FOLIA SPELEOTHEMS, A HYPOGENIC DEGASSING ORIGIN

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Abstract
Bubble trails are subaqueous features in carbonate caves, which are made by the corrosion by ascending carbon dioxide bubbles. Folia are calcite deposits resembling inverted rimstone dams in saturated pools. Based on morphological studies in Adaouste Cave (Provence, France) and on studies elsewhere in the world, we propose a new genetic model for folia, close to the model of Green (1991). The association of bubble trails and folia, occurring on overhanging walls, is interpreted to be an indicator of hypogenic degassing occurring just below the water table. The association is the result of juxtaposed processes composed of corrosion along bubble trails and calcite deposition in calcite-saturated pools.

Introduction
Bubble trails are small channels developed subaqueously in the walls of carbonate caves by corrosion by carbon dioxide bubbles. Folia are among the most curious and rarest calcite speleothems: these subaqueous calcite coatings cover overhanging walls and resemble inverted rimstone dams. Their origin is still debated and several hypotheses have been suggested, among which the two main hypotheses are: deposits at the surface of water bodies (pools with oscillating water level) or subaqueous speleothems in thermal caves. In Adaouste Cave, bubble trails and folia are intimately associated, which is a paradox involving both corrosion and deposition, respectively. This paper presents a detailed analysis of their morphology and spatial distribution that provides a better understanding of their origin and significance.

Our observations of bubble trails and folia from Adaouste Cave (Provence, France), and comparison with other occurrences worldwide, allow us to ascribe to them a hypogenic origin by degassing. Moreover, the association between bubble trails and folia provides us with an indicator for hypogenic processes by carbon dioxide degassing that is highly useful for the interpretation of inactive hypogenic caves.

Previous genetic theories
Bubble trails have been only recently identified (Chiesi and Forti, 1987). The discovery of folia occurred earlier (Emerson, 1952), but the understanding of their genesis is still debated.

Bubble trails (bubble-flow canals)
Bubble trails are smooth and regular solution channels cut in overhanging walls. The cross-section is roughly half-circular, with diameters of 0.5 to 10 cm, ranging from a shallow print (Figure 1C) to a deep channel (Figure 1D). The course is essentially straight, with some gentle curves following the steepest slope

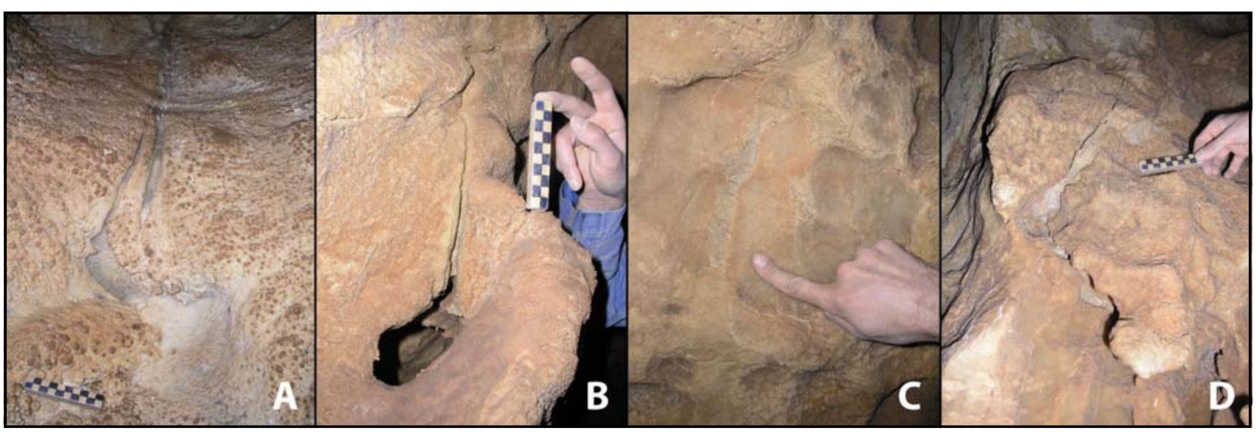

***Figure 1**. Bubble trails in Adaouste Cave. Corrosion is limited to the channel, whereas the rest of the wall is covered with a subaqueous calcite coating. A and D: views from below; B and C: front views (photos. J.-Y. Bigot, http://catherine.arnoux.club.fr/photo/13/adao/adao.htm).*

(Figure 1A). Bubble trails were first identified in the caves of the Iglesiente metallic district in Sardinia (Chiesi and Forti, 1987). They are also mentioned in some sulfuric acid caves, such as the Frasassi Caves in Italy (Galdenzi and Sarbu, 2000). In Hungary, they were first identified in the cave Ferenc-hegy barlang, and later in the Buda Hills caves, other karst massifs (Bükk, Pilis), and close to the Balaton Lake in Tapolca barlang (Szabó, 2005). Their development is due to carbon dioxide degassing (Chiesi and Forti, 1987). In the Santa Barbara 2 Cave, the degassing is due to the oxidation of sulfur ore deposits (De Waele and Forti, 2006). At depth, carbon dioxide remains dissolved because of the high pressure. During the rise of water in the phreatic zone, water degasses CO_2 as depth decreases, typically 15-30 m depth at the maximum (Luiszer, 1997). Bubbles converge into the steepest upward courses along overhanging walls. The carbon dioxide bubbles locally enhance the solutional aggressivity of the adjacent water. Bubble trails are produced by the continued corrosion along these unchanging routes. Such corrosion features are probably more frequent than suggested by the sparse sites mentioned above. Theoretically, such phenomena should be present in most hypogenic caves where carbon dioxide degassing occurs. On the contrary, they do not seem to exist in any other type of cave. Bubble trails should not be confused with other types of wall and ceiling channels such as paragenetic wall channels, convective channels in deep-seated caves (Klimchouk, 2007), hydrothermal condensation-corrosion channels (Audra, 2007), etc.

