Petrified Colonies of Microorganisms in Agates from Kerrouchen, Atlas-Mountains, Morocco

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(English translation by Johann Zenz using the software DeepL)

"Cauliflower-like" looking mm- to cm-sized inclusions are frequently found in agates from Kerrouchen (Morocco). In the inner areas of such aggregates, the filigree, branched, tubular-looking structural elements are particularly striking. Stromatolite-like and dendrite-like formations can also be observed. The morphology of these formations and their structural components indicates that microorganisms played a role in their formation. The "cauliflowers" are to be regarded as early formations created in an aqueous solution on the walls of former rock cavities.

**Fig. 1: Agate from Kerrouchen, Morocco. 16.8 cm. Example of an agate in which the wall of the former geode cavity is covered with many relatively small "cauliflowers".
All photos in this article were taken from the authors.
The agates shown here are all in the author's collection.**

1 Introduction

The present article is mainly concerned with the mm- to cm-sized, scrub-like and cauliflower-like inclusions that occur in large numbers in agates from Kerrouchen (Atlas Mountains, Morocco) (Figs. 1, 2). The question arises as to how to interpret what we have seen. Are they inorganically formed objects or are there organisms behind them? In any case, the morphology of the structural components of the formations indicates that organisms were involved in their formation. The organisms in question could be bacteria. The fact that the formations have a striking morphology is occasionally noted. McMahan (2009:634), for example, mentions them and refers to them as "plumes". No further details can be found. We too can only describe the formations here. A microbiologist could certainly say more about them. We have drawn attention to smaller inclusions in agates from the Kerrouchen area, which are also interpreted as biosignatures, in a previous note (Thewalt & Dörfner 2024).

Fig. 2: Agate geode from Kerrouchen, Morokko. 13.1 cm.
It is noticeable here that the "plants" are of different sizes. The probable reason for this is explained in more detail in the text.

2 Appearance of the „cauliflowers“

For the sake of simplicity, the structures of interest here are referred to below as “cauliflowers” and “bushes” and their components as “tubes” (each in quotation marks).

When looking at the “cauliflower” under a stereo magnifying glass, it can be seen that they essentially consist of (1) a central area in which filigree structural elements - especially tubular-looking ones - occur (Fig. 3) and (2) yellow to dark brown, warty sheaths that are, so to speak, placed over them (Fig. 4). It is these sheaths that give the “cauliflower-like” appearance. It should be noted, however, that “thread-tube” aggregates without special sheaths also occur.

Fig. 3: Inner area of a “cauliflower”. In this example the many tubular components are striking. Image width 1.6 mm.

Fig. 4: „Cauliflower“. Image width 4 mm.

Figure 4 shows a "cauliflower" embedded in slightly cloudy chalcedony. The surface looks irregularly warty. This indicates that chalcedony was not the determining factor in its formation. Otherwise, the smooth hemispherical surfaces characteristic of chalcedony would have formed. Iron-oxidizing bacteria interfered in that the resulting iron minerals brought their own construction plans with them. The reason for the conspicuous elongated shape of parts of the "cauliflowers" in Fig. 2 is probably that the formations in question grew from the ceiling of the former agate cavities, hanging downwards under the influence of gravity. This type of formation is also attributed to the "pseudo-stalactites" in agates from the basalts of the Deccan volcanic province in India (Götze & al. 2023). Building materials of the "cauliflowers" are mainly oxidic iron minerals and embedding chalcedony (Fig. 5).

Fig. 5: A cut and polished agate fragment with enclosed small "cauliflowers" was treated with diluted hydrofluoric acid. The SiO_2 was clearly dissolved. The framework of oxidic iron minerals is well preserved. Image width 1.6 mm.

3 More information on the sheaths of the „cauliflowers“

The sheaths can have quite different structures: Their thickness varies and, in addition to simple envelopes, there are several thin ones packed on top of each other, as in Fig. 6, or irregularly warty ones (Fig. 4). The fine structure of the shells depends on the amount of iron minerals incorporated in the chalcedony. If the amount is low, chalcedony bands are found in which iron oxide particles float or chalcedony bands between which small flat iron oxide deposits are present.

When the proportion is high, the iron minerals determine the fine structure of the crusts, which also results in the irregular warty structure (Fig. 4). The intense yellow color, which can often be observed, is caused by tiny needle-shaped crystals. Sometimes the formation is also granular (Fig. 8). It is probable that this is goethite. The light yellow color is caused by the special shape and size of the crystals (Cornell & Schwertmann 1996).

Fig. 6: Here, thin, envelope-like precipitates appear, alternating with almost transparent chalcedony layers. Image width 1.6 mm.

