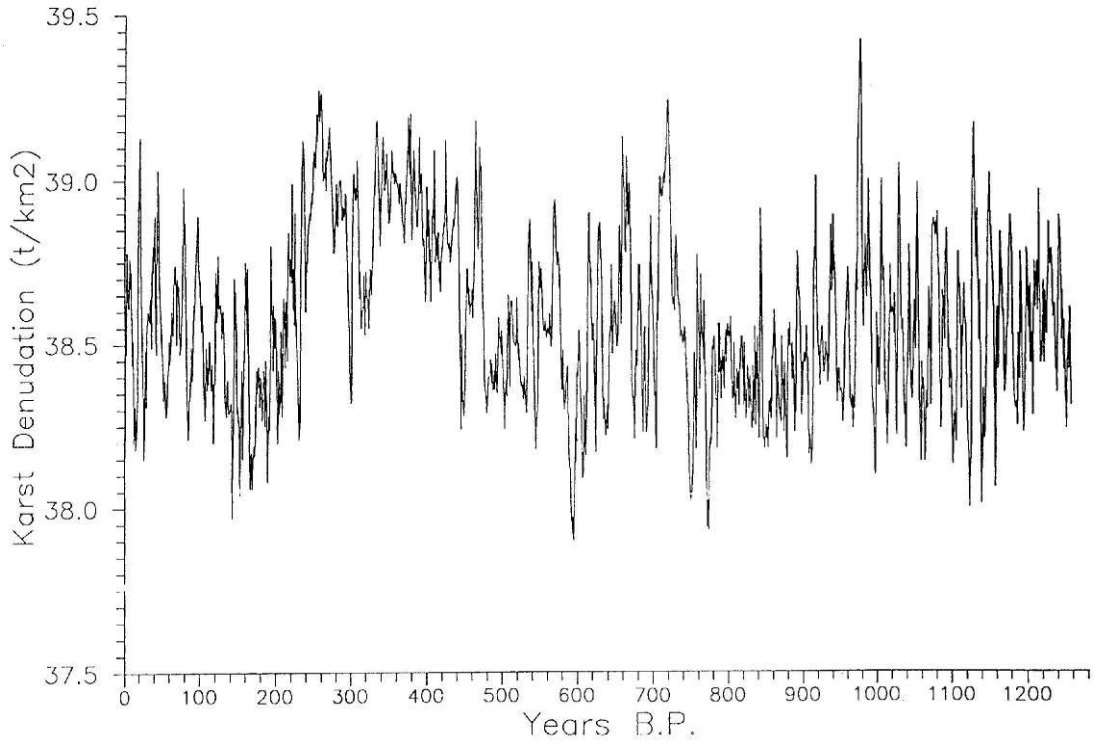

Fig.2. Reconstruction of annual variations of carbonate denudation rate in Kananaskis karst region, Alberta, Canada in the last 1250 years in dependence on the temperature.

References

.SHOPOV Y.Y., GEORGIEV S.L., GEORGIEV L.N.(1989)Climatic Reasons for Karstification of Pirin Mts.- Exped. Ann. of Sofia Univ., 3/4:42-53.

.SHOPOV, Y., GEORGIEV L.N. (1991) Quantitative theory of the solubility of carbonate rocks in dependence ofthe physico- chemical and climatic conditions.- Exped. Ann. Univ. Of Sofia, v.5-A: 9-16.

.SHOPOV Y.Y,DERMENDJIEV V, BUYUKLEV G.(1991) A New Method for Dating of Natural Materials with Periodical Macrostructure by Autocalibration and its Application for Study of the Solar Activity in the Past.- Quad. Dip. Geo., n.13, pp.17-22.

.SHOPOV, Y.Y., FORD D.C., MORRISON J., SCHWARCZ H.P., GEORGIEV L.N., SANABRIYA M. E., DERMENDJIEV V. & BUYUKLIEV G., 1992. High resolution records of Quaternary Solar Activity, Climate and Variations. *GSA Abstr.*, 24 (7), 268.

.SHOPOV, Y.Y., FORD D.C. & SCHWARCZ H.P., 1994. Luminescent Microbanding in speleothems: High resolution chronology and paleoclimate. *Geology,* v.22: 407 -410, May 1994.

.SHOPOV Y.Y., et al (1996a) Speleothems as Natural Climatic Stations with Annual to Daily Resolution- in book "Climatic Change- the Karst Record", Ed. by S.E. Lauritzen. KWI , Bergen, p. 150-151.

.SHOPOV Y.Y.,et al (1996) Speleothem Luminescence proxy Records of Annual Rainfall in the Past. Evidences for "The Deluge" in Speleothems."- in book "Climatic Change- the Karst Record", Ed. by S.E. Lauritzen. KWI , Bergen, p. 155-156.

.SHOPOV Y.Y., et al (1998) High Resolution Records of Climatic Variations and SolarForcing from the Luminescence of Speleothems from Duhlata cave, Bosnek, Bulgaria, Cold Water cave, Iowa, USA and Rats Nest cave,Calgary,Canada- in:"Global Karst Correlation"- Chapter 15, ed. by Y.Daoxian & L.Zaihua, Science Press, New York and VSP BV- Utrecht, The Netherlands & Tokyo pp. 269-289.