Folia (Hill and Forti, 1997)

Folia are speleothems resembling inverted rimstone dams or mushroom caps. They occur as undulating ribbons, stacked like leaves, and hence their name (Figure 2). They grow downward as a continuous coating, exclusively on overhanging walls. The lower rim is horizontal or gently tilted about several degrees. Individual ribbons are on average of 1 cm thick, less than 10 cm wide, and separated vertically by empty spaces up to 5 cm. In places they are influenced by currents and are arranged parallel to the flow direction (e.g. in Indian Burial Cave, Nevada; Green, 1991). At the micro-scale, the calcite is deposited in a dendritic microcrystalline fabric. Eventually, this porous dendritic texture is overgrown by large columnar crystals, up to 10 mm in length (Kolesar and Riggs, 2004). Such dendrites and skeleton crystals are the result of a rapid growth and a limited supply of material. For carbonate solutions, this is often caused by the pressure fluctuations associated with mechanical degassing, e.g. the growth tips of stalactites (Maltsev, 1999), or by high supersaturation under periodic very low-flow-regime periods that result in prolonged outgassing (Frisia et al., 2000). Folia are formed below the water table, down to several meters or dozens of meters deep. More rarely they mark an

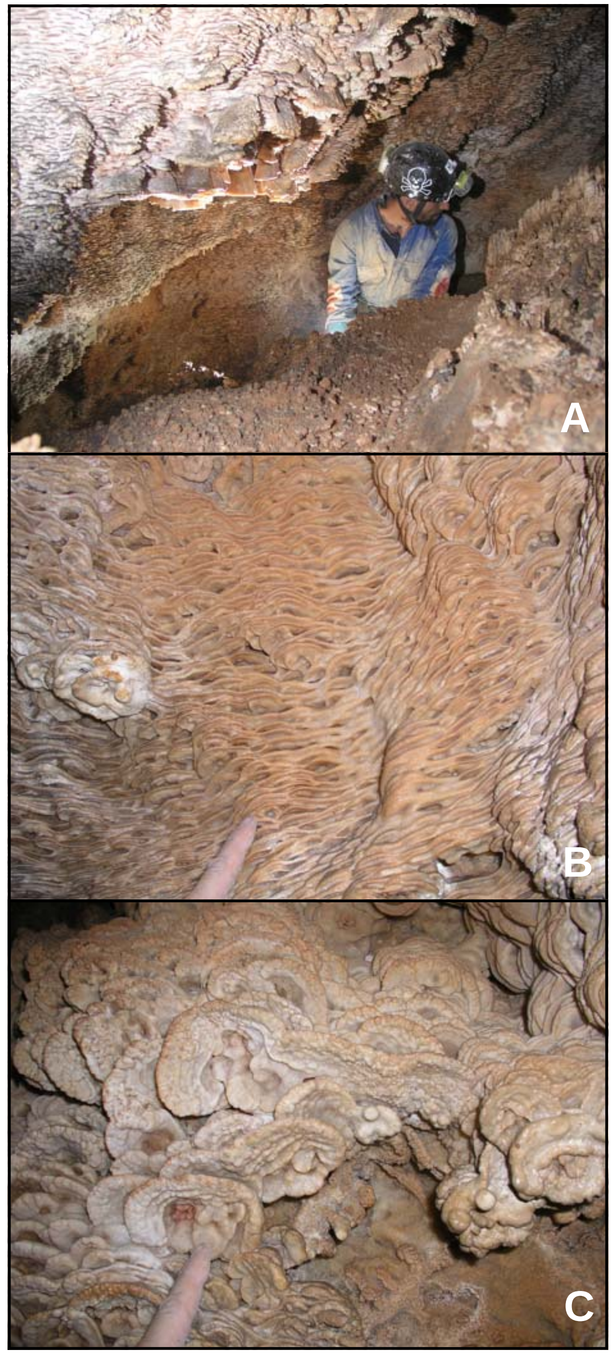

***Figure 2**. Folia in Adaouste Cave. Top: folia occur exclusively below overhanging walls; middle: front view toward the top showing the "inverted rimstone" morphology; bottom: view from below showing the outward and downward development as inverted cups (photos by J.-Y. Bigot, http://catherine.arnoux.club.fr/photo/13/adao/adao.htm).*

