

MICROBIAL ORIGIN OF OPAL SPELEOTHEMS IN VENEZUELAN QUARTZITE CAVES (RORAIMA GROUP, GUYANA HIGHLANDS)

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Abstract

The largest and longest silicate caves in the world created in arenites of the Roraima Group in Venezuela have been explored on Chimantá and Roraima plateaus (tepuis) of Guyana Highlands. Geological and geomorphological research showed that most feasible way of the caves genesis is winnowing and erosion of unlithified or poorly lithified arenites. Dissolution is also present but it probably plays neither the trigger role, nor volumetrically important role in the cave-forming processes. The strongest dissolution/reprecipitation agent is the condensed air moisture which is most likely the main agent contributing to growth of siliceous speleothems. As such, it can be active only after, not before the cave is created. Siliceous speleothems are mostly microbialites except of some normal stalactites, cobweb stalactites and flowstones which are formed inorganically. They consist of two main types: 1. fine-laminated columnar stromatolite formed by silicified filamentous microbes (either heterotrophic filamentous bacteria or cyanobacteria) and 2. a porous peloidal stromatolite formed by *Nostoc*-type cyanobacteria. The initial stages of encrusted shrubs and mats of microbes were observed, too, but the surrounding arenitic substrate was intact. This is a strong evidence for the microbial mediation of the silica precipitation.

Keywords: speleology, tepuis, Venezuela, sandstone caves, siliceous speleothems, microbialites, cyanobacteria, stromatolites. Cueva Charles Brewer. Cueva Ojos de Cristal.

INTRODUCTION

In the last time, several Works emerged which apply the term karst to silicate caves that occur either in granites (Willems et al., 2002) or, more frequently, in sandstones (see the reviews in Wray, 1999, 2003). According to these authors dissolution, although slow, is the main process that forms the caves. For sandstone rock, the term “arenization” was introduced by Martini (1979). This term involves both – the dissolution of the cements in the arenitic rocks, with subsequent erosion and winnowing of the loose sand material. If the “arenization” theory was true, most of the sandstone caves could really be attributed to karst as the dissolution is considered there to be trigger process of the cave formation. The main proof of that the dissolution is important in silicate caves are silica speleothems which occur in most of the silicate caves. They are mostly composed of opal-A, which slowly turns to opal-CT and then to microquartz. The question remains, whether the silica dissolution is so important that the silicate caves can be really ranked among the karstic ones. This paper brings one of the first results of several speleological and scientific expeditions to Venezuelan Gran Sabana, Guyana Highlands (Fig. 1), where largest caves evolved in the sandstone plateaus called tepuis. Tepuis are the key area where sandstone “karstic” phenomena can be studied and where the term “arenization” is widely used (e.g. Urbani, 1986). In our last papers (Aubrecht et al. 2007; 2008) we bring different views on the genesis of sandstone caves and of siliceous speleothems

which occur in most of them, base on our geological, geomorphological, hydrogeochemical and speleological observations.