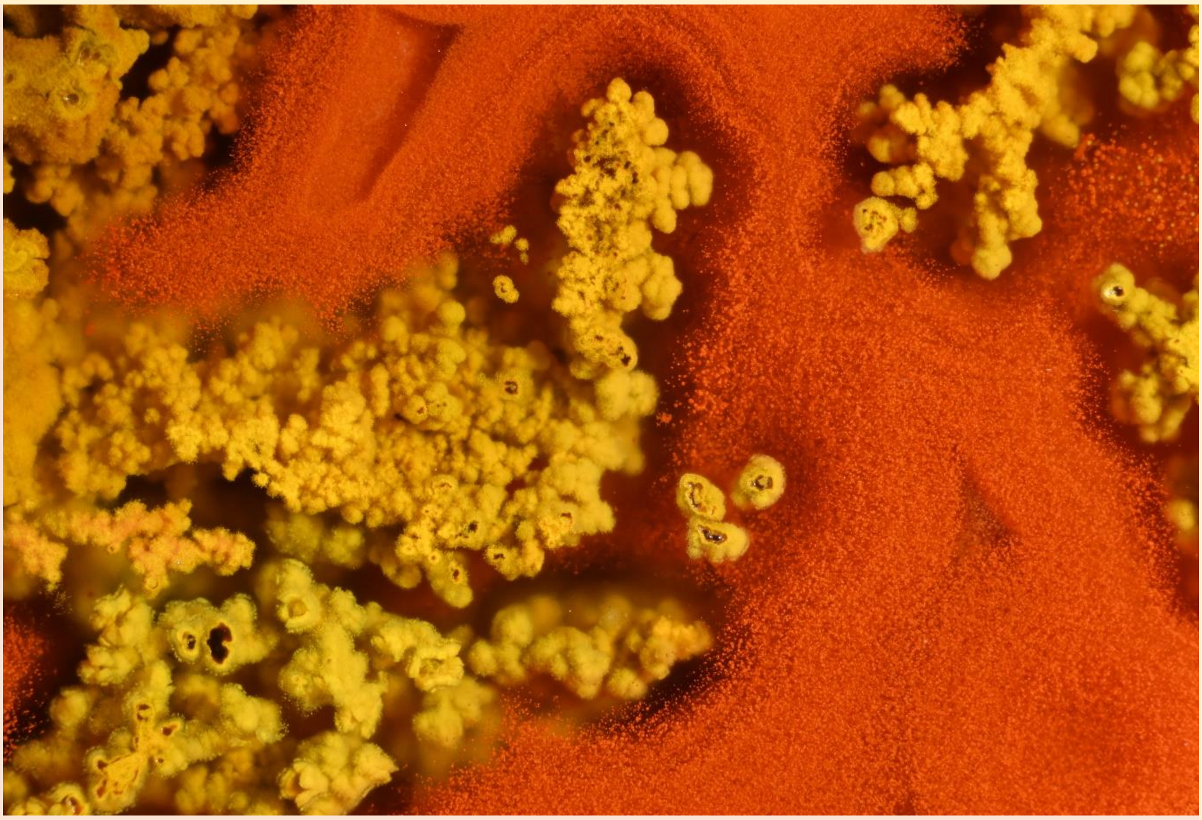

Fig. 7: The sheaths of the plants often show a canary yellow color. Image width 4 mm.

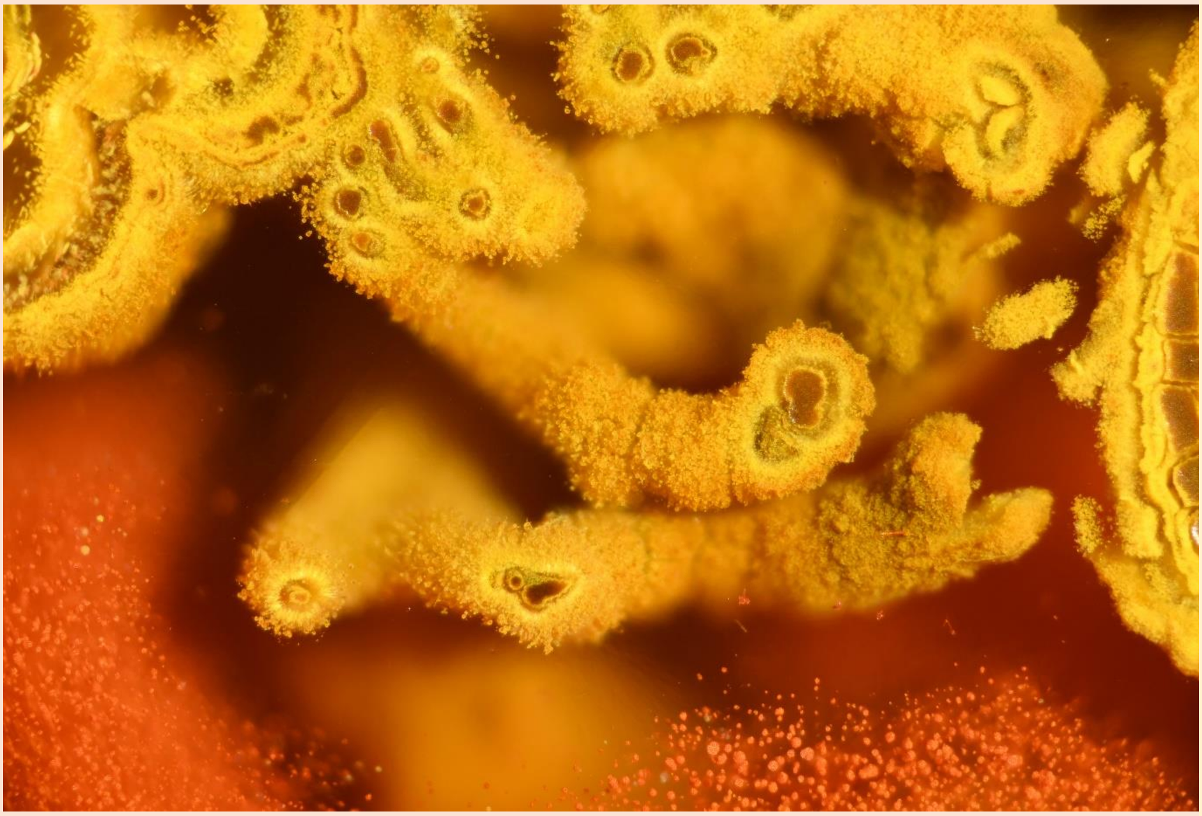

Fig. 8: The yellow material is partly needle-like and partly fine-grained. The latter is the case with the “tubes” shown here. Image width 1.6 mm.

