Insights in the spatial and temporal heterogeneity of biofilm lithification

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Aims

The role of microbes in the precipitation of carbonate minerals has often been discussed and precipitation mechanism at multiple spatial dimensions still needs to be unravelled. This study highlights the importance of multi-scaled X-ray computed tomography and 3D visualization at micro- and meso-scale combined with field (in-situ) and lab (in-vitro) experiments to understand the precipitation mechanisms of microbial-mediated Ca-Mg carbonates in natural settings.

Method

Different case studies have been selected showing how in-situ 3D visualization at multiple scales may unveil the pathway from crystal nucleation over crystallization to lithification. Mineralogy has been further identified using XRD (X-ray diffractometry) and TEM (Transmission Electron Microscopy). Correlative microscopy combining confocal laser scanning microscopy, SEM and microCT scanning made it possible to study the tight interaction between the cell wall, the biofilm (with EPS) and the nano-crystals.

Samples have been measured with the Bruker Skyscan 2211 (multi-scale X-ray nano-CT system) using an open X-ray source (energies varying between 60 and 120 kV, <4W) with Be-window. Two types of detectors have been used (resp. the 6 Mp flatpanel detector and the 11Mp cooled CCD detector) and voxel resolution was varying between 500 nm and 10 micrometer. Filter-sets were evaluated to enhance the segmentation of different carbonate minerals (calcite, dolomite, aragonite). Defined carbonate standards have been added during the scans facilitating segmentation. Images have been reconstructed using InstaRecon. Image segmentation and visualization have been performed using resp. CT-An, CT-Vox and Avizo (FEI).

Results

The first case study presents field precipitation experiments on different substrates of continental tufa deposits in the Gotteron Valley (Fribourg, Switzerland) and of hot spring deposits in Greece and Hungary. Scanning and microscopy at different scales shows that calcite and aragonite starts precipiting within distinct layers and/or directly on the cell-wall of cyanobacterial filaments (Figure 1).

The second case study visualizes microbial-mediated precipitates in biofilms produced under aerobic and anaerobic conditions in constrained lab experiments. Results show that nucleation of nanocrystals and crystallization processes are clustered within the biofilm and that only in a second phase nanocrystals are clustering together forming spherical aggregates and/or dendritic structures.

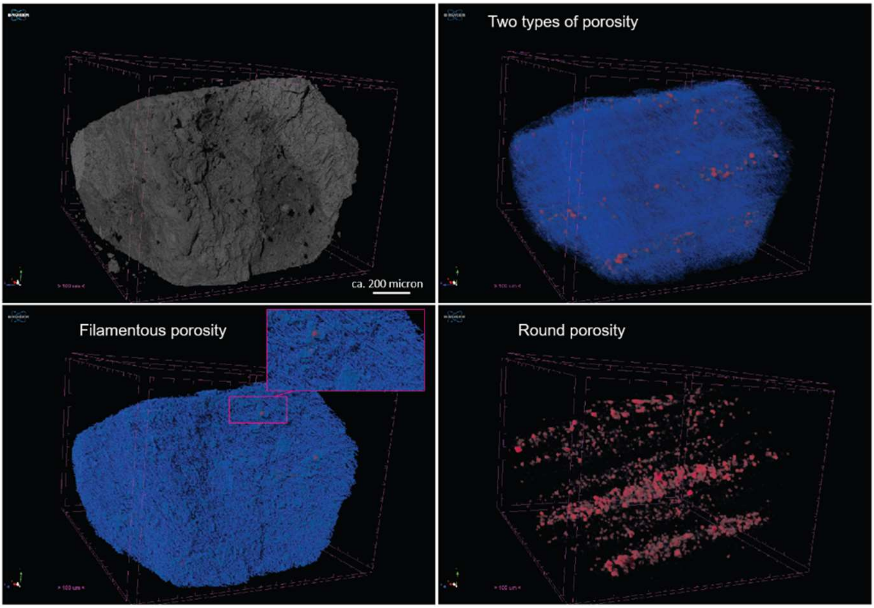

Figure 1: CT-scan image of tufa-deposits (Gotteron Valley, Fribourg). Image represents the precipitation of calcite within distinct layers and around the cell wall of cyanobacterial filaments leading to elongated, filamentous pores (blue color). Degradation of organic matter results in distinctive types of porosity along laminae (red color).

Conclusion

This study highlights the necessity of high-resolution CT-scanning in combination with other microscopy techniques to understand the mechanisms and processes involved in the precipitation of microbial-mediated carbonates.