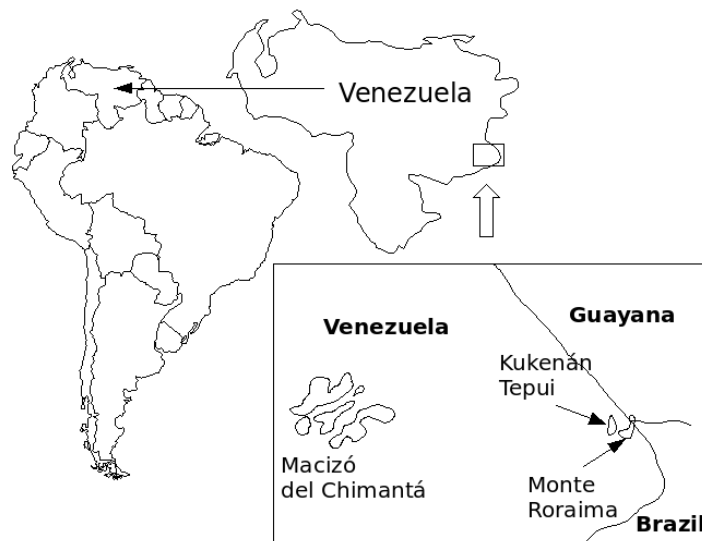


Fig. 1: Location of the studied table mountains

MATERIAL AND METHODS

The geological and speleological observations were focused on the differential weathering of various sorts of arenites of the Matauí Formation, Roraima Group on the Macizó Chimantá and Roraima tepui surfaces and in the caves – particularly in Cueva Charles Brewer and Cueva Ojos de Cristal (Fig. 1). Four sites with different lithification and erosion phenomena in arenites were sampled in detail for petrographic analysis (thin-sections and SEM) the results of which will be published later. Equally important was sampling of siliceous speleothems. A limited number of samples was collected for study to prevent excessive damage to the speleothem decoration of the cave. They were studied in petrographic thin-sections. Fresh speleothem surfaces in growth position, as well as surfaces of broken speleothems (some etched by hydrofluoric acid), were coated by thin gold films and observed under SEM. The samples were gold coated and then observed in JEOL JXA 840 A scanning electron microscope, with an accelerating voltage of 5 kV. Mineralogical composition of the speleothems was determined optically and by X-ray diffraction analysis (XRD). Analyses were performed with a DRON-3 analyser, using $\text{CoK}\alpha$ of the wavelength λ : 1.79021 Å, filter Fe, voltage 30 kV, intensity 15 mA, diaphragms 1;1;0.1, or $\text{CuK}\alpha$ of the wavelength λ : 1.54178 Å, filter Ni, voltage 40 kV, intensity 20 mA, diaphragms 1;1;0.5.

Speleothem surfaces were also sampled for microbiological analyses. Part of the samples was fixed in agar for further cultivation (about 20 samples – results not included yet); about 40 samples were fixed in formaldehyde (for microscopic observations only).

GENESIS OF THE SILICEOUS SPELEOTHEMS

Caves formed in silicate rocks are characterized by siliceous speleothems, in which the dominant mineral is opal. Unlike in carbonate speleothems, microbial mediation is much more common in precipitation of siliceous speleothems. Siliceous speleothems commonly represent small forms, rarely exceeding 2 cm in size. In all the examined caves, peculiar forms of speleothems were found (see also Aubrecht et al., 2008). They have various shapes

and forms and they most of them bear signs of microbial origin (Fig. 2). Many of the speleothems remind classical stalactites and stalagmites known from limestone caves but their structure and genesis are different. Apart from variable shapes, the microbial speleothems show identical principal texture, corresponding to various stages of their evolution (Fig. 3). They consist of two principal zones: 1. laminated columnar stromatolite, consisting of non-porous compact opal, forms mostly the internal zones of the speleothems, 2. strongly porous zone formed by white chalk-like opal, represents accumulation of microbial peloids and forms mostly the outer zones of the speleothems. In some speleothems, both zones may alternate.



Fig. 2: Large microbial speleothem forms called “champignons” are frequently more than 30 cm in size (Cueva Charles Brewer, Chimantá). Photo: B. Šmída

The **columnal stromatolite zone** consists of finely laminated layers of pure opal, intercalated by some zones of filamentous microbialite, with thin filaments oriented in the direction of the stromatolite growth. SEM study of the etched surfaces of the columnal stromatolite showed that it mostly consists of concentric laminae formed by dense parallel tubes representing casts after filamentous microbes. The microbes are most similar to filamentous cyanobacteria from the order Oscillatoriales (Golubic, 1976). In other places, irregular, larger-scale, doublelayered cross-sections of microbe tubes occur. They resemble casts after cyanobacterial cells of the genus *Cyanostylon* or *Entophysalis* (Golubic, 1976). The **zone of peloidal microbialites** consists of ovoidal peloids of relatively uniform shape. They are densely packed, arranged in concentric laminae. The size of peloids varies from 0.1 to about 0.3 mm. Microscopic study revealed that the peloids are formed by *Nostoc*-type cyanobacteria. Fungal hyphae, metazoan and plant remains also subordinately contribute to speleothem construction. In many places, initial colonization of the surface by *Nostoc*-type cyanobacteria was observed, forming mats and shrubs covering the underlying arenites (Fig. 4)). The microbial filaments are commonly encrusted by white silica, whereas the surrounding arenites are intact. This is a strong evidence that the microbes were not only passively encrusted by silica but the

encrustation was microbially mediated, either by their metabolism, or by changing physico-chemical conditions. This phenomenon is common in the limestones but it was not yet evident for the siliceous microbialites. Some speleothems, e.g. the cobweb stalactites (Aubrecht et al., 2008) represent mostly inorganic precipitates, encrusting various structures, such as spider threads. There are also large inorganically precipitated stalactites and flowstones. Comparing the size of the speleothems from various caves, there seem to be dependence between the cave size and speleothems size. Cueva Charles Brewer hosts the largest recorded silica speleothems (up to several dm in size) whereas those in other caves were not so large (cm to dm. size).