4 Tube-like looking structures

Such groups play a role in the majority of the "cauliflowers". Two types stand out: (1) Those with a recognizable central, very thin thread (Fig. 9). Several such threads can also be packed together within a "tube". The threads originate from former bacterial colonies, as can be found (and recognized) in moss agates from many sites worldwide (Thewalt & Dörfner 2012). In the Kerrouchen agates, combinations of "tube" and (recognizable) central filament play a rather subordinate role (this does not mean that central filaments are missing, but only that they are not or only poorly preserved). Thin threads without sheaths, interpreted as bacterial colonies, on the other hand, are found more frequently in the Kerrouchen agates, as in some places in Figures 10, 11 and 19. The fundamental question concerning moss agates as to what the tube-like formations around the central threads actually are and why they have formed there in particular will not be discussed here.

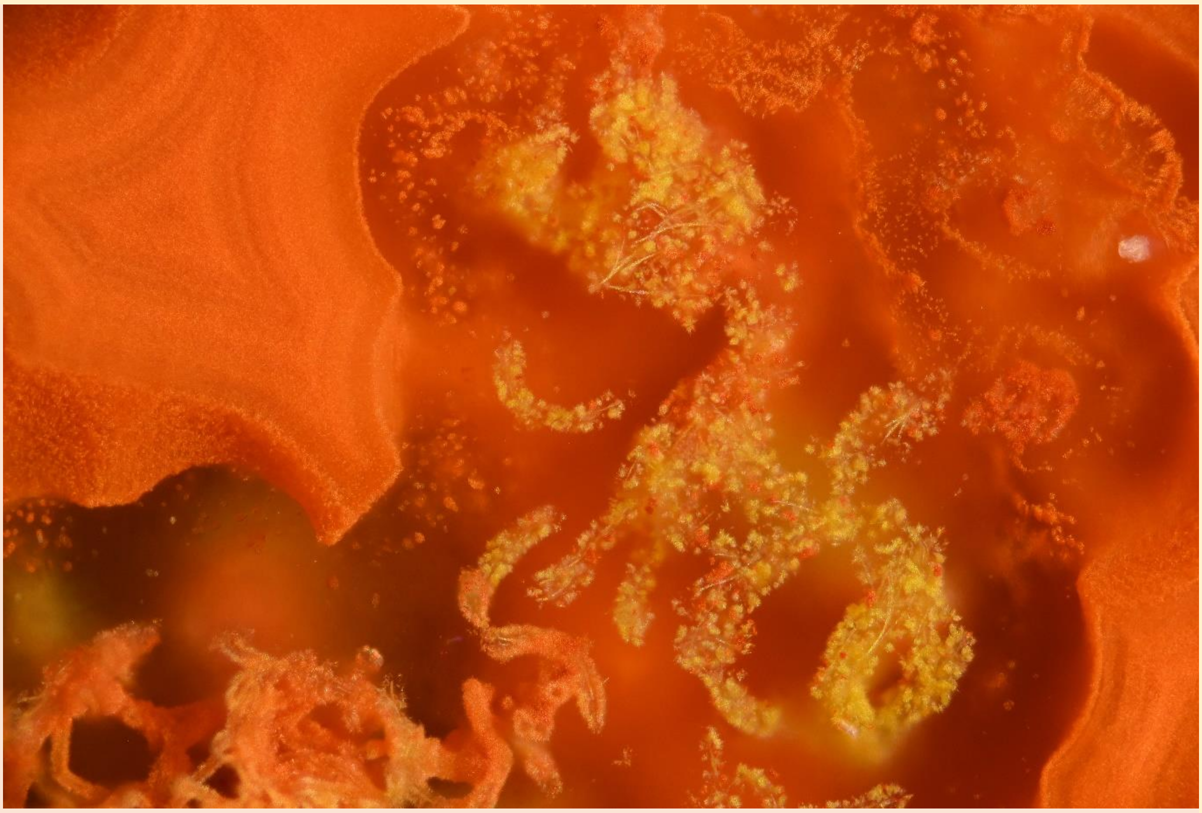

Fig. 9: Heavily corroded thread aggregates and tube combinations from the edge area of a "tube unit". The special feature: The central threads are still preserved and visible in some places. They have been preserved by early silicification. Image width 0.8 mm.

