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Genesis of folia in a non-thermal epigenic cave (Matanzas, Cuba)

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ABSTRACT

Folia are an unusual speleothem type resembling inverted cups or bracket fungi. The mechanism of folia formation is not fully understood and is the subject of an ongoing debate. This study focuses on an occurrence of folia present in Santa Catalina Cave, a non-thermal epigenic cave located close to Matanzas (Cuba). The sedimentology, morphology, petrology, permeability and geochemistry of these folia have been studied to gain new insight on the processes leading to their development. It is concluded that folia in Santa Catalina Cave formed at the top of a fluctuating water body, through CO_2-degassing or evaporation, which may have been enhanced by the proximity to cave entrances. Two observations strongly support our conclusions. (1) When compared to other subaqueous speleothems (e.g. cave clouds) present in the same rooms, folia occur exclusively within a limited vertical interval that likely represents an ancient water level. Folia occur together with calcite rafts and tower cones that developed, respectively, on top of and below the water level. This suggests that a fluctuating interface is required for folia formation. (2) The measured permeability of the folia is too high to trap gas bubbles. Thus, in contrast to what has been proposed in other studies, trapped bubbles of CO_2 cannot be invoked as the key factor determining the genesis and morphology of folia in this subaqueous environment.

1. Introduction

Folia are relatively rare speleothems resembling inverted rimstone dams (also described as inverted cups, bells, or bracket fungi) growing mostly on overhanging ledges and walls, often covering the bedrock completely (Hill and Forti, 1997). In scientific papers folia have been reported from 31 caves globally, but the number of these locations is likely to increase. To the list of 25 caves reported in Audra et al. (2009), we have added La Baume Cave in France (reported in Davis, 2012), Odelsteinhöhle in Austria (Plan and De Waele, 2011), Cave of the Winds, Colorado, and Fort Stanton Cave, New Mexico, both reported in Davis (2012), Cueva de Villa Luz in Mexico (Hose, 2009), the Sima de la Higuera near Murcia in Spain (Gázquez and Calaforra, 2013), the cavelets of Glenwood Canyon, Colorado (Polyak et al., 2013), and the Santa Catalina Cave near Matanzas in Cuba, subject of this paper. Most of the caves in which folia have been reported are of thermal and/or hypogenic origin, such as Sima de la Higuera (Gázquez and Calaforra, 2013), Devil's Hole in Nevada (Kolesar and Riggs, 2004), Giusti cave in Tuscany, Italy (Piccini, 2000), and the Buda Hills caves (Takacsné Bolner, 1993; Leel-Ossy et al., 2011). However, this is not the rule, as folia have also been described from epigenic-cold caves, such as Hurricane Crawl Cave in California (Davis, 2012) and Odelsteinhöhle in Styria, Austria (Plan and De Waele, 2011). This new occurrence of folia in Santa Catalina Cave appears to be another example of a non-thermal epigenic cave.

Many of the reported folia are found in association with subaqueous or water-surface type speleothems forming in supersaturated lakes or pools, such as rafts and cones, and cave mammillaries, and folia are sometimes found associated with typical degassing corrosion morphologies such as bubble trails (Audra et al., 2009). The exact mechanism and the key conditions required for the development of folia are not fully clear, and are the subject of an ongoing debate. Existing hypotheses can be divided into three fundamentally different models: (1) the fluctuating-interface particle-accretion theory of Davis (1997, 2012);

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(2) the thermal phreatic degassing theory of Green (1991, 1997) or its slightly modified version of hypogenic degassing just below the water level theory (Audra et al., 2009); and, ultimately, (3) the brine-mixing theory proposed by Queen (2009).

According to Davis (2012), most carbonate folia form by accretion from adherent particles at a fluctuating water level, and would thus be very reliable water level indicators. For example, folia growing during the rise and fall of the water level (marking this level with a precision of only a few centimeters). Green (1991) and Audra et al. (2009) believe folia form in a subaqueous environment, by CO_2-degassing close to but below the water table. The water level is precisely recorded, according to these authors, by the top of the folia zone. Queen (2009) proposes a possible mechanism of folia formation at indefinite depth in the phreatic zone by mixing of fresh water with brine water. Folia would thus indicate the location of the brine/freshwater interface and, as a consequence, would be unrelated to the position of the water table or water level. Each of these genetic theories requires particular conditions and are valid for specific folia occurrences, thus there is not yet a clear and unified theory.

This study presents new data on folia that formed in an epigenic non-thermal cave, Santa Catalina Cave, in Cuba. Detailed sedimentological, morphological, petrographical and geochemical analyses, permeability measurements, and SEM examinations were performed on folia in this tropical near-to-the-coast cave. Finally, the possible genesis of these speleothems in this new setting is discussed.