Table 1. *Folia occurrences, about 25 sites worldwide.*

Cave	Location	Active / fossil	Hydrothermalism	CO_2 degassing	Tectonic / hydrogeology	Reference
Indian Burial Cave	USA, Nevada	F	86-119° C (T_H of the fluid inclusions)			Emerson, 1952; Green, 1991; Halliday, 1957
Hurricane Crawl Cave	USA, California	A	No (river cave)	From upwelling phreatic water		Davis, 1997
Crystal Sequoia Cave	USA, California					Davis, 1997
Goshute Cave	USA, Nevada	F				Halliday, 1954b
Devil's Hole	USA, Nevada	A	Water table 34 °C	x	Non karstic active extensional fault	Kolesar and Riggs, 2004
Gneiss Cave	USA, Utah	F			Calcite folia coating onto a gneiss wall	Green, 1997
Bida Cave	USA, Arizona					Davis, 1965; Hill, 1982
Groaning Cave	USA, Colorado					Davis, 1973
Agua Caliente Cave	USA, Arizona	A	Cave at 38 °C			McLean, 1965
Carlsbad Cave	USA, New-Mexico	F	Carlsbad 20-25 °C		Basin margin	Davis, 1970
Lechuguilla Cave	USA, New-Mexico	F	Carlsbad 20-25 °C		Basin margin	Davis, 2000; Hose, 1992
Cinco Cuevas (caverna de las)	Cuba					Nuñez-Jimenez, 1975
Pulpo (sima del)	Spain, Murcia	A	Water table 21 °C			Ferrer Rico, 2004
Benís (sima de)	Spain, Murcia	A	Water table 21 °C			Ferrer Rico, 2004
Ermite (grotte de l')	France, Pyrénées	A	Water table 19 °C Thermal sulfidic spring 38 °C	x	Artesian flow path in deep syncline	Bigot and Nobecourt, unpub.
Adaouste (grotte de l')	France, Provence	A	Abandoned at 11 Ma Thermal springs along Durance fault	x	Durance active transcurrent fault	Audra et al., 2002
Pál-Völgy - Matyas-Hegy barlang	Hungary, Buda Hills	F	Springs 20-27 °C		Rim of the Danube rift	Takacsné Bolner, 2005
Jószef-hegy barlang	Hungary, Buda Hills	F	Springs 20-27 °C		Rim of the Danube rift	Takacsné Bolner, 2005
Molnar-Janos	Hungary, Buda Hills	A	Water table 20-27 ° C	x	Rim of the Danube rift	Takacsné Bolner, 1993
Matyas-Farras	Hungary					Takacsné Bolner, 1993
Giusti (grotta)	Italy, Tuscany	A	Thermal spring 34 ° C	x		Forti and Utili, 1984; Piccini, 2000
Ryan Imperial Cave	Australia, Queensland					Jennings, 1982
Cupp-Coutunn Cave	Turkmenistan	F	80-170° C (T_H of the fluid inclusions, from fluorite and calcite)		Basin margin	Maltsev, 1997; Maltsev and Self, 1993

oscillating water table, as a horizontal ring that covers the walls, within a vertical range of several centimeters to decimeters as in Hurricane Crawl Cave, California (Davis, 1997); and Devil's Hole, Nevada (Kolesar and Riggs, 2004).

Folia are frequently associated with subaqueous speleothems originating from calcite deposition in supersaturated pools, such as cave clouds, calcite rafts, tower cones, and coral towers. All of these deposits are generally, but not systematically, induced by hypogenic degassing producing oversaturation in the pools (Audra et al., 2002). Folia were first identified in Indian Burial Cave, Nevada (Emerson, 1952). Currently, they are recorded in fewer than 25 caves worldwide, some active, some inactive (Table 1). Many of these sites are in thermal caves. However, hydrothermal conditions do not seem to control the presence of folia: the temperature of water and the temperature of calcite crystallization deduced from fluid inclusions range across a large spectrum (from 20 to 120 °C; Table 1), and Hurricane Crawl is a cold epigenic cave.

Two main hypotheses have been proposed for the origin of folia:

The oscillation of a saturated pool surface (Davis 1997). At the surface of supersaturated pools, precipitation is due to evaporation (Halliday, 1954a; Davis, 1973; Jennings, 1982). Precipitation can be due to strong degassing, trapped gas is involved in shaping the folia growth around bubbles, and water-level oscillations are essential to explain upper and lower limits of the folia (Davis 1997). Calcite precipitation occurs either directly by particle accretion, or by accretion of calcite rafts. Hill (1987) specifies that after the lowering of the water, the sloping folia edges developed like draperies, where calcite botryoids ("popcorn") may grow. Kolesar and Riggs (2004) correlate folia with the water oscillation due to earth-tidal waves, which would favor calcite precipitation by degassing and subsequent saturation of the capillary film during the lowering of the water.

Phreatic degassing in thermal water (Green, 1991, 1997): the CO_2 bubbles originating from degassing are trapped below wall irregularities. These small gas pockets focus the precipitation of calcite around the bubbles with downward-orientated growth. Successive upward "sloughing" produces the structure of inverted rimstones. Thermal rising flow concentrates the deposition below overhanging walls.

Regarding these hypotheses and observations as a whole, Hill and Forti (1997) do not distinguish the variety of physical settings (e.g. in perched pools, water table, or shallow depth in the phreatic zone) and come to no single explanation for folia genesis. However, they admit a close relationship with the water table and with subaqueous speleothems such as cave clouds, as well as with pool speleothems such as rafts.