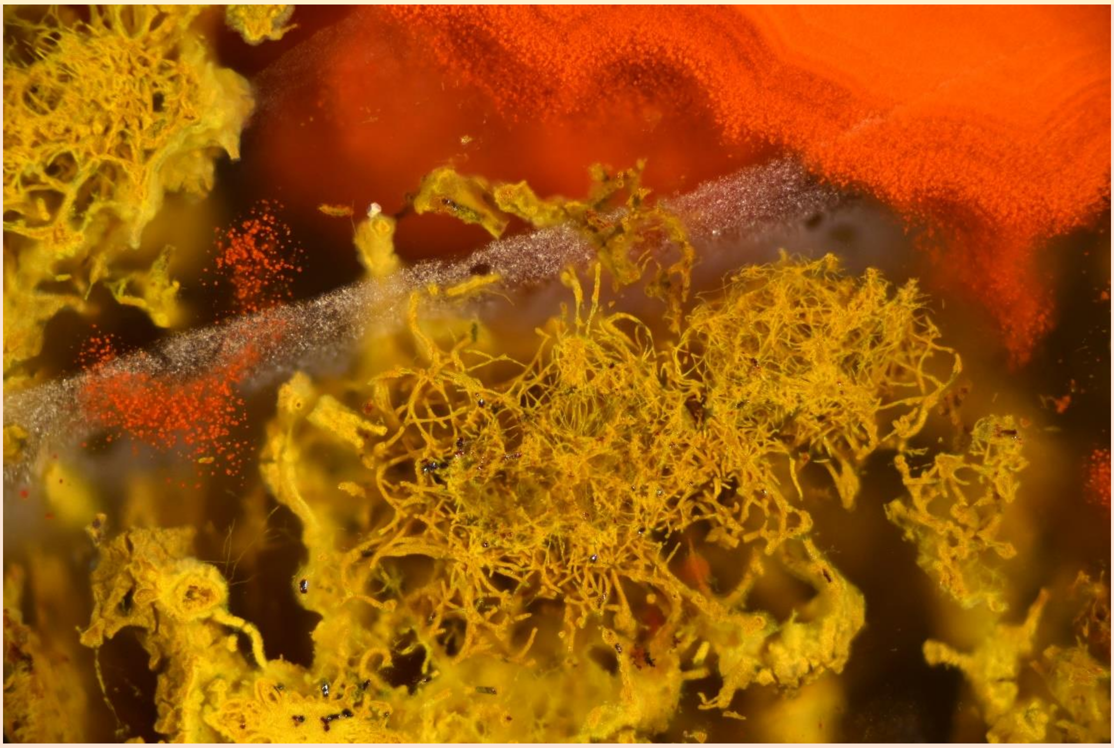

Fig. 10: Here there are central filaments, which are obviously encrusted with small yellow crystals (goethite?) to varying degrees. Image width 1.6 mm.

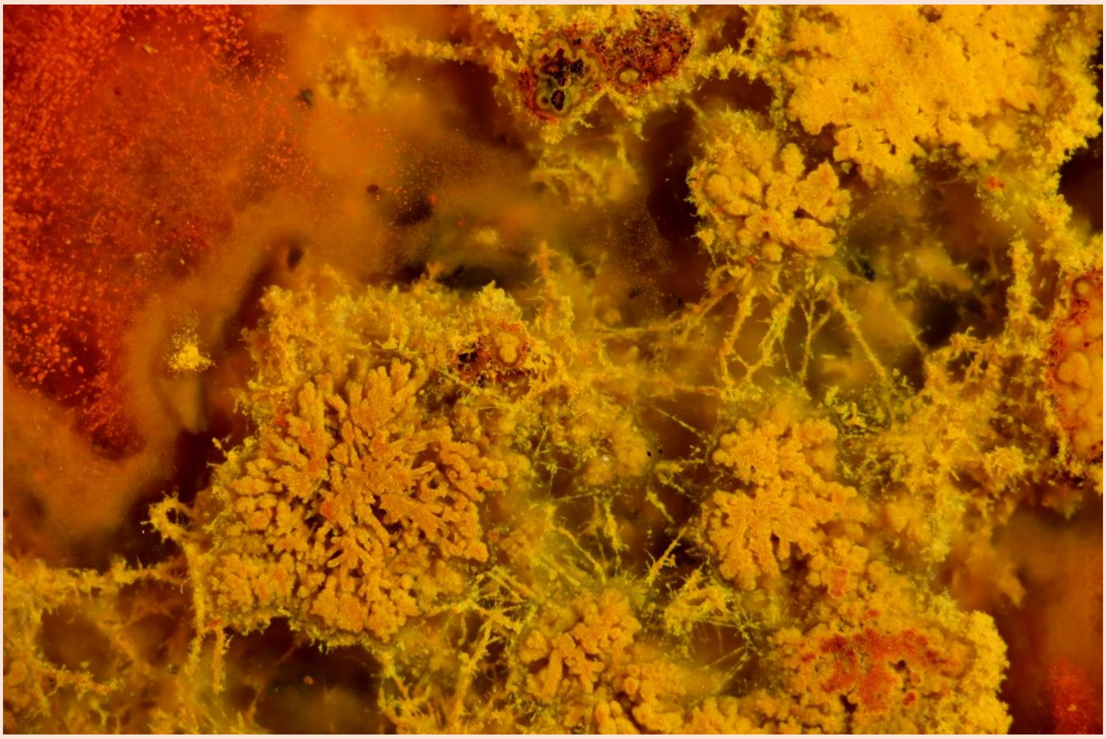

Fig. 11: Different architectural styles are recognizable (corresponding to different types of bacteria?): (1) Rosette-shaped, dendrite-like colonies of plump structural elements. (2) Relatively thin, straight filaments more or less encrusted with small yellow crystals. Image width 1.6 mm.