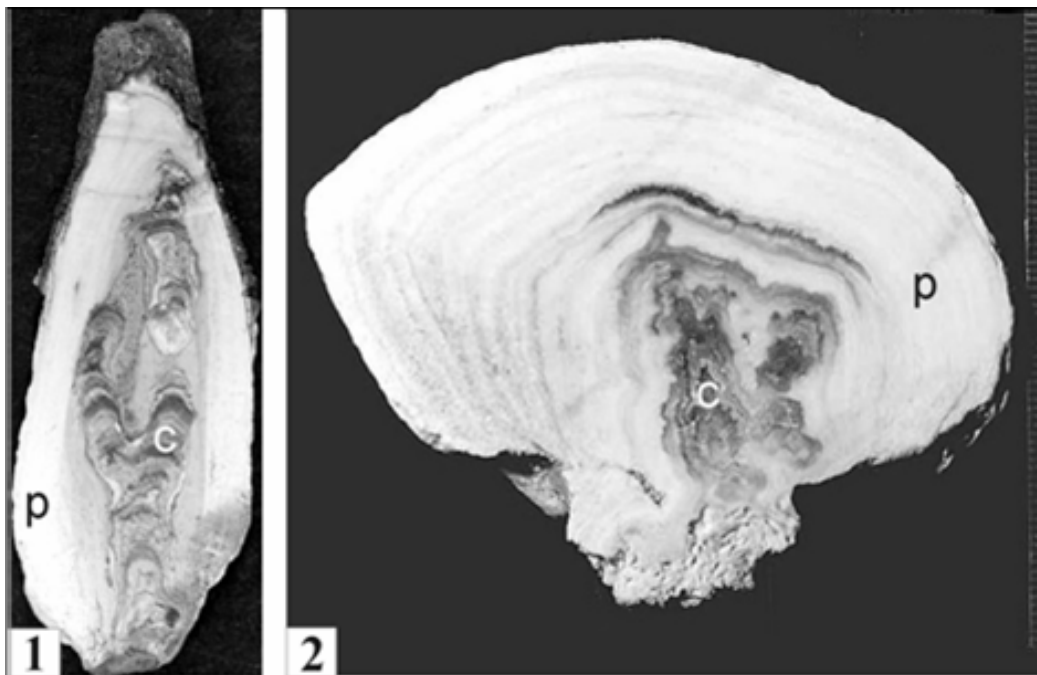


Fig. 3: Slabs of “muñeco” (1) and “champignon” (2) speleothems from Cueva Charles Brewer (Chimantá) showing common principal inner structure, consisting on the columnal stromatolite (c) forming the inner zones and white, chalk-like peloidal layer (p). Photo: R. Aubrecht

Microbial origin of the siliceous speleothems was recognized by previous workers (e.g. Forti, 1994; Léveill e et al., 2000; Willems et al., 2002; Urbani et al., 2005) but very few of them attempted to make a closer description of the microbes. Siliceous microbialites of much larger forms are known from hot springs and geysers (opal sintres). These also contain abundant microbial assemblages, dominated by cyanobacteria, i.e. phototrophic organisms (Jones et al., 2001; Konhauser et al., 2001; 2003). Phototrophic organisms – diatomaceans – were also found to contribute to formation of similar speleothems in Japan and USA (Kashima et al., 1987; Kashima & Ogawa, 1995). These speleothems, however, occurred still close to the entrance, whereas speleothems presented in this paper came from the deepest parts of the cave. Therefore, it is surprising that considerable part of the central compact stromatolite of the speleothems is probably formed by cyanobacteria. Biological investigations of microbes of opal speleothems from similar sandstone cave on Sarisari nama Plateau (Cueva de los Gu acharos – Kunicka-Goldfinger, 1982) showed mostly presence of heterotrophic microorganisms, the trophic life mode of which was adapted to decaying of excrements of bats and birds guarachos, as well as fruit remnants coming from their diet. What is the basis of microbe ecology in Cueva Charles Brewer is yet unclear. Presence of these otherwise phototrophic organisms in caves is not so surprising as it seems to be. Some cyanobacteria do not withstand an excess solar light that can damage their cells (Vincent & Roy, 1993; Quesada & Vincent, 1997). Some of them produce protective pigments in extracellular sheath

(e.g. *Lyngbya estuarii* produces pigment scytonemine – Kylin, 1937); others are even able to protect themselves against the excess light by boring the substrate, e.g. endolithic boring cyanobacteria *Hormathonema* and *Hyella* (Golubic, 1976). The genera *Fisherella* and *Calothrix* are even able to change their mode of life to slow heterotrophic in complete darkness (Whitton, 1987). Finally, the most convincing fact is that some cyanobacteria, e.g. *Geitleria calcarea* and *Scytonema julianum* were found to live in caves (Friedman, 1955; Bourrely & Depuy, 1973). It is obvious that the cyanobacteria in Venezuelan caves are also adapted to heterotrophic mode of life.

The reason for the size dependence between the caves and the speleothems is yet unclear. One of the possible explanations would be that the larger the cave is, the more siliceous material undergoes the dissolution/reprecipitation cycle. Larger cave corridors and galleries of the Cueva Charles Brewer have several times larger surface than other caves available for the condensed air moisture which plays the most important role in the cycle.



Fig. 4: Silica-encrusted shrubs forming an initial mat of *Nostoc*-type microbes on the quartzite substrate (Cueva Cañon Verde, Chimantá). Photo: B. Šmída

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