2. The Santa Catalina Cave

The Santa Catalina Cave is located approximately 20 km east of Matanzas, on the northern coast of Cuba, in an area known for its beautiful and well-decorated caves (Fig. 1). In 1996 Santa Catalina Cave was declared a National Monument by the Cuban Government for its exceptional speleothems and its historical value. The area is characterized by the outcropping of a series of marine terraces composed of eogenetic limestones dated from Pliocene to present (Ducloz, 1963). The entrances of the cave open on the Yucayo terrace (Lower Pleistocene) at around 20 m asl and less than 1 km from the present coastline.

The upper level of the cave is composed of a maze of passages connecting irregular wide and narrow rooms. Based on the general morphology, it can be classified as a flank margin cave, which formed in the mixing zone between fresh and brackish water (Mylroie and Carew, 1990, 2000). Regional uplift and a lowering of sea level have moved this upper sector of the cave out of the mixing zone such that mixing speleogenesis is no longer active.

The upper part of the cave hosts speleothems such as stalactites, stalagmites, columns, gours, flowstones, and cave pearls. Besides these conventional morphologies, widespread in many Cuban and tropical caves, Santa Catalina Cave also hosts more exotic speleothems, including cave clouds, tower cones, significant deposits of calcite rafts, folia, and the very rare composite speleothems called “mushrooms” (Fig. 2).

The floor of the studied part of the cave is: i) flat, except for some local collapses or flowstones, and the roof is never higher than 6 m; and ii) nearly entirely covered with whitish calcite rafts, which are composed of flakes up to 1 cm wide and less than 1 mm thick (Fig. 2A). These observations indicate that in the past the cave hosted pools with water and that evaporation (or CO_2-degassing) at the pool surface was high enough to precipitate calcite. Calcite raft deposits can reach a thickness of >2 m, especially along the sides of the passages. In the center of the galleries, below dripping points, calcite rafts sank to the bottom of the pools forming typical tower cones, entirely comprised of packed calcite flakes (Fig. 2B). Both calcite rafts and tower cones appear to be eroded away by a water flow along the central parts of the

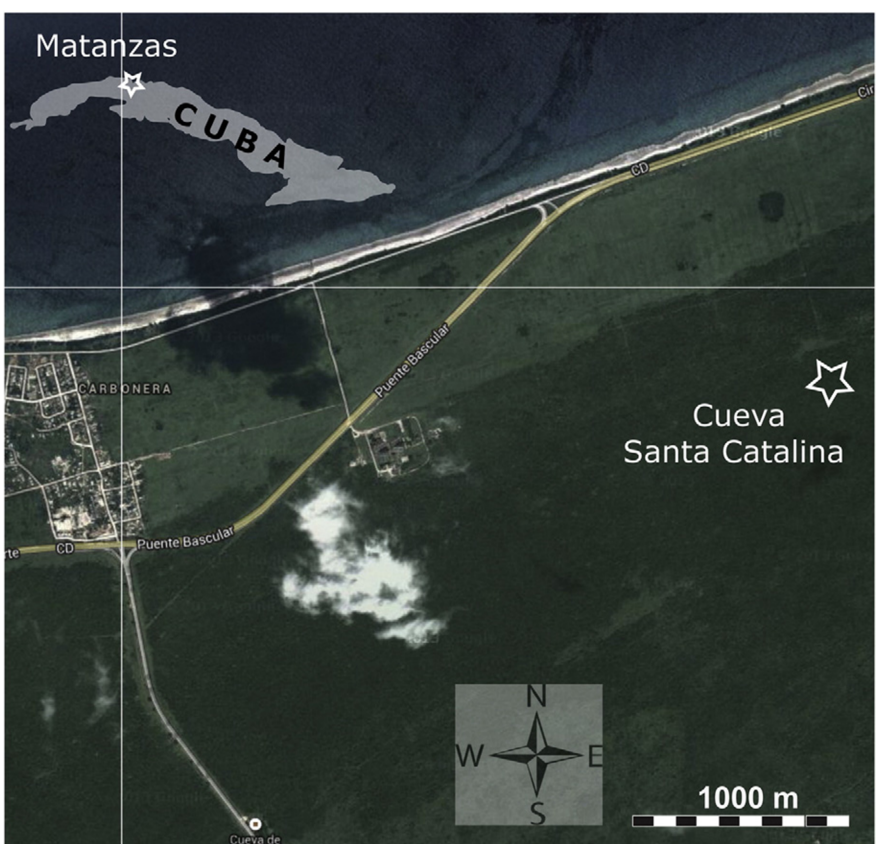

Fig. 1. Location of Santa Catalina Cave, east of the small village of Carbonera and only 1 km from the northern coast of Cuba. From Google Maps.