(2) The second type of tubular-looking formations are compact formations consisting largely of a yellow to black material (oxidic iron mineral, clay mineral, bitumen?) (Fig. 12). A pattern of interlocking tubes and radially oriented needle-like crystals is recognizable in places, but a central thin thread is not.
This can be interpreted to mean that the bacterial strands or central filaments with their coating of biogenic iron minerals were encrusted with comparatively large quantities of dark minerals and thus swallowed, so to speak, before the structure-preserving SiO_2 deposition started. The associated "tubes" are often encrusted with a fur of small yellow crystals (Fig. 9). It is striking that the diameters of the "tubes" vary greatly, even those of closely neighboring specimens. This is probably related to small-scale differences in the availability/concentration of dissolved salts from which the sheaths have formed.

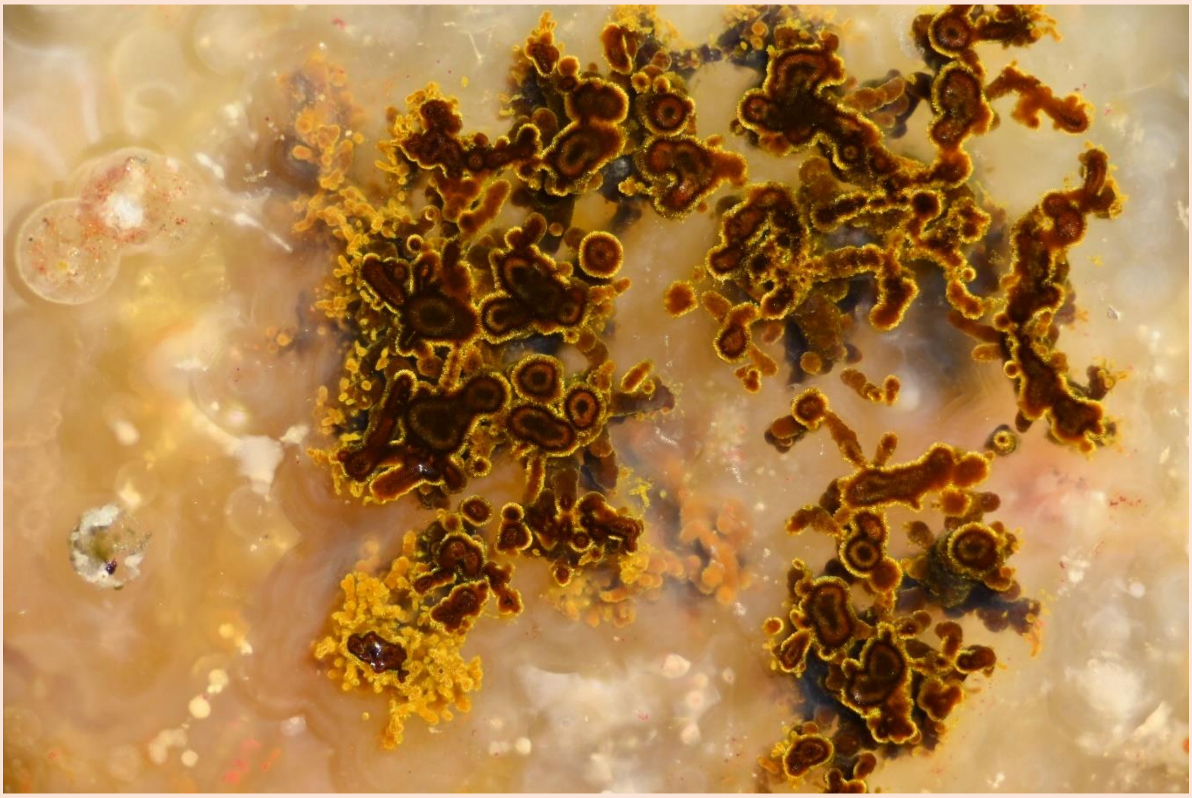

Fig. 12: The poorly structured „tubes" with brown filling were formed before the deposition of the chalcedony (otherwise there would also be chalcedony inside of them). Central threads/bacterial strands cannot be recognized. Image width 1.6 mm.

5 Dendrite-like structures

A construction pattern reminiscent of manganese dendrites is also frequently realized in the “cauliflowers”. In contrast to the typical two-dimensional manganese dendrites, however, here we are dealing with three-dimensional structures (Fig. 13, 14). The building blocks of these dendrites appear to be largely small yellow crystals (goethite?).

It is conceivable that these formations originated from colonies of strand-forming bacteria and that the local chemical environment caused the threads to disappear through dissolution and recrystallization processes. The aggregate shown in Fig. 15 is possibly a corresponding precursor. Often many dendrite-like aggregates are crowded together and largely fill the available space. However, direct contact between the individual “clusters” is obviously avoided. This indicates a formation mechanism in which diffusion has played an important role (the relevant keyword is “diffusion limited aggregation”, DLA).

Fig. 13: A pattern also found in many “cauliflowers”: three-dimensional dendrites. Image width 4 mm.

Fig. 14: Section of a relatively large dendritic structure of a "cauliflower".
Image width 1.6 mm.

