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Sandstone caves on Venezuelan tepuis: Return to pseudokarst?

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ABSTRACT

Venezuelan table mountains (tepuis) host the largest arenite caves in the world. The most frequently used explanation of their origin so far was the "arenization" theory, involving dissolution of quartz cement around the sand grains and subsequent removing of the released grains by water. New research in the two largest arenite cave systems – Churi-Tepui System in Chimanta Massif and Ojos de Cristal System in Roraima Tepui showed that quartz dissolution plays only a minor role in their speleogenesis. Arenites forming the tepuis are not only quartzites but they display a wide range of lithification and breakdown, including also loose sands and sandstones. Speleogenetic processes are mostly concentrated on the beds of unlithified sands which escaped from diagenesis by being sealed by the surrounding perfectly lithified quartzites. Only the so-called "finger-flow" pillars testify to confined diagenetic fluids which flowed in narrow channels, leaving the surrounding arenite uncemented. Another factor which influenced the cave-forming processes by about 30% was lateritization. It affects beds formed of arkosic sandstones and greywackes which show strong dissolution of micas, feldspars and clay minerals, turning then to laterite ("Barro Rojo"). The main prerequisite to rank caves among karst phenomena is dissolution. As the dissolution of silicate minerals other than quartz appears to play not only a volumetrically important role but even a trigger role, these arenitic caves may be ranked as karst.

1. Introduction

The legendary Venezuelan table mountains (tepuis) host some of the largest non-carbonate caves in the world. They have become a matter of dispute among geologists, geomorphologists and speleologists all over the world. Caves are common in limestone terrains and karstic phenomena can easily evolve in limestone or other rock materials with better solubility, e.g. gypsum or salt. All the karst-like phenomena that evolved in non-carbonate environments were initially attributed to pseudokarst; only later the term karst was extended to some non-carbonate rocks (see Doerr and Wray 2004 for overview). Most recent definitions of karst consider dissolution to be the main factor that determines the true karstic processes (Wray, 1997; Doerr and Wray, 2004; Martini, 2004). Solubility of silicate rocks is generally very low and caves which formed in silicate rocks were often attributed to pseudokarst because most workers believed that mechanisms other than dissolution play the main role in their formation. However, recently several works emerged which apply the term karst for silicate caves that occur either in granites (Willems et al., 2002; Vidal Romaní and Vaqueiro Rodrigues, 2007) or, more frequently, in sandstones (see the reviews in Wray, 1997, 1999). According to these authors dissolution, although slow, is the main process that forms the caves. For sandstone rocks, Martini (1979) proposed the term "arenization" for silicate weathering. This term involves both, the dissolution of the cements in the arenitic rocks (resulting in turning the quartzites to "neosandstone"—see Martini, 2004) and the 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. Doerr (1999) even concluded that the dissolution does not selectively affect only the cements but the whole rock ('corrosion' instead of 'arenization'). The main evidence that the dissolution is important in silicate caves are silica speleothems which occur in most of the caves developed in silicate rocks. They are mostly composed of opal-A (cf. Aubrecht et al., 2008a), which slowly turns to opal-CT and then to microquartz (chalcedony). Aubrecht et al. (2008b) presented a

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different view on the genesis of sandstone caves in which they challenged the karstic origin on the basis of the preliminary results of two speleological expeditions to the Venezuelan Gran Sabana. The question is whether the silica dissolution is so important that the Venezuelan caves in arenites (for which the term "arenization" is widely used—e.g. Urbani, 1986) can be ranked among the karstic ones. This paper brings further data to elucidate this problem.

2. Geological setting and studied areas

The studied area is located in the Venezuelan Guyana of northern South America (southeastern Venezuela–Gran Sabana, Bolívar State - Fig. 1). The area of the Gran Sabana is formed by the Archaean rocks of the Guyana Shield which represents the northern segment of the Amazonian Craton of South America. The Guyana Shield is covered by the Proterozoic sedimentary cover represented by rocks of the Roraima Supergroup consisting principally of clastics derived from the Trans-Amazonian Mountains to the north and deposited in braided-river, deltaic, and shallow-marine environments in a foreland basin (Santos et al., 2003). The supergroup mostly forms tabular plateaus, cuestas and hogbacks that rise abruptly above the Paleoproterozoic basement. Its thickness ranges from 200 m to ~3000 m. Local sedimentological studies show that environments of deposition range from alluvial fans to fluvial braided deposits plus lacustrine, aeolian, tidal, shallow-marine deposits and some shallow water turbidites (Reis and Yánez, 2001, Santos et al., 2003), although sandy continental deposits predominate. The supergroup consists of the following formations (arranged stratigraphically): Arai, Suapi, Uaimapué and Matauí (Reis and Yánez, 2001). The tepuis developed mainly within the uppermost of them—the Matauí Formation which consists of quartzites and sandstones. The age estimated for all but the uppermost parts of the Roraima Supergroup is 1873 ± 3 Ma (Late Paleoproterozoic), determined by U-Pb analyses of zircons from a green ash-fall tuff of the Uaimapué Formation (Santos et al., 2003). The present landscape including the start of the cave-forming processes is considered to be inherited from the Mesozoic period (e.g. Cretaceous—see Galan and Lagarde, 1988; Briceño et al., 1991) as the widely accepted theory of quartz dissolution requires a long time. However, this estimation has not been supported by any data. On the contrary, the U-Th dating of siliceous speleothems provide only Pleistocene ages (Lundberg et al., 2010).