New evidence in The Adaouste Cave

The Adaouste Cave opens below the top of the Mirabeau anticline. This fold is cut by the Durance water gap, along an active transcurrent fault, lined by thermo-mineral springs (Audra et al., 2002). Hypogenic flow tends to converge toward the highest places of buried aquifers, where discharge can occur. Consequently, the outflow is located at the intersection between the anticline hinge and the water gap, which acted as the regional base level. The Adaouste Cave was probably active in the Tortonian (11 Ma), at the beginning of the Durance water gap entrenchment. The main entrenchment phase of the water gap occurred in the Messinian (Clauzon, 1979). The cave drained, became perched, and consequently has been preserved from any further reworking. The temperature of homogenization (TH) of fluid inclusion, even if not reliable, tends to shows a trend of temperatures of crystallization higher than cold meteoric environment (Audra and Häuselmann, 2004). Some ore deposits in the neighborhood (Fe-Mn) are associated with hypogenic karst and have preserved microbial evidence in metallic pool fingers (Audra and Hofmann, 2004). The cave is made of two steep passages following the anticline dip, which rise from about 200 m depth (Figure 3). These steep passages connect to the horizontal upper levels (-18 and -27) which record past water-table elevations (Audra et al., 2002). These horizontal levels display intense condensation-corrosion features, suggesting the presence of a nearby thermal body (Audra et al., 2007). Below the water table, corrosion concentrated in bubble trails. At depth, carbon dioxide gas was trapped in blind bells with a high pressure, giving rise to hyper-corrosive atmospheres, where condensation-corrosion produced boxwork at the ceiling, as well as drip holes (Figure 4). Simultaneously, degassing led to supersaturation and massive calcite deposition, as various morphologies: botryoids (popcorn) above the water table; and rafts, tower cones, folia, and coral towers, beneath the water table (Audra et al., 2002). The water/gas interfaces are very clear, showing transition between atmospheric corrosion and subaqueous precipitation (Figure 5)

Folia and bubble trails in Penitents Chamber

Observations have been made in Penitents Chamber (-124 m), together within the main passage above the chamber (Figure 4). The diversity of subaqueous corrosion and deposition features in this area allow us to establish some relationships, particularly between bubble trails and folia. The bubble trails converge upward and can reach several meters in length before connecting to blind domes (Figure 1A) or disappearing where the overhanging walls become vertical. No

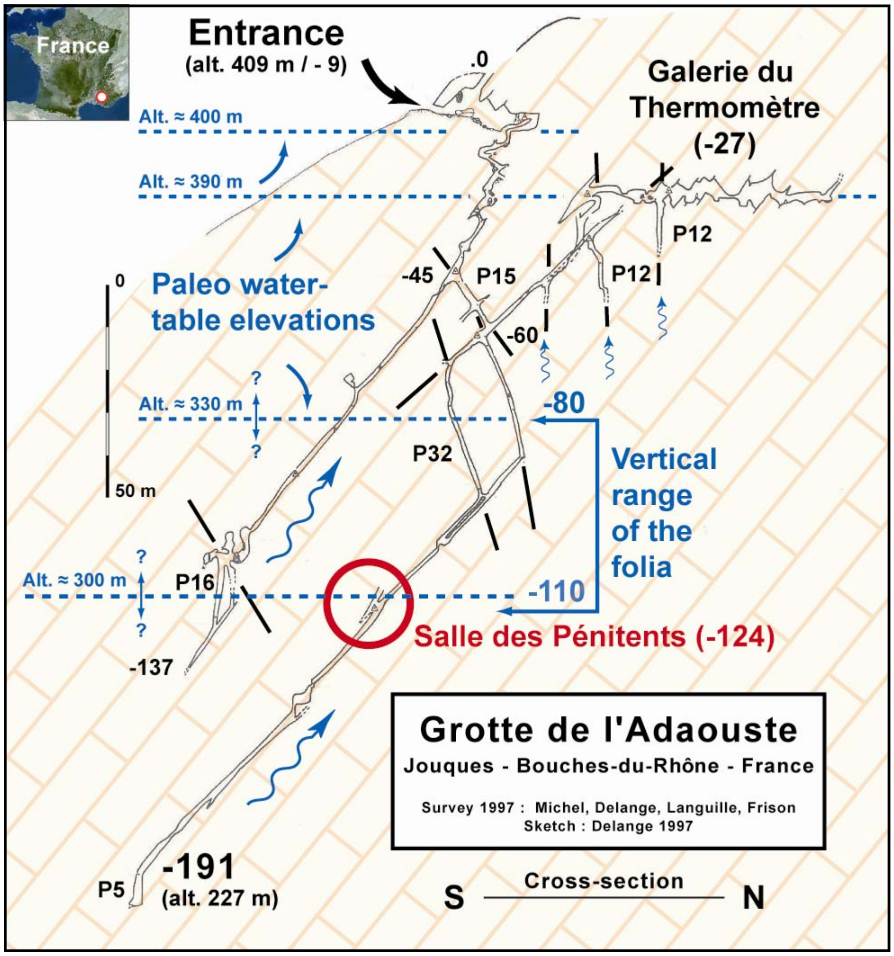

***Figure 3**. Adaouste Cave survey. Hypogenic flow (undulated arrows) welled up through conduits along dip and through fissures (black lines); horizontal levels record past water table positions.*