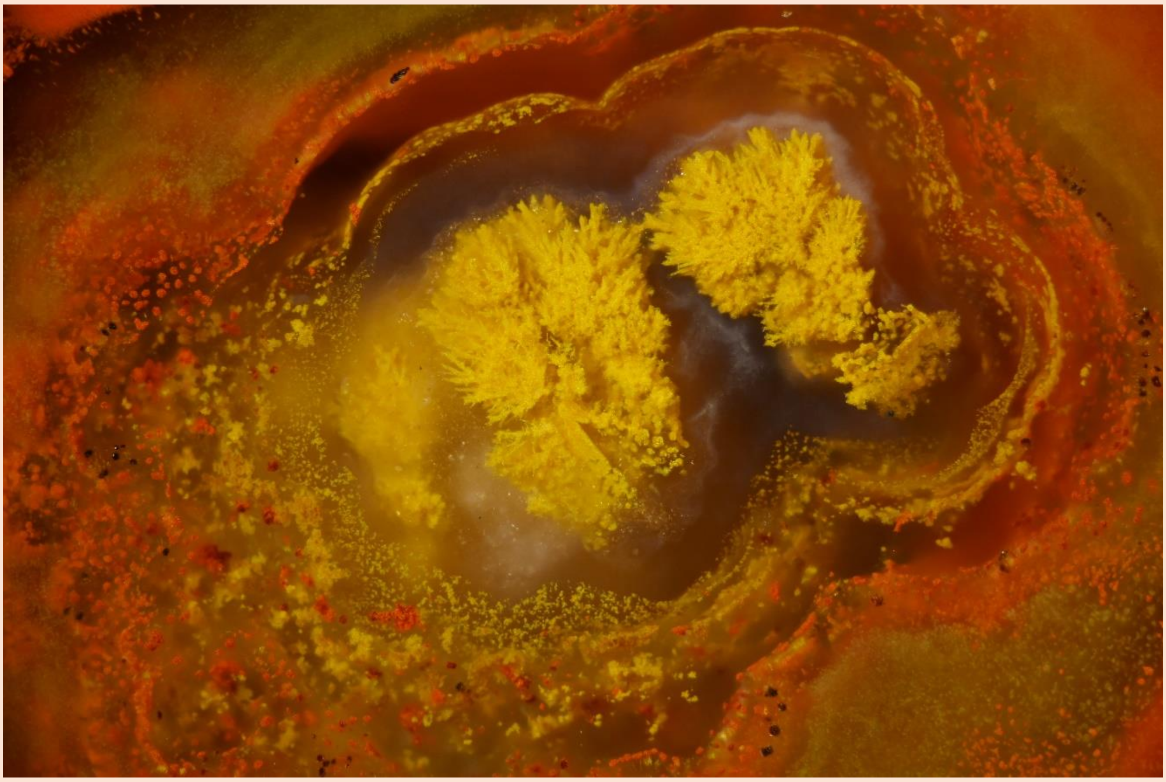

Fig. 15: This aggregate consisting of elongated components possibly represents a precursor of three-dimensional dendrites. Image width 1.6 mm.

6 Stromatolite-like structures

Differently densely packed and differently colored layers, which now consist of iron oxides and clay minerals, create the visual impression of stromatolites (Fig. 16). Such a pattern is also occasionally seen in connection with the thin, shard-like inclusions mentioned in section 9(1).

Fig. 16: „Ministromatolites" as early formations in an agate from Kerrouchen. Image width 14.5 mm.

7 The peripheral areas of the colonies

The edge of the central "bushes" in the "cauliflowers" shows a variety of patterns. Threads and "tubes" are particularly common, which can be found in the surrounding chalcedony. (Fig. 17 - 20). Remarkable: The diameter of the "tubes" increases with increasing distance from the center of the "cauliflower".

Fig. 17: The diameters of the tube-like components are significantly larger in the edge area of the unit than in the interior. Image width 0.8 mm.