The data presented in this paper were collected during the expeditions in dry seasons of the years 2007 and 2009 (preliminary data from the 2007 expedition were published by Aubrecht et al., 2008b). The foci of the research were the surface geomorphological forms on the Chimanta (partial plateau named Churi) and Roraima tepuis, as well as the caves in them which form the two largest sandstone cave systems in the world (Fig. 2): Churi-Tepui Cave System (Šmída et al., 2010) and Ojos de Cristal System (Šmída et al., 2003). In the Churi-Tepui Cave system, geochemical and geotechnical measurements, together with samplings were done in the largest cave — Cueva Charles Brewer, as well as in Cueva Cañon Verde, Cueva Colibri and Cueva Juliana. In the Ojos de Cristal system, the research focused on Cueva de los Pemones and Cueva de Gilberto.

3. Materials and methods

The geological and speleological observations were focused on the differential weathering of various sorts of arenites of the Matauí Formation on the tepuis surfaces and in the caves. Sites with different lithification and weathering phenomena in arenites were sampled (40 samples) for petrographic analyses (thin-sections and SEM). Differences in the rock hardness were measured by Schmidt hammer; 23 sites were measured. The Schmidt hammer device enables a simple and quick field test of the rebound hardness of rock, which serves for relatively cheap estimation of the overall physical state of a rock mass and rock material. At the same time it allows the delineation of horizons of various weathering/alteration stages along a given profile.

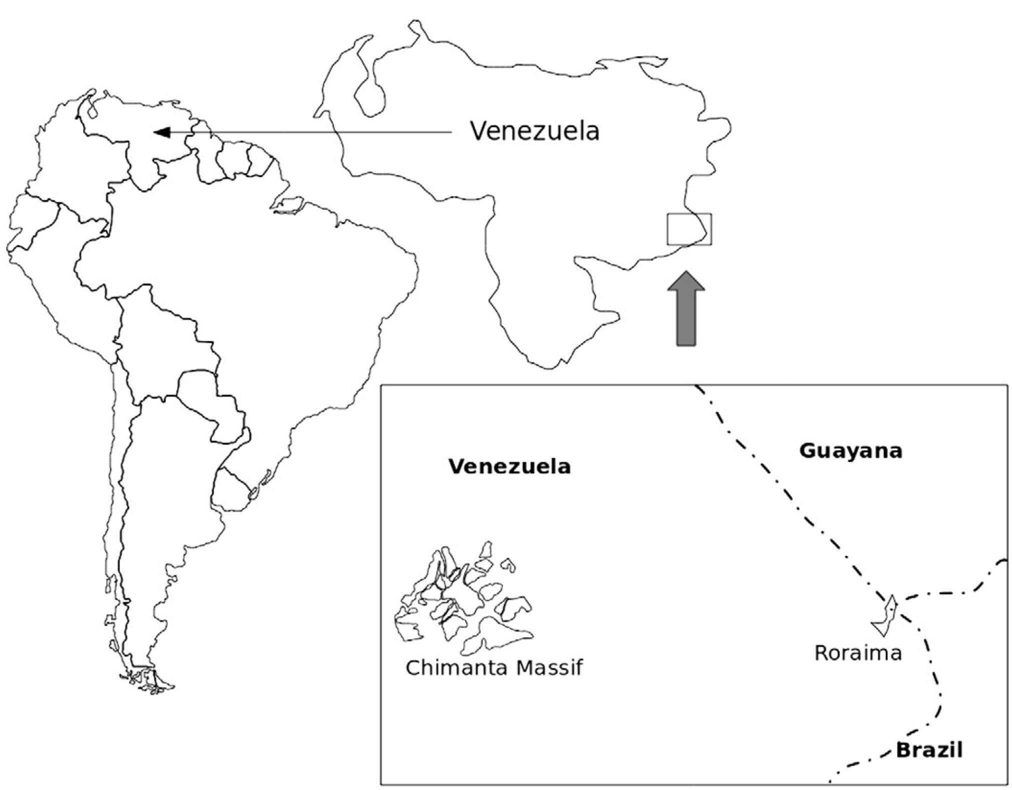

Fig. 1. Location of the examined tepuis.