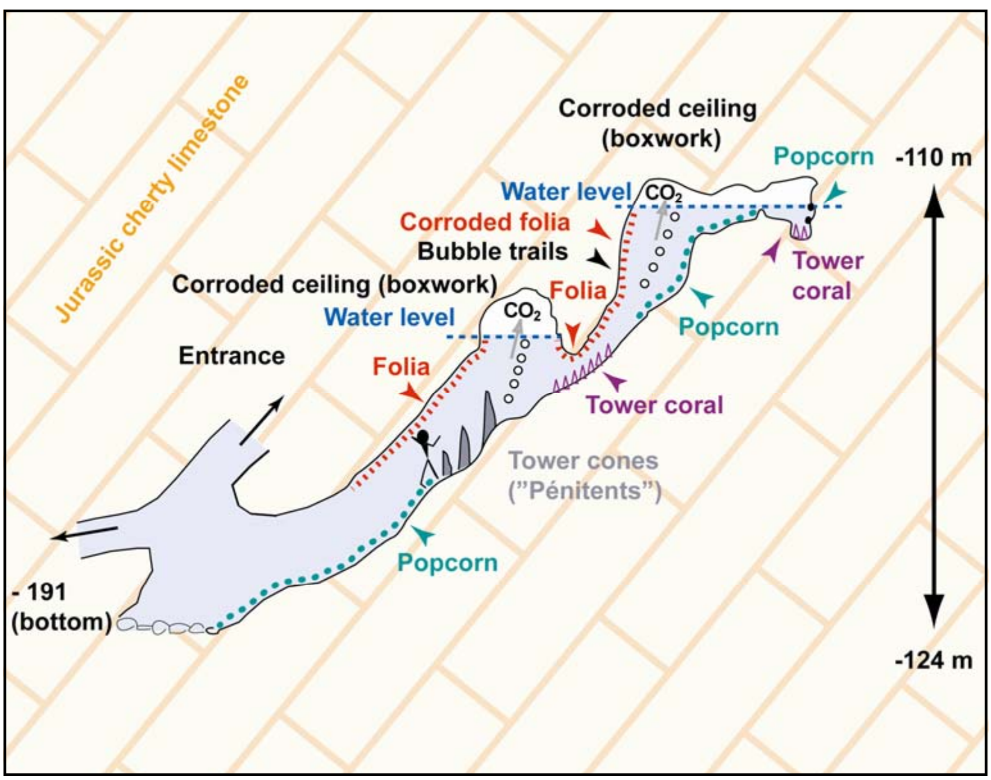

***Figure 4**. The Penitents Chamber, an ancient blind phreatic conduit where the cupolas were filled with CO_2 from degassing. Distribution of features originating from atmospheric corrosion and subaqueous calcite deposition.*

***Figure 5**. Interface between a carbon dioxide-rich gas pocket with walls corroded as boxwork (top) and subaqueous calcite deposits below: folia below over-hanging walls, tower cones below the caver (photo by J.-Y. Bigot).*

deposits are present in the bubble trails. When a calcite coating occurs on neighboring walls, it is cut by the bubble trails (Figure 1C).

Folia are developed continuously between -80 and -120 m (Figure 3). In the upper part, they are uniformly corroded and partly covered with subaerial popcorn. In the lower part, folia are not corroded. A standing water level is visible in the Penitents Chamber, around -110 m. The size of folia increases upward in sequences several meters high. From these observations, we can deduce that:

- After their deposition, the highest folia (-80 to -95 m) have been exposed to air by a water-table lowering, then they have been corroded by condensation-corrosion;
- The influence of condensation-corrosion is intense in the upper horizontal levels, it decreases downwards, and seems to be absent below -95 m.
- The lowest folia (-95 to -120 m) have been deposited either simultaneously with upper ones, with a vertical range of about 30m, or subsequently as the result of a water-table lowering;
- There is no evidence of any subsequent water-table rising, since popcorn covering folia is not covered with any new subaqueous calcite;
- The upward increase of folia size reflects the upward increase of gas volume, both by the degassing and by the addition of rising bubbles.

Folia bubbles

We observed several calcite bubbles inside the folia hollows. We call these speleothems folia bubbles. They are composed of calcite that forms at the water-air contacts of bubbles, by centripetal growth. The development of such features needs the presence of a solution shifting to oversaturation at the water-bubble interface. We suggest the following origin (Figure 6):

- A film of condensation water appears at the vaulted solid top of the bubble, due to the thermal gradient between the thermal water and the rocky ceiling. The gradient is maintained by thermal flux through the rock;
- In the high-CO_2 atmosphere of the bubble, condensation water becomes hyper-aggressive;
- The corrosive water dissolves the calcite and flows along the wall. This migration makes the solution progressively saturated;
- At the base of the bubble, evaporation leads to supersaturation;
- The calcite precipitates on the lower edge of the folia. The precipitation zone propagates along the bubble, at the water-bubble interface. Since this process involving calcite redistribution inside the cavity seems to be limited, calcite particle accretion from the degassing water-body may also participate to the building of the calcite bubble.

