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Speleothem microstratigraphy: some clues for paleoclimate series reconstruction at centennial to decadal scales

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Summary

Carbonate stalagmites have an enormous potential for high-resolution paleoclimate series reconstruction, as they can be accurately dated by radiometric methods and concurrently they can yield multi-proxy records of past climate conditions. Reliable series however requires a precise characterization of the speleothem internal micro-stratigraphy. For this task, a new methodological approach is herein presented, in which the micro-stratigraphy of stalagmites is studied under the perspective of the "architectural element analysis", a powerful method widely used by sedimentologists for categorizing internal stratigraphic heterogeneity in sedimentary deposits.

Keywords: Paleoclimate reconstruction, Speleothem, Stalagmite, Stratigraphy

Carbonate speleothems (and stalagmites in particular) are commonly used for reconstructing high-resolution paleoclimate series, as they can be: a) precisely dated by radiometric methods, particularly the ^{238}U-^{234}U-^{230}Th disequilibrium technique; and b) analyzed for paleoenvironmental proxies. None of these is a simple task. U-series age-dating requires the application of sophisticated, expensive, and time-consuming spectrometric techniques on samples that must show favorable geochemical characteristics (adequate uranium content, low initial ^{230}Th, absence of diagenesis; e.g., Dorale *et al*., 2004), and proxy acquisition requires reliable calibration with instrumental climatic data and long-term environmental and hydrochemical monitoring programs of cave sites (e.g., Fairchild & Baker, 2012). In this research framework, the understanding of the internal micro-stratigraphy of the studied stalagmites appears as an essential task, because of three key points: 1) rationalization of any subsampling (e.g., for radiometric dating, stable isotopes analyses, etc.), 2) improvement of the geocronological framework of time series, and 3) better understanding of geochemical paleonvironmental proxies. Additionally, the micro-stratigraphy itself is a rich source of information for both cronostratigraphy and paleoenvironmental interpretation.

The use of stratigraphic methods in these studies is however poor and rarely systematic. In this contribution, a new and simple approach for the study of stalagmites based on their internal stratigraphic architecture is presented. The proposal is centered in calcite stalagmites, which is the most common mineralogy in speleothems, although it can be easily extended to stalagmites showing different mineralogies (e.g., aragonite), and methodologically based in the philosophy of “architectural element analysis”, which is by the first time applied to speleothem deposits.

Architectural element analysis is widely used for categorizing internal stratigraphic heterogeneity in of depositional systems (from alluvial to deep marine). Following the same principles, the internal micro-stratigraphy of stalagmites can be defined by the identification of units of genetically related deposits (architectural elements) as well as bedding contacts (element bounding surfaces) which can be organized in a hierarchical scheme which is time-dependent. In our proposal, the strata organization of calcite stalagmites is described in terms of a four-fold hierarchy of architectural elements and their bounding surfaces (Fig. 1):

First-order architectural elements are represented by individual crystallites, the smallest “building blocks” formed within each basic accretion layer of a stalagmite (Kendall & Broughton, 1978) and that could be defined as the smallest crystals which form under uniform local conditions.

Second-order architectural elements are represented by single growth layers, generated through ‘synchronous crystallization’ (Stepanov, 1997), during a discrete lapse of time, for example during one season, one year, or a more prolonged interval.

The identification and characterization of 1st and 2nd order architectural elements in ancient speleothems is based in petrographical and geochemical analyses. Their interpretation should be supported by present-day monitoring of caves, with emphasis in the environmental conditions, the hydrochemistry of dripping points, and the present-day speleothem formation (carbonate precipitation).

From a chronostratigraphic perspective, 1st and 2nd order architectural elements define the smallest accretional units in a speleothem, commonly basic growth beds that corresponds to a season, a year, or a longer time interval. These beds are usually bounded by abrupt or gradational changes in the crystallographic properties of the carbonate, which reflect changes in drip conditions.