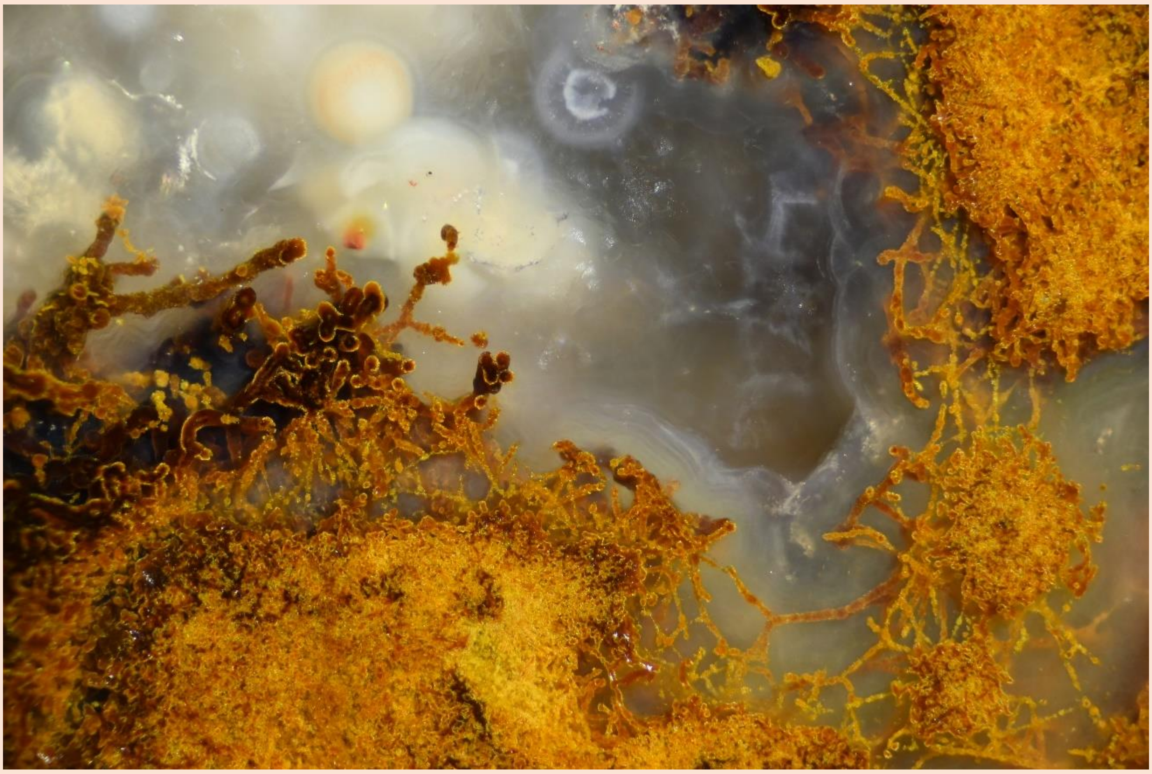

Fig. 18: It is also true for this example that the “tubes” on the edges have larger diameters than the densely packed inner ones. Image width 1.6 mm.

Fig. 19: In the border area of this "cauliflower", many filamentous organisms obviously tried to grow simultaneously under the same external conditions. This resulted in the tubular sheaths being approximately the same size. Remains of filamentous bacterial colonies can be seen in the lower half of the image. Image width 1.6 mm.

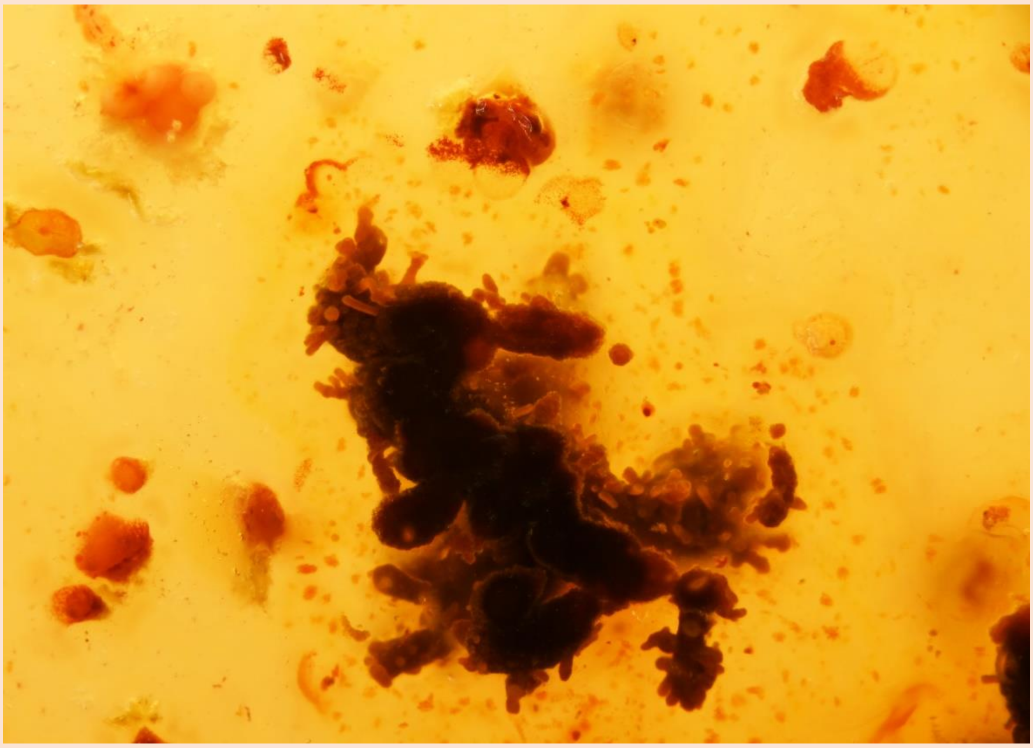

Fig. 20: The smooth surface of the round objects is striking here. The shapes look very "organic". It is easy to see the small, worm-like ones grow in places on relatively large, roundish shapes – possibly the offspring? Image width 0.8 mm.

8 Conceivable sequences of the „cauliflower" development

It is difficult to imagine an "inorganic" origin of the thread- and tube-like formations (e.g. via a "chemical garden" or a similar mineral-chemical process). The morphology of the formations is much more consistent with three-dimensional bacterial colonies with possibly several bacterial species involved. The iron-oxidizing bacterial species *Gallionella ferruginea* is occasionally mentioned as being able to produce tuft-like colonies (Schmitt-Riegraf & Riegraf 2015).

The following scenario is plausible for the formation of the colonies: the rock cavities in which agates are now present were initially filled with an aqueous solution. This contained dissolved metal salts and silicic acid (H_4SiO_4), which were released during the weathering of the volcanic host rock. The composition was apparently such that certain microorganisms were able to live and multiply. Colony-forming bacteria settled on the walls of the cavities and built their species-specific dwellings. Iron-oxidizing species are likely to have played a significant role. This corresponds to the fact that the building material of the colonies is yellow to dark brown and red. These are the colors of oxidized iron(III) minerals. Much of this material remains when the chalcedony is removed (Fig. 5).
Did the deposition of SiO_2 already begin when the "cauliflowers" were still developing or only later? The former is probably the case (Götze & al. 2011). In any case, the SiO_2 was also deposited within the loosely built iron oxide formations, as can be seen in almost all the figures shown. During the following time periods, the chalcedony layers formed or solidified in the remaining free areas, i.e. the fortification agate structure developed.

