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# Atmospheric alteration of stained glass: influence of Mn-oxidising bacteria (*Pseudomonas putida*)

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For several centuries, the external and internal surfaces of mediaeval stained glass windows are continuously exposed to water (rain events, humidity, condensation/dry cycle), which causes the alteration of their external/internal surfaces. These conditions of high humidity also favours the development of microorganisms. Due to their composition, medieval glasses can be attractive substrates for the development of biofilms, as they represent a source of nutrients for microorganisms [1]. However, due to the multitude of parameters involved, these interactions are not well understood and are still poorly documented.

To test the influence of glass substrates on their colonisation and alteration processes, a panel of 5 model medieval glasses was subjected to short term (closed system, 7 days) and medium term (opened system in bioreactor, 1 month) alteration experiments in an aqueous environment. Five glasses having identical potash-lime-silica base and variable Mn and Fe contents (between 0 and 2 wt% of oxide) were chosen, in order to target specifically the role of Mn and Fe in the development of bacteria/biofilm formation, and investigate the potential role of bacteria in the browning pathology known to develop at the surface stained glass windows containing Mn. The *Pseudomonas putida* strain, known for its affinity for Fe and its Mn oxidation properties, was selected in a first step. In a second step, experiments were carried out with *Arthrobacter Crystallopoietes* strain, which was collected from exposed stained glass windows and is known for its altering capacity.

The five glasses were immersed in a minimalist liquid medium at 25°C in the presence of microorganisms and the (bio)altered glasses (7 days, 1 month) were characterised by SEM. In the short-term experiments, the filtered cultures were periodically analysed by ICP-OES in order to study the dissolution kinetics of the different glasses in the presence of bacteria. The results of show that the presence of *P. putida* has no real effect on the short-term hydrolysis rate of glasses, but significantly modifies the dissolution and the speciation of certain elements (Mn, Fe, P) from the glass. The bacterial growth is also strongly linked to the composition of the glass: in the presence of Mn-bearing glass, consistent biofilms are observed, whereas in the presence of Fe-bearing glass, bacteria mostly develop in a planktonic form. Moreover, the absence of Fe in the glass triggers the production of siderophores. In all experiments with Mn and without Fe, the production of siderophore is followed by the formation of Mn oxides in solution and in biofilms attached on the glass surface.

## References

[1] Marvasi M. et al. (2009), Journal of Cultural Heritage 10, 124-13.

[2] Valbi V (2023), International Biodeterioration and Biodegradation 177, 105529.