Discussion: folia genesis and association with bubble trails, a record of thermal water-table dynamics

Rebuttal to the previous hypotheses

<u>Oscillation of a saturated pool surface</u> (Davis 1997). The main argument supporting this hypothesis is that the constant upper boundary of the deposit is a record of the slow rise and fall of the water body. During these oscillations, accretion of solid material grows downward to enlarge the speleothem. Trapping of bubbles when the water rises, or from degassing, would accentuate this process. However, we identify numerous arguments negating this hypothesis:

- The oscillation of a saturated pool is not sufficient by itself to form folia, because such a condition is present in all karst beneath a vegetal cover, and yet folia are on the contrary extremely rare.

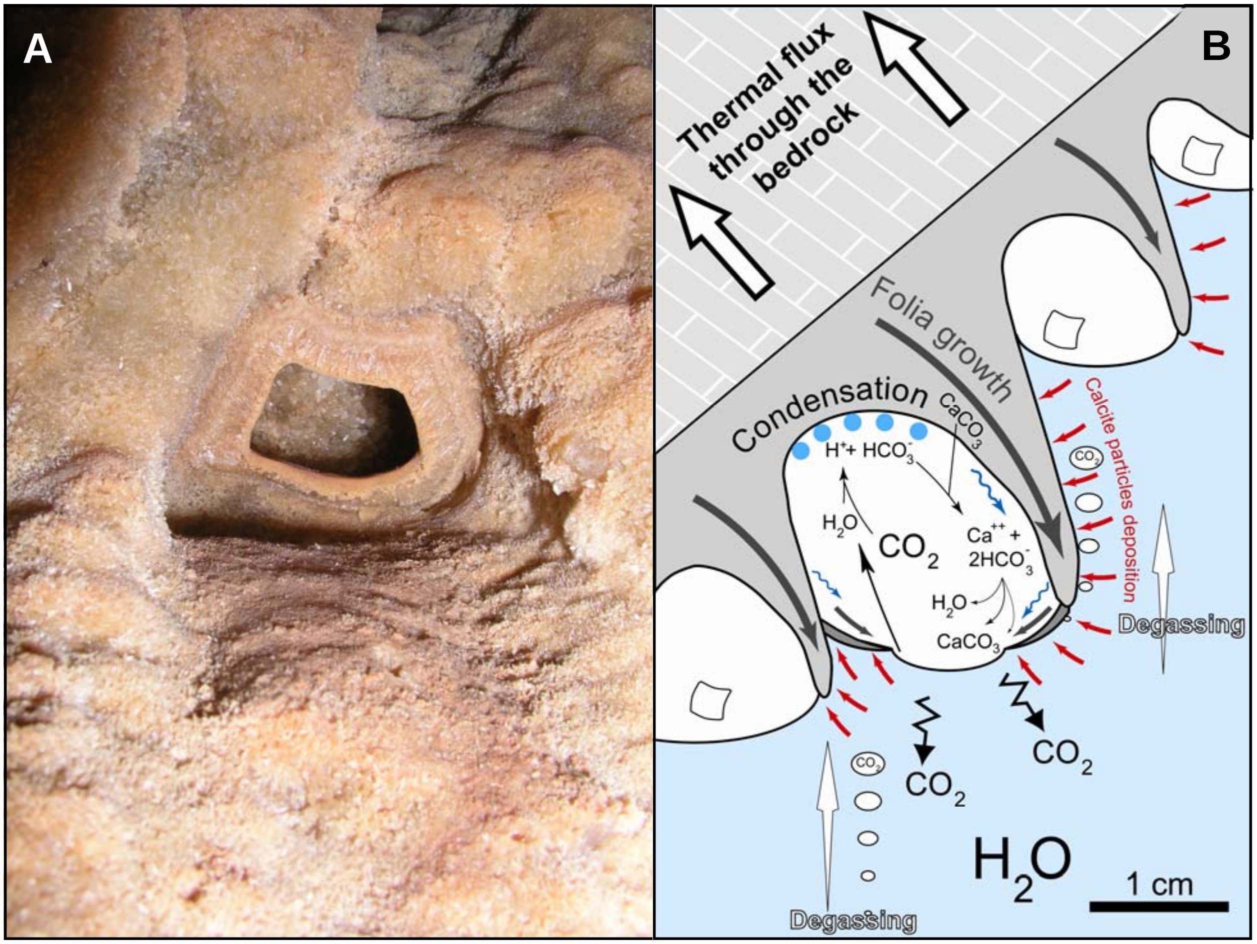

***Figure 6**. Left: folia bubble (photo by J.-Y. Bigot). The aperture is about 4 cm wide. Right: folia and folia bubble development by condensation-corrosion at the top of the carbon dioxide bubble and then by calcite deposition through evaporation at the base of the bubble, at the interface between gas and saturated water. The calcite closing the bubble is shown in dark grey. White arrows show CO_2 degassing; red arrows show subaqueous calcite particle accretion; grey arrows show the growing direction of the folia.*

- The systematic distribution of folia below overhanging walls excludes a simple mechanism of an oscillating pool, which would have similar consequences on non-overhanging surfaces.
- Except for their upper limit, folia never display horizontal patterns which would record some lower water surface.
- Regarding the calcite texture, a random texture would be expected from the accretion of particles or rafts; on the contrary, a dendritic texture is observed deriving from the mechanical effect of degassing (Maltsev, 1999).
- The particular morphology of inverted rimstone is never clearly explained.