9 Further observations that have something to do with microorganisms

(1) In some of the Kerrouchen agates, thin, flat, shard-like inclusions occur which are covered (often only on one side) with relatively small "cauliflowers" and/or stromatolite-like aggregates (Fig. 16, 21). How are these flat formations to be interpreted? This seems plausible: During the early phase of agate genesis, floating layers of bacteria, bacterial colonies and their decomposition products formed on the water surface in geode cavities that were only partially filled with aqueous solution. When the liquid level changed, the thin crusts broke up and the fragments sank to the bottom of the geode cavities.
A more detailed interpretation of the nature of the shards can be found in Campos-Venuti (2018: 176, 2022: 449): According to this, the bacterium *Haloquadratum walsbyi*, which is tolerant to high salt concentrations, is said to be behind it. This bacterium loves flat surfaces and produces square patterns on them. This should also result in the fact that the shards can stand vertically on top of each other, whereby they can simulate metamorphoses of cubic minerals.
(2) In addition to the bacterial colonies, there are other early deposits on the geode walls. These are minerals whose crystals were later replaced by SiO_2 and which are now present as pseudomorphs. Fig. 22 shows a corresponding example. The rhombohedral shape is compatible with carbonates of divalent metals. Calcite is a possible candidate. The figure shows that the bacterial colony already existed when the crystal developed.
(3) Cloud agate-like formations occur, albeit rarely (Fig. 23).
According to Campos-Venuti (2022), microorganisms were also involved in the formation of this type of SiO_2 deposits.

Fig. 21: Fragments of thin plates are often found in agates from Kerrouchen. Bacteria were probably involved in their formation. Image width 1.6 mm.

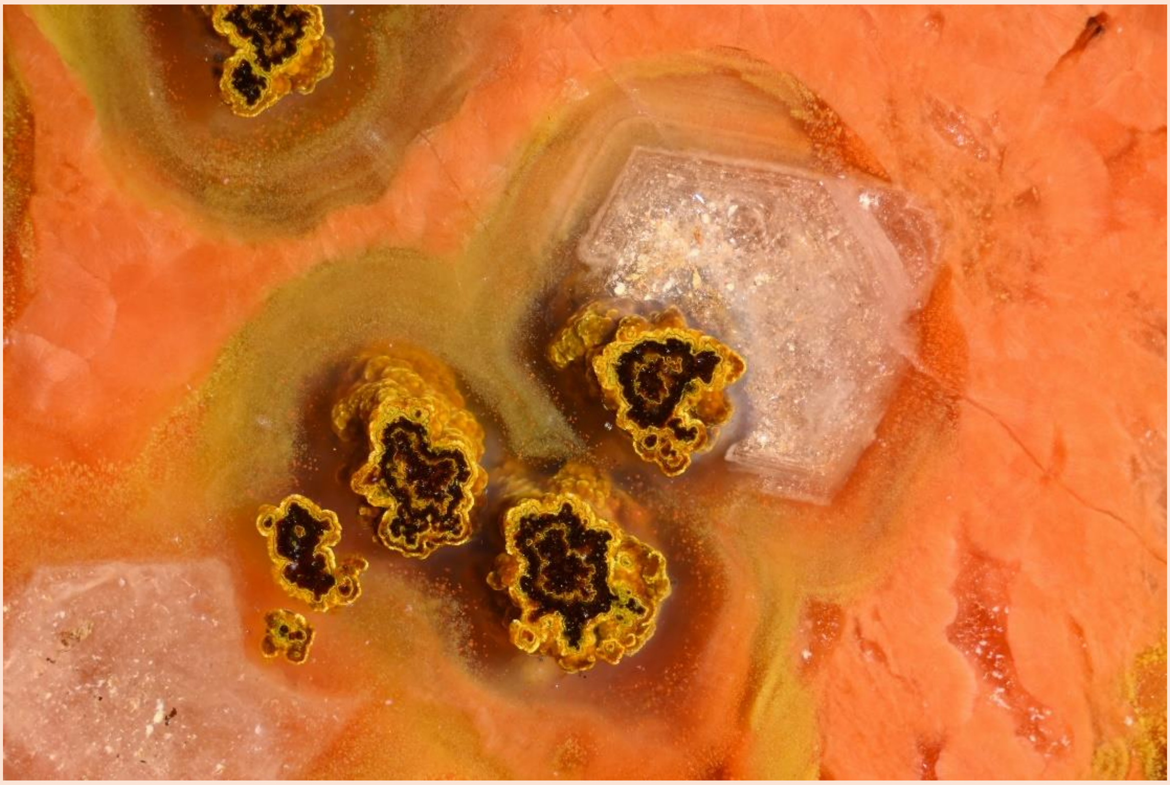

Fig. 22: „Cauliflowers“ and a mineral pseudomorph exist side by side here. The “cauliflower” already existed when the rhombohedral crystal grew around it. Image width 4 mm.

Fig. 23: One of the rare examples of so-called "cloud agate" for the Kerrouchen deposit. Image width 4 mm.

Notes

We acquired the agates on which this article is based at several agate shows and via ebay on the internet.
The micro photos were taken on polished specimens with a classic microscope combined with a system camera.

Several individual images were "stacked" using the Helicon Focus program (HeliconSoft, 61062 Charkiv, Ukraine). This made it possible to achieve an increased depth effect compared to individual shots.

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