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The use of advanced spectroscopy and microscopy approaches in biogeochemistry: some recent approaches and current challenges

KARIM BENZERARA

IMPMC, Sorbonne Université, CNRS UMR 7590, MNHN

Biogeochemistry has revealed the significant impact of life on the chemical functioning of the Earth's surface both in the present and past times. We are now faced with several challenges: (i) finely document the extent and modalities of past and current biosphere-geosphere interactions, including by identifying traces of microbes and their activities in the modern sediments and the geological record; (ii) identify the mechanisms of these interactions, i.e. determine the diversity of involved biological actors (biological species, macromolecules) and derive reaction rates and parameters affecting them so that eventually, these interactions might be well modelled at large scales. While a diversity of bulk approaches has been successfully used to address these questions, there have been constant improvements of spectroscopy and microscopy techniques, including those based on the use of synchrotron radiation, capable of characterizing living organisms, their chemical composition, and their geochemical activities at the submicrometer-scale. These techniques are often developed by distinct scientific communities. Yet, as biogeochemists, we have to test and adapt them to the specific features of our samples, in particular an intrinsic biological and geochemical complexity and heterogeneity. We also need as a community to identify and communicate our specific needs so that facility upgrades can eventually meet our requirements.

Here, I will review some capabilities that seem important to study biogeochemical processes. I will use some recent studies to illustrate how these capabilities are provided by some recent analytical advances and also discuss their current limits. This will include (i) correlative or multimodal approaches to scan large samples with a spatial resolution high enough to detect microorganisms and measure diverse signals/properties such as luminescence and elemental composition [e.g., 1]; (ii) nanoscale spectromicroscopy conducted under native or near-native conditions to characterize biogeochemical processes [2, 3].

[1] Medjoubi, Benzerara, Debrie, Tang, Bazin, Letavernier, Desjardins & Somogyi (2024), *Frontiers in Environmental Chemistry* 5:1339829.

[2] Chevrier & al. (2023), *Proc Natl Acad Sci USA*. 120:e2216975120.

[3] Mangin & al. (2025), *ISME J*. 19:wrae260.