



Intracellular Amorphous Carbonate Inclusions (micropearls) in unicellular eukaryotes: A previously unknown type of non-skeletal biomineralization

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As a truly curious personality, controversial and novel issues dealing with carbonate formation have always attracted Bob Ginsburg. In the early 90's he published a short article about the vices and virtues of the still existing controversy about stromatolites formation. He argued that a major virtue of having this controversy was to emphasize the need for multiple answers to questions about the relative roles of organisms versus environment. Recent discoveries have clearly shown that calcium carbonate biomineralization can take place not only around cyanobacteria cells, but also inside the cell of specific cyanobacteria species (Couradeau et al., 2012). Unicellular phytoplankton species of Lake Geneva (Switzerland) have also been signaled to form intracellular inclusions of amorphous carbonates (Martignier et al., 2016), a novelty for eukaryotic unicellular organisms. These granules, formed by unicellular phytoplankton, have been named micropearls. They are rich in calcium, strontium and barium showing concentric and oscillatory zoning on a nanometric scale. Being widespread in certain species of phytoplankton present in Lake Geneva, they represent a previously unknown type of non-skeletal biomineralization, revealing an unexpected pathway in the geochemical cycle of alkaline-earth metals. The reason why they have been overlooked so far might be that micropearls appear translucent under the optical microscope and are easily altered, dissolved or expelled during usual biological sample preparations.

Our results suggest that several planktonic organisms form micropearls of different chemical composition. Only one micropearl-forming organism has been identified to this day in Lake Geneva: *Tetraselmis cf. cordiformis* (Chlorophyta, Prasinophyceae) produces micropearls containing strontium ($[Ca,Sr]CO_3$). Barium and strontium concentrations measured in micropearls are extremely high compared with the undersaturated water of Lake Geneva. For example the Ba/Ca ratio in the barium-rich micropearls is up to 800,000 times higher than in the surrounding lake water. This can only be explained by a high biological pre-concentration of these elements.

So what? as Bob used to ask surprising sometimes a stunned audience. Besides the discovery of a new biomineralization pathway with plausible impact on geochemical cycles of various elements, these results might be of interest to develop alternative bio-remediation methods. Thus, there are still lots of things to discover keeping carbonate sedimentology as young as Ginsburg always taught us!

Couradeau E, Benzerara K, Gérard E, Moreira D, Bernard S, Brown GE Jr, & López-García P (2012) An early-branching microbialite cyanobacterium forms intracellular carbonates. *Science* 336: 459-462.

Ginsburg RN (1991) Controversies about stromatolites: Vices and virtues. In: DW Müller, JA McKenzie & H Weissert (eds.): *Controversies in Modern Geology*. Academic Press Limited, 25-36.

Martignier A, Pacton M, Filella M, Jaquet J-M, Barja F, Pollok K, Langenhorst F, Lavigne S, Guagliardo P, Kilburn MR, Thomas C, Martini R, Ariztegui D. (2016) Intracellular amorphous carbonates uncover a new biomineralization process in eukaryotes. *Geobiology* 15: 240-253.