Phreatic degassing in thermal water (Green, 1991, 1997). Following this author, calcite particles appear after degassing due to sudden pressure reduction when the fluid expands from a small orifice; the thermal buoyancy raises the particles and accretion occurs around gas bubbles that are trapped below irregularities of the overhanging walls. This hypothesis is consistent with our observations on the whole; however some statements do not seem to be relevant:

- Folia are frequently associated with thermal fluids, but not systematically (Table 1).
- Decompression at constrictions sufficient to cause bubbling by cavitation is not feasible because cavitation requires flow velocities far above those reasonably possible at all observed sites.

New perspectives for the genesis of folia

Since previous hypotheses are not or only partly relevant, respectively, we propose a new process to explain the genesis of folia, partly based on Green's (1991, 1997) hypothesis:

- Below the water table at shallow depth, CO_2 degassing produces bubbles rising toward the surface;
- The bubbles are trapped beneath irregularities in the overhanging walls, and when the spaces are filled the bubbles slough upward into the next hollow; We effectively observed such underwater process in grotta Giusti (Tuscany, Italy) (Piccini, 2000).
- Degassing makes the solution supersaturated, which produces ubiquitous calcite precipitation, except in hollows filled with bubbles. Calcite protrudes outward and downward from wall projections to form the lower edges of the folia. By positive feedback, the size of each trapped bubble increases, and so on.

The folia bubbles clearly show crystallization at the gas-water interface. Consequently, the genesis of folia in subaqueous conditions, due to hypogenic degassing, is demonstrated here. Trapping of bubbles is admitted by both Green (1991) and Davis (1997), as the main consequence for degassing, or as a secondary factor occurring when water rises, respectively. We demonstrate that the trapping of bubbles from a strong degassing is essential to obtain the typical hollow morphology of inverted rimstones. Their size increases upward by addition of rising bubbles. Consequently, we think that folia are almost exclusively associated with degassing from a hypogenic origin. Only two extremely rare cases mimicking the hypogenic environments were identified in non-hypogenic settings: (1) Hurricane Crawl Cave, where degassing into saturated pools is due to the inflow of epigenic water originating from a mountain karst with dense vegetation; (2) cuevas de Bellamar - El Jarrito, Cuba (Hall, 2008), where the air is mechanically trapped by tidal fluctuations.

The thermalism does not seem to be a necessity, even if frequent. Rising hypogenic flow looks more adequate to explain both the folia morphology and the degassing.

We also demonstrate that folia develop by degassing at shallow depth below the water table, no deeper than about 30 m (Luiszer, 1997). Sudden degassing deeper in the phreatic zone by decompression at the outlet of constriction is unlikely. The water table acts as the upper boundary, the lower boundary corresponds to the lower limit of degassing. Both boundaries determine the vertical range of the folia deposits. In these conditions, a water-table oscillation (such as in Devil's Hole) is not necessary; it is only occasionally present. The small vertical range of folia in Hurricane Crawl Cave could correspond to some sediment filling which may since have been removed. Regarding the maximum vertical range of the folia, few data are available. They reach about 40 m in Lechuguilla Cave, and 30 m at Adaouste. Such a depth is compatible with the depth of degassing, and also with the amount of water-table lowering that is documented in Adaouste.

Association between bubble trails and folia

Many bubble trails emerge from folia or cupolas where carbon dioxide has been concentrated (Figure 7, 1A). The juxtaposition of both features, with a sharp transition lacking any overlap (in the stratigraphic sense), shows that they are coeval. Moreover, their association shows they originate from a common process, i.e. carbon dioxide degassing. Their association is controlled by wall geometry: if an overhanging wall is absent, the bubbles rise vertically in the water: neither folia nor bubble trails develop; below a convex-downward overhanging wall, the bubbles pour from folia into folia while diverging; below a con-