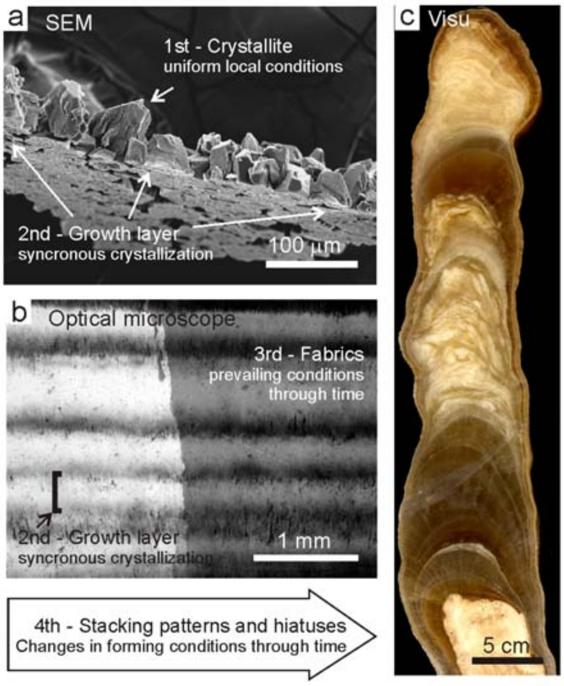

Fig. 1 – The internal micro-stratigraphy of stalagmites is defined by architectural elements and element bounding surfaces, which is framed in four-fold hierarchy.

Third-order architectural elements are speleothem microfacies. These are considered as equivalent to “calcite fabrics” of Frisia & Borsato (2010) and the classification by these authors can be adopted for identification. Most calcite stalagmites used for paleoclimate studies consist of one or more of the following six fabrics (or subfabrics): short/proper columnar, elongated columnar, open columnar, microcrystalline, dendritic and acicular.

Each of these microfacies types results from specific prevailing conditions for the formation of speleothem carbonate during time (e.g., drip rates, relative humidity, saturation conditions...). The time covered on each 3rd-order architectural element will depend on the maintenance of those prevailing factors controlling its generation, and can range from several years to centuries or longer periods.

Fourth-order architectural elements comprise stacks of similar accretional units (growth layers), characterized by one or more microfacies, and defined by growth geometries and stratigraphic stacking patterns of sets of accretional units. We propose six distinct types of 4th-order architectural elements, each of them defining different genetic factors controlling speleothem growth. These are named after the geometry of the inner stratigraphic patterns: bell-shaped, stacked-hay, puff-pastry, arrow-head, candle, flame-like, and coralline pattern.

Stalagmites are usually composed of two or more 4th-order architectural elements, indicating changing conditions (environment or karstological) during growth. These elements can record relatively long periods of time during which the stalagmite grows under broadly homogeneous conditions, and are thus ideal for retrieving high resolution paleoclimate series.

The 4th-order architectural elements are limited by “transitional zones” indicating progressive changes in the forming conditions or, more commonly, by “bounding surfaces” that usually represent hiatuses of variable time span. According to their main geometrical features, the bounding surfaces can be classified as: truncation surfaces, minor-corrosion surfaces, non-depositional hiatuses and highly condensed intervals, corrosion hiatuses, pervasive internal dissolution surfaces (sinkholes), and detritic horizons. These micro-stratigraphic unconformities often yield very interesting paleoenvironmental data, which complete the information given by the depositional elements.

In conclusion, the architectural element analysis is shown as a useful tool for systematically characterizing and interpreting the internal micro-stratigraphy of speleothems in general and, in particular, stalagmites used for paleoclimate studies. The method improves traditional paleoclimatic approaches in speleothems because: 1) it rationalizes any geochemical subsampling (e.g., for radiometric dating, stable isotopes analyses, etc.), 2) improves the geochronological framework of the time series, 3) helps to better understand the geochemical paleoenvironmental proxies, and 4) gives additional valuable paleoenvironmental and paleoclimate information at scales ranging from seasonal to millennial.

Case studies in speleothems from different karstic environments show the potential of the architectural element analysis for the reconstruction of high-resolution paleoclimate series.

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References

DORALE J. A., EDWARDS R. L., ALEXANDER E. C. JR., SHEN C.-C., RICHARDS D. A. & CHENG H. (2004) – Uranium-series dating of speleothems: Current techniques, limits, & applications. *In* SASOWSKY I. D. & MYLROIE J. (Eds.), *Studies of Cave Sediments. Physical and Chemical Records of Palaeoclimate*. Kluwer Academic, New York, 177-197.

FAIRCHILD I. J. & BAKER A. (2012) – *Speleothem Science*. John Wiley & Sons, Oxford, 416 p.

FRISIA S. & BORSATO A. (2010) – Chapter 6. Karst. *In* ALONSO-ZARZA A. M. & TANNER A. (Eds.), *Carbonates in Continental Settings*. Developments in Sedimentology 61, 269-318.

KENDALL A. C. & BROUGHTON P. L. (1978) – Origin of fabric in speleothems of columnar calcite crystals. *Journal of Sedimentary Petrology* 48, 550-552.

STEPANOV V. I. (1997) – Notes on mineral growth. *Proceedings Univ. Bristol Speleological Society* 21, 25-42.