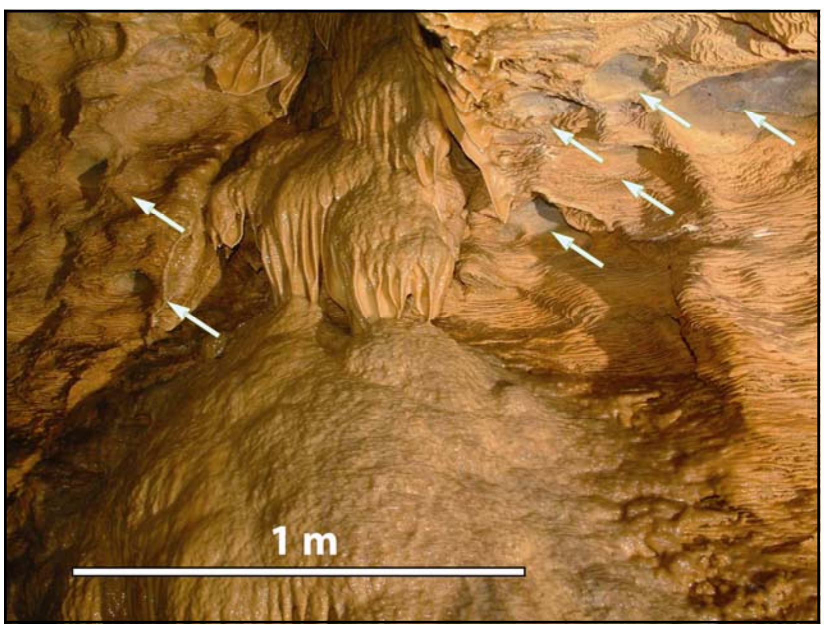

***Figure 7**. Folia in Pál-Völgy barlang, Hungary. Arrows indicate cupolas where gas bubbles are trapped and where intense corrosion showing bare rock is clearly visible, whereas walls are covered with a thick folia coating. The flowstone in the center developed after draining (photo by A. Kiss, with permission).*

cave-downward overhanging wall, the bubbles converge toward an invariable trajectory, and a bubble trail gradually appears in the wall; the bubble trail could reach a cupola, from which another bubble trail emerges.

Record of paleo-water tables

In the Adaouste Cave, the vertical range of the folia, their corrosion in the upper part, and their absence below -120 m, allows us to reconstruct the lowering of the thermal water table (Figure 3). It demonstrates:

- The presence of a thermal water table at about -80 m, at the boundary between popcorn corrosion above and of folia deposition below;
- The lowering of the water table to the top of the Penitents Chamber (≈ -110 m). This lowering caused the smoothing by condensation-corrosion of the overlying folia and the development of the underlying folia.
- The distribution of folia record the recession of thermal activity in the Adaouste Cave.

Non-carbonate features and the term folia

Some features resembling folia are made of minerals other than calcite:

- In clay: Cave of the Winds and Orient Mine Cave, Colorado (Davis, 1982, 1984, 1997), Vass Imbre barlang (Maucha, 1993), and Matyas-Farras, Hungary (Takacsné Bolner, 1993). However, their morphology differs significantly: rims do not overlap and do not form individual inverted cusps. Since they are much too soft to be generated by oscillating water, these clay rims are apparently produced by the regular lowering of a turbid water body (Green, 1997);
- In halite: Liquid Crystal Cave, Israel. Initially published as folia (Frumkin, 1997). Actually they correspond to rimstone shelves (Frumkin, personal communication).
- In sulfur: Cueva de Villa Luz (Hose et al., 2000; Hose, pers. comm.). Soft sulfur forms inverted and overlaid hollowed cusps. Some are similar to coalescent mushroom caps with a flat bottom. They develop in confined areas in very acid atmosphere close to the sulfur springs. Their genetic process is still enigmatic; however they appear to develop in the air, maybe under the influence of acid gas convection.

Despite the visual similarities of these features in non-carbonate material, they are not related to the process of bubble trapping. Sulfur features would develop from sulfuric gas convection by crystallization of sulfur. For the mud features, the genetic process is not physico-chemical, it rather involves mechanical processes, by the transport of solid particles (in phreatic conditions by lowering of levels of turbid water, or by thin sheets of runoff over walls). Their morphology, roughly as horizontal ribs, with flat bottoms in the case of sulfur folia, do not display holes capable of trapping bubbles. Their genetic process, although still largely unknown, is hardly similar to that of folia. Consequently, we think that true folia are exclusively made of calcite; we suggest restricting "folia" to a precise descriptive term for downward-concave calcitic features, and by extension to a genetic term, since these features are associated with a given process. Similar features that owe their existence to different genetic processes should have different names, to avoid confusion.

Conclusions

Folia clearly seem to be connected to hypogenic flow. Hydrothermal conditions are typical; however they do not seem necessary, as long as a strong carbon dioxide degassing is present. The original hydrothermal hypothesis was initially proposed at a time when hypogenic caves were mainly considered hydrothermal, which is only one aspect of hypogenic speleogenesis, neither systematic nor a principal feature (Klimchouk, 2007).

Folia cover large areas and have unambiguous morphology. Consequently, their occurrence seems to be strongly correlated to a carbonic acid, hypogenic context, involving degassing at shallow depth below the water table. Similar features that occur in non-hypogenic context (e.g., in halite or clay) are clearly different, from both a morphological and a genetic point of view. Their inclusion in the term "folia" should be abandoned.

The appearance of folia results from the following combination:(1) strong (hypogenic) degassing below the water table making bubbles and leading to supersaturation; (2) overhanging walls; (3) trapping of carbon dioxide bubbles, making calcite precipitate at the periphery of bubbles, in a downward growth. If the overhanging wall geometry is dihedral, then there is an association between folia and bubble trails. Folia, and moreover the association between folia and bubble trails, can be considered a very reliable record of hypogenic conditions.

The hypothesis of an oscillating supersaturated water pool must be abandoned. First, because folia formed in this way should be widespread, when in fact they are extremely rare. Moreover, this hypothesis does not give a global explanation for the specific morphology of folia, such as inverted rims.

Since degassing occurs at shallow depth below the water table, folia and bubble trails can also be considered a precise record of the water-table position, located at the top of the